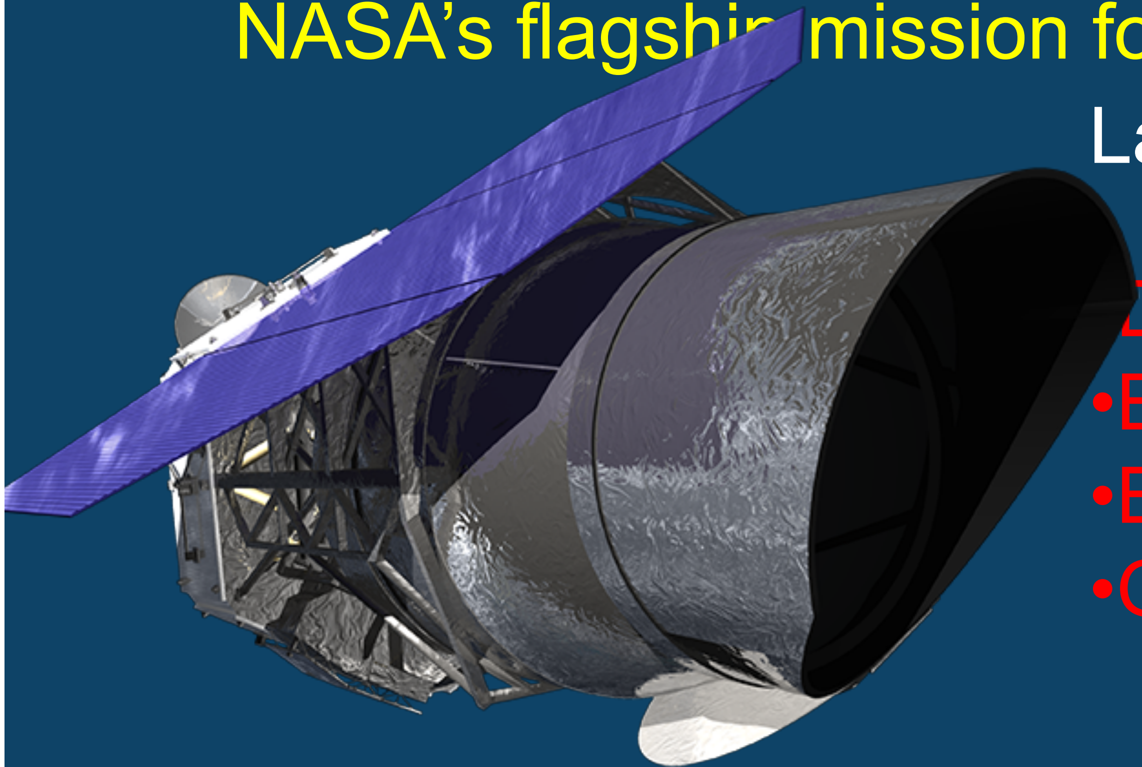
WFIRST

(Wide Field Infra Red Survey Telescope)

Recommended by Decadal survey astro2010

NASA's flagship mission following HST, JWST

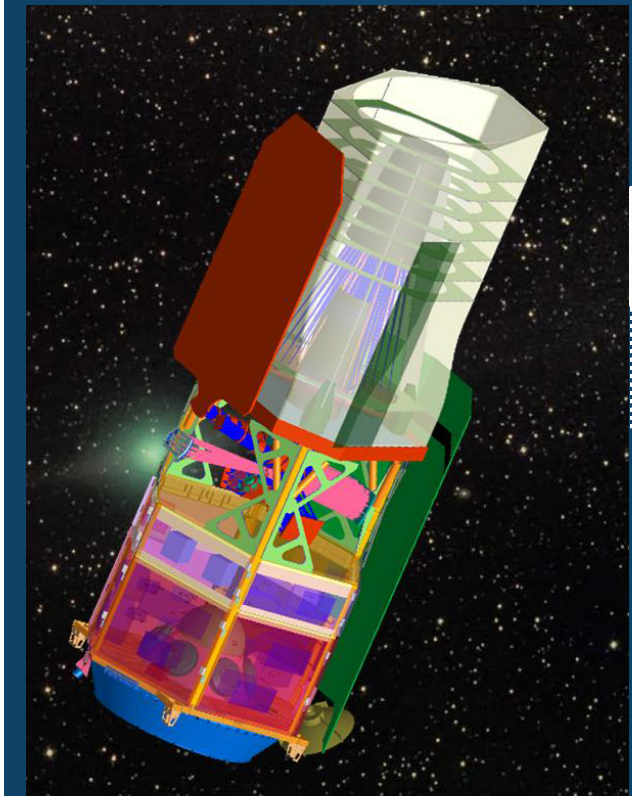
Launch in 2025



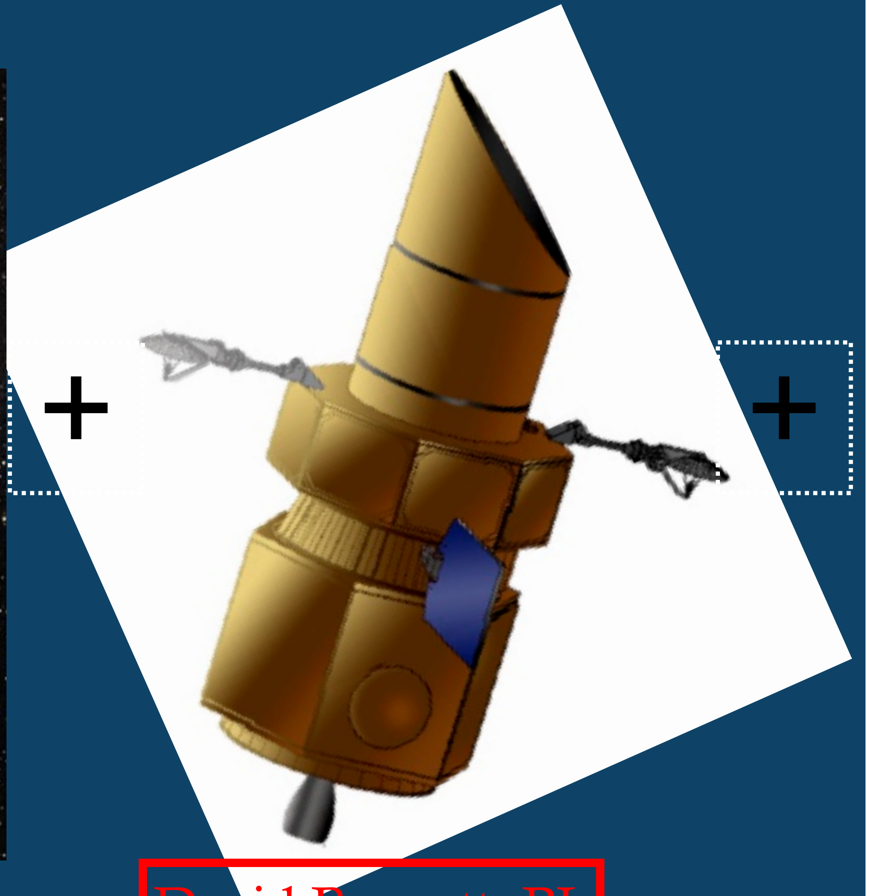
•Dark Energy
•Exoplanet Microlensing
•Exoplanet Coronagraph
•Guest Observing Prog.

Takahiro Sumi (Osaka U.), PI: JAXA WFIRST WG

WFIRST =

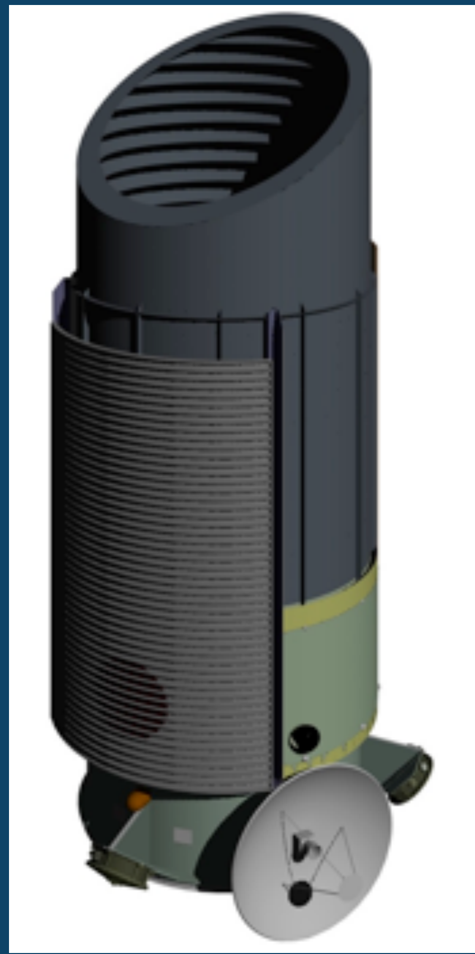


+



David Bennett, PI

+



JDEM

Joint Dark Energy Mission

MPF

Microlensing Planet Finder

NIRSS

Near InfraRed Sky Survey

2.4m WFIRST

Diameter: 2.4m given from NRO (National Reconnaissance Office)

Wavelength: λ=0.6–2μm

WFI: (FOV：0.281deg.^{2})

Coronagraph

Orbit: L2

Mission life time: 5 years: Serviceable

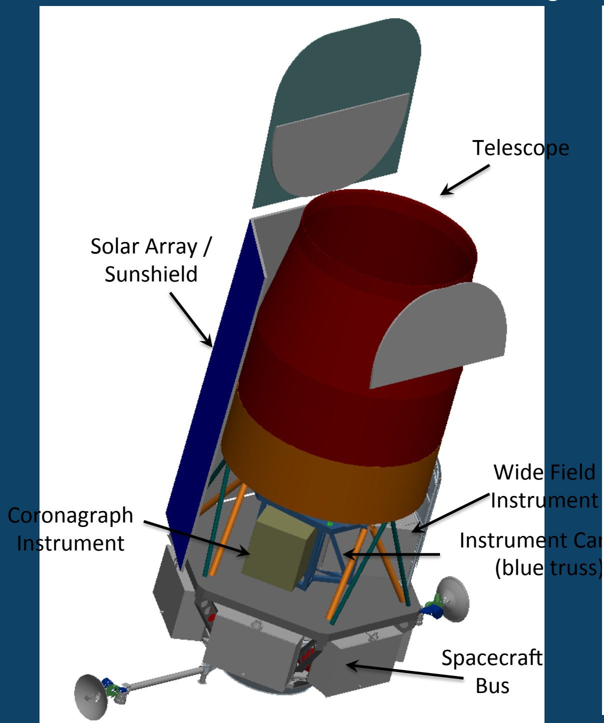
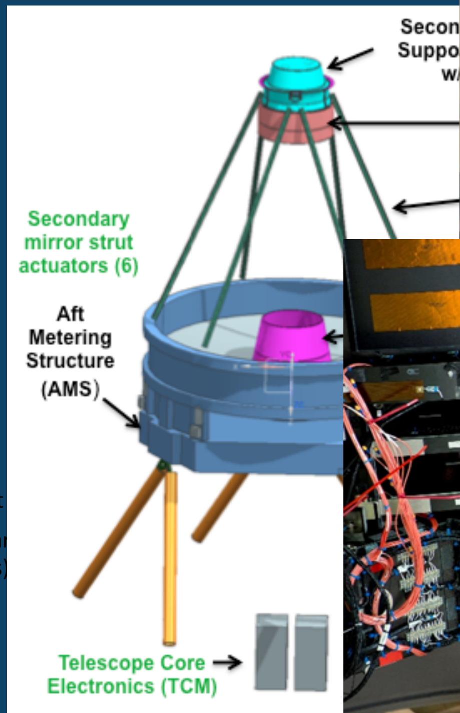


Figure 3-3: WFIRST-2.4 Observatory configuration featuring the 2.4-m telescope, two modular instruments and a modular spacecraft. bus



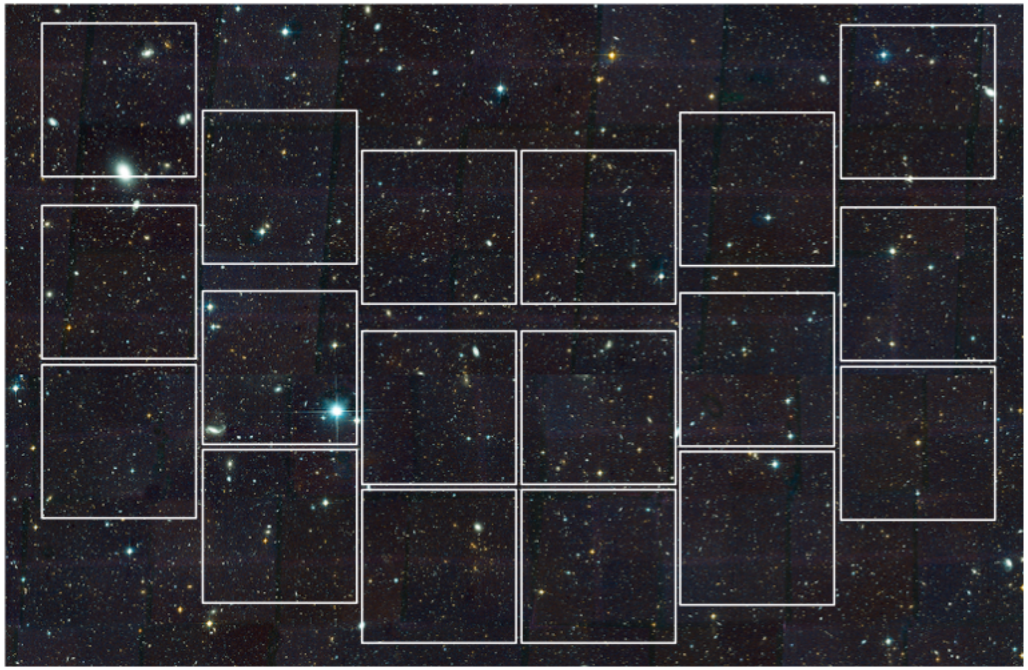
Channel field layout for AFTA-WFIRST wide field instrument

4k x 4k pixel H4RG-10   18 detectors
0.11 arcsec/pixel   0.28 deg^2

0.788° wide
0.427° high

X gaps 2.5mm
Y gaps 8.564mm

Moon (average size seen from Earth)

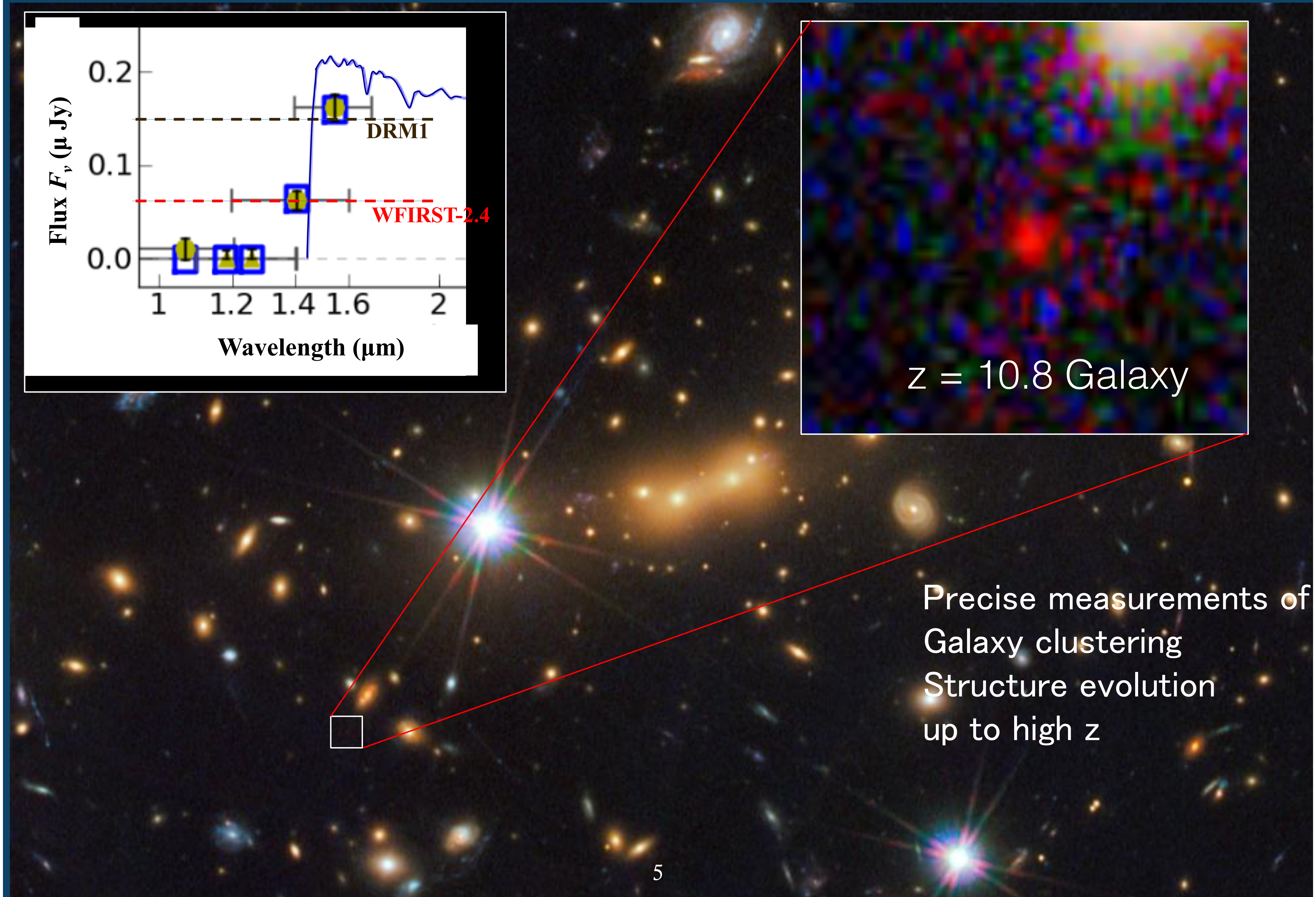


~90 × bigger than HST–ACS FOV,
~200 × bigger than IR channel of WFC3

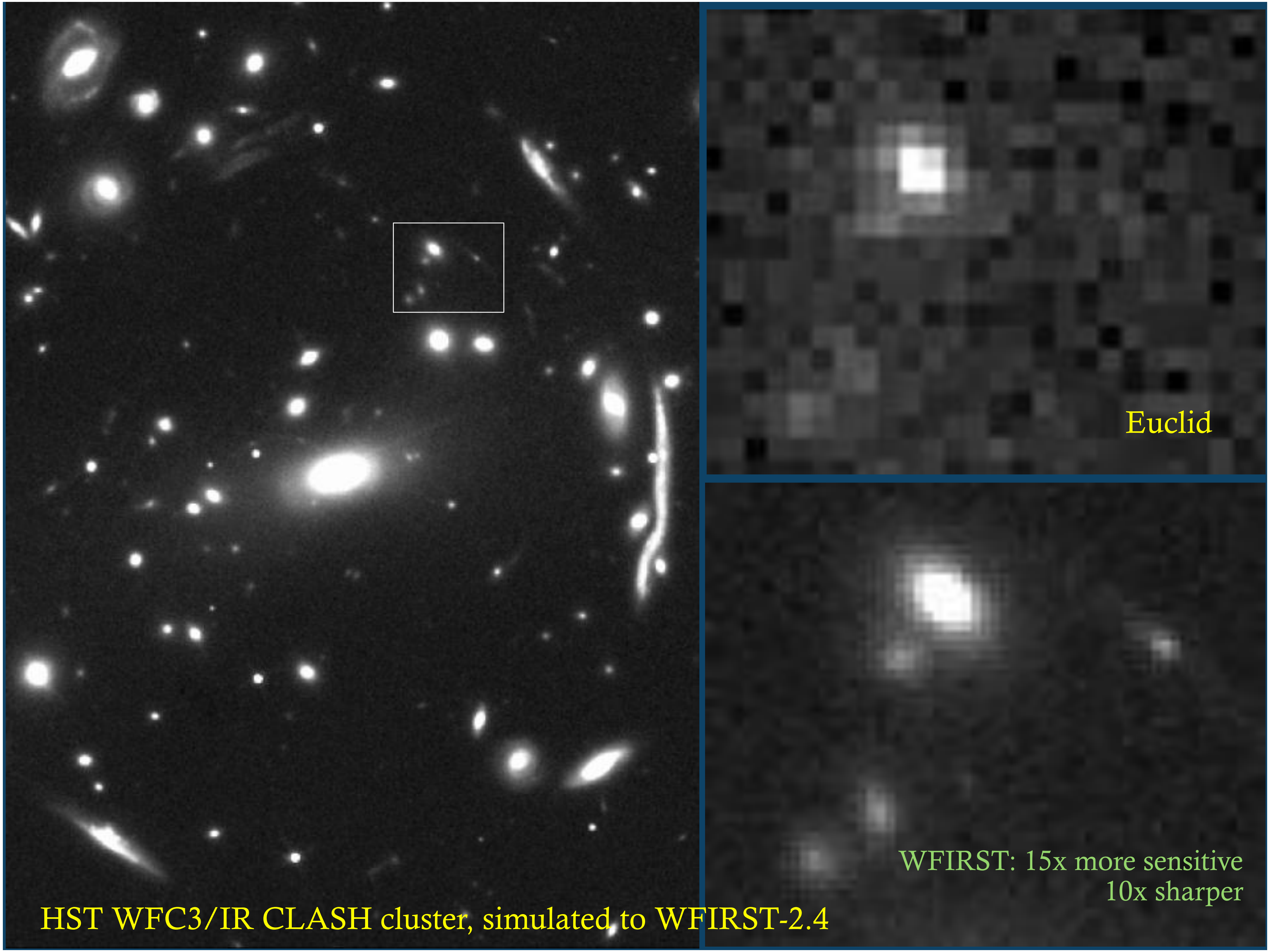
Each square is a H4RG-10
4k x 4k, 10 micron pitch
288 Mpixels total

Slitless spectroscopy with grism in filter wheel
R_θ ~ 100 arcsec/micron

Hubble x 200 Discovery of High-z Galaxies



Precise measurements of
Galaxy clustering
Structure evolution
up to high z



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

Dark matter distribution by Weak lensing

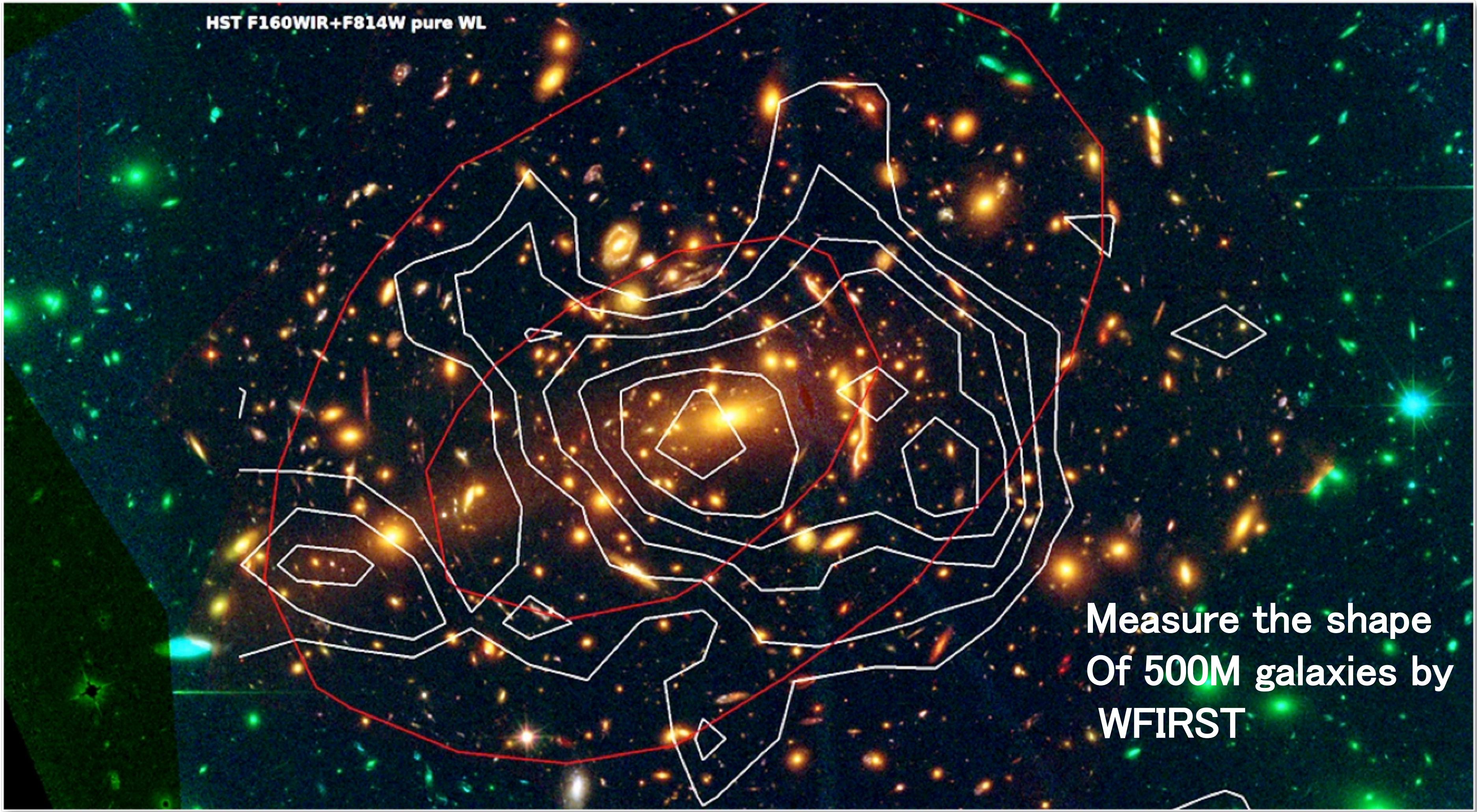
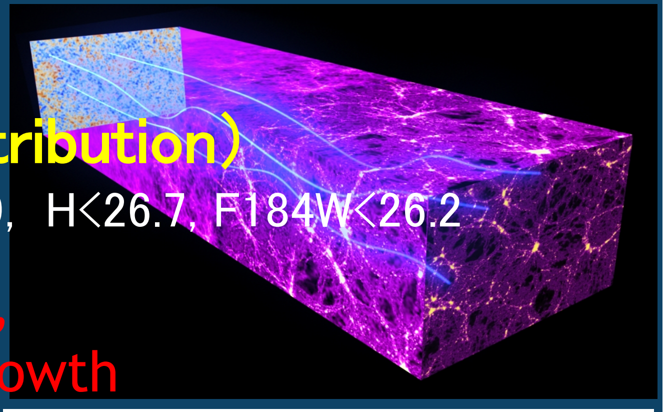


Figure 2-12: Mass density contours around the cluster MACS J1206.2-0848 derived from a ground-based weak lensing survey with Subaru (red) vs. a weak lensing study with HST/ACS+WFC3 (white). The 10x higher surface density of lensed galaxies achieved from space yields ~3x higher spatial resolution maps. The HST data

WFIRST Observation strategy

- Dark Energy/Modified Gravity(～2.5yr)



◆ High Latitude Survey (HLS)（galaxy distribution）

$2000deg^2$、image(YJH)＋spectra(R~800) Y<26.7, J<26.9, H<26.7, F184W<26.2

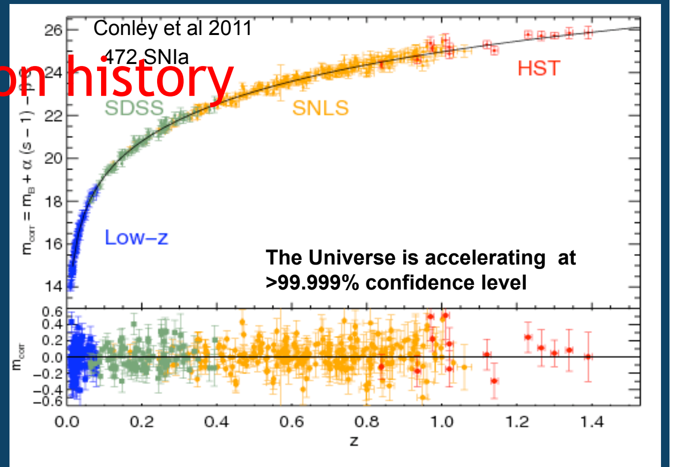
・Weak Lensing（WL）

・Red shift space distortion (RSD)

・Baryon Acoustic Oscillation (BAO)

→ Dark matter, Structure growth

→ Cosmic acceleration history



◆ IaSNe survey

5, 9, $27deg^2$、imaging＋IFC (R～100)

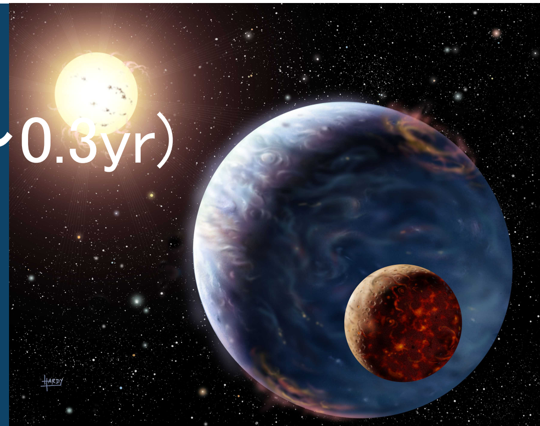
- Exoplanets：

◆ Microlensing exoplanet search (～1yr)

Complete statistical census of Planetary systems which Kepler started

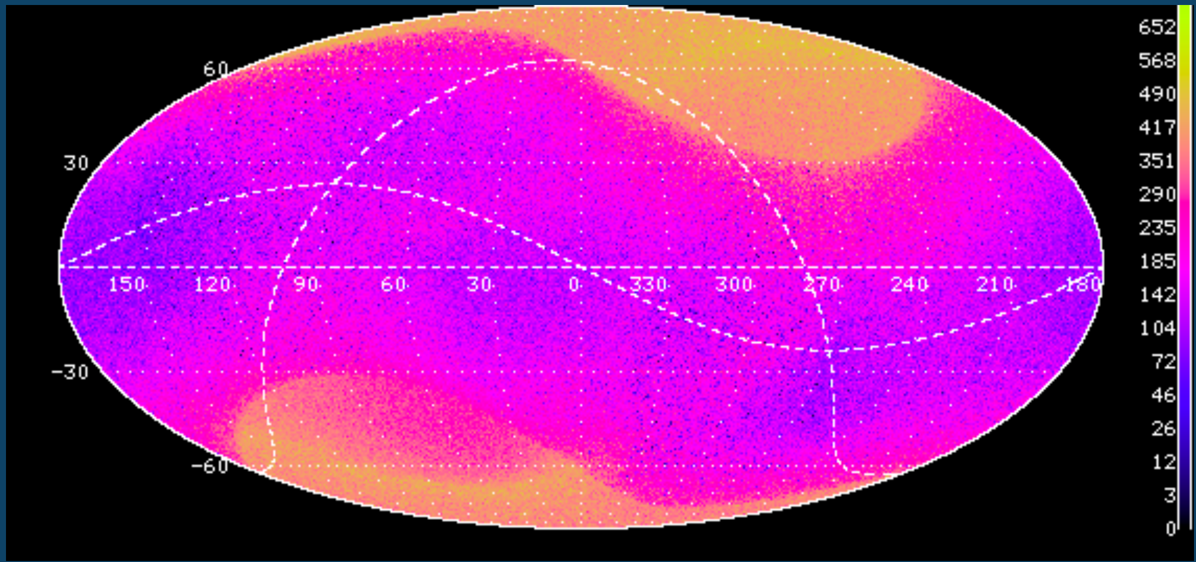
◆ Direct observation by coronagraph(～0.3yr)

optical、contrast 10^{-9}, IWA 0.2”

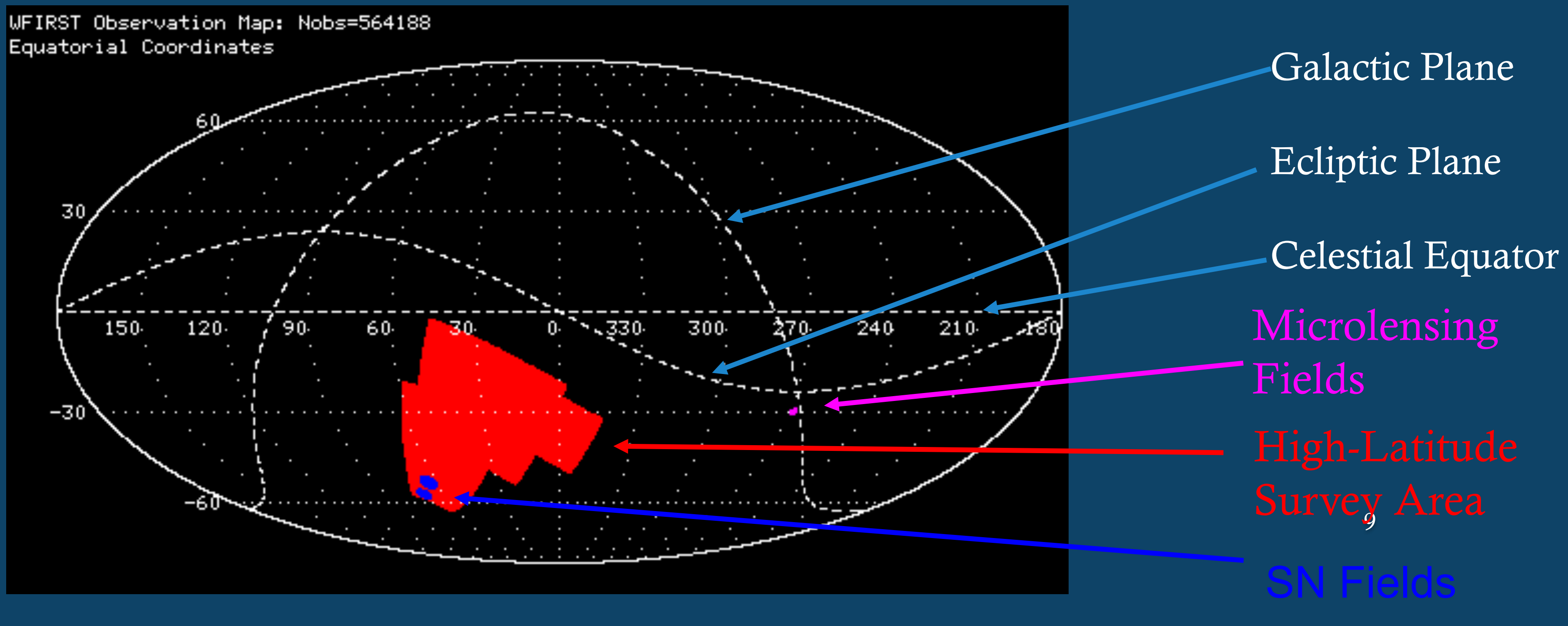


- **Guest Observer（25%,1.5yr）**

WFIRST Observational fields



Available for GO



dark energy equation-of-state parameter **w** at redshift z = 0.47 (the redshift at which it is best determined by WFIRST- 2.4) and its derivative with respect to expansion factor **dw/da**.

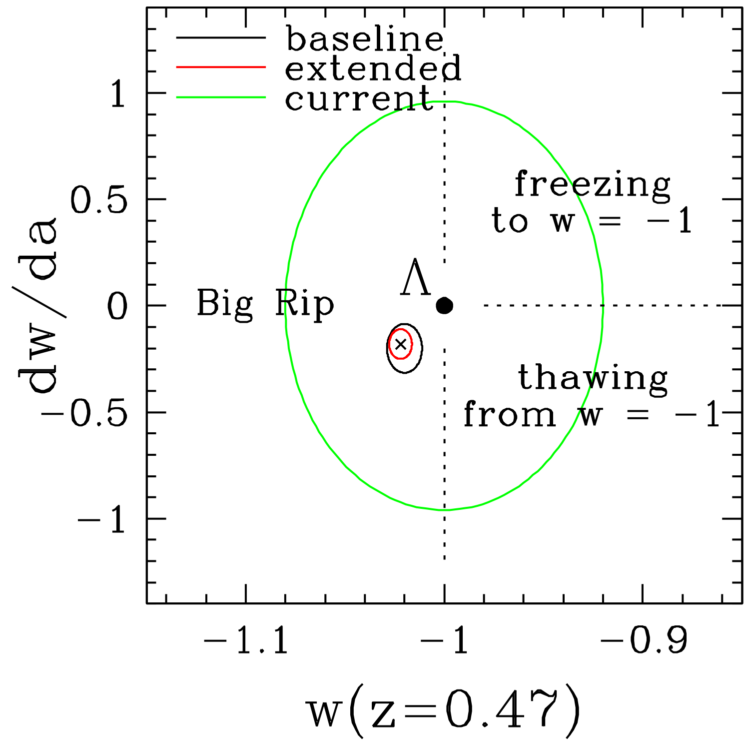
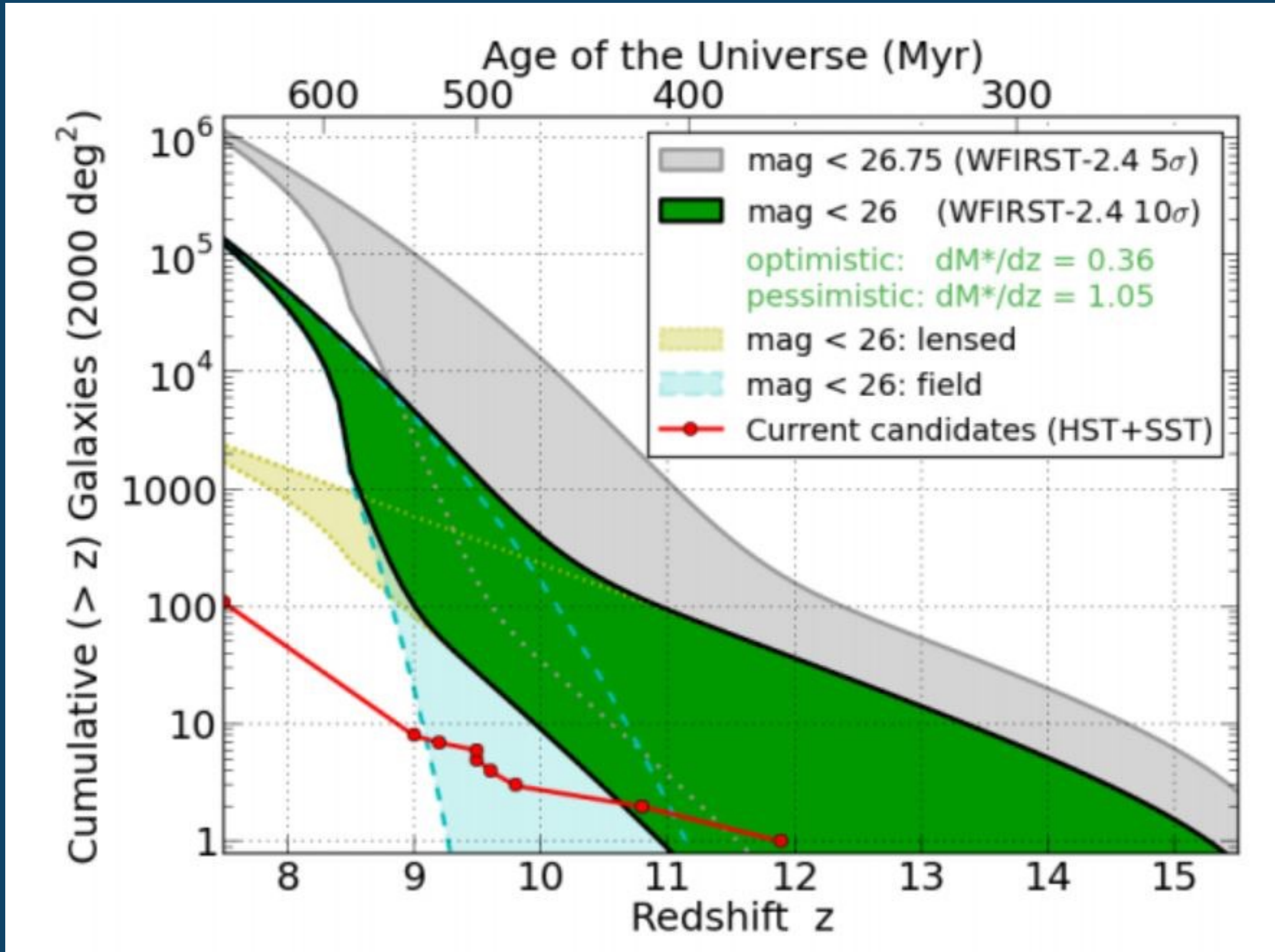


Figure 2-7: $\Delta\chi^2 = 1$ error ellipses on the value of the dark energy equation-of-state parameter w at redshift z = 0.47 (the redshift at which it is best determined by WFIRST-2.4) and its derivative with respect to expansion factor dw/da. The green ellipse, centered here on the cosmological constant model (w = -1, dw/da = 0), represents current state-of-the-art constraints from a combination of CMB, SN, BAO, and H_0 data.[20] For this figure, we have imagined that the true cosmology is w(z=0.47) = -1.022 and dw/da = -0.18, well within current observational constraints. The black ellipse shows the error forecast for the baseline WFIRST-2.4 SN, GRS, and WL surveys, combined with CMB data from Planck, a local supernova calibrator sample, and BOSS BAO and RSD measurements at z < 0.7. The red ellipse shows the "extended" case in which the precision of the WFIRST-2.4 measurements (but not the Planck, local SN, or BOSS measurements) is increased by a factor of two, as a result of a longer ob-

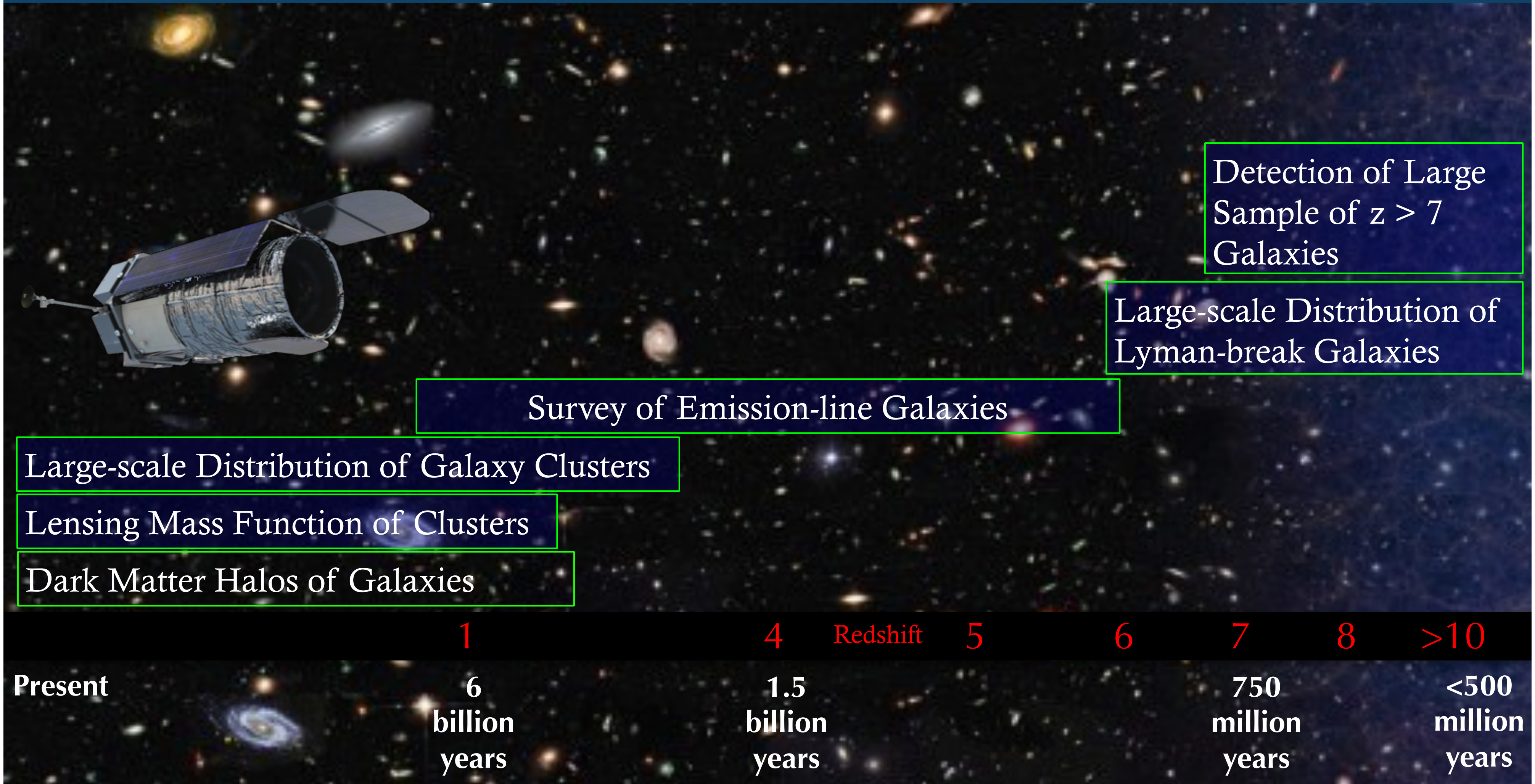
Galaxy Luminosity Function

WFIRST's High-Latitude Survey will yield up to 2 orders of magnitude more high redshift galaxies than currently known



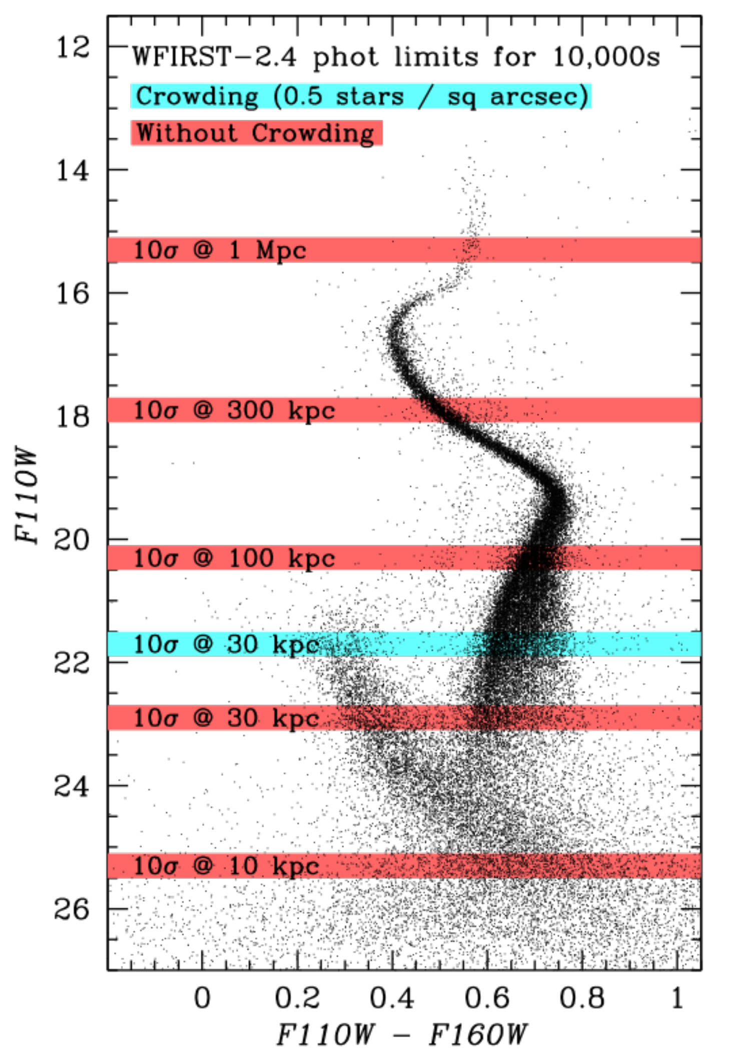
WFIRST: A Unique Probe of Cosmic Structure Formation History

Using Observations from the High-Latitude Survey and GO Programs

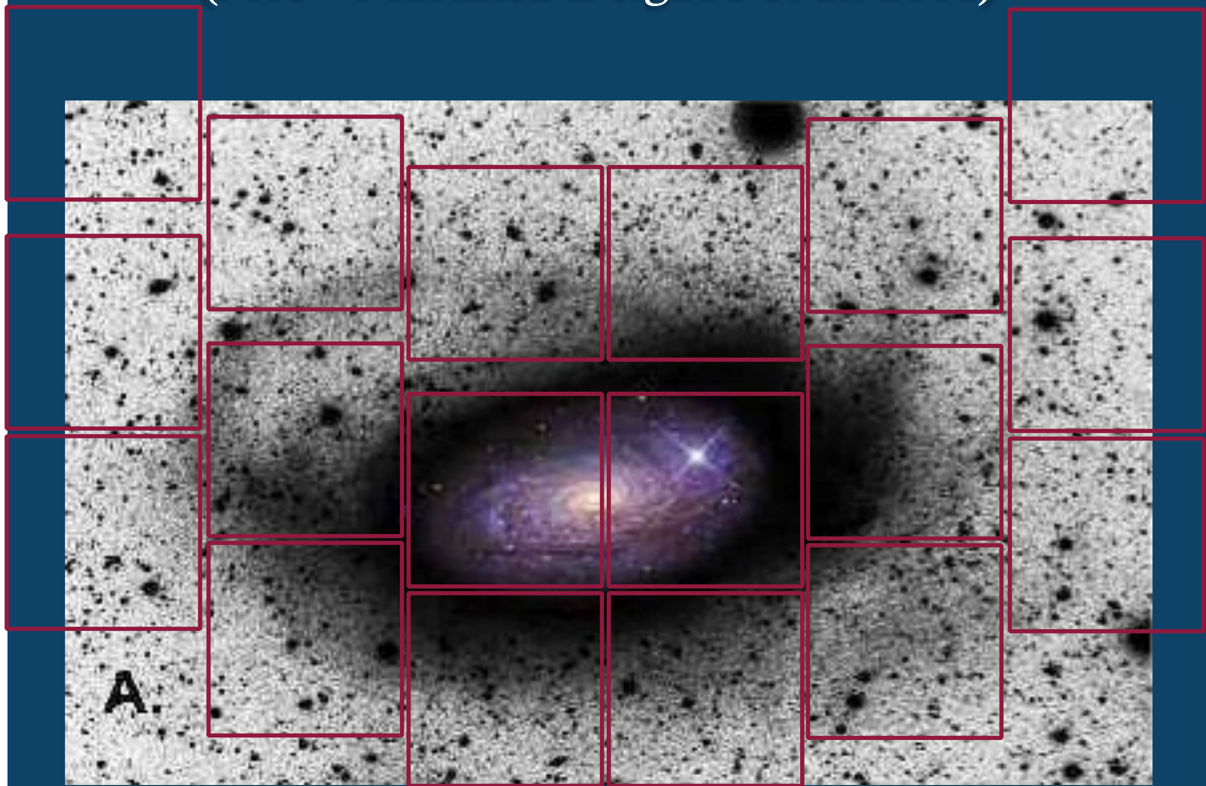


WFIRST – A Unique Probe of Stellar Populations and Nearby Galaxies

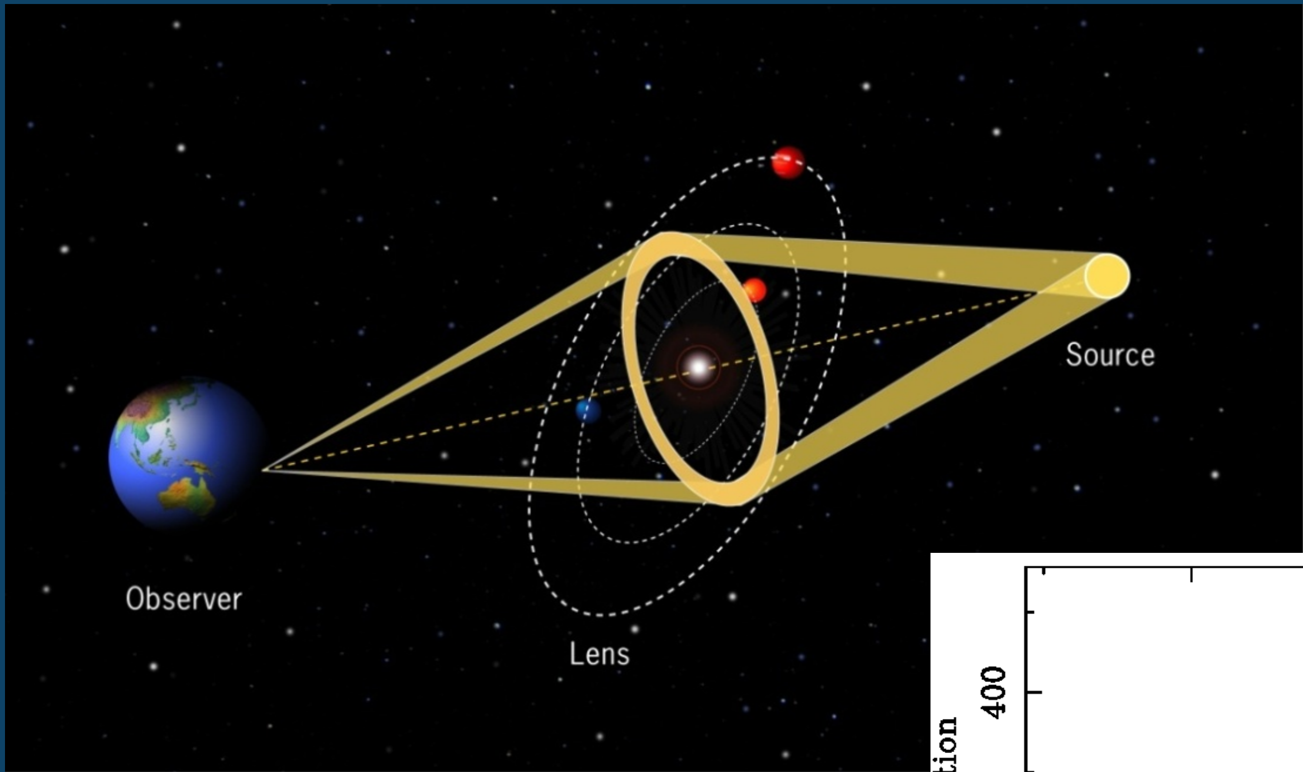
Resolve and characterize stellar pops out to
large distances (47 Tuc and SMC - Kalirai et al. 2012)

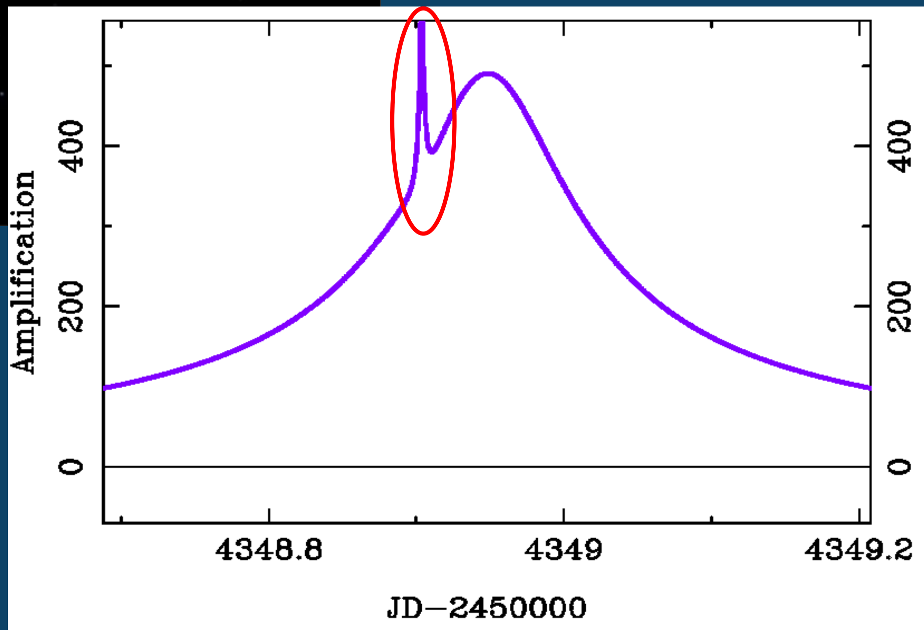


Ultra-deep imaging of galaxy halos
(M63 - Martinez-Delgado et al. 2010)

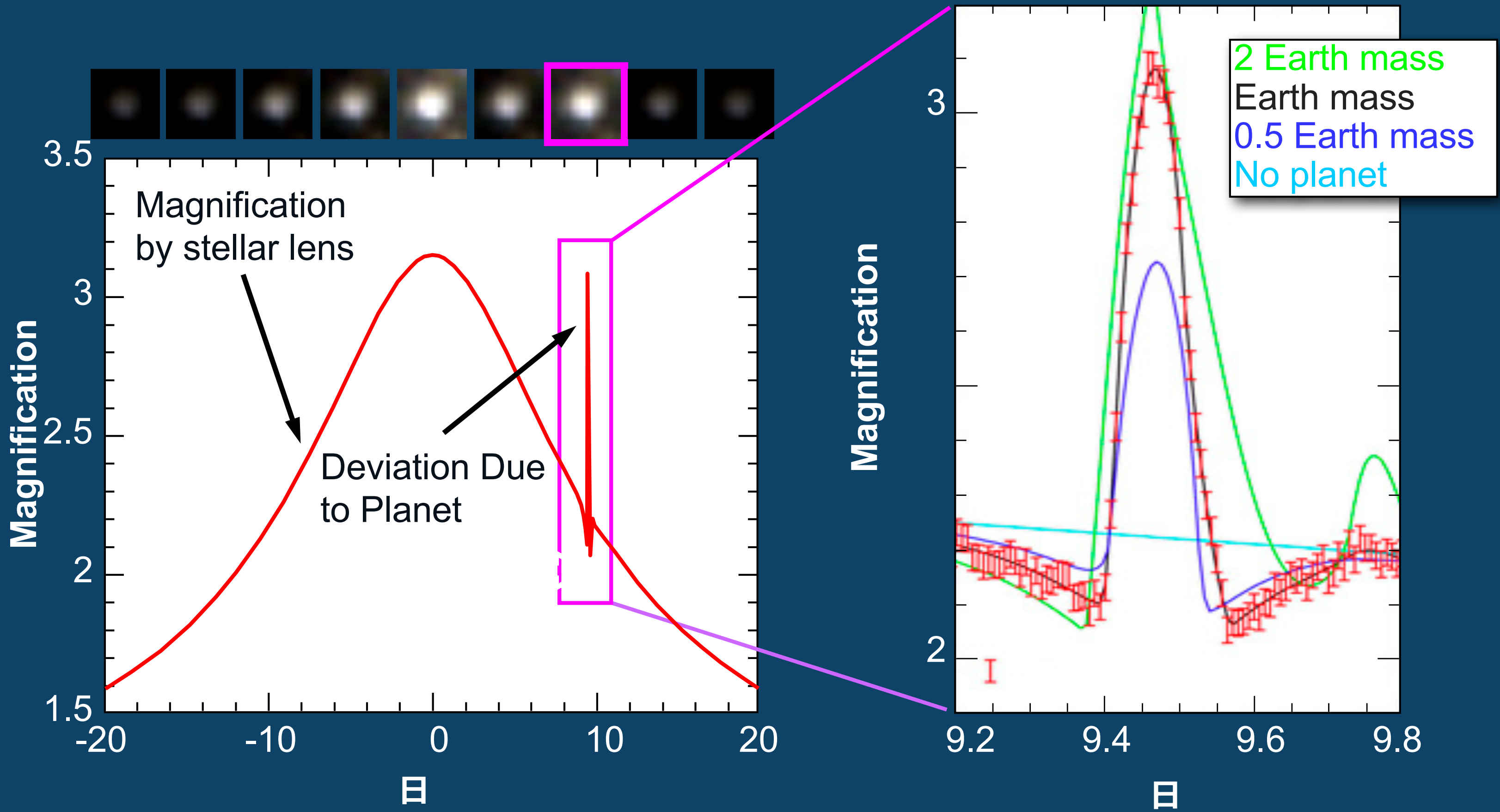


Microlensing exoplanet search





Earth mass planet by WFIRST

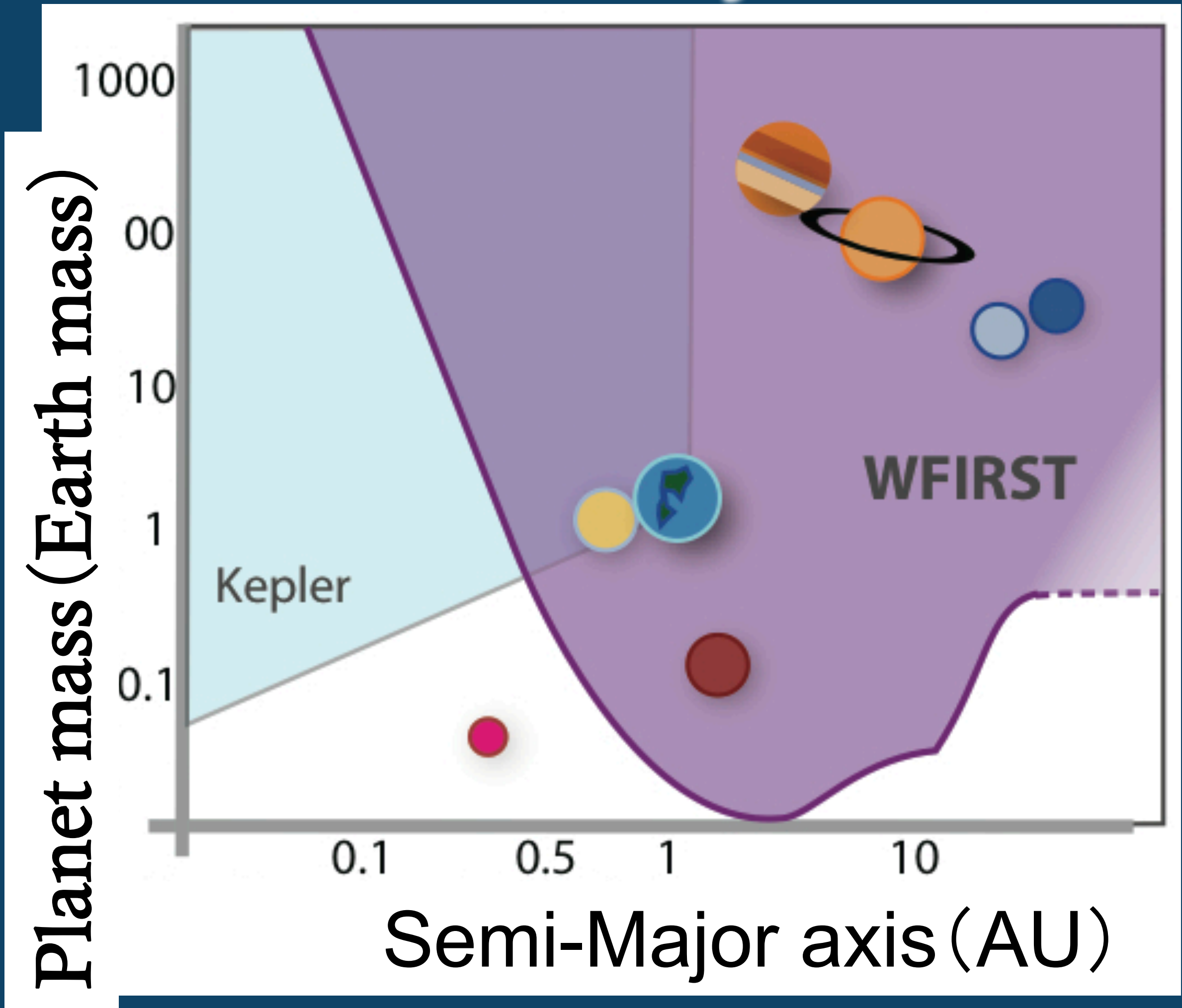


- 300M stars in 2.8 deg.^{2}in the GB
- 15min cadence in 24hrs, 72 days
- 6 seasons（1.2yr total）

4−5hr signal by Earh mass planet

Expect 3000 exoplantes
（~200 less than Earth mass）

Microlensing exoplanet search by WFIRST

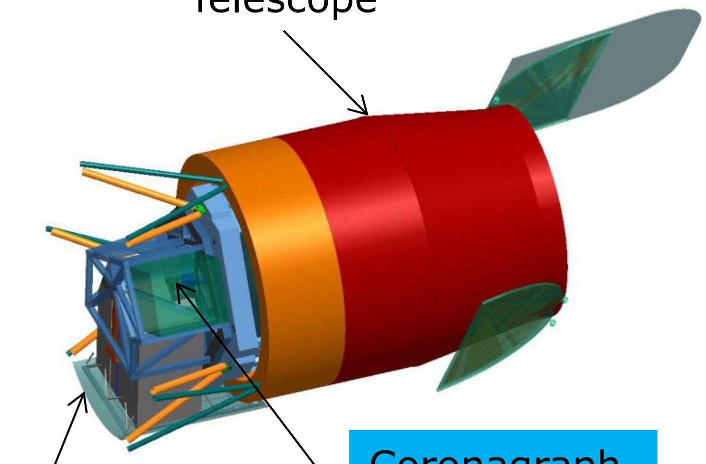


3000 exoplantes
（～200 with <M_E）

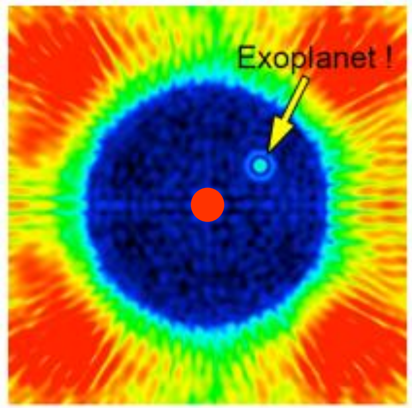
All solar system planets
Except mercury

Complete statistical census of Planetary Systems with Kepler

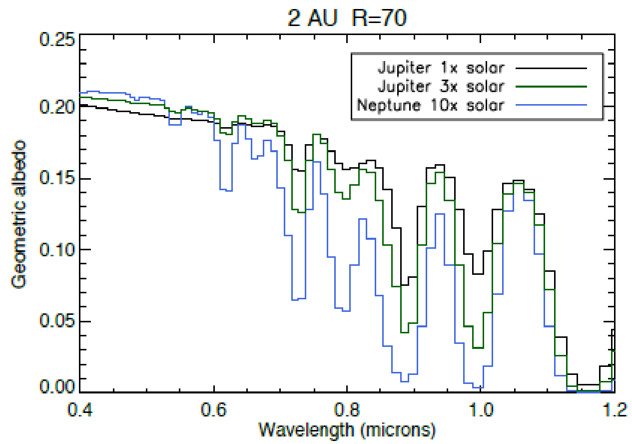
Coronagraph Instrument



Coronagraph Instrument



Exoplanet Direct imaging



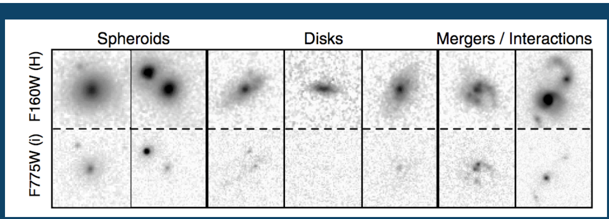
Exoplanet Spectroscopy

- 400–1000nm band pass
- 10^{-9} contrast
- 100 milliarcsec inner working angle at 400nm
- R=70 spectra and polarization at 400–1000 nm

- Image and spectra of Nearby gas giants, ice giants.
- Proto-planetary disk
- Technology demonstration for LUVOIR and HaBEX

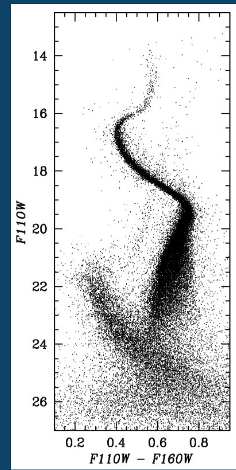
WFIRST Yields Summary

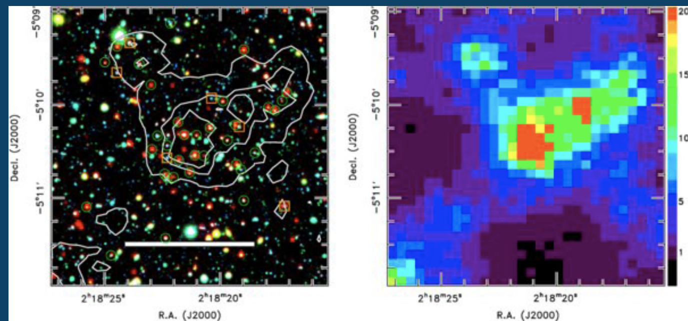
Attributes	WFIRST Yields
Imaging survey	J ~ 27 AB over 2000 sq deg
	J ~ 29 AB over 3 sq deg deep fields
Slitless spectroscopy	R~461λ over 2000 sq deg
Number of SN Ia SNe	2700 to z~1.7
Number galaxies with spectra	$2x10^7$
Number galaxies with shapes	$4x10^8$
Number of galaxies detected	few x 10^9
Number of massive clusters	$4x10^4$
Number of microlens exoplanets	3000
Number of imaged exoplanets	10s

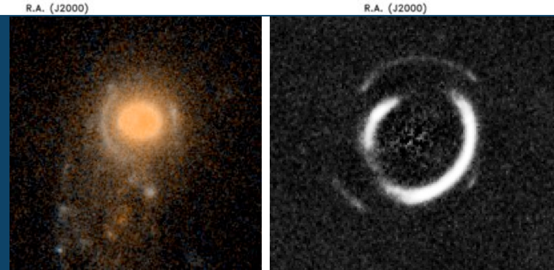


GO & Archive sciences

1. Open Cluster and Star Forming Region IMFs to Planetary Mass
2. Exoplanet via transit and Astrometry
3. High-precision IR CMDs of stellar populations.
4. Quasars as a Reference Frame for Proper Motion Studies (LMC,GB)
5. Proper Motions and Parallaxes of Disk and Bulge Stars (~10μas/yr)
6. White dwarfs.
7. Nearby Galaxies
8. Galaxy Structure and Morphology
9. Evolution of Massive Galaxies
10. Distant, High Mass Clusters of Galaxies
11. Obscured Quasars
12. Strongly Lensed Quasars
13. Strong Lensing
14. High-Redshift Quasars and Reionization
15. Faint End of the Quasar Luminosity Function
16. Probing the Epoch of Reionization with Lyman-α Emitters







WFIRST activity & schedule

- 2010/12, first WFIRST Science Definition Team(SDT), Japan rep. Sumi
- 2013/7, WFIRST-AFTA SDT, JAXA rep. Toru Yamada(ISAS)
- 2013/8, launch「WFIRST informal WG」
- 2014/2, WFIRST coronagraph WACO WG at JAXA
- 2015/3, SDT final report
- 2016/1, launch JAXA WFIRST WG(PI:Sumi)
- 2016/2, NASA started phase A.
- 2016/6, Toru Yamada became JAXA rep for NASA FSWG
- 2016/7 Subaru-WFIRST synergy obs. White paper
- 2017/9 proposal submitted to ISAS/JAXA.

- 2017/8～10, WIETR independent review
- 2017/11, descope plan submitted to HQ
- 2017/2/19, NASA WFIRST SRR(System Requirements Review), MDR (Mission Definition Review)
- 2018/3, President budget request to cancel WFIRST
- 2018/5, NASA WFIRST passed into phase B!
- 2018/5, $150M for WFIRST in house budget

SRR explain the flow from objective to requirement. MDR is reverse.

Japanese Contribution "Package" for WFIRST

■ JAXA WFIRST WG (PI：Sumi)

1. Subaru–WFIRST Synergy Survey
   (～100nights from 2025)
   1. photo-z calibration (PFS etc.)
   2. Narrow band filters (HSC etc.)

   2016/11：Director of Subaru telescope and Subaru SAC、agreed to the Commitment

2. Contribution to Coronagraph Instrument
   - Polarimetry capability
   - Development of Polarimetry Compensation Unit

3. Ka-band Data Downlink Station in Japan

4. Ground base microlensing data sharing (MOA)
   pre/concurrent Ground microlensing obs. with new 1.8m (PRIME)

Discussins on Subaru Synergistic Observations

- 2016/4, Workshop on synergy with Subaru and space missions
- 2016/7, Subaru-WFIRST synergy obs. White paper
- 2016/9, Support in GOPIRA symposium opt/IR community
- 2016/11, Subaru Telescope and Subaru Advisory Committee concluded the commitment
- 2016/11, Letter of Intent sent to Director of ISAS from Director of Subaru telescope. (cc: NASA HQ)
- 2017/1 Reported in Subaru Users' Meeting
- 2017/10 1st domestic meeting for synergy workshop(20participants)
- 2017/11/15 Second domestic meeting: (34 participants)
- 2017/12/18-20 WFIRST/Subaru synergistic workshop @Mitaka(>90participants,including 16 from US)
- 2017/1/19 Subaru UM. Report and discussion.
  NAOJ and JAXA prepare the Letter of Commitment
- 2018/12 2nd WFIRST/Subaru synergistic workshop

White paper Subaru-WFIRST synergistic observation

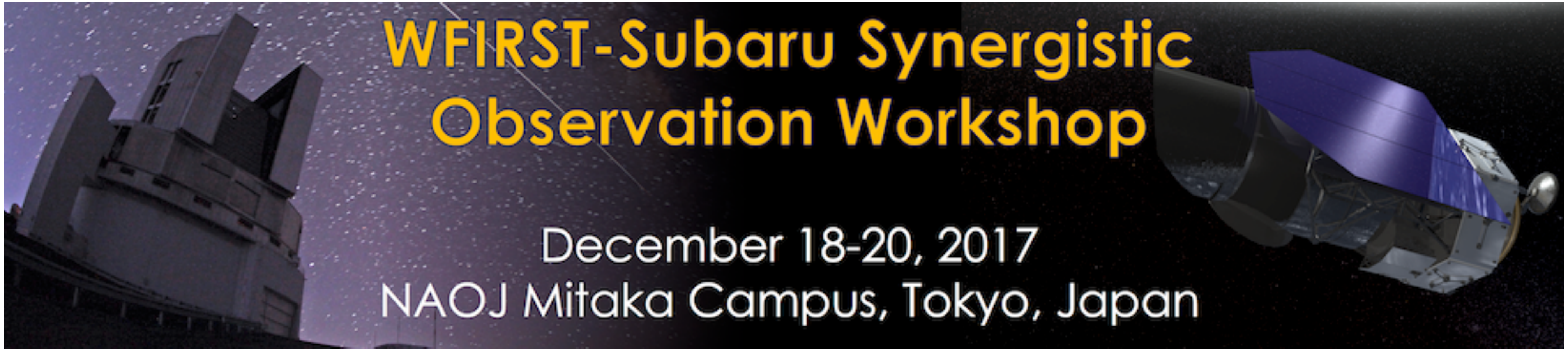
2016/5/15: call for white paper

30 proposals by 82 people

7/16, released at
http://iral2.ess.sci.osaka-u.ac.jp/~sumi/Subaru-WFIRST-Synergy.pdf

Science Program	Authors	HSC	PFS	IRD	SCE	ULT
Cosmology/Extragalactic Astrophysics						
Cosmology with large-scale structure probes	Takada+	○	○	–	–	–
Quasars in the Reionization Era	Matsuoka+	○	–	–	–	–
Finding and Characterizing high-z Clusters	Oguri	○	–	–	–	–
Searching for Bright Lensed high-z Galaxies	Oguri	○	–	–	–	–
Protoclusters across Cosmic Time	Toshikawa+	○	–	–	–	–
Protoclusters in the Reionization Epoch	Toshikawa+	○	–	–	–	–
Precise photo-z for Weak Lensing	Tanaka+	–	○	–	–	–
Low-Mass Galaxies at up to $z \sim 1.5$	Yabe+	○	○	–	–	–
Galaxy and IGM Co-Evolution	Ouchi+	○	○	–	–	–
Superluminous SNe at Reionization Epoch	Moriya+	○	–	–	–	–
Mass Assembly History of Galaxies since z=4	Kodama+	○	–	–	–	–
Galactic Astrophysics / Local Volume						
Milky Way Disk Flare behind the Bulge	Matsunaga+	–	–	–	–	○
Deep NIR Imaging of the Galactic Bulge	Nakada +	○	○	–	–	–
Hypervelocity Stars in the Galactic Bulge	Nishiyama	–	○	–	–	○
Dark Matter on Dwarf Spheroidal Galaxies	Hayashi+	–	○	–	–	–
Structure of the Galactic Outer Stellar Disk	Toyouchi+	–	○	–	–	–
Stellar Astrophysics						
Low-Mass End of the Initial Mass Function	Tomida	○	○	○	–	–
Bulge Stellar IMF & Low Mass Close Binary	Ita	–	○	–	–	–
Dust Condensation Region around AGB Stars	Ueta+	–	–	–	○	–
Properties of the Bulge Dwarfs by IR Spectra	Fukui+	–	–	○	–	○
Solar System						
Surface Characterization of TNOs	Terai	○	–	–	–	–
Water Ices in the Inner Solar System	Yoshida	○	–	–	–	–
Exoplanets						
Probing Dust Grains in Circumstellar Disks	Muto	–	–	–	○	–
Polarimetry of Planets/Protoplanetary Disks	Murakami+	–	–	–	○	–
Exoplanets Search by Astrometry	Yamaguchi+	–	–	–	○	–
Extinction in WFIRST Microlensing Fields	Suzuki+	○	–	–	–	–
Concurrent Microlensing Observations	Suzuki+	○	–	–	–	–
Imaging of Microlensing Planetary Hosts	Fukui+	–	–	–	○	○
Characterization of Transiting Exoplanets	Narita	–	–	○	–	–
Exoplanets around Late-M Dwarfs	Kuzuhara+	–	–	○	–	–

Note. — SCE and ULT indicate the SCExAO and the ULTIMATE-Subaru, respectively.



Organized by JAXA WFIRST WG, Hawaii observatory, NASA WFIRST FSWG

Participants:>90, including 16 from US, WFIRST FSWG, SIT

2018/12 2nd WFIRST/Subaru synergistic workshop

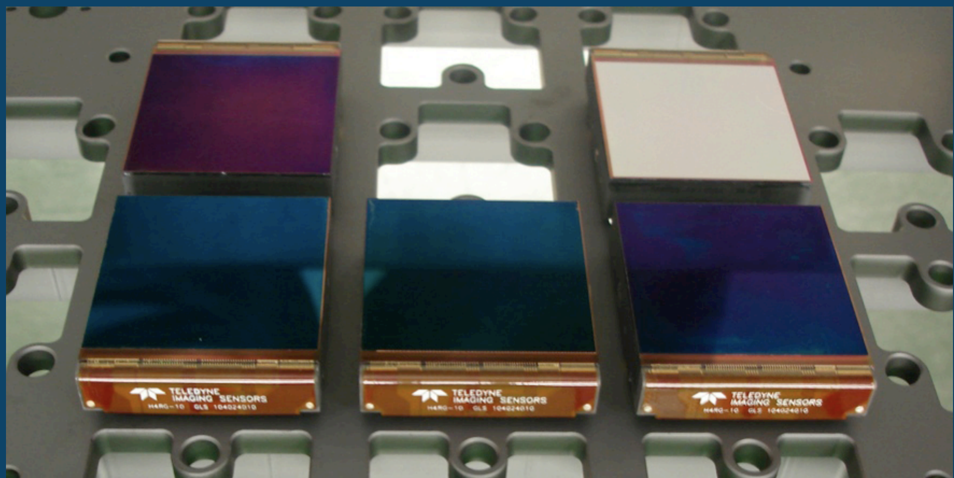
PRIME (PRime-focus Infrared Mirolensing Experiment)

Funded by JSPS

Diameter: 1.8m, (f/2.29)

FOV : 1.3 deg^2, (6 x full moon)

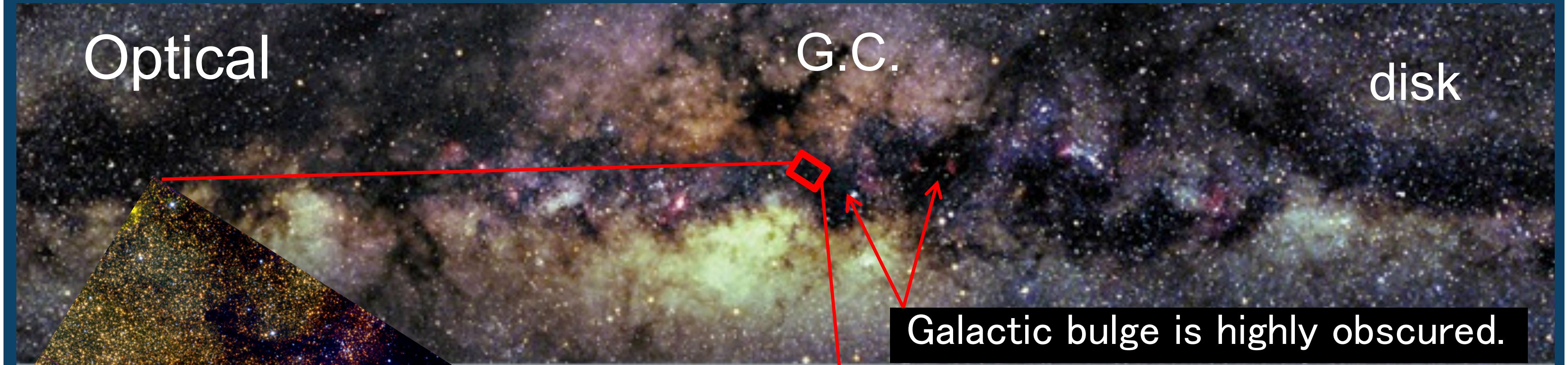
Largest FOV in IR

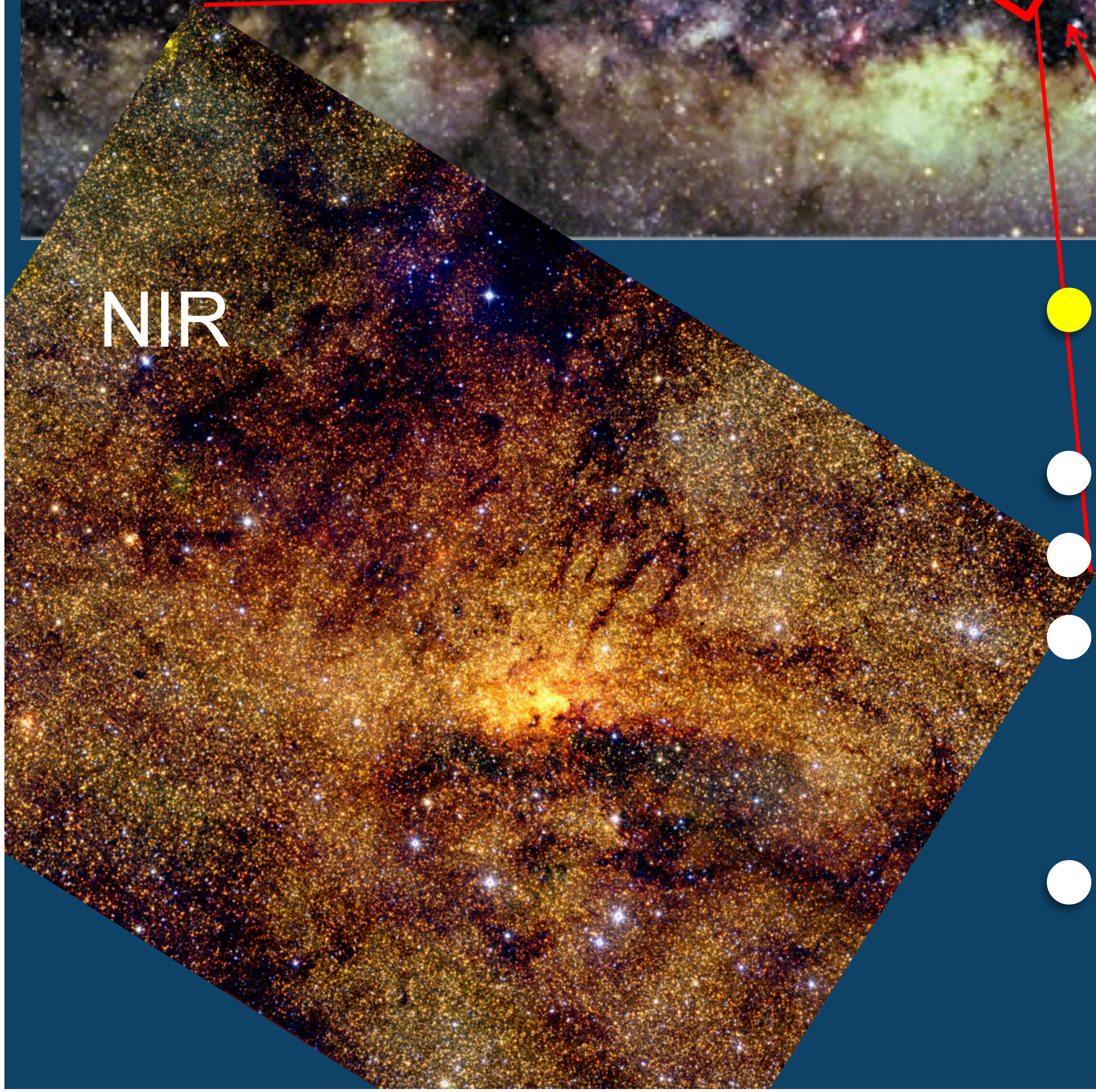


World Largest class NIR camera by using four 4kx4k H4RG arrays loaned from WFIRST team

Current status of telescope

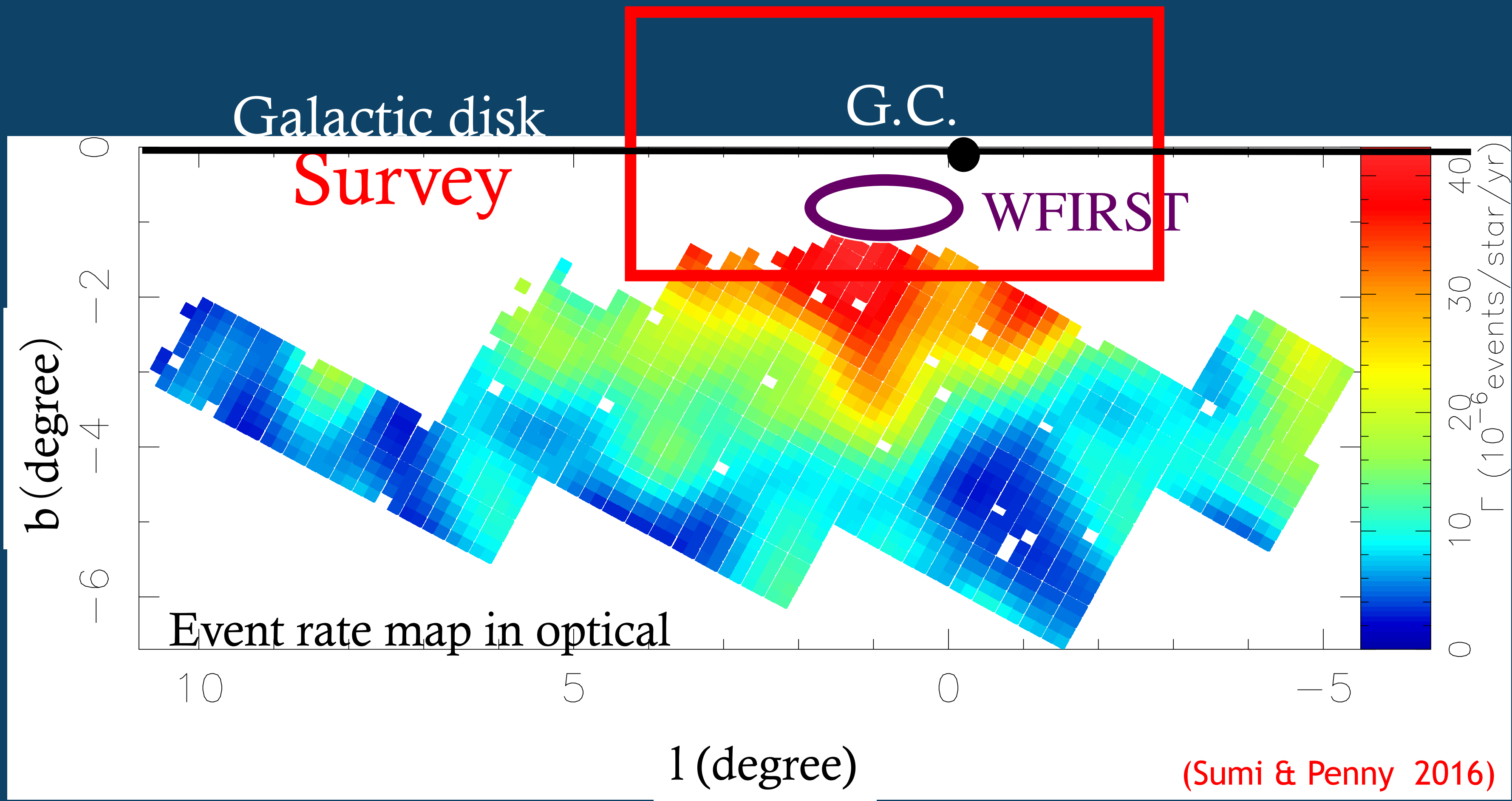
More events & planets in NIR at G.C.



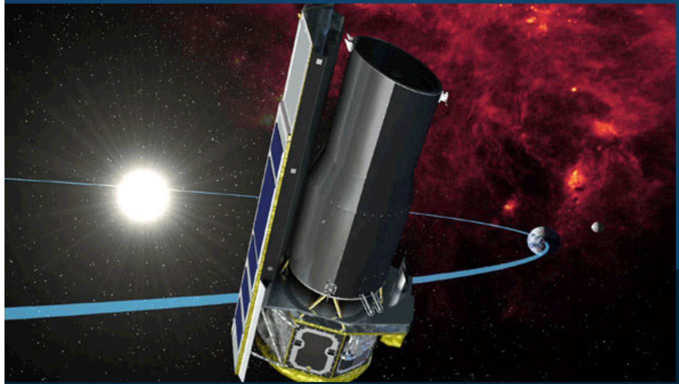


- More stars & more events at GC.
- Planet frequency at GC.
- Select WFIRST fields.
- Simultaneous observation with WFIRST to measure lens mass.
- Mass Function at GC (planet–Black Hole)

Study the galactic structure & Optimize WFIRST microlensing survey fields by mapping the event rate in NIR

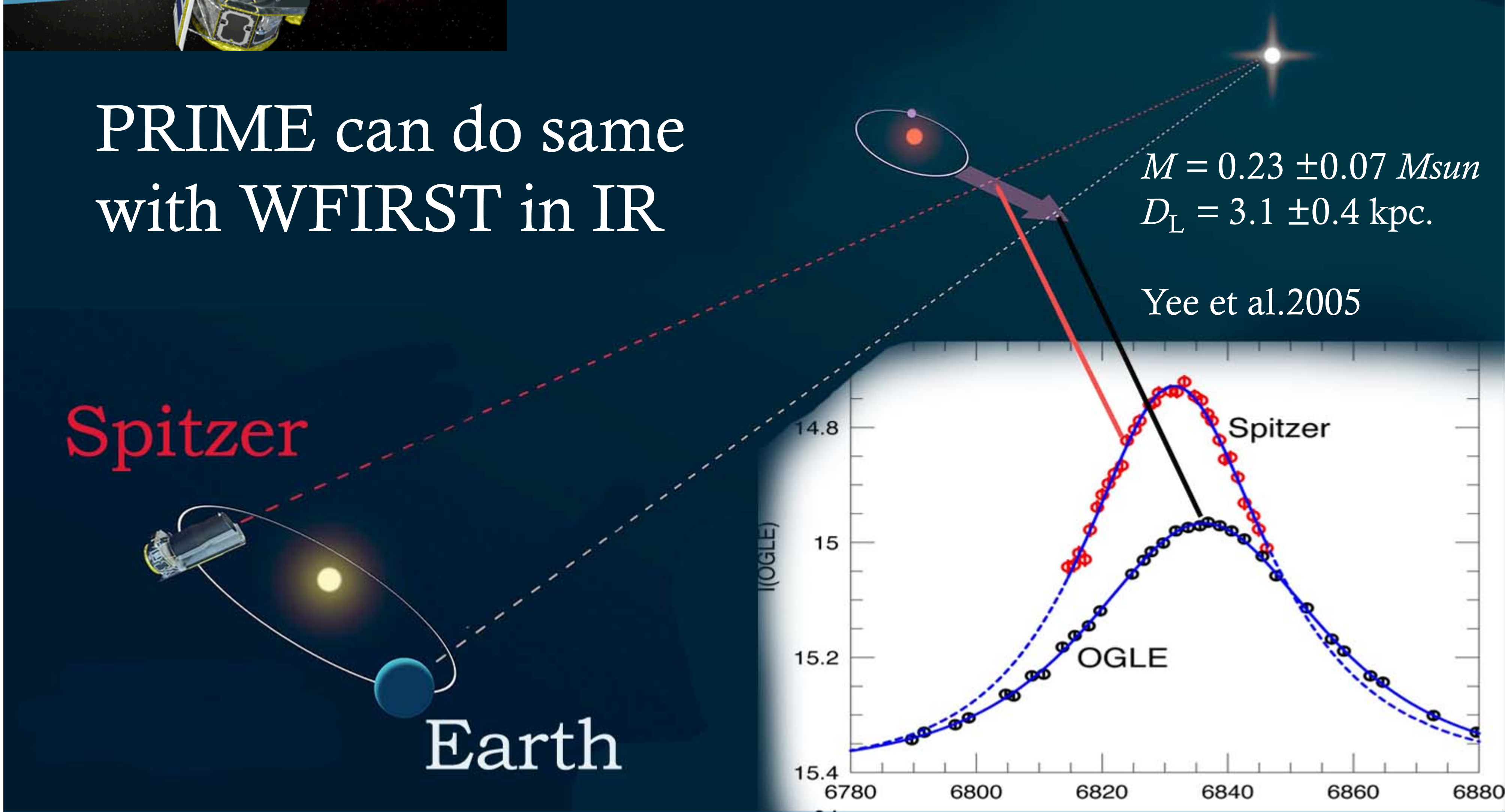


Event rate vary by a factor of 2 (peak is at l=1°)



Simultaneous Ground-Space monitoring to measure lens mass

PRIME can do same with WFIRST in IR



Off-bulge season sciences
50% of time

- Transit search for M-dwarfs

- Search for counterparts of high-z GRB, GW.

- WFIRST calibration

- H-band spectrograph: RV for giant planets around M-dwarf.

Welcome NEW idea!

Summary

● WFIRST will study Dark Energy/Modified Gravity, exoplanets with massive statistics

● GO program →anyone in all field can join
→complimentary to SPICA, TMT

●Japanese contributions

1) Subaru synergitic survey ready
2) Ground microlensing data and survey ready
3) Coronagraph hard ware on going
4) Ground station on going

Proposal submitted to JAXA (戦略的海外協同計画)

Welcome to join.