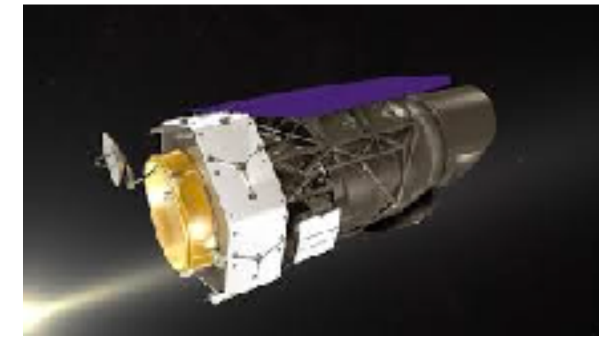

WFIRST High Latitude Survey

and Synergies with Ground-based Surveys

Chen Heinrich
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Cosmo2018, Daejeon, South Korea

High Latitude Survey SIT Team

Yun Wang, David Weinberg,

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Rachel Bean (Cornell)

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Christopher Hirata (Ohio State, Weak lensing lead)

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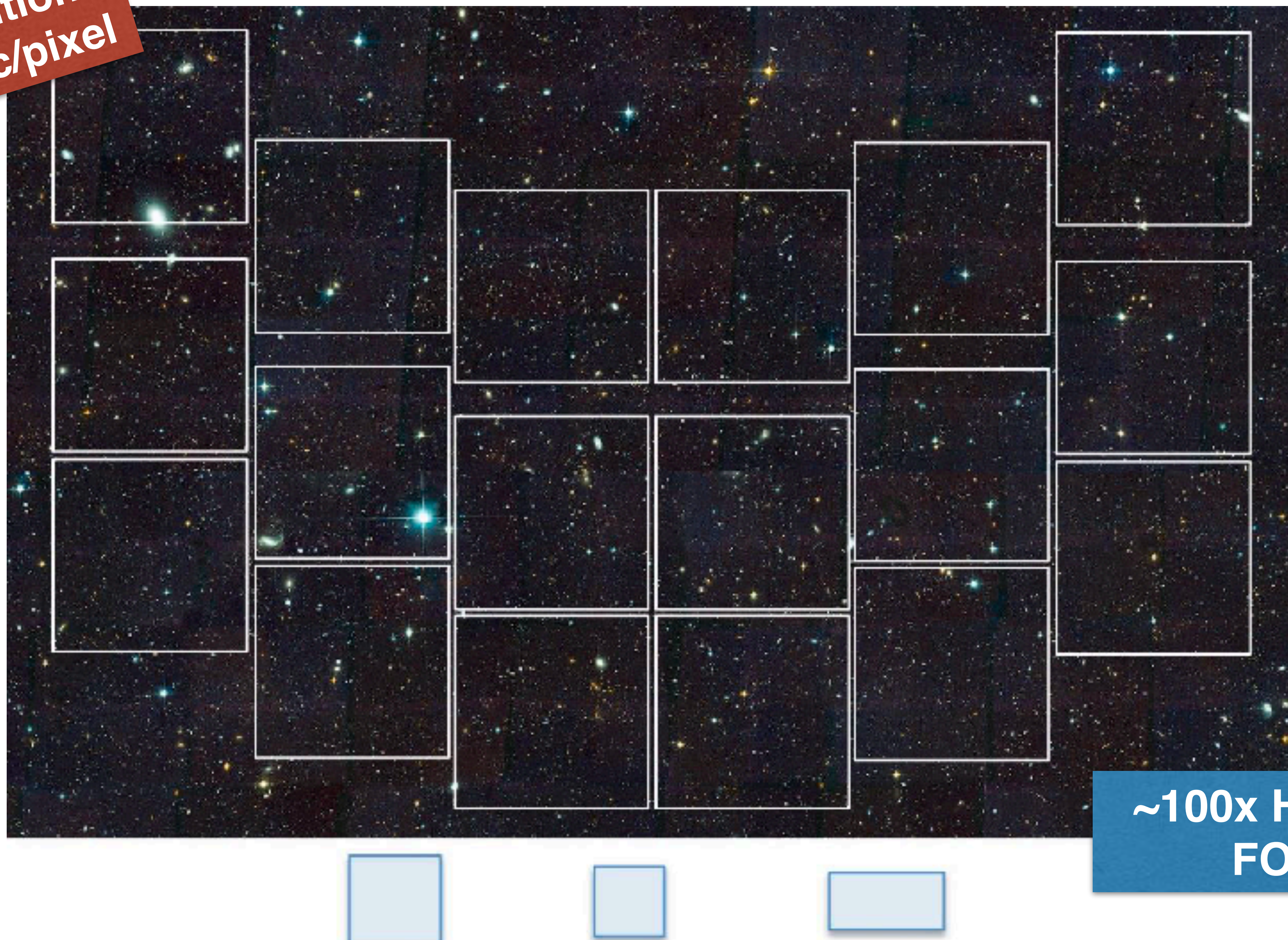
WFIRST = Wide-Field Infrared Survey Telescope

Primary mirror: https://wfirst.gsfc.nasa.gov/gallery-photos.html

Large Field of View: 0.28 deg^2

High resolution: 0.11 arcsec/pixel



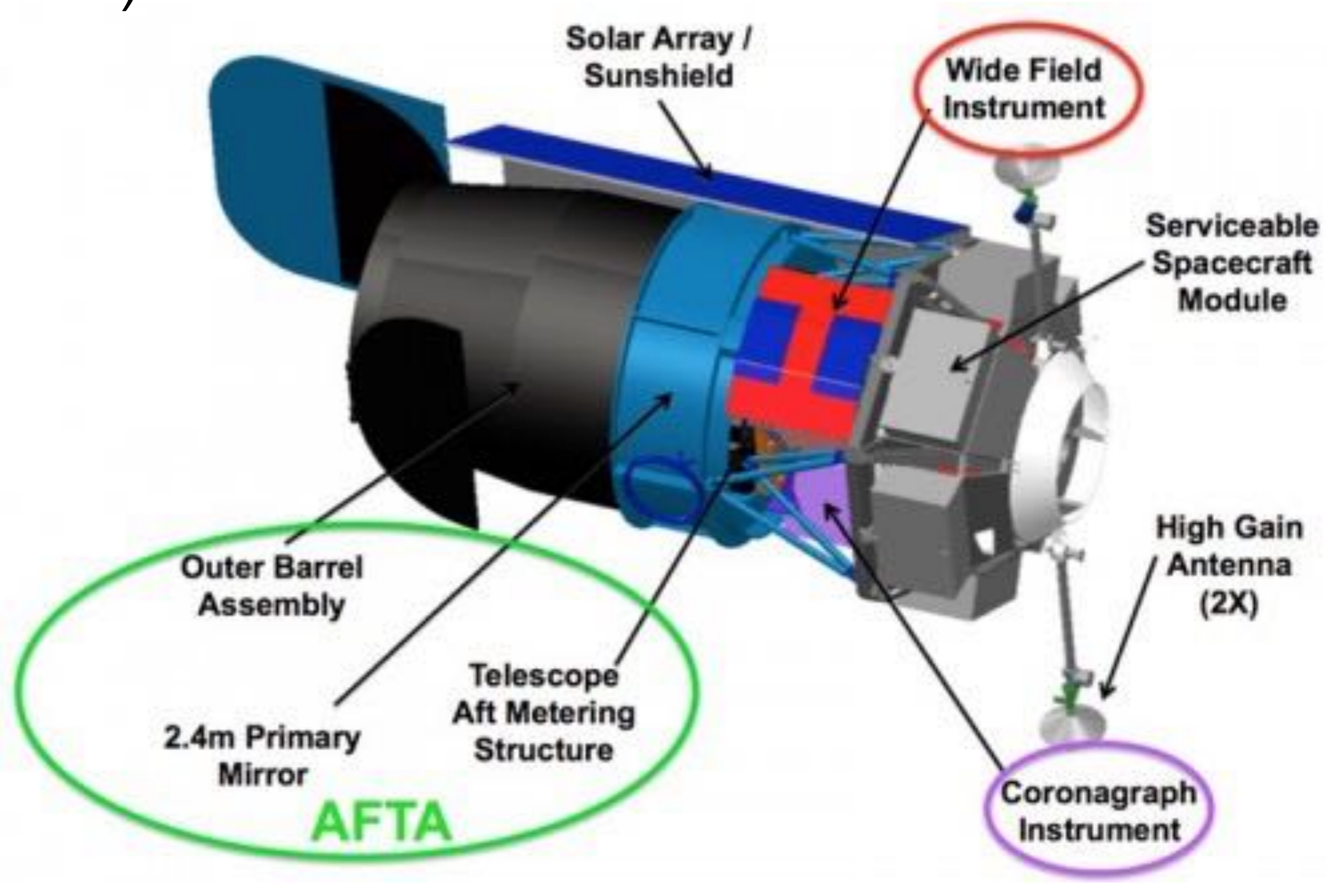
~100x Hubble FOV

6 x 3 array of 4k x 4k HgCdTe detectors

Wide-Field Infrared Survey Telescope (WFIRST)

- **Wide** field of view (~100 x Hubble)
- **Near-infrared** observations
- 2.4m primary mirror
- Launch in 2025
- 5 years nominal mission

Wide-field instrument



Coronagraph Instrument

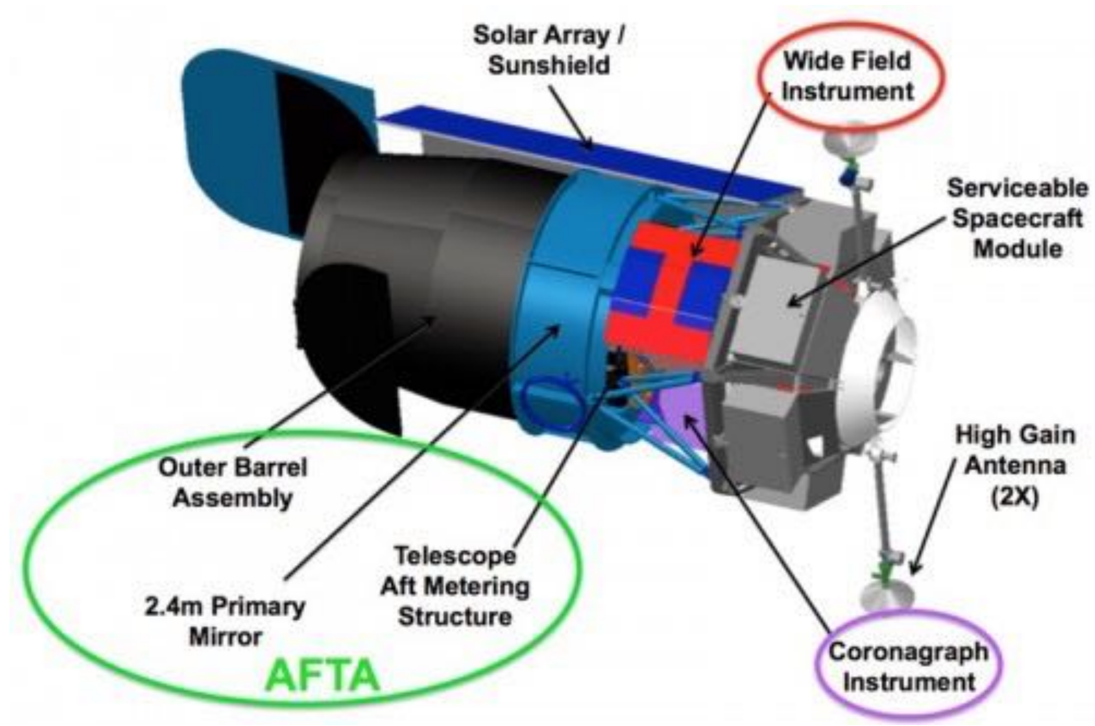
***Science**: dark energy, exoplanets, infrared astrophysics*

WFIRST Instruments

Wide-Field Instrument

- Imaging + spectroscopy over 2000 deg^2
- 0.11 arcsec/pixel resolution
- Imaging: 0.7 - 2.0 μm , 7 filters
- Spectroscopy: 1.35 - 1.95 μm (grism)
- Microlensing survey for exoplanets
- SN search and monitoring

Wide-field instrument



Coronagraph Instrument

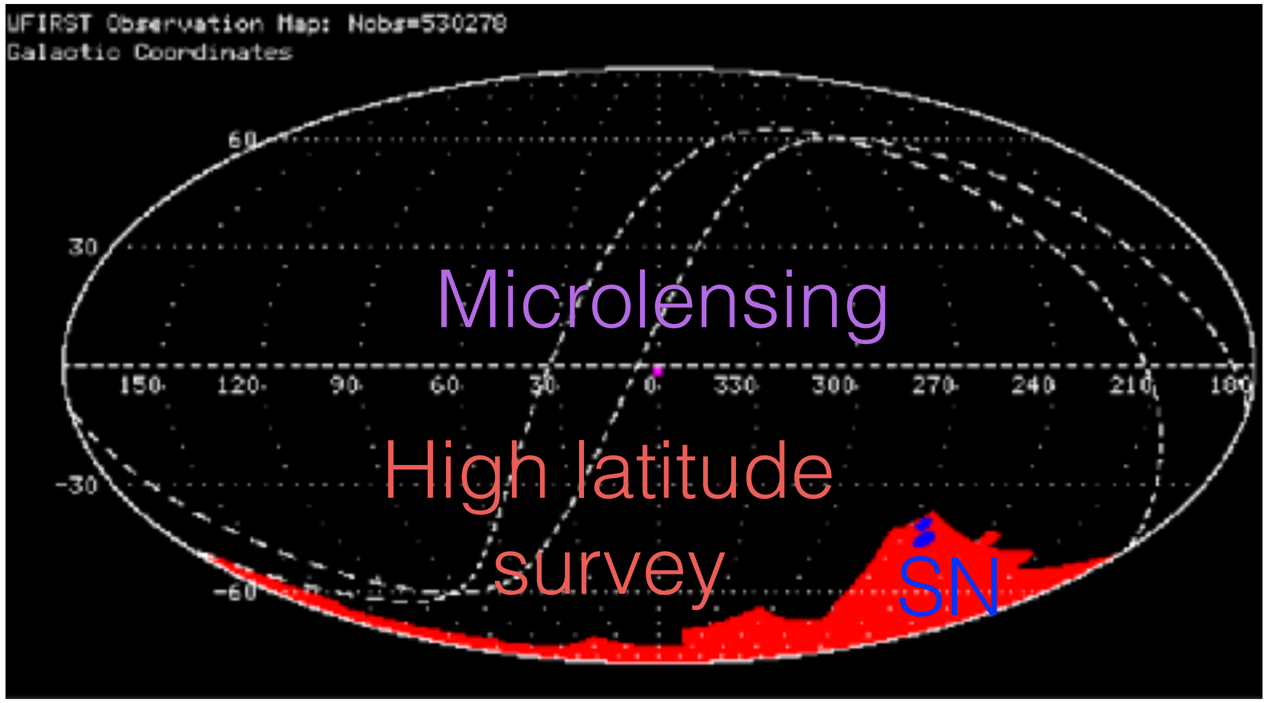
Coronagraph

- Image and spectra of exoplanets
- 430 - 970 nm (imaging), 600 - 970 nm (spec.)

WFIRST

Wide-Field Instrument

- High latitude survey (~1.5 years)
- Microlensing survey (~1 years)
- Supernova survey (~0.5 years)



All data public after they are taken

Coronagraph

- Coronagraph science program (0.3 year)

Guest observer program (~1.5 years)

***Science**: dark energy, exoplanets, infrared astrophysics*

Nominal mission strategy still in flux; flexible for follow-up on LSST, DESI, etc.

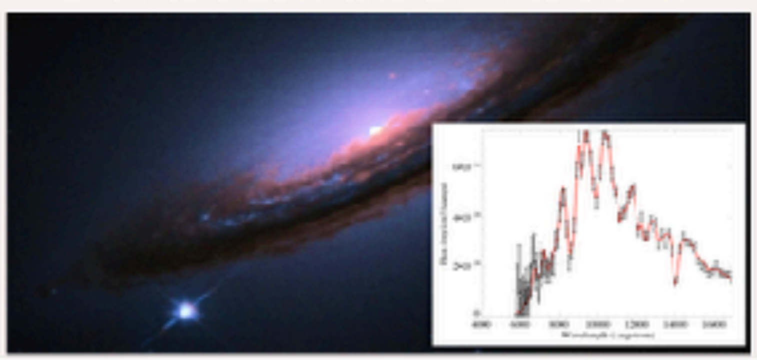
WFIRST Dark Energy Roadmap

Supernova Survey

wide, medium, & deep imaging

2700 type Ia supernovae
$z = 0.1–1.7$

standard candle distances
$z < 1$ to 0.20% and $z > 1$ to 0.34%



High Latitude Survey

spectroscopic: galaxy redshifts

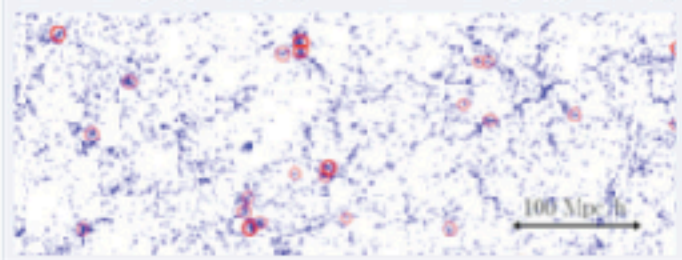
16 million Hα galaxies, $z = 1–2$
1.4 million [OIII] galaxies, $z = 2–3$

imaging: weak lensing shapes

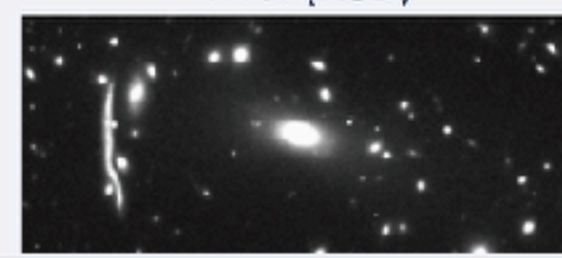
380 million lensed galaxies
40,000 massive clusters

standard ruler

distances	expansion rate
$z = 1–2$ to 0.5%	$z = 1–2$ to 0.9%
$z = 2–3$ to 1.3%	$z = 2–3$ to 2.1%

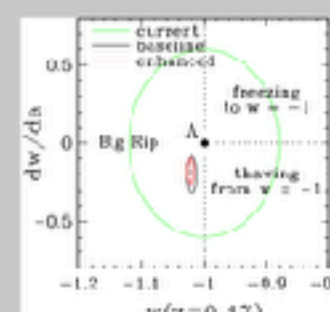


dark matter clustering
$z < 1$ to 0.21% (WL); 0.24% (CL)
$z > 1$ to 0.78% (WL); 0.88% (CL)
1.1% (RSD)

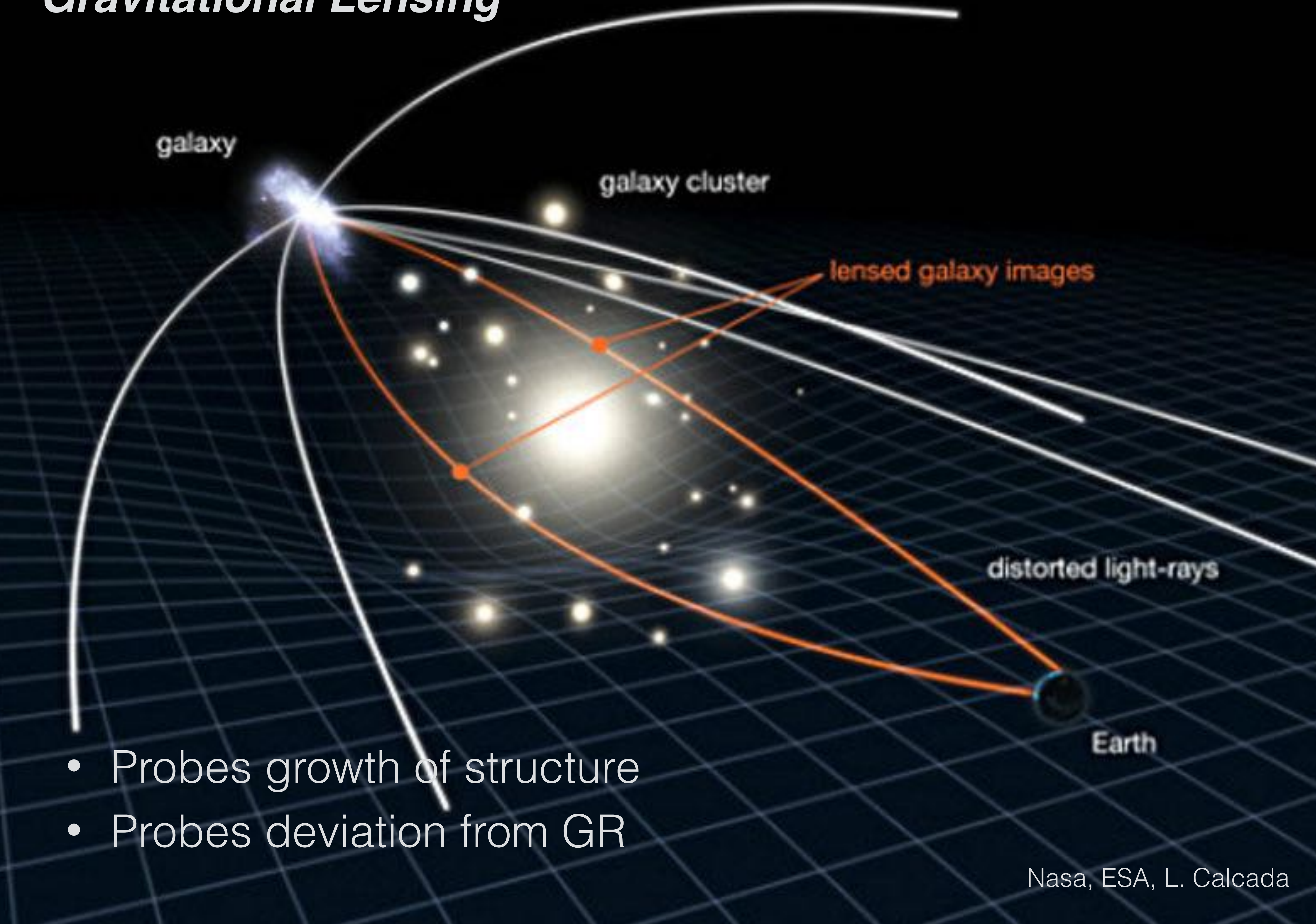


history of dark energy
+
deviations from GR

$w(z)$, $\Delta G(z)$, Φ_{REL}/Φ_{NREL}



Gravitational Lensing



- Probes growth of structure
- Probes deviation from GR

Nasa, ESA, L. Calcada

HLS Imaging

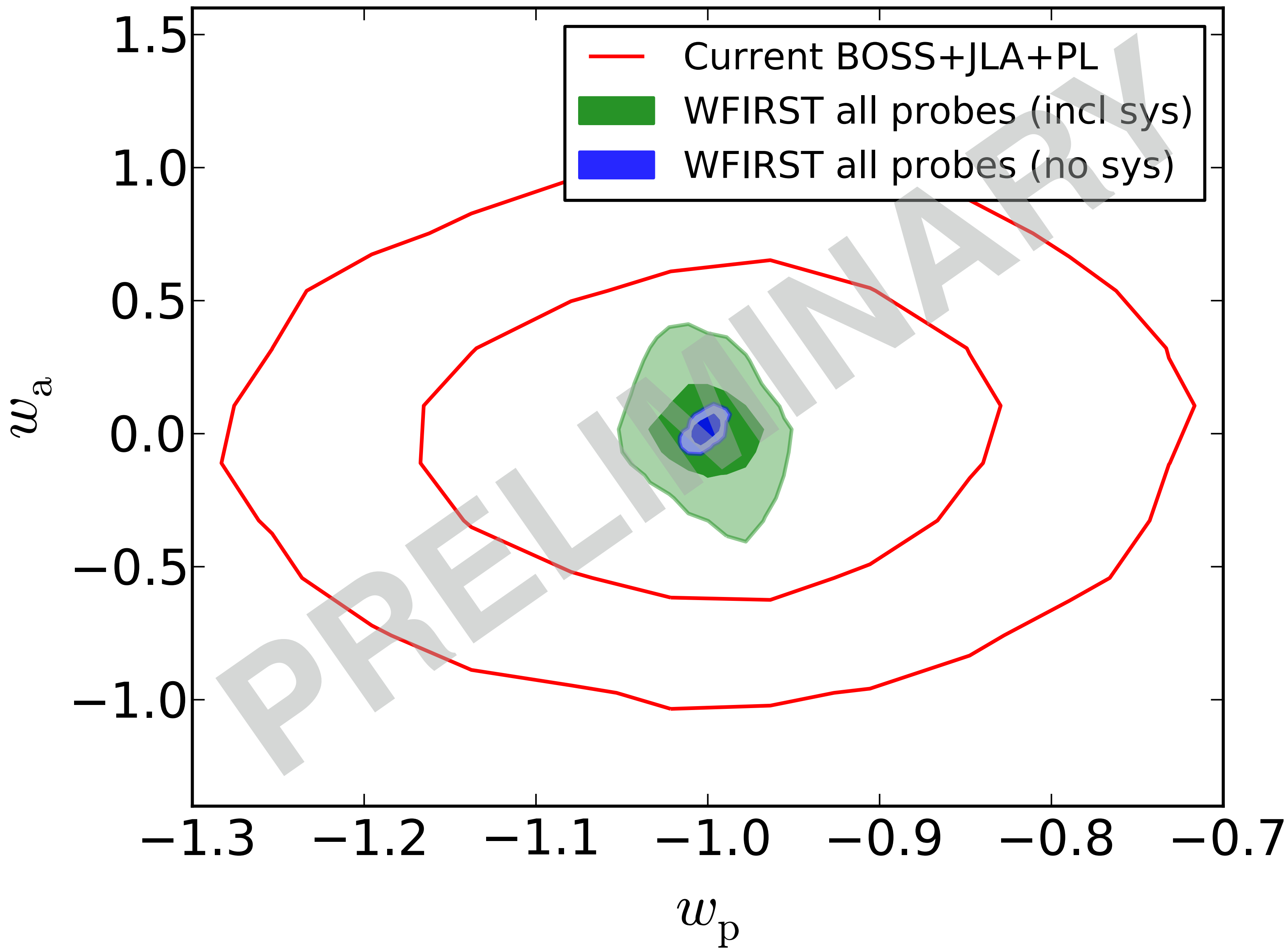
Weak lensing of galaxies

- Data: position, redshifts for lens & source galaxies; + shape for source galaxies
- Probes: 3 x 2 point functions (cosmic shear, galaxy-galaxy lensing, galaxy clustering)
- Constrains growth of structure, deviation from GR.

Galaxy clusters

- Data: position, redshifts, optical richness (proxy for mass)
- Probes: cluster number counts (4 z bins, 7 richness bins); cluster x source galaxies
- Constrains growth of structure

WFIRST HLS (nominal survey)
+ External (BOSS+JLA+Planck)



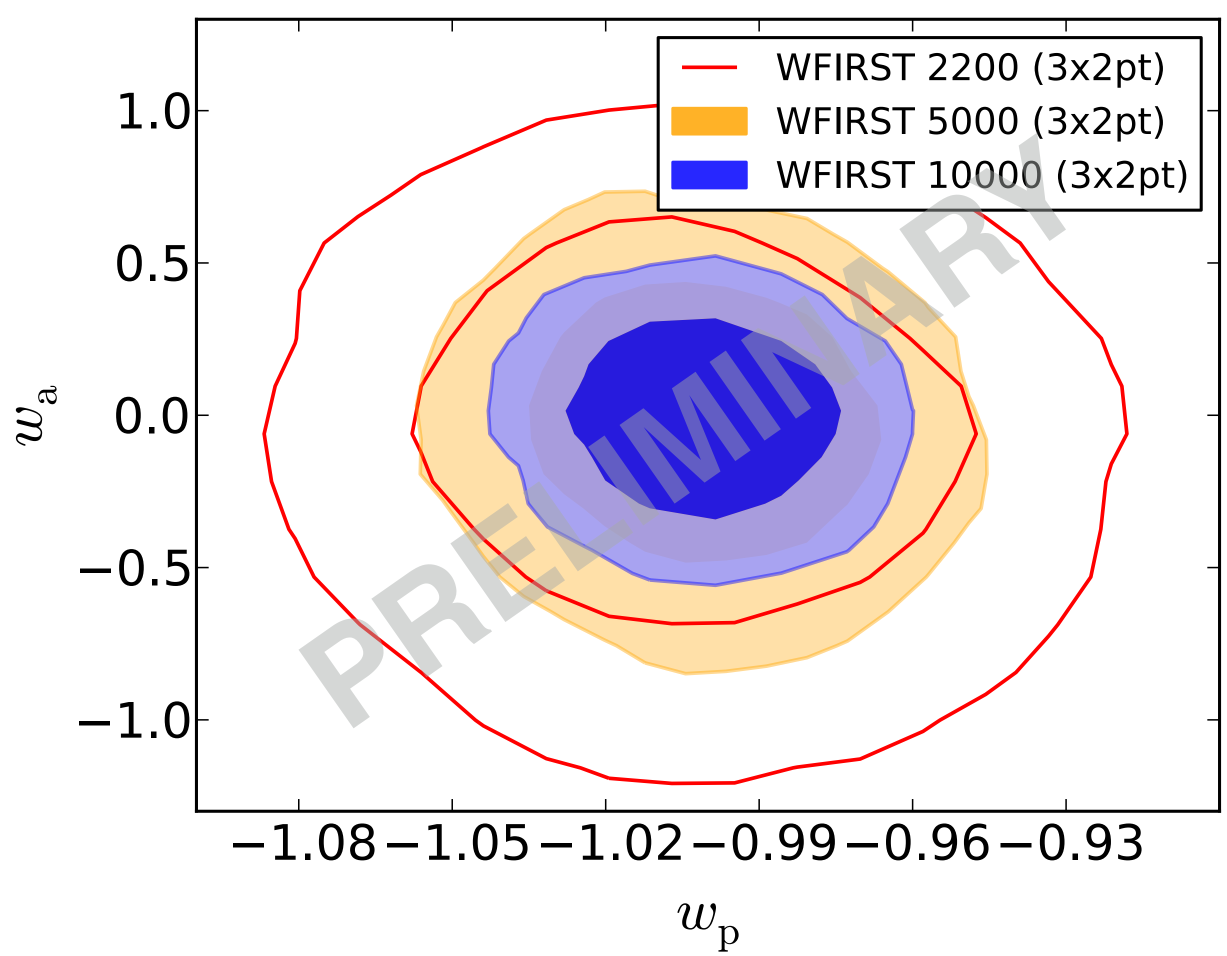
Measurement uncertainties: e.g. redshift, galaxy velocities, etc.
Modeling uncertainties: e.g. galaxy bias, cluster mass-richness relation, etc.

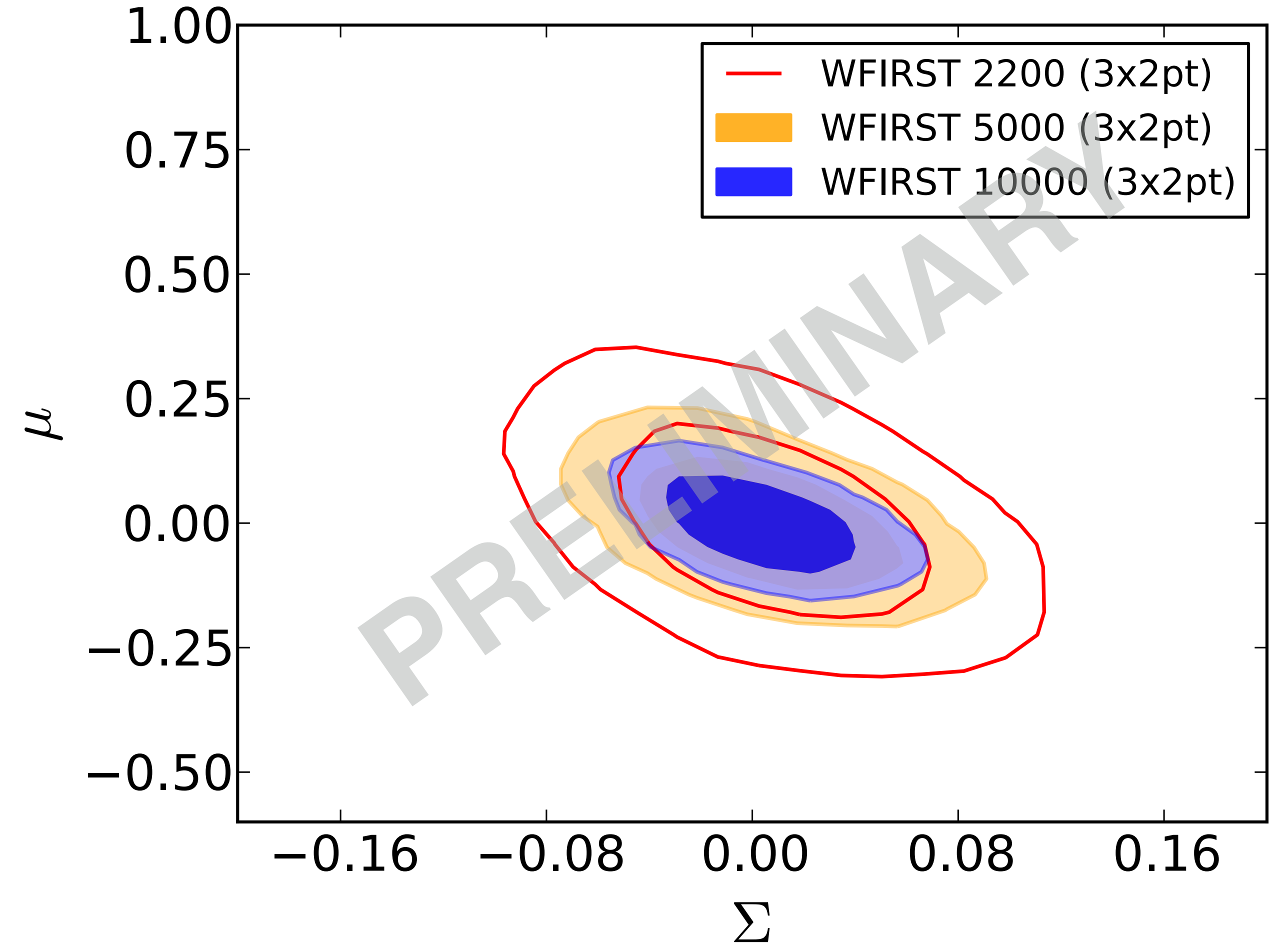
Eifler et al. incl. **CH** (in prep.)

WFIRST — Extended survey

- Nominal survey: 5 years
- Extended survey: can be up to 10 years
- Extension can also become nominal survey if high priority
- What science can we do in an extended survey?

HLS Imaging (weak lensing) — Extended survey

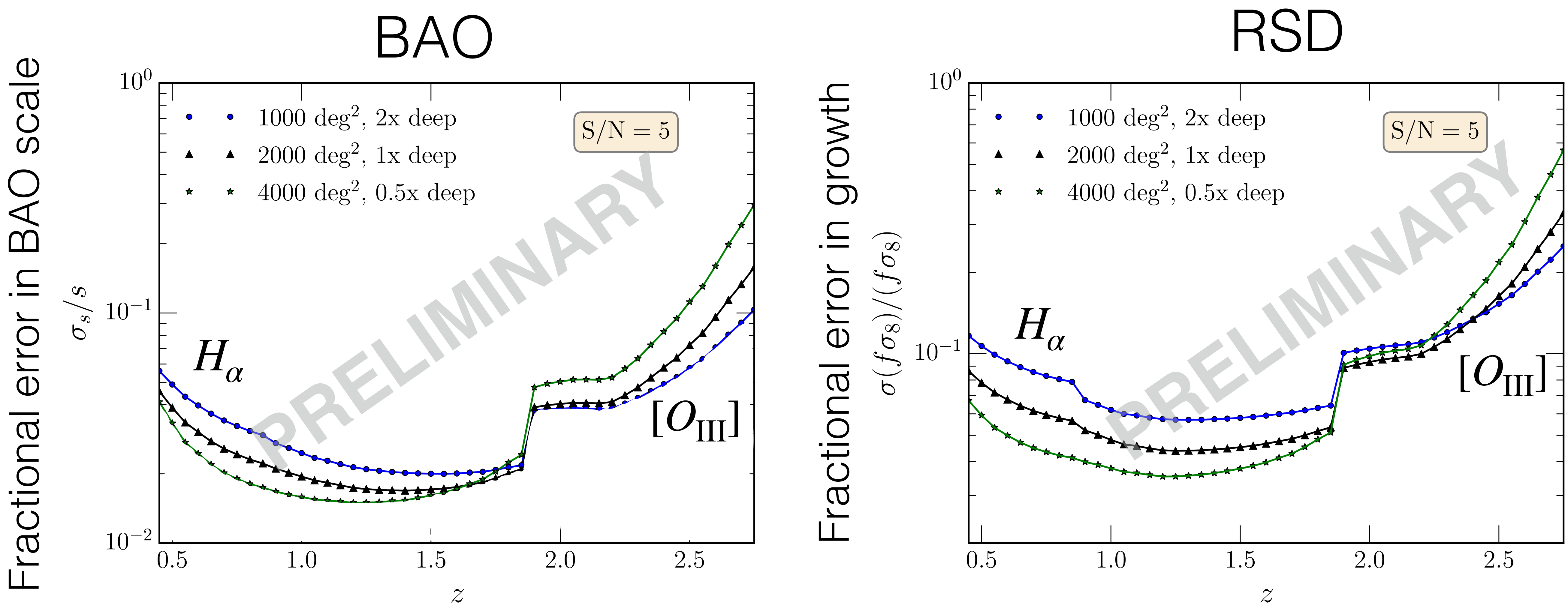




Eifler et al. incl. **CH** (in prep.)

HLS Galaxy Redshift Survey

(vary depth, area for fixed time)



Low-z: better w/ **wider** and shallower survey

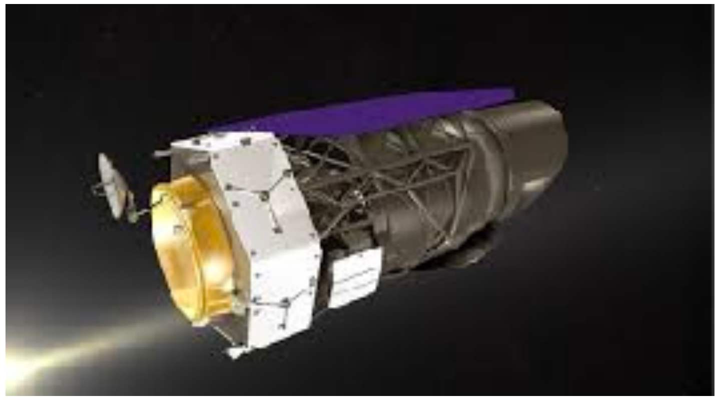
High-z: better w/ **deeper** and narrower survey

Eifler et al. incl. **CH** (in prep.)

WFIRST

Powerful and versatile instrument able to address relevant cosmological questions after LSST and DESI

- E.g. WFIRST could do the 6 years of Euclid spectroscopy in 1 year
- E.g. WFIRST could cover LSST footprint to LSST depth with 1 band in 1 year
- Extended mission can target specific questions
- Designed to be highly synergistic

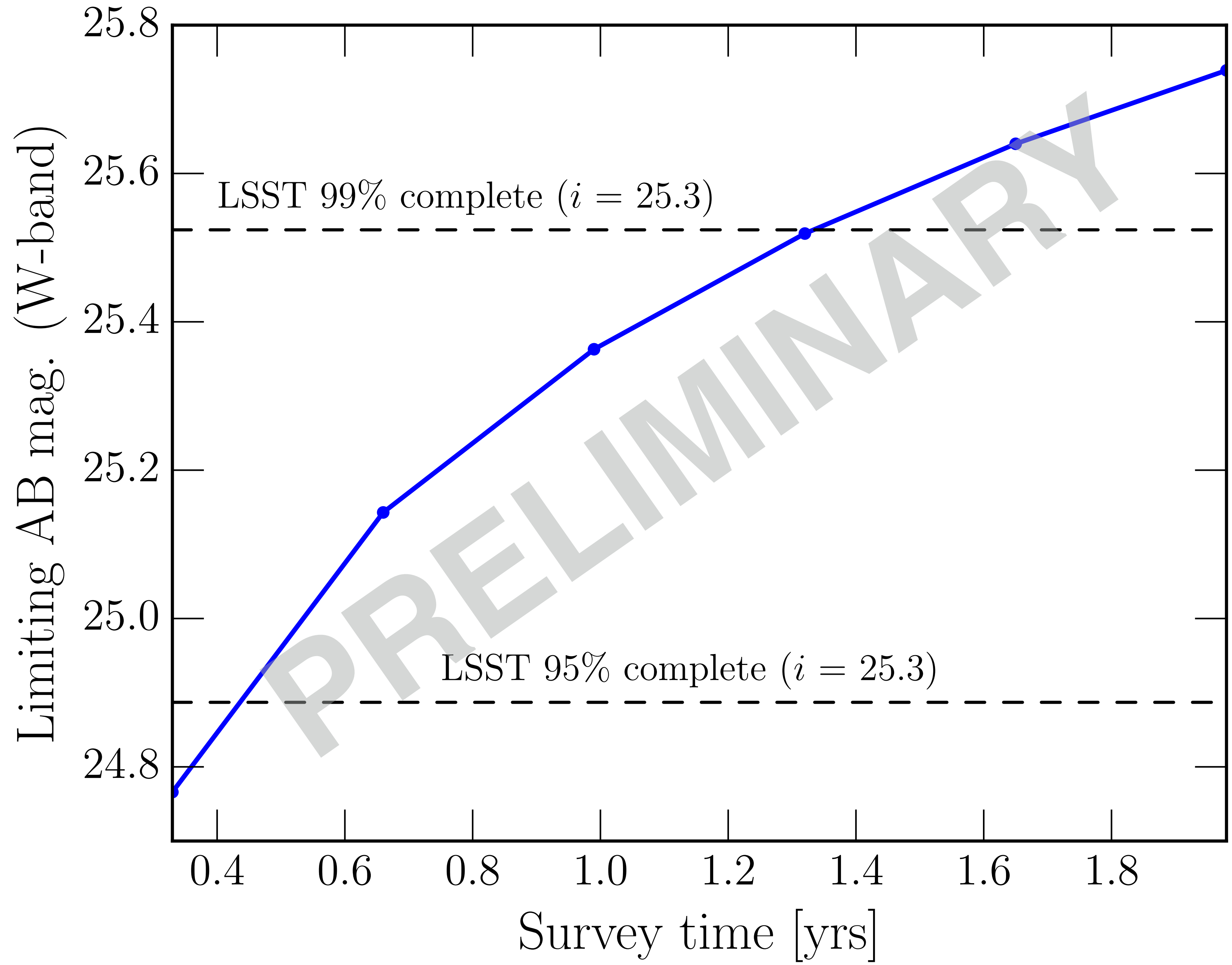


	DESI	Euclid	LSST	WFIRST
Start, duration	2019, 5yr	2021, 6yr	2022, 10yr	~2025, 5(-10)yr
Area (sq. deg.)	14,000 (N)	15,000 (N+S)	20,000 (S)	2,000 (S)
FOV (sq.deg.)	7.9	0.53	10	0.281
Mirror diameter (m)	4	1.3	6.7	2.4
Spectroscopic Survey	Fibers R=2000-5500 0.36-0.98 μm	Grism R=250 1.25-1.85 μm		Grism R=461λ 1-2μm
Spectroscopic Galaxies	LRGs + ELGs z~0.6-1.6 (20M-30M)	ELGs: z~0.9-1.8 (~30M)		ELGs: z ~ 1-2 Ha (~20M) z ~ 2-3 [OIII] (~2M)
Photometric Survey		4 bands (YJH+VIS)	6 bands (urgizY)	4 bands (YJH+F184)
Photometric Galaxies (/w shapes) (#/arcmin^2)		~30 in 1 band (VIS)	~30 in 6 bands (ugrizY)	~45 in 3 bands (YJH)
SN1a			10k-100k/yr z=0-0.7 photometric	2700 z=0.1-1.5 IFU spectroscopy

Synergies with LSST

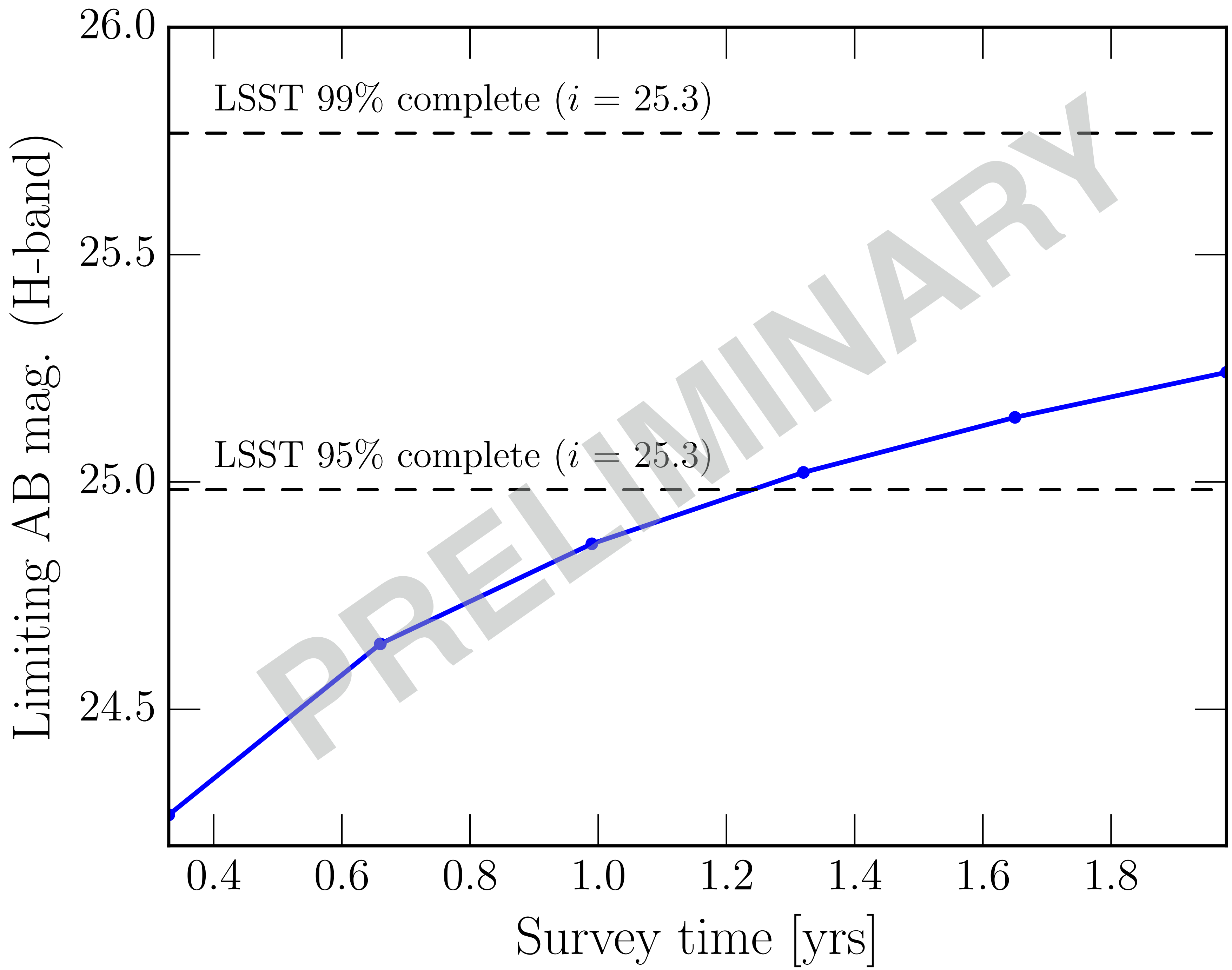
- LSST: 6 optical bands; WFIRST: 4 near-infrared bands
- LSST: photometric redshift
- WFIRST: galaxy shapes
- What if WFIRST + LSST:
    - similar depth
    - large overlap of detected galaxies

With W-band, WFIRST can do all of LSST area to LSST depth (99% i-band) in **1.3 years**



Eifler et al. incl. **CH** (in prep.)

With H-band, WFIRST can do all of LSST area to most of LSST depth (95% i-band) in **1.3 years**

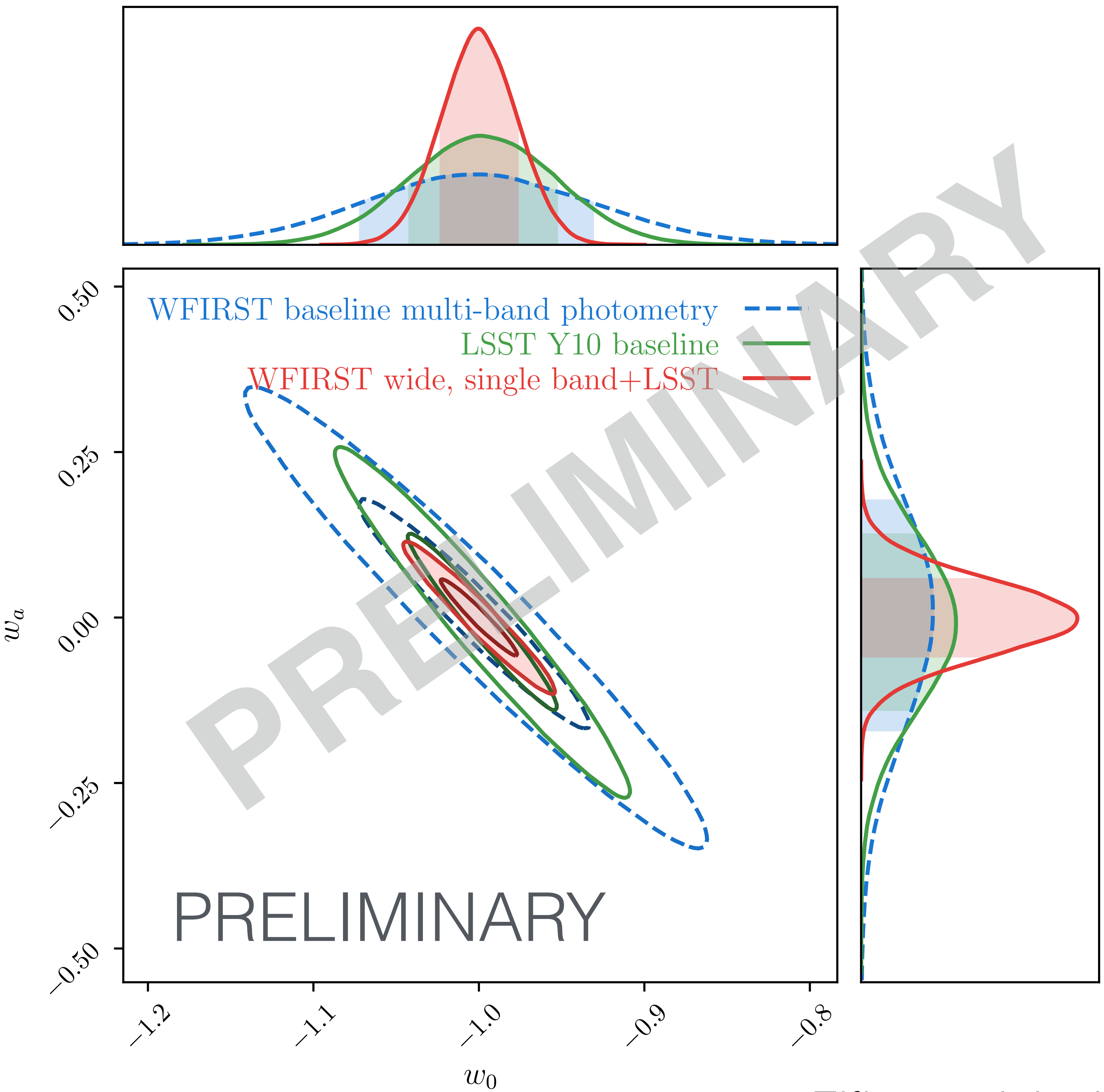


Eifler et al. incl. **CH** (in prep.)

A powerful instrument

WFIRST: shapes

LSST: photo-z



Eifler et al. incl. **CH** (in prep.)

Summary

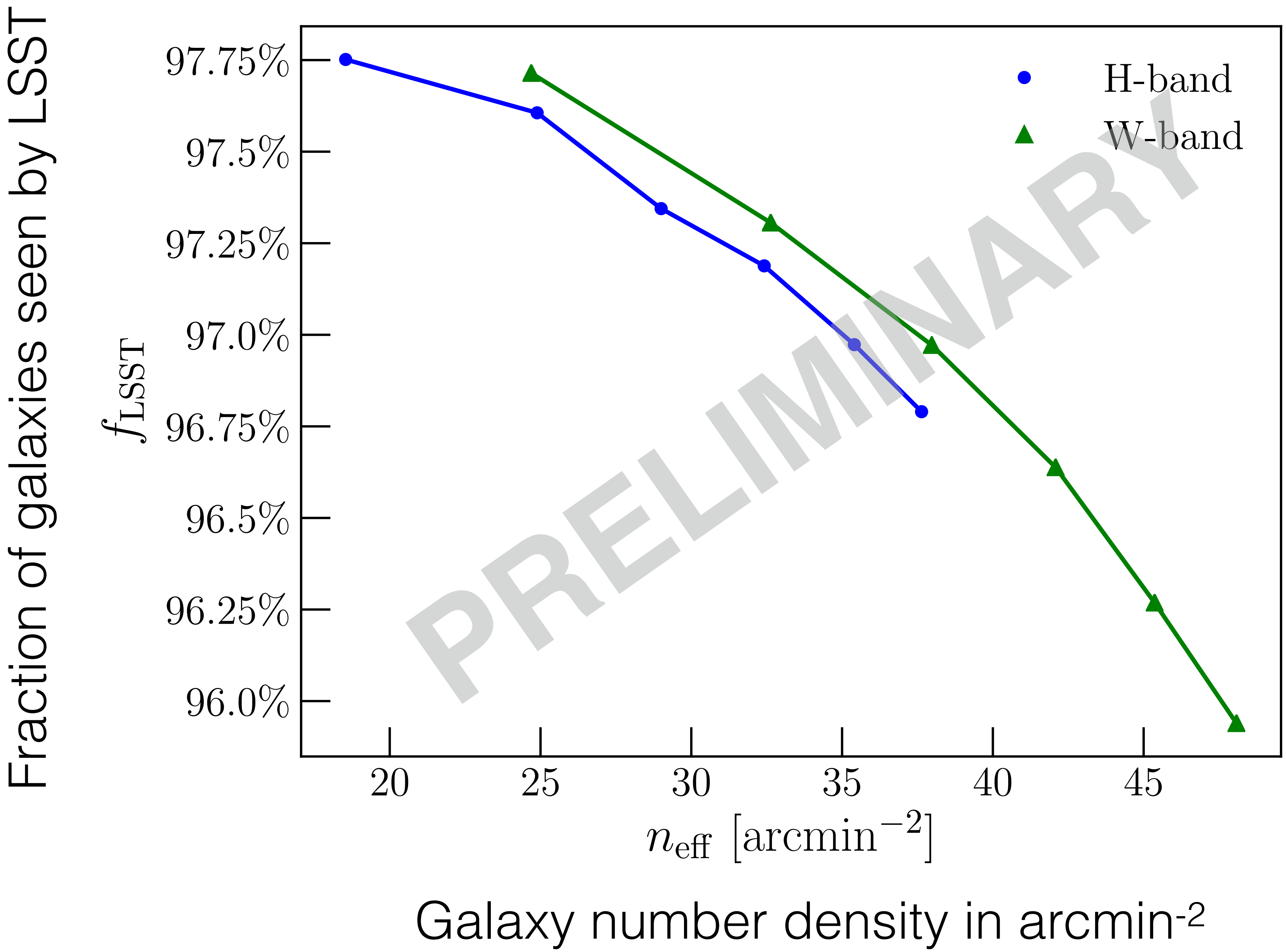
- WFIRST has Hubble resolution at 100x more sky
- High Latitude Survey highly optimized for dark energy:
  - designed to optimize systematics
  - multi-probe strategies: BAO, RSD, weak lensing, clusters
- WFIRST is a powerful and versatile instrument — highly synergistic with other surveys:
  - Baseline survey; strategies still explored: deeper vs wider vs # bands
  - Nominal survey 5 years, extendable to 10 years (e.g. LSST overlap in 1 year)
  - Able to address relevant cosmological questions after LSST (yr 1-2) / DESI

"Cosmology with the High Latitude Survey" Annual Report 2017: arxiv 1804.03628

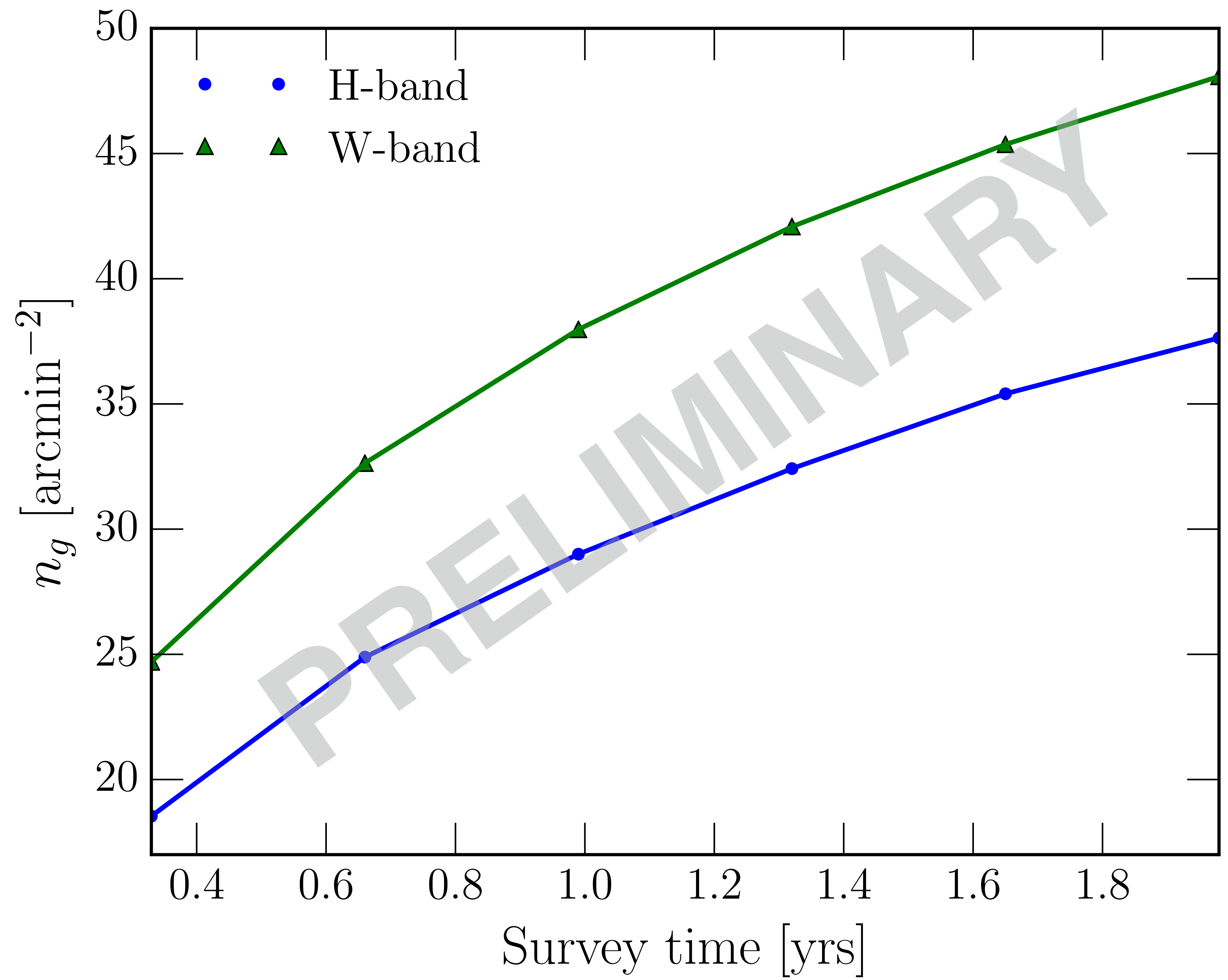
www.wfirst.gsfc.nasa.gov, www.wfirst-hls-cosmology.org

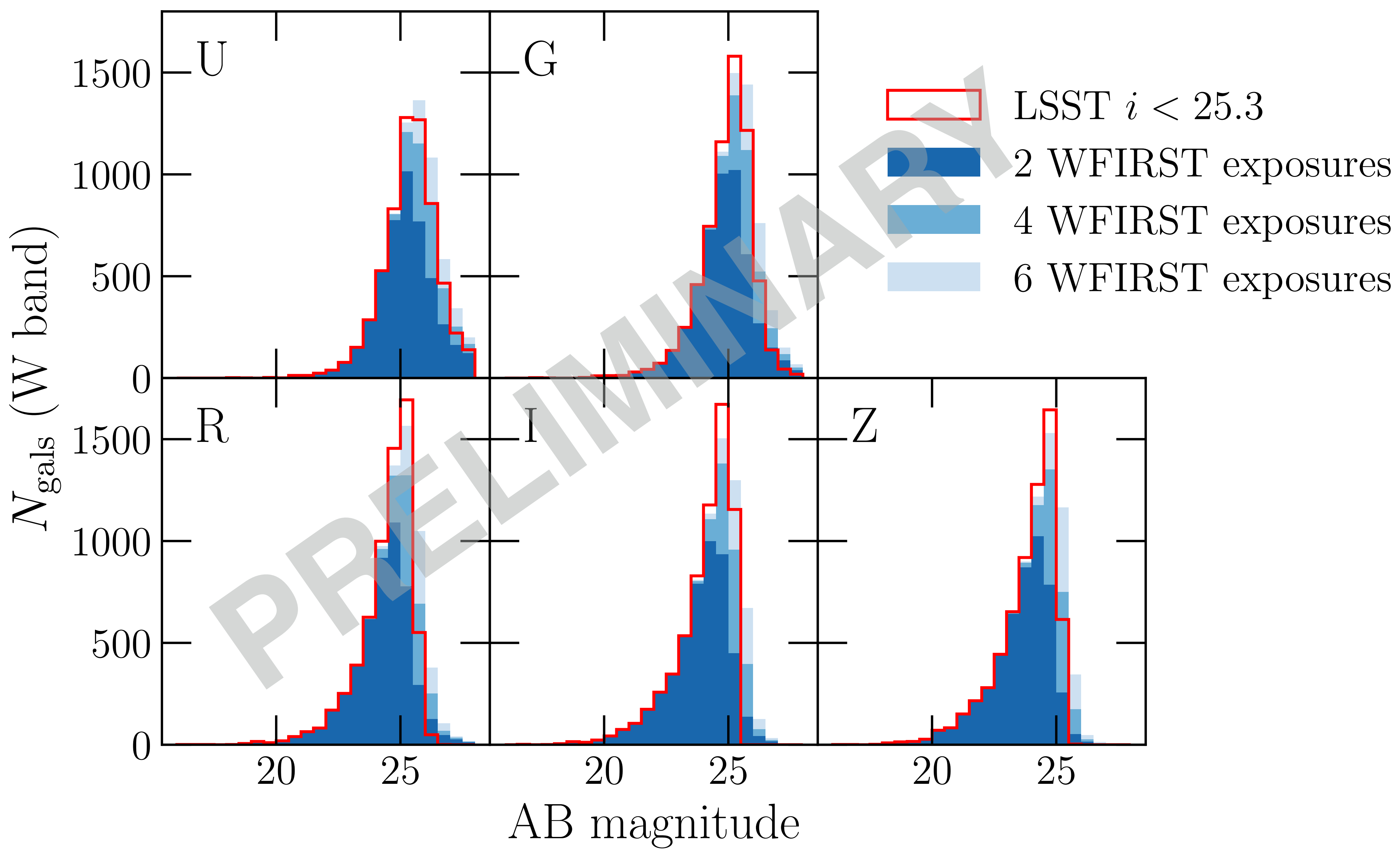
Backup slides

Fraction of WFIRST galaxies
With LSST photometry

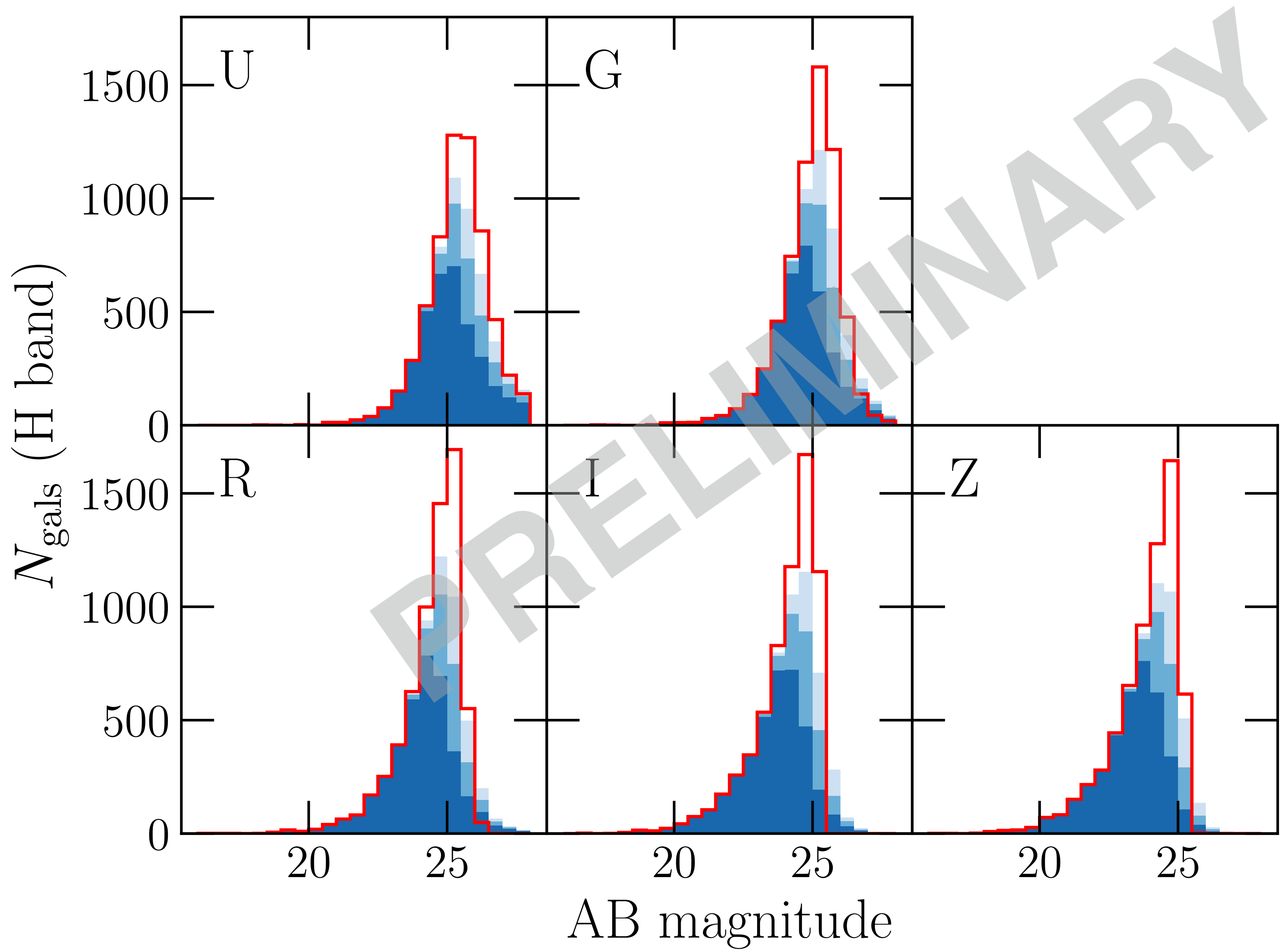


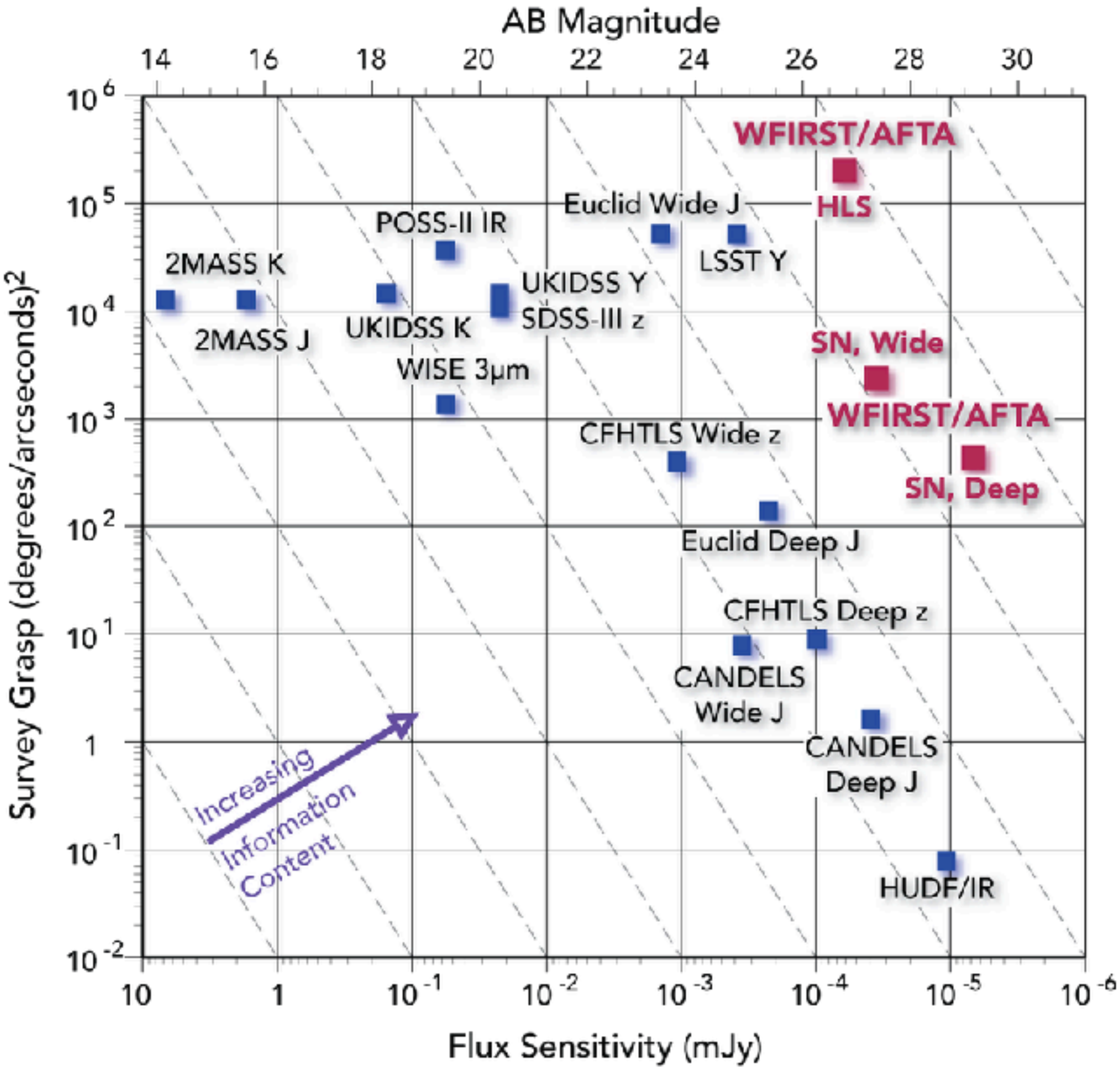
Galaxy number density vs survey time in years



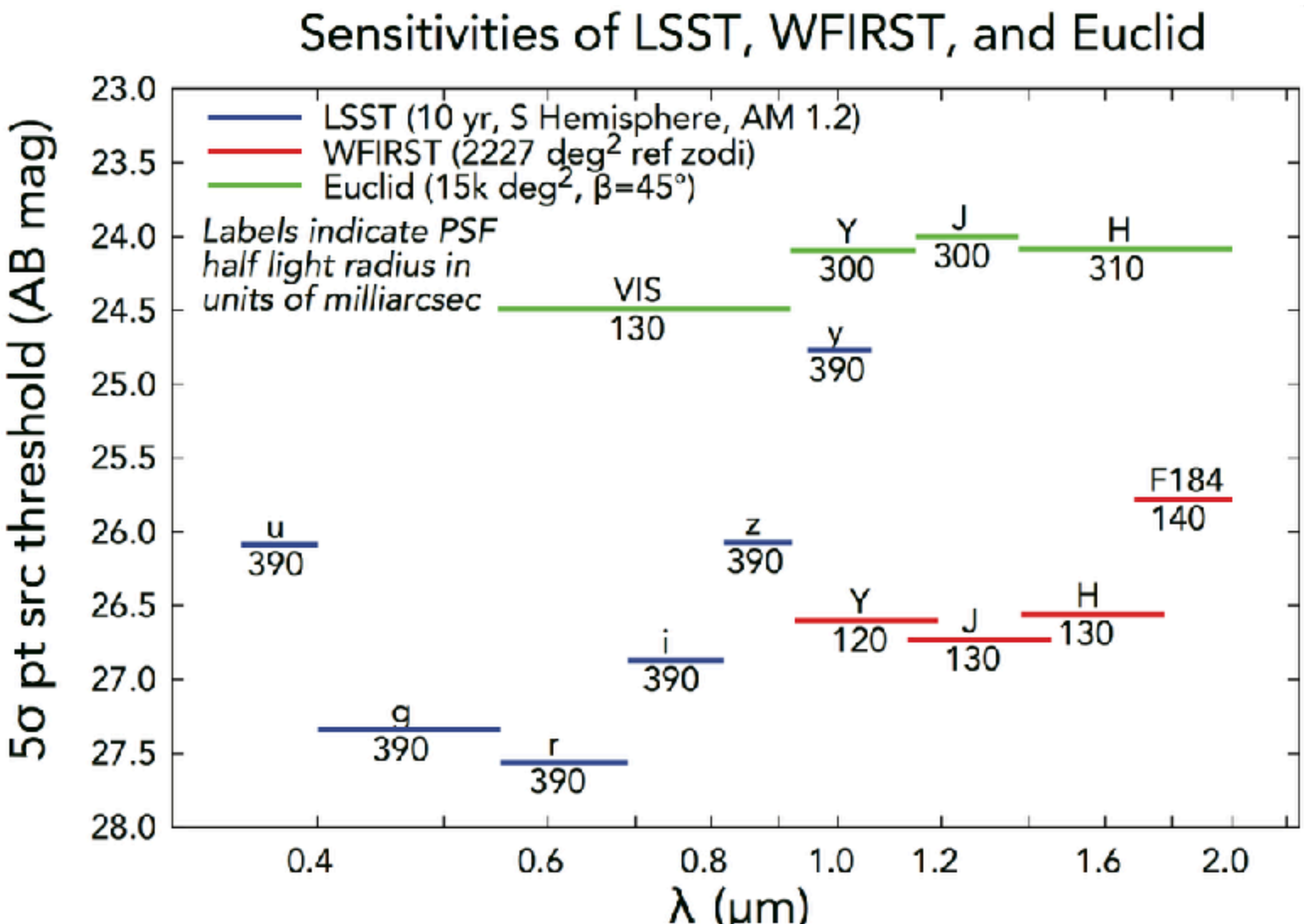


U
G
R
I
Z
LSST $i < 25.3$
2 WFIRST exposures
4 WFIRST exposures
6 WFIRST exposures
PRELIMINARY
$N_{\rm gals}$ (W band)
AB magnitude
0
500
1000
1500
20
25


U
G
R
I
Z
1500
1000
500
0
20
25
$N_{\rm gals}$ (H band)
AB magnitude
PRELIMINARY



source: wfirst.gsfc.nasa.gov



Spergel et al. (2015)

Clusters

$$\mathcal{N}^i(\lambda_\alpha) = \Omega_{\rm s} \int_{z^i_{\lambda,\rm min}}^{z^i_{\lambda,\rm max}} dz \frac{d^2V}{dz d\Omega} \int dM \frac{dn}{dM} \int_{\lambda_{\alpha,\rm min}}^{\lambda_{\alpha,\rm max}} d\ln\lambda \, p(\ln\lambda | M, z)$$

$$p(\ln\lambda|M,z) = \frac{1}{\sqrt{2\pi}\sigma_{\ln\lambda|M,z}} \exp\left[-\frac{(\ln\lambda - \langle\ln\lambda\rangle(M))^2}{2\sigma^2_{\ln\lambda|M,z}}\right]$$

$$\sigma_{\ln\lambda|M,z} = \sigma_0 + q_M \ln\left[\frac{M}{M_{\rm pivot}}\right] + q_z \ln[1+z]$$

$$\langle\ln\lambda\rangle(M) = A + B\ln\left[\frac{M}{M_{\rm pivot}}\right] + C\ln[1+z]$$

Baseline survey

Parameter	Fid	Prior
Survey		
Ω_s	2,000 deg^2	fixed
$n_{\rm eff}$	45 gal/arcmin^2	fixed
σ_ϵ	0.26	fixed
Cosmology		
Ω_m	0.3156	flat (0.1, 0.6)
σ_8	0.831	flat (0.6, 0.95)
n_s	0.9645	flat (0.85, 1.06)
w_0	-1.0	flat (-2.0, 0.0)
w_a	0.0	flat (-2.5, 2.5)
Ω_b	0.0492	flat (0.04, 0.055)
h_0	0.6727	flat (0.6, 0.76)
Galaxy bias		
b_g^1	1.35	flat (0.8, 3.0)
b_g^2	1.5	flat (0.8, 3.0)
b_g^3	1.65	flat (0.8, 3.0)
b_g^4	1.8	flat (0.8, 3.0)
Lens photo-z (red sequence)		
$\Delta^i_{\rm z,lens}$	0.0	Gauss (0.0, 0.0004)
$\sigma_{\rm z,lens}$	0.01	Gauss (0.01, 0.0006)
Source photo-z		
$\Delta^i_{\rm z,source}$	0.0	Gauss (0.0, 0.002)
$\sigma_{\rm z,source}$	0.05	Gauss (0.05, 0.003)
Shear calibration		
m_i	0.0	Gauss (0.0, 0.004)
Cluster Mass Observable Relation		
A	3.207	
B	0.993	
C	0	See Section 3.4
σ_0	0.456	
q_M	-0.169	
q_z	0.0	

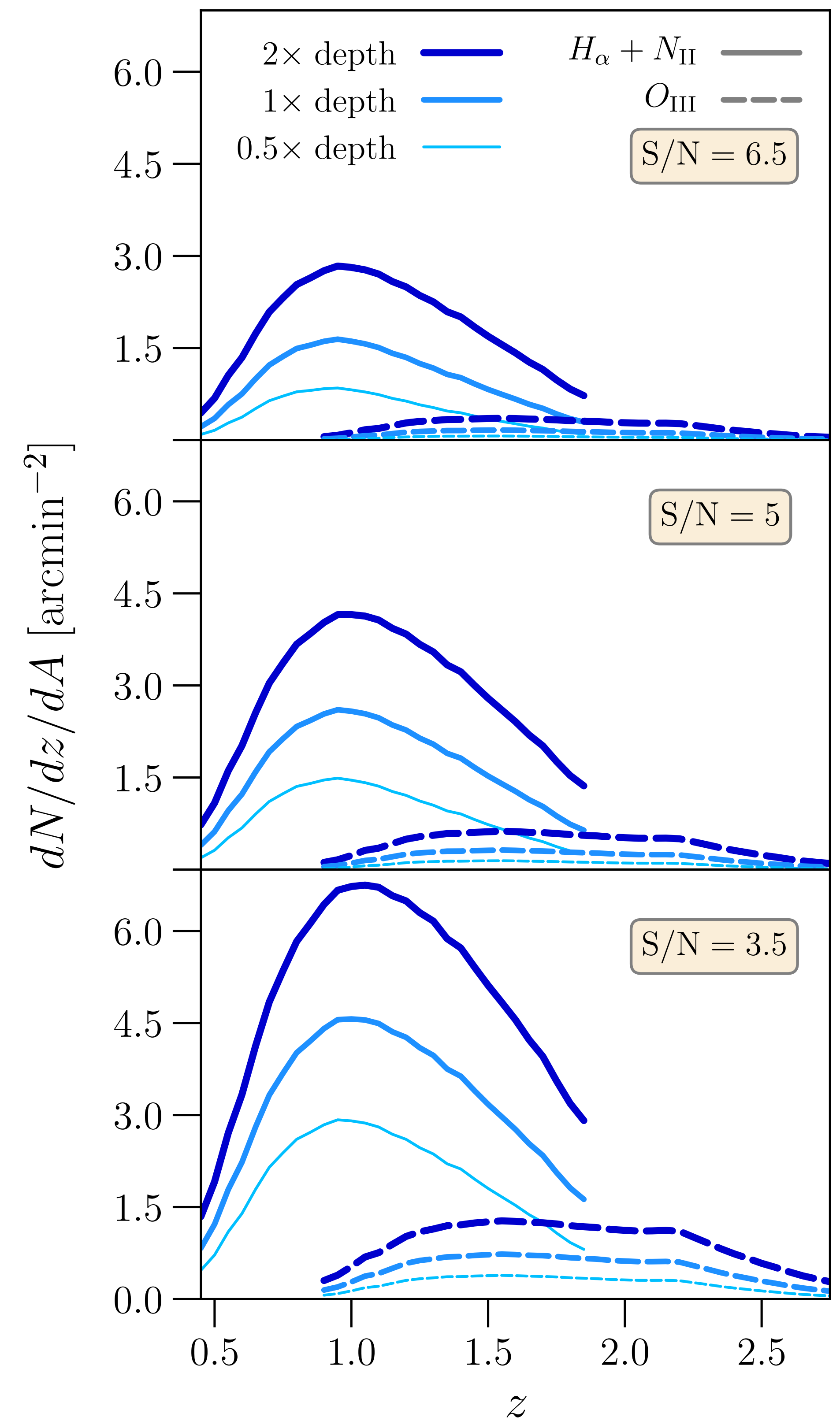
Systematics: Photo-z uncertainties, Linear galaxy bias, Multiplicative shear calibration, Cluster mass-observable relation, Intrinsic alignment, Other (baryonic effects, small scale power spectra; galaxy cluster mis-centering assembly bias)

HLS spectroscopic galaxy distributions

Baseline survey:
Area = 2000 deg², S/N = 5.

Variation 1:
2x, 1x, 0.5x depth (or 0.5x, 1x, 2x area)

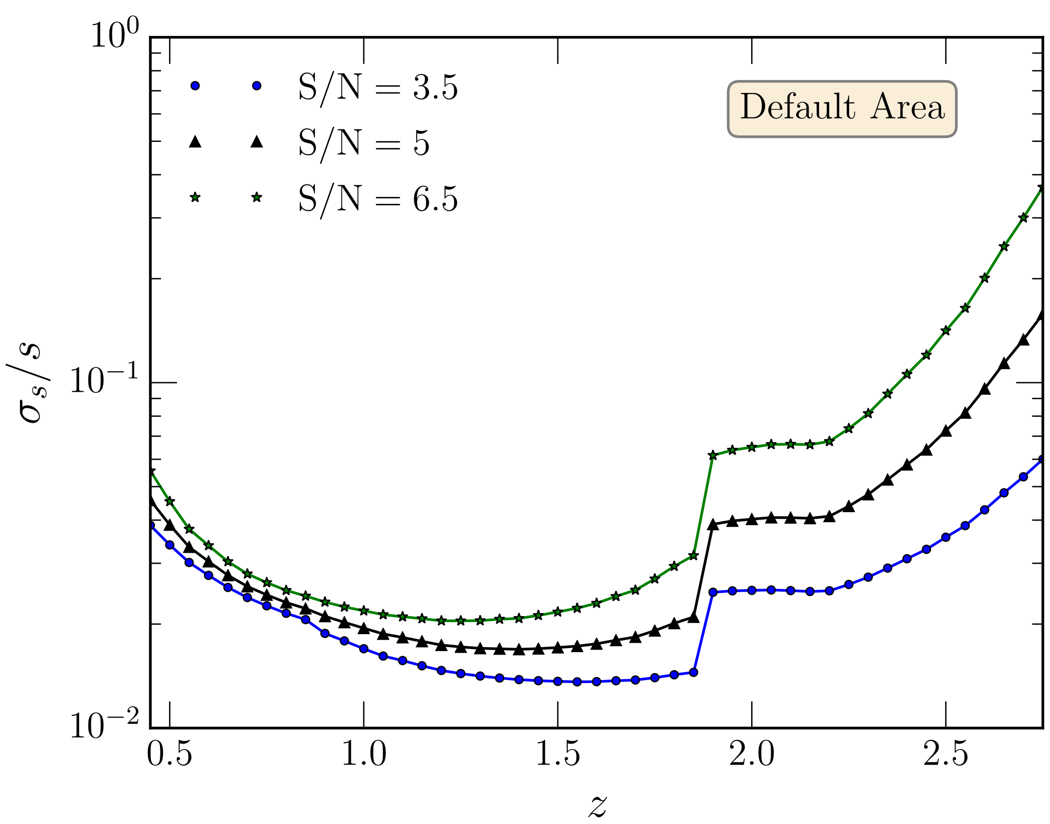
Variation 2:
S/N cutoff = 6.5, 5, 3.5



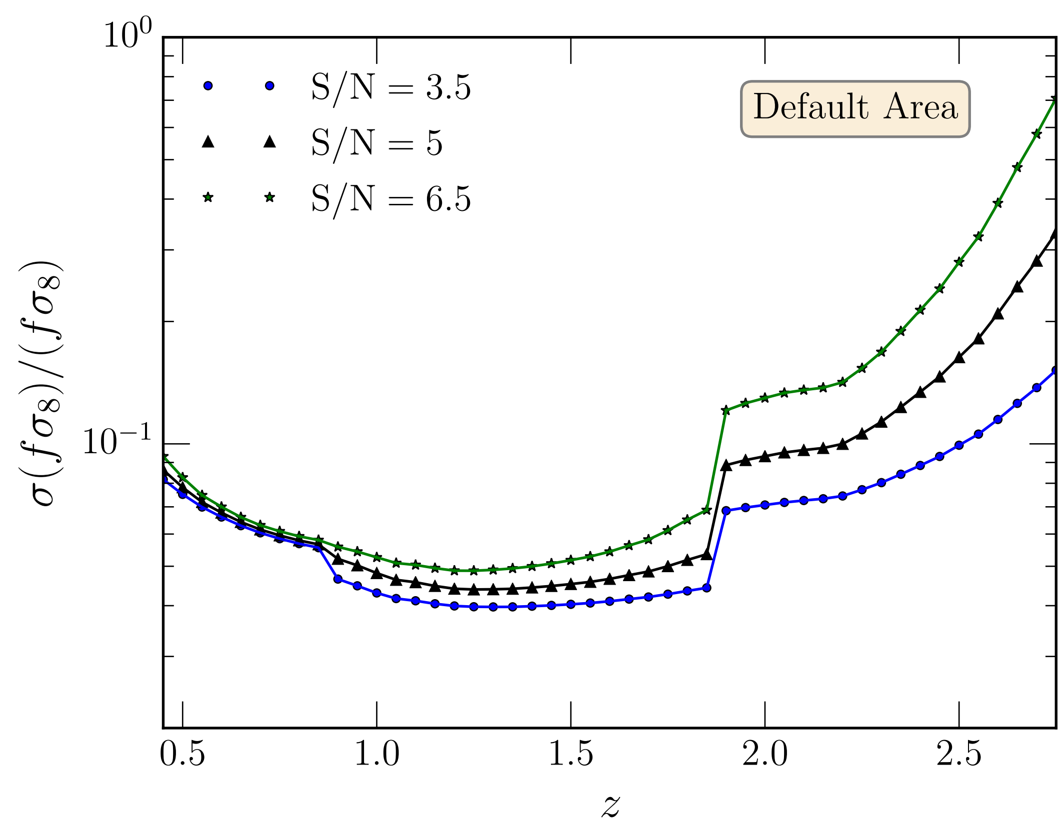
GRS: baseline survey

vary S/N (@ default area)

BAO



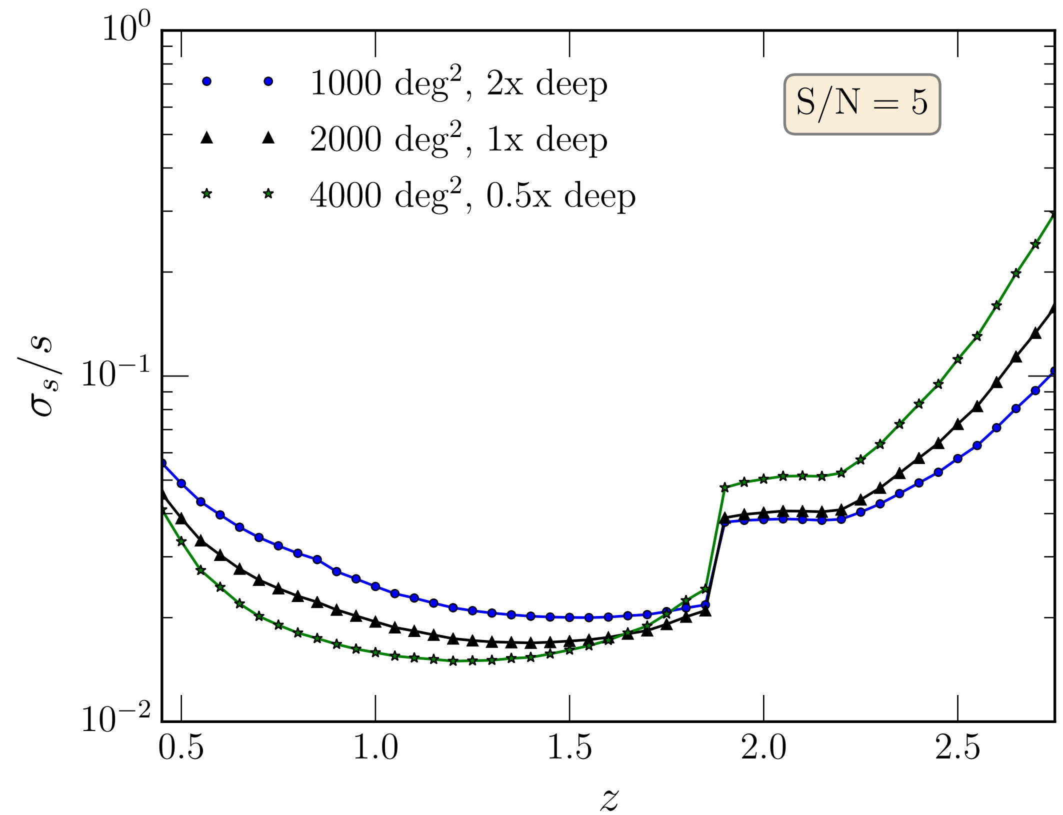
RSD



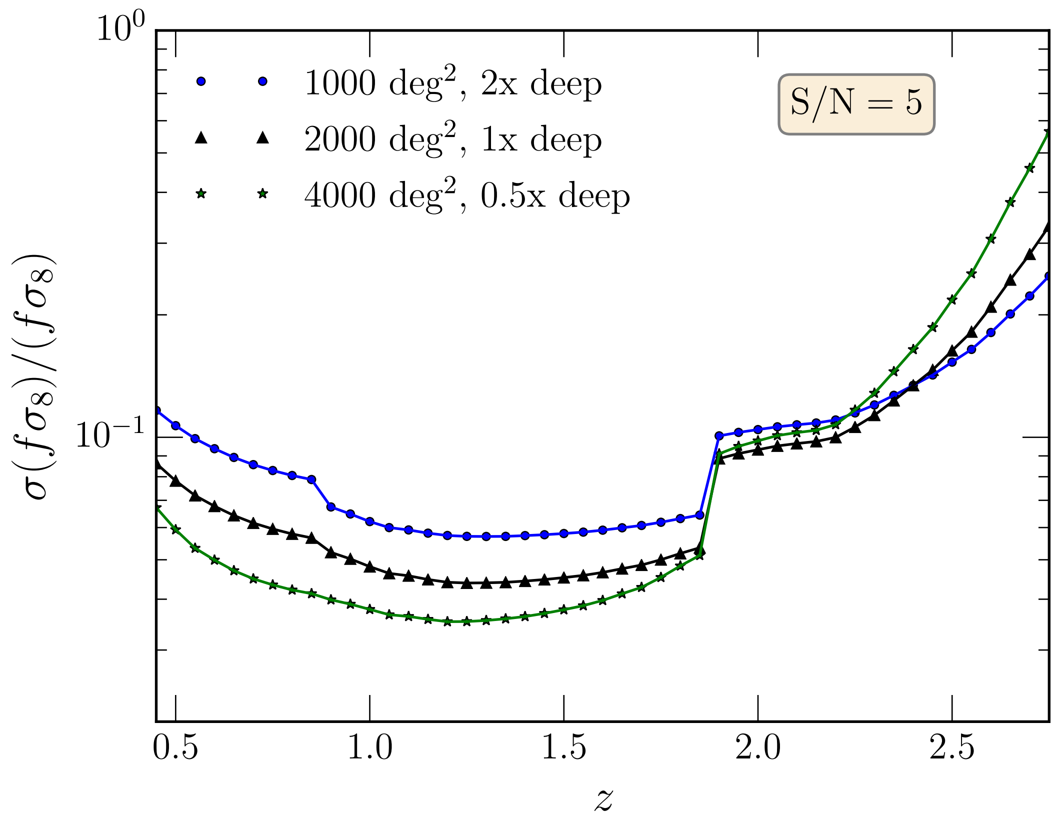
GRS: baseline survey

vary depth (@ S/N=5)

BAO

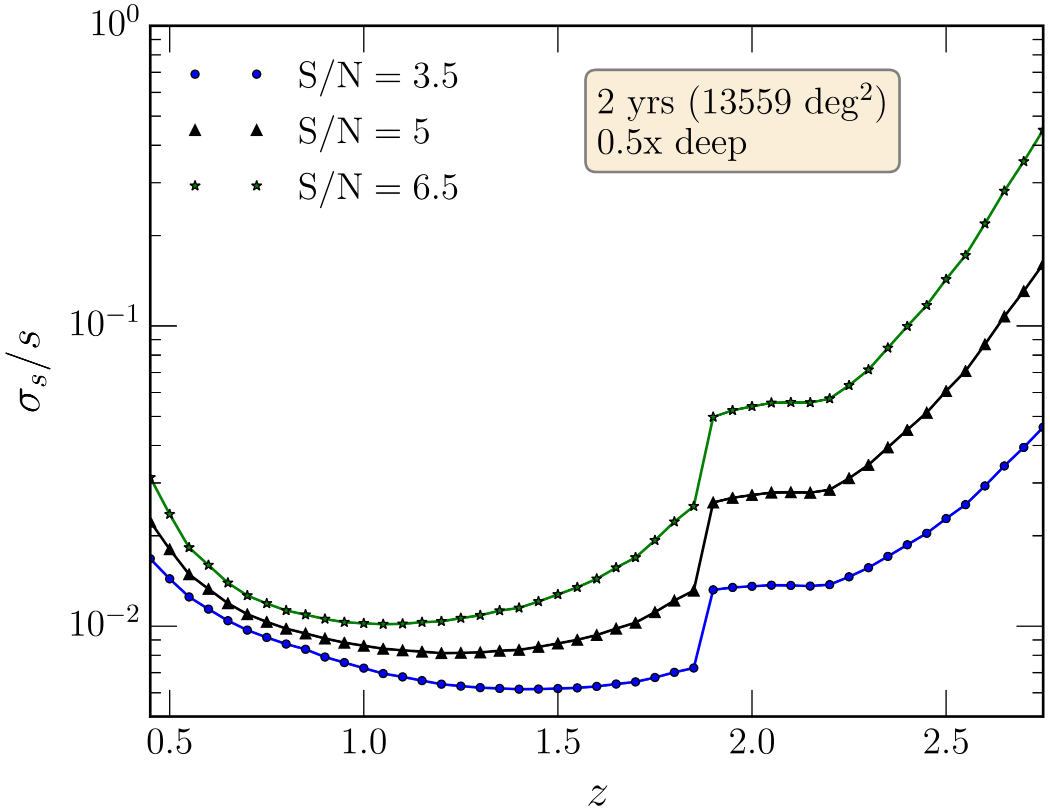


RSD

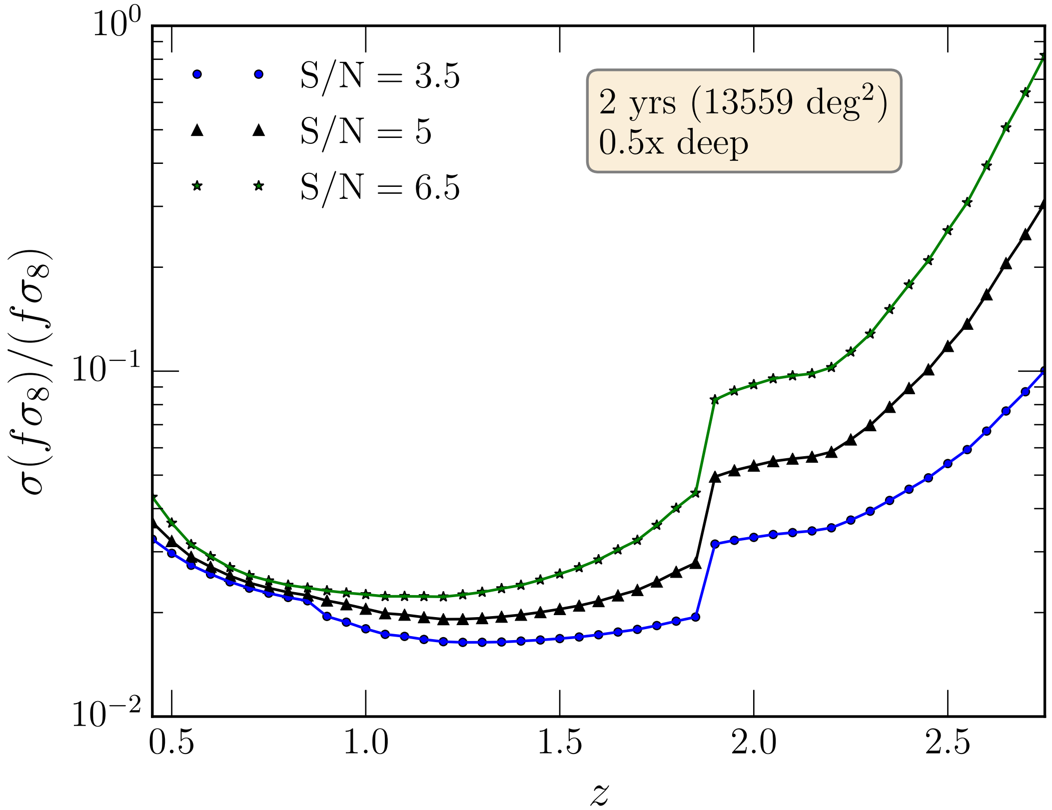


GRS : 2 year survey

BAO

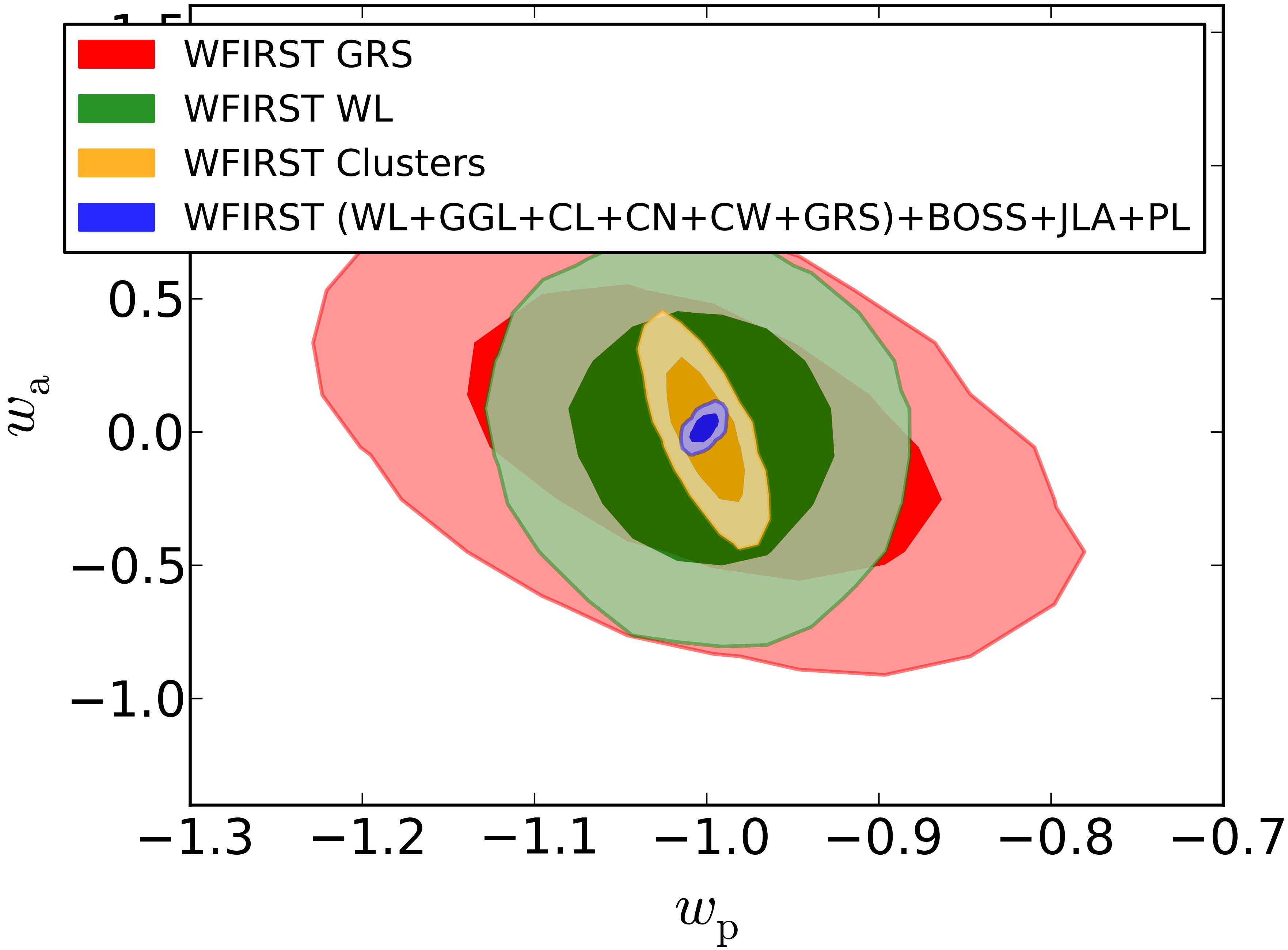


RSD



WFIRST designed to be extendable to up to 10 years.

WFIRST HLS (nominal survey)
+ External (BOSS+JLA+Planck)

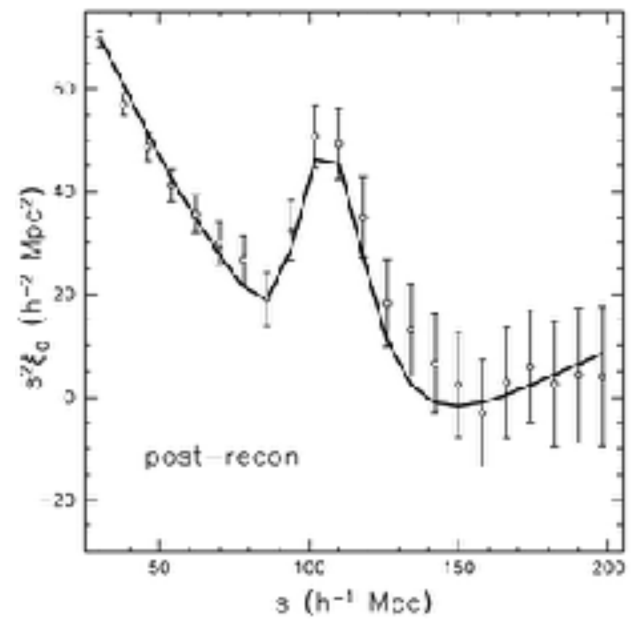


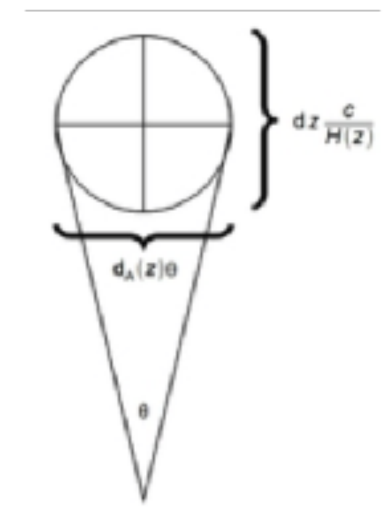
Eifler et al. (in prep)

HLS Spectroscopy
— Galaxy redshift survey (GRS)

Baryon acoustic oscillations (BAO)

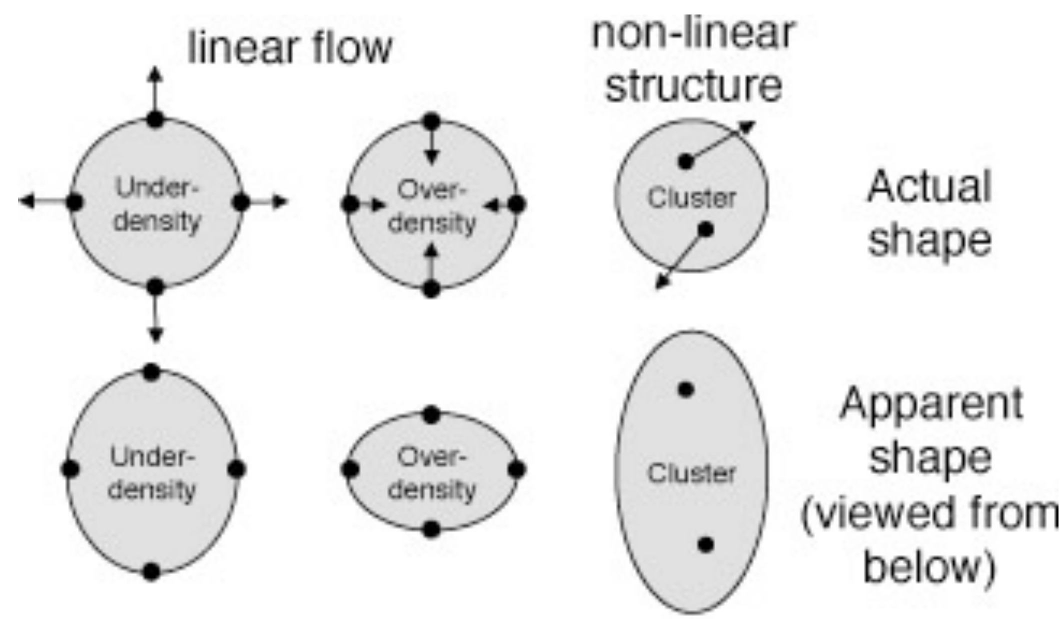
- Constrains $d_A(z)$ and $H(z)$ —> $s(z)$
- Robust measurements





Redshift space distortions (RSD)

- Constrains $f\sigma_8(z)$, $w(z)$
- Theoretical uncertainties



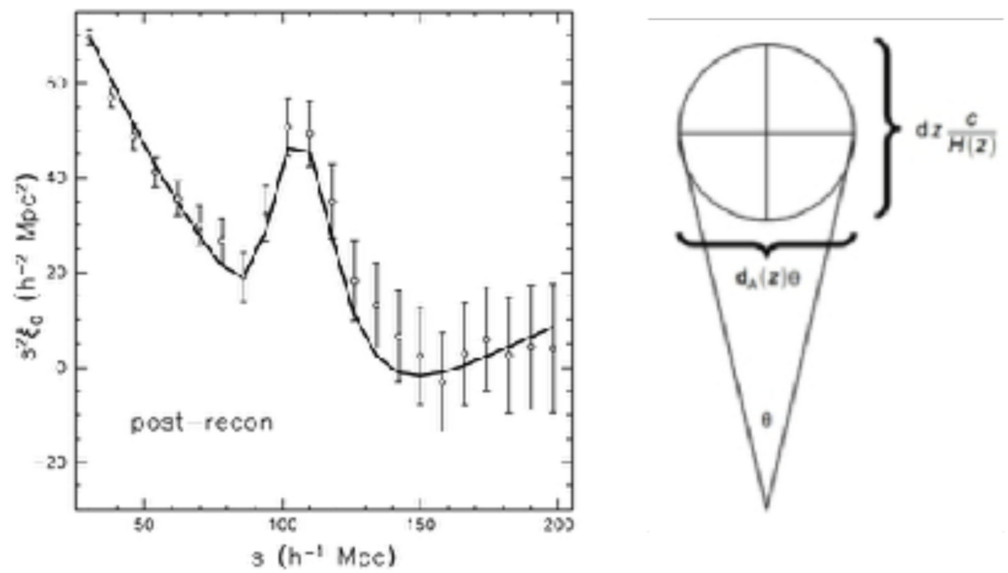
DE SURVEY COMPLEMENTARITY AT A GLANCE

STAGE IV	LSST	WFIRST	Euclid	DESI
Start, duration	2022, 10 yr	~2025, 5 (-10) yr	2021, 6 yr	2019, 5 yr
Area (sq. deg.)	20,000 (S)	2,000 (S)	15,000 (N+S)	14,000 (N)
FOV (sq. deg.)	10	0.281	0.53	7.9
Diameter (m.)	6.7	2.4	1.3	4
Photometric Survey	6 bands (u,g,r,i,z,y)	6 bands (Z,Y,J,H,F,184,W149)	4 bands (VIS,Y,J,H)	
Photometric Galaxies (w/ shapes) (#/arcmin^2)	~30 in 6 bands (ugrizy)	~45 in 4 bands (YJHF184)	~30-35, in 1 band (VIS)	
SN1a	10^4-10^5/yr z=0-0.7 photometric	2700 z=0.1-1.5 IFC spectroscopy		
Spectroscopic Survey		Grism R=550-800 1-2 μm	Grism R=250 1.1-2 μm	Fibers R=4000 0.36-0.98 μm
Spectroscopic Galaxies		ELGs z=0.5-1.8 (Ha/ ~20M) z=0.9-2.8 (OIII/ ~2M)	ELGs, z~0.7-2.1 (20M)	LRGs+ELGs z~0.6-1.7 (20-30M) QSOs/Lya 1.9<z<4 (1M)

HLS Spectroscopy
— Galaxy redshift survey (GRS)

Baryon acoustic oscillations (BAO)

- Constrains expansion rate
- Constrains distances



Redshift space distortions (RSD)

- Constrains growth of structure
- Constrains dark energy evolution

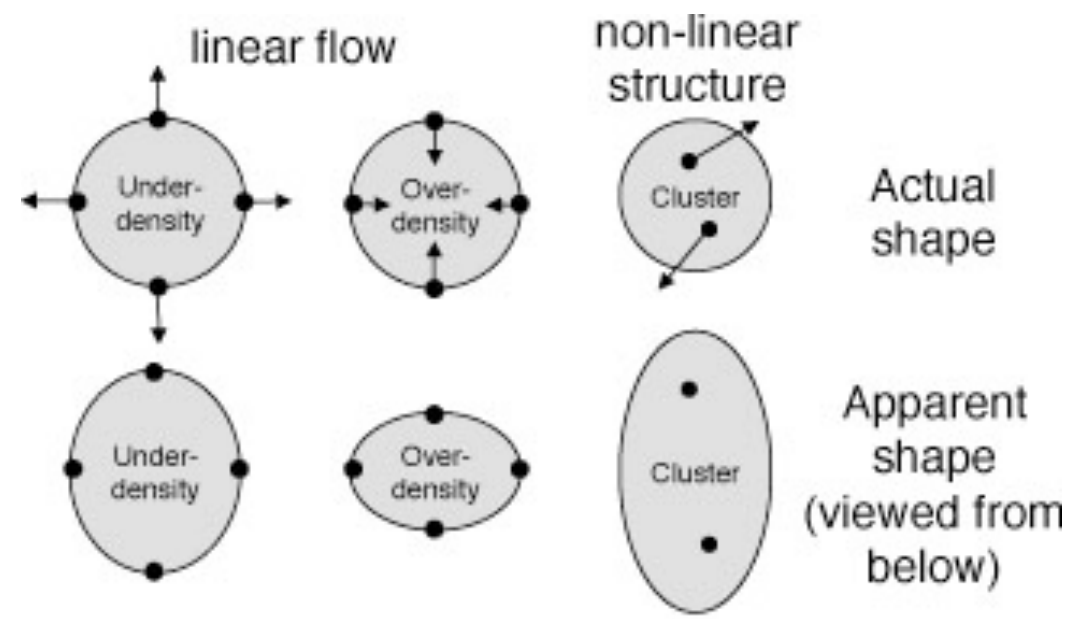


Image credit: SDSS, Will Percival