WISH Exploration of Galaxies in the Epoch of Cosmic Reionization

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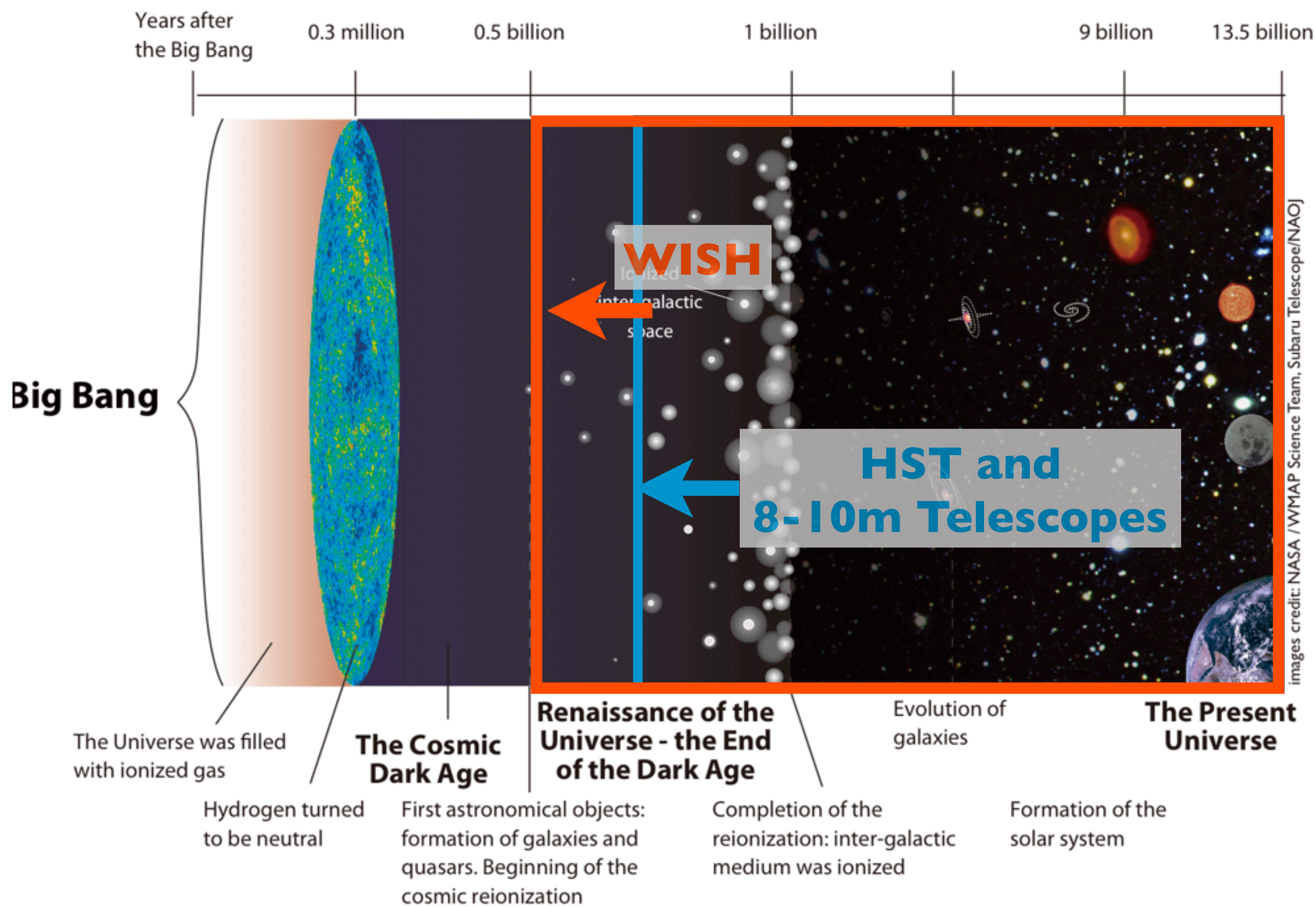
Ikuru Iwata (NAOJ)

Scientific Objectives

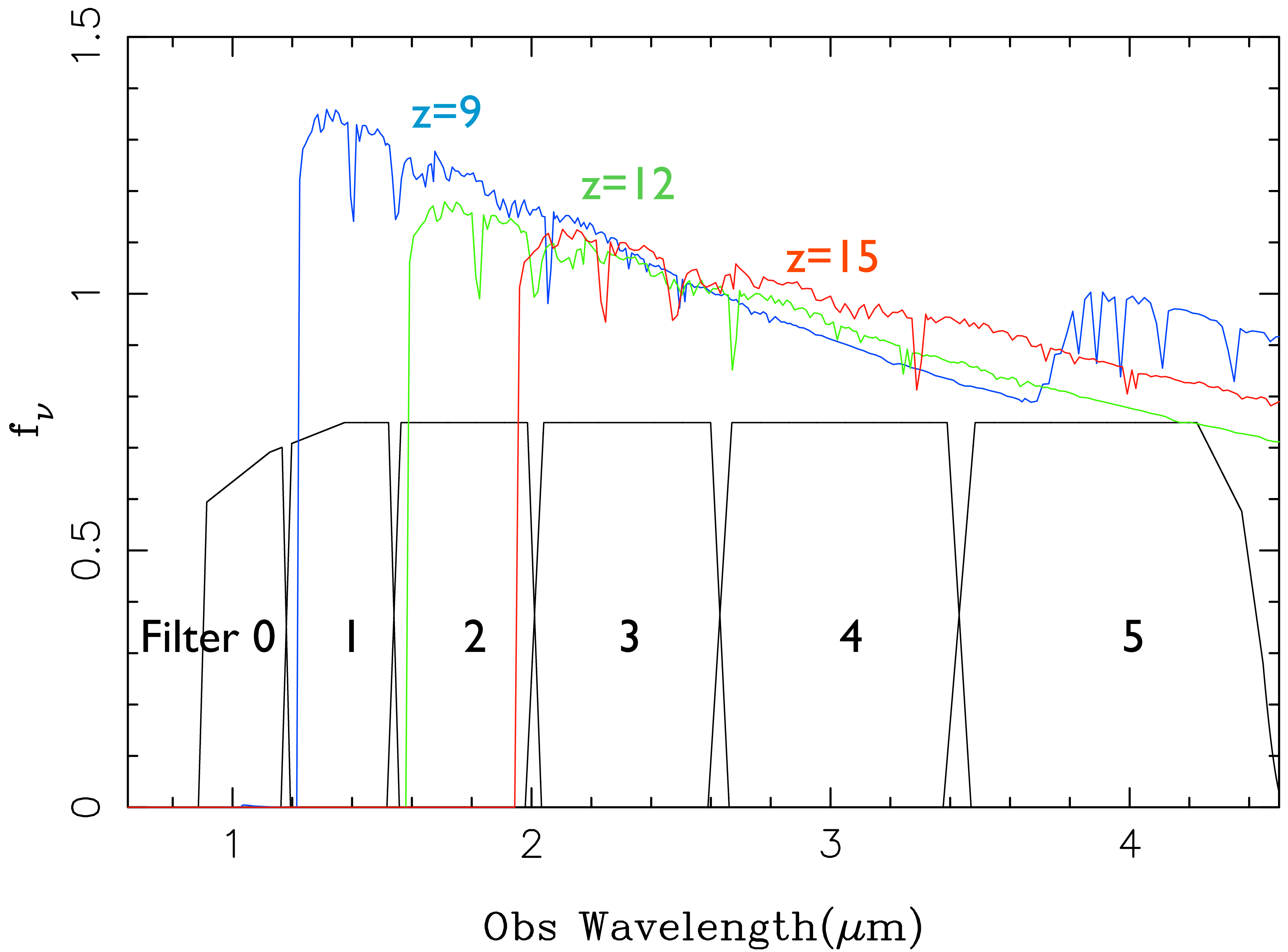
- Detections of 'First Galaxies' (z>10)
- Understanding of the Cosmic Reionization



1. What will we know with WISH Ultra-Deep Survey?
2. Narrow-band Survey
3. Comparisons with JWST, Euclid, and WFIRST

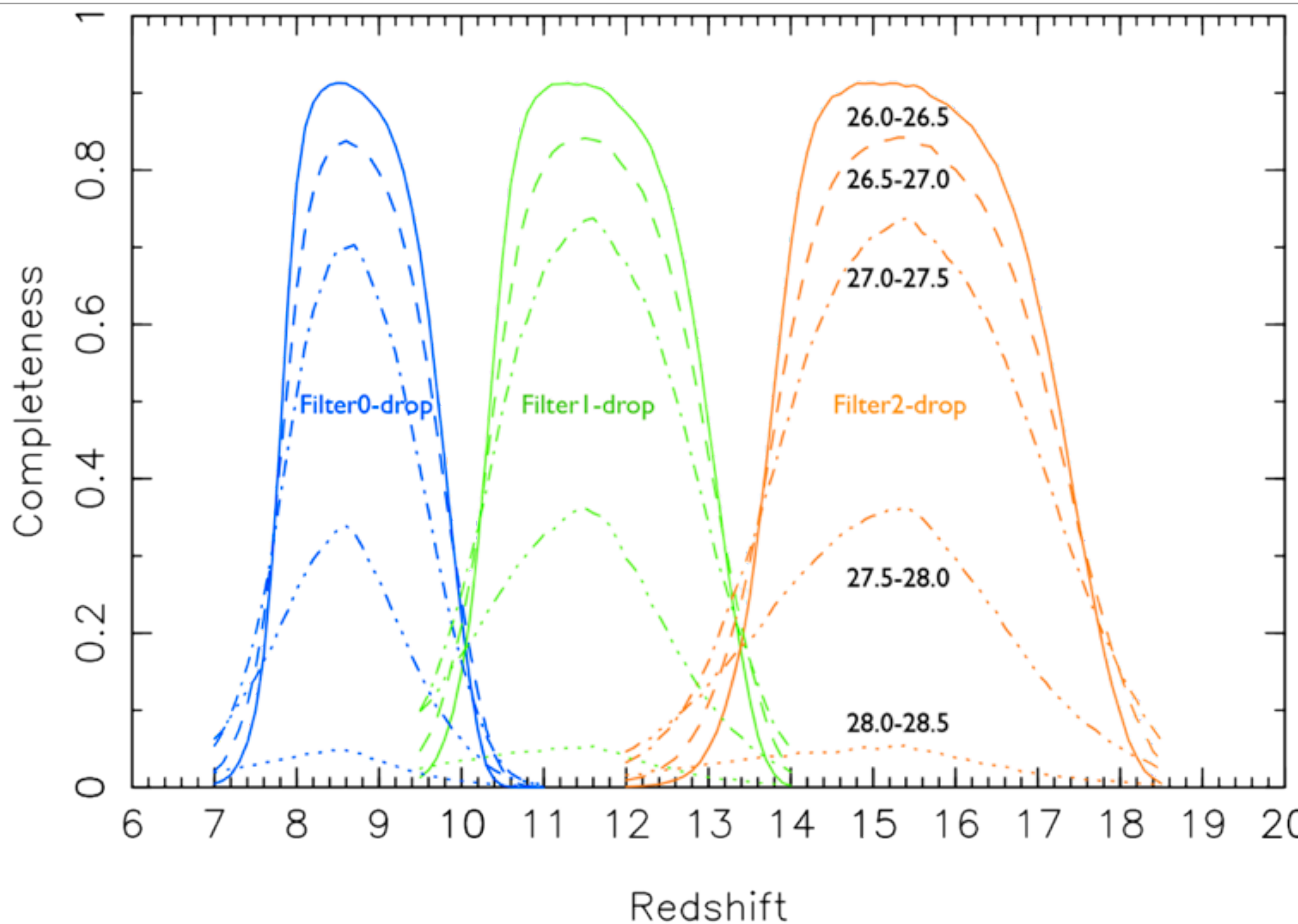
1. What will we know with WISH-UDS?

z=9,12,15 E(B−V)=0.1



- Continuous Sampling for z>8
- Determine UV Slope

Completeness Estimates

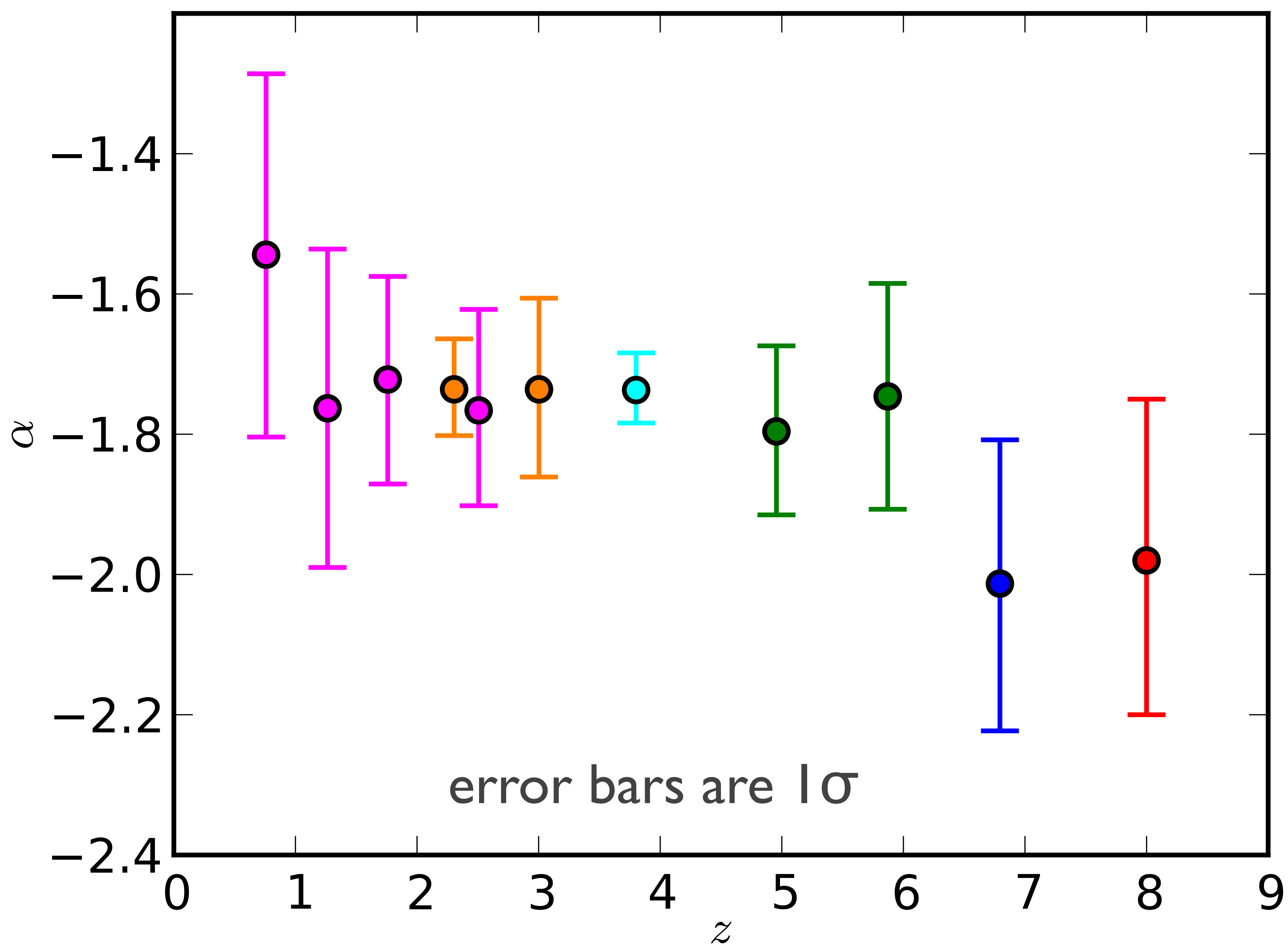


* Redshift distribution of objects depends on LF evolution

What will we know with WISH-UDS?

- Evolution of UV luminosity function at $8<z<15$
  - Number density of luminous LBGs
  - Ionization photon budget
- UV slope of LBG candidates
- Large-scale distribution of LBG candidates
  - $\Delta z \sim 3$ for each dropout populations

Faint-End Slope of UVLF



Bradley et al. 2012 ApJ 760, 108

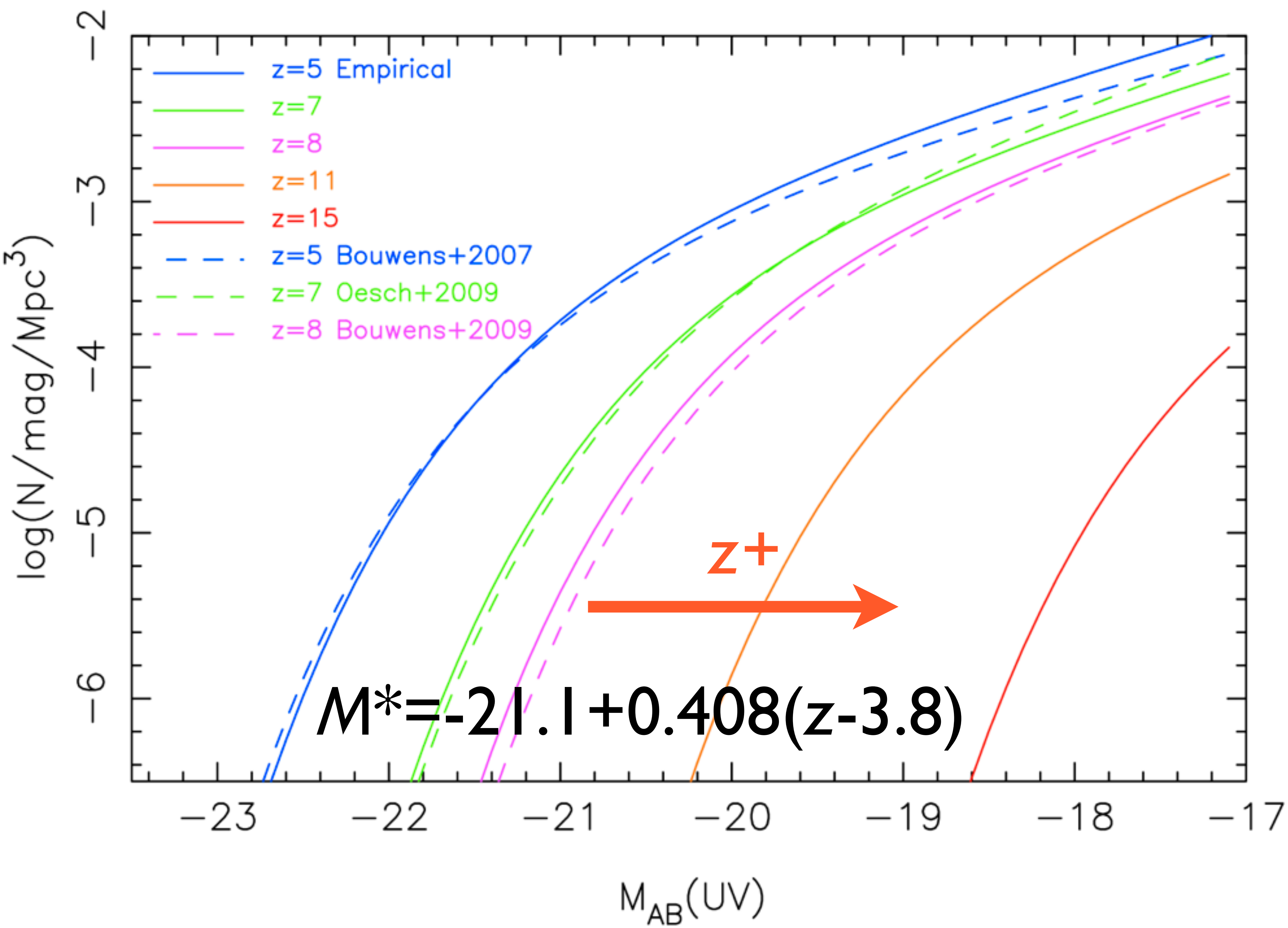
- Number density of faint galaxies has critical importance in Ionization Photon Budget.
- Some numerical simulations return steep UV slope at z>6 (Jaacks et al. MNRAS 420, 1606)
- Very deep observations are required.

Is WISH UDS (28AB) Deep Enough?

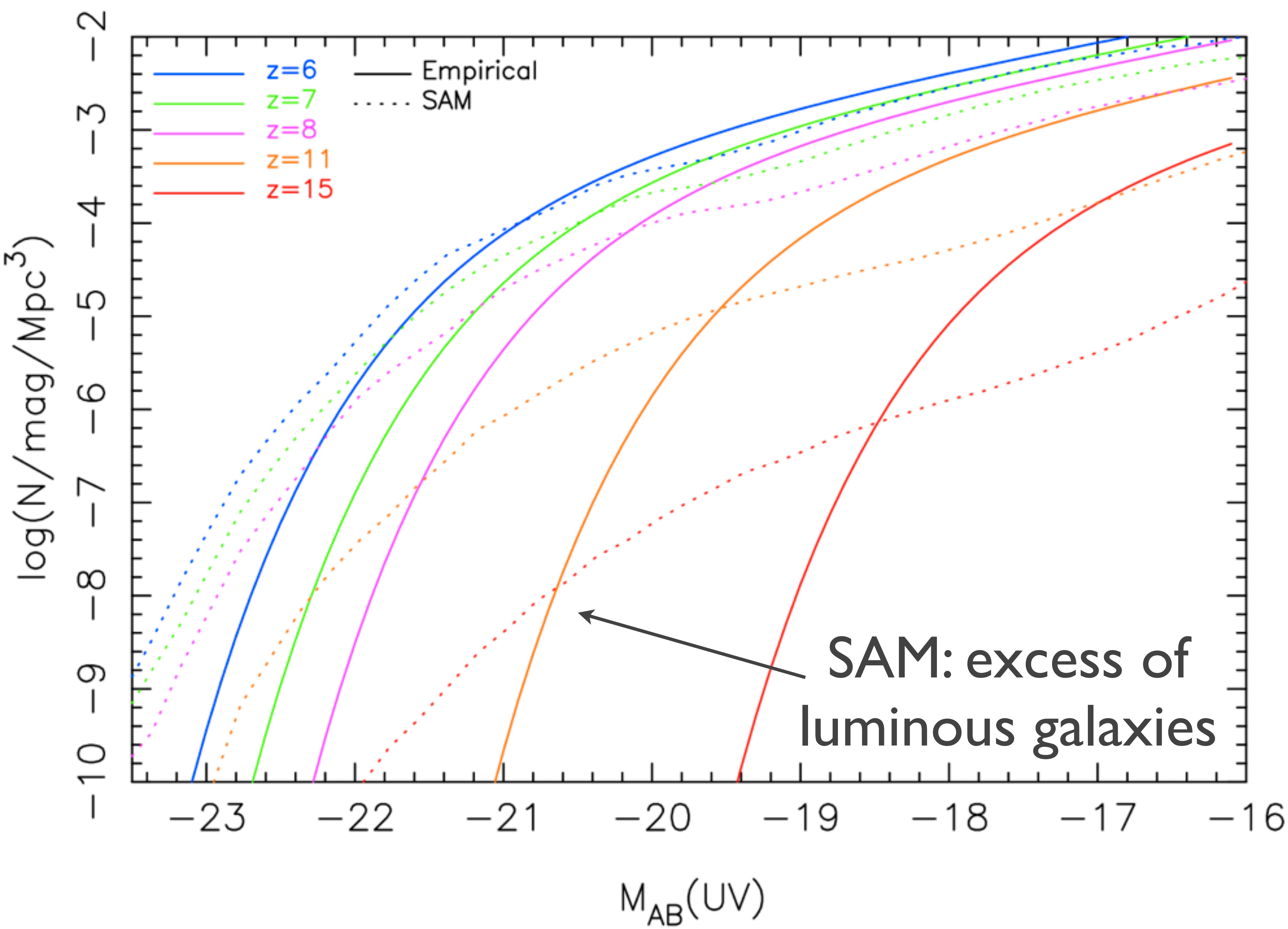
WISH Survey Plan

	Depth [AB mag.]	Area [sq. deg]	Days
Ultra Deep Survey	28.0	100	1,500
Ultra Wide Survey	25.0	1,000	50-100
Extreme Survey	~29.5	~1	<100

Assumption on Evolution of Luminosity Function(1) Empirical Evolution



Assumption on Evolution of Luminosity Function(2)
Semi-Analytic Model by Kobayashi et al.



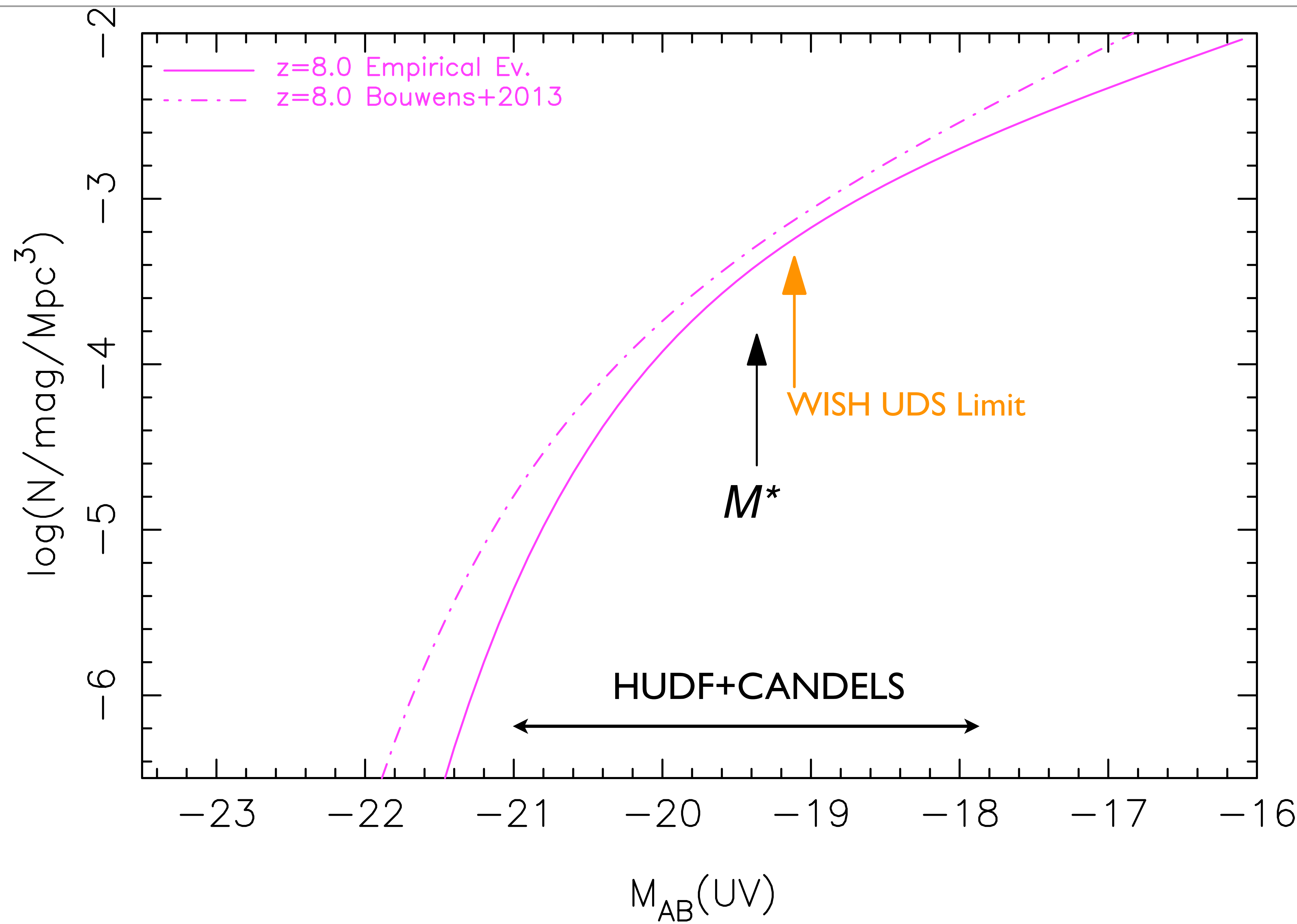
Expected Numbers with WISH Ultra-deep Survey

- 100 sq. deg survey with 5 filters from 1.0μm to 3.0μm
  - Limiting magnitudes 28AB (point source, 3σ)
  - Total 1,500 days

N/deg^2	z=8-9	z=10-12	z=13-17
Empirical Ev.	1690	104	0.72
SAM	631	49.7	1.07
DMH	852	4.12	0.003

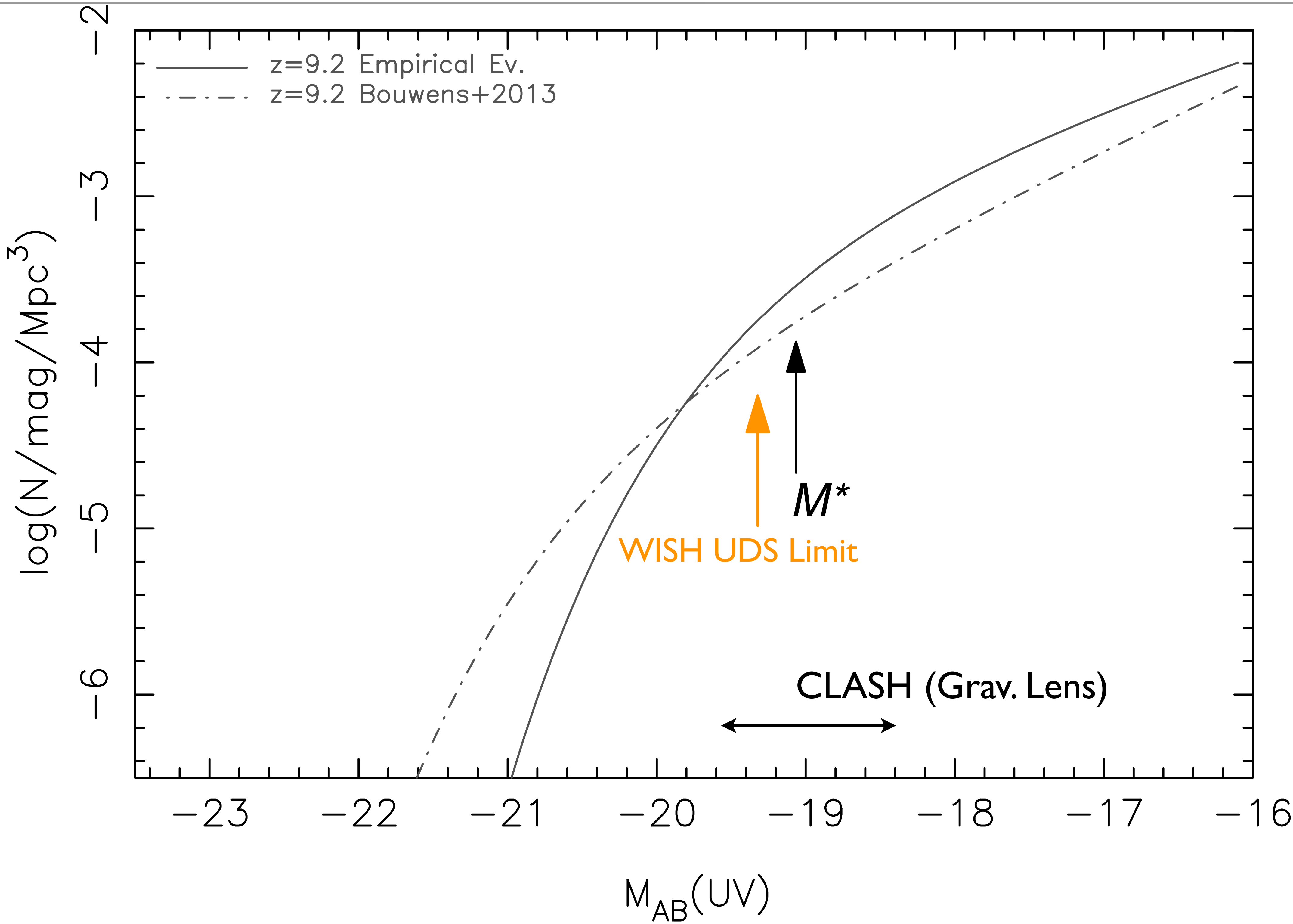
WISH Can Determine
How Bright-End of UVLF Evolves at z>8

z=8 Observations vs. Assumed Model



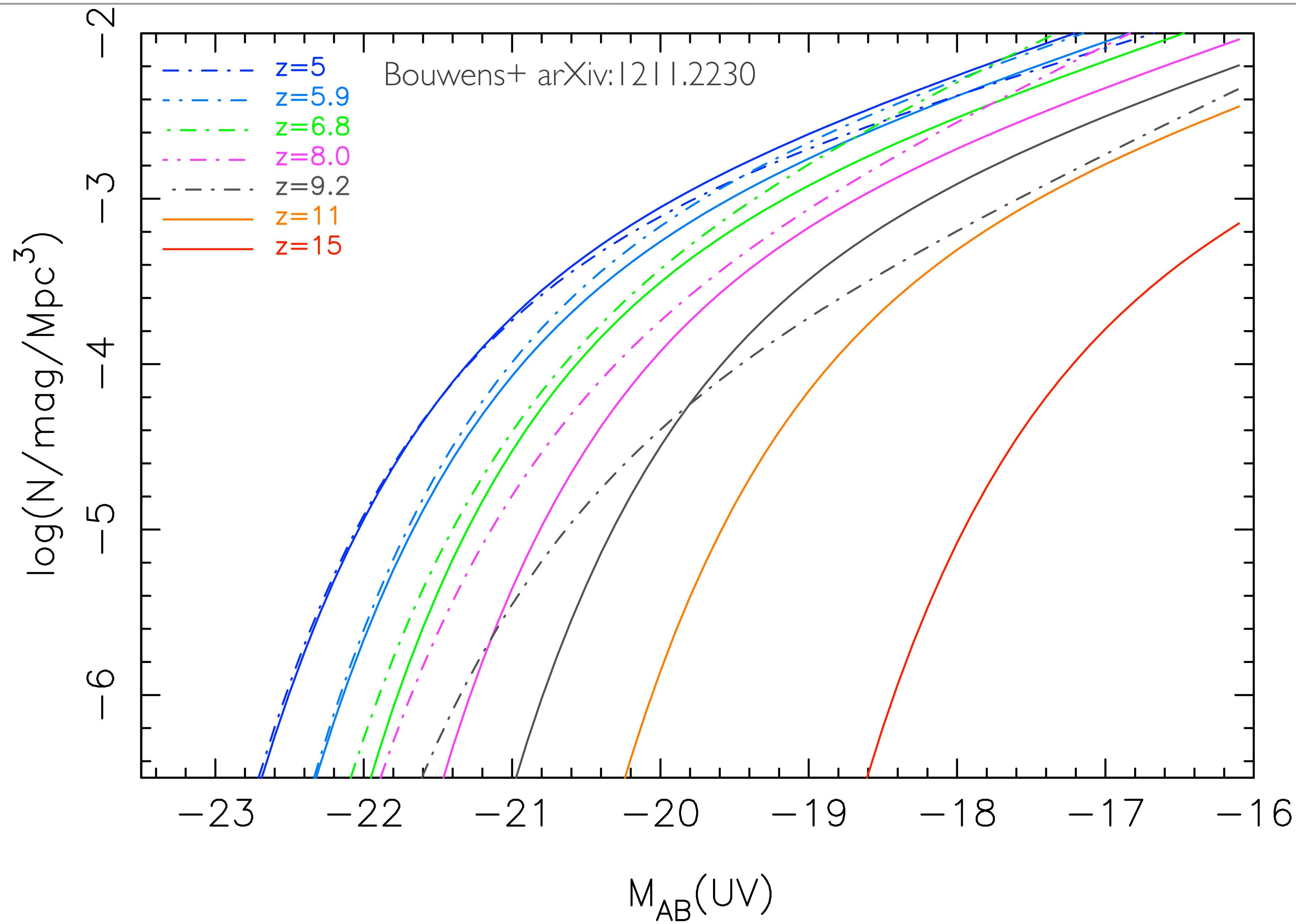
z=8 LF comes from Oesch+ ApJ 759, 135 (2012)

z=9 Observations vs. Assumed Model



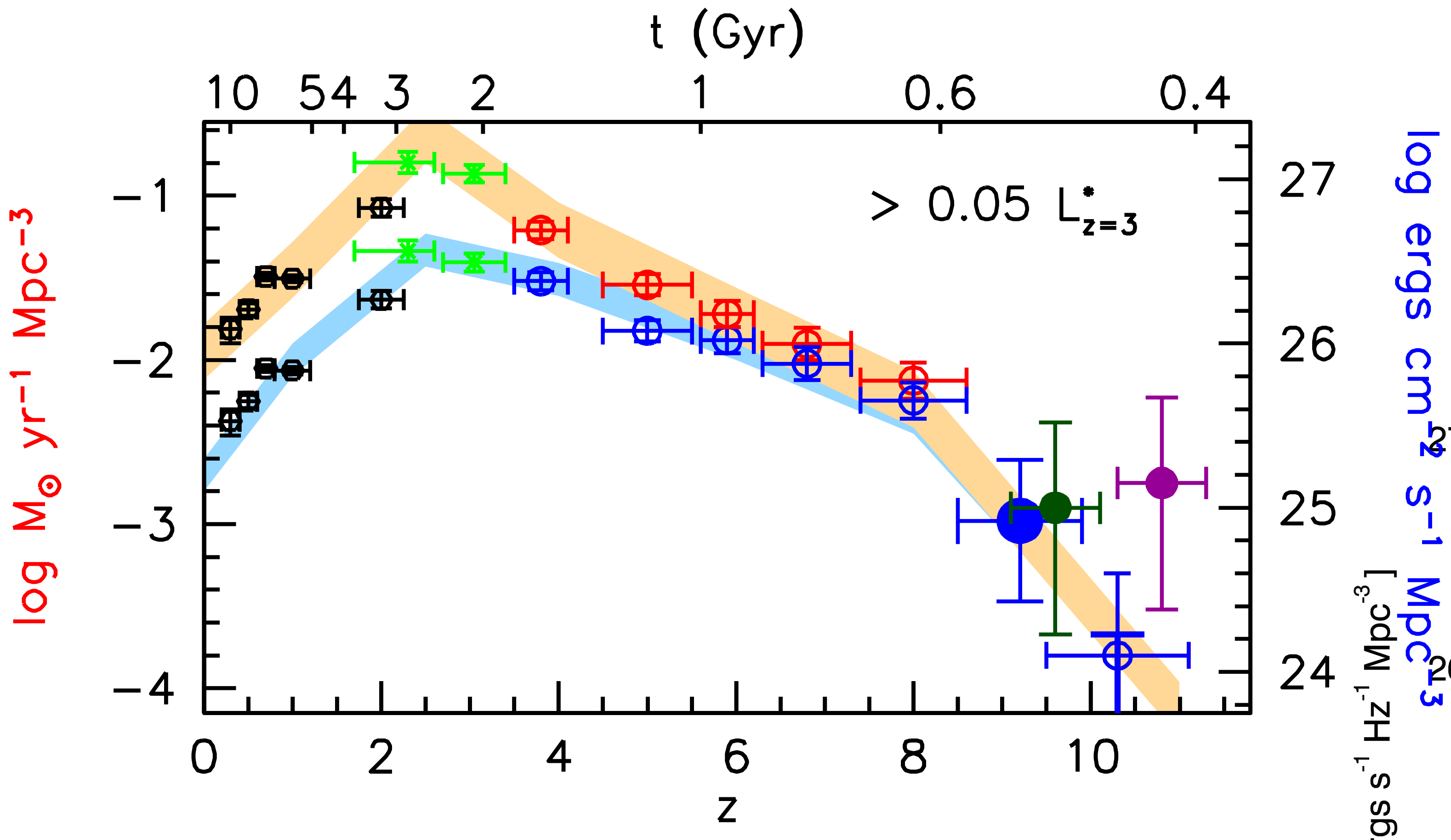
z=9.2 LF comes from Bouwens+ arXiv:1211.2230

Comparison with Recent Observations using HST

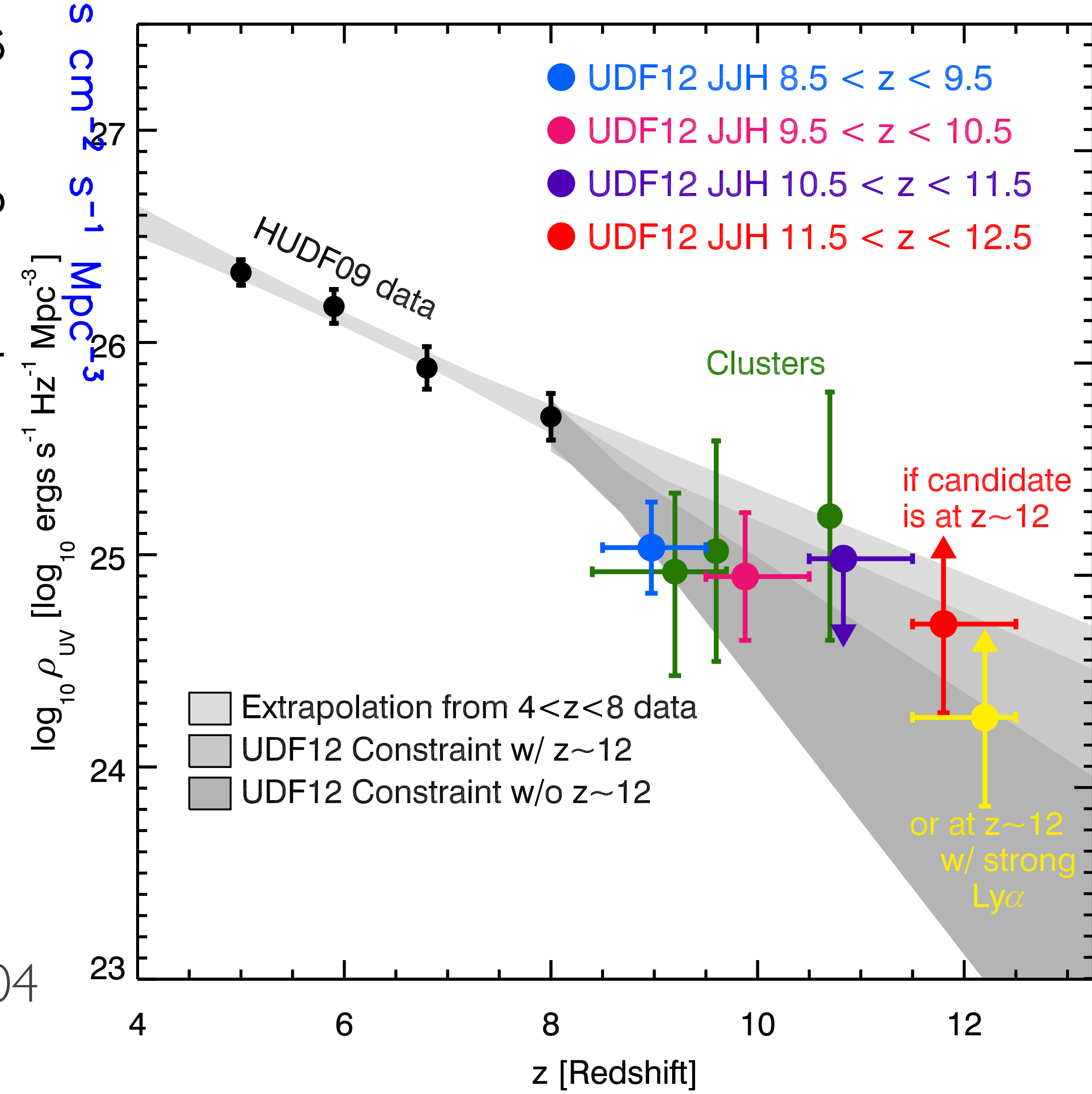


Solid lines: 'Empirical' evolution assumed for WISH-UDS

UV Luminosity Density (SFR Density)



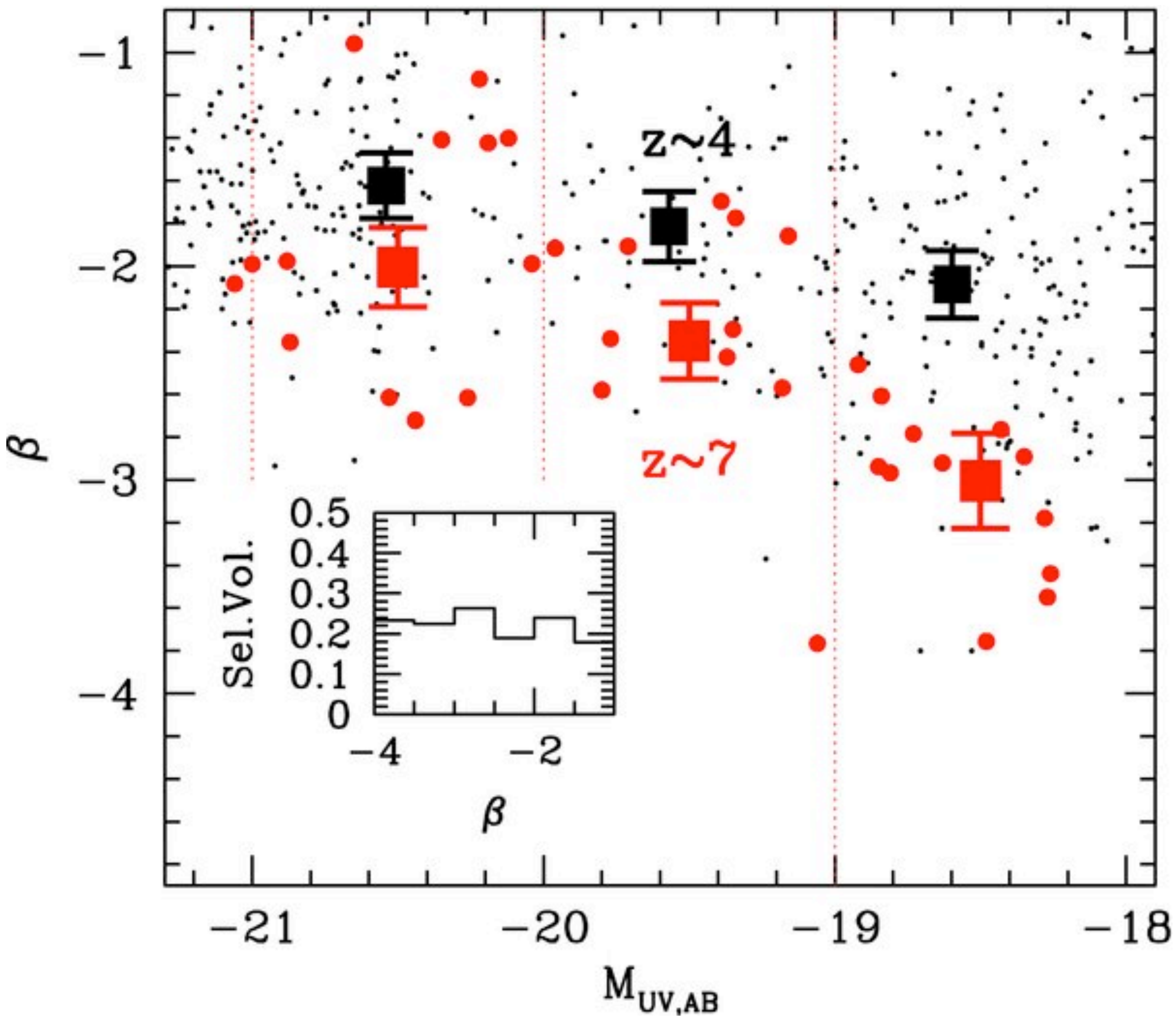
Bouwens+ arXiv:1211.2230

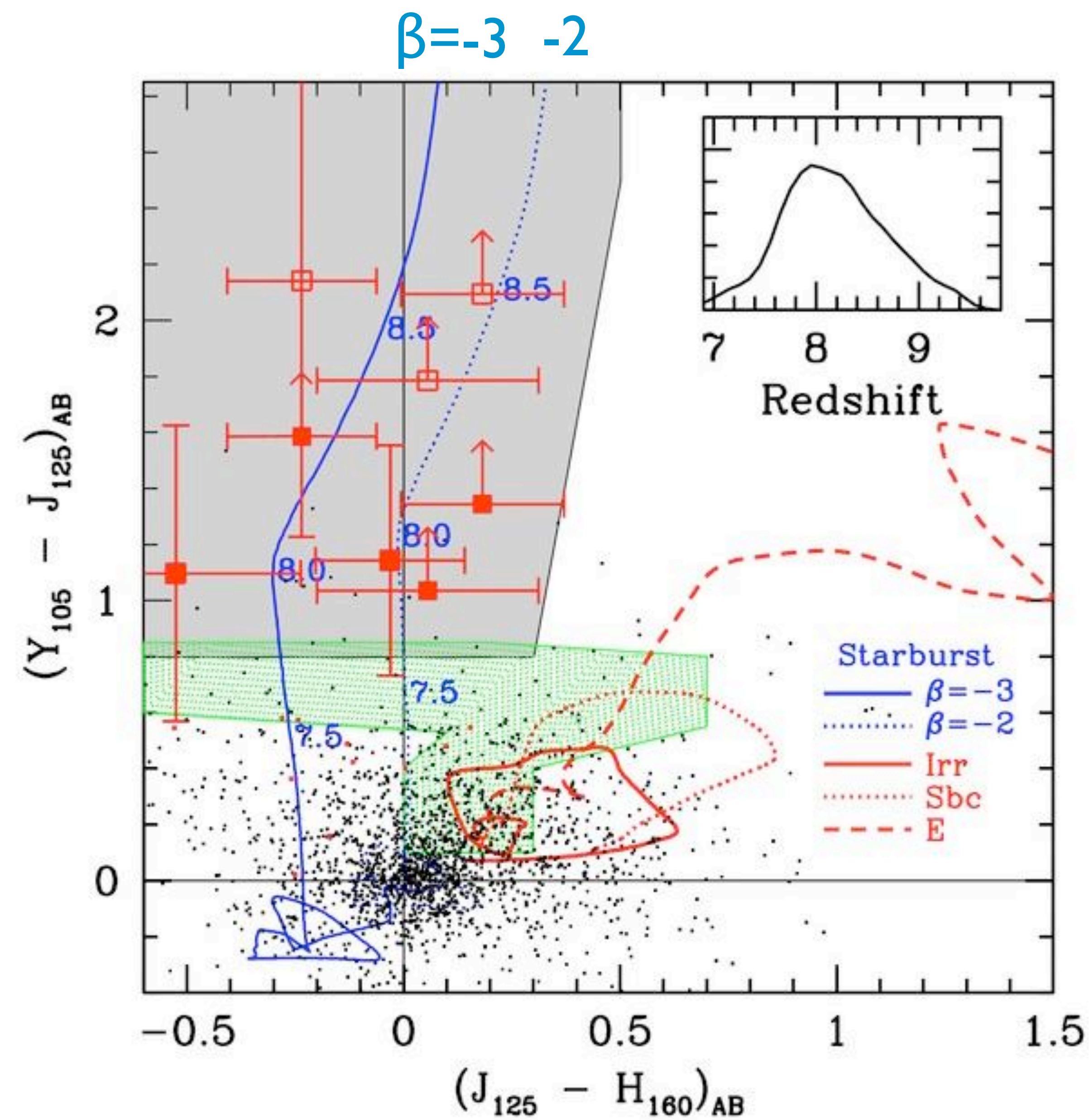


Ellis+ arXiv:1211.6804

Steep UV Slope - Extreme Stellar Populations?

- Bouwens et al. 2010, ApJ 708, L69; ApJ 709, L133; Finkelstein arXiv:1110.3785



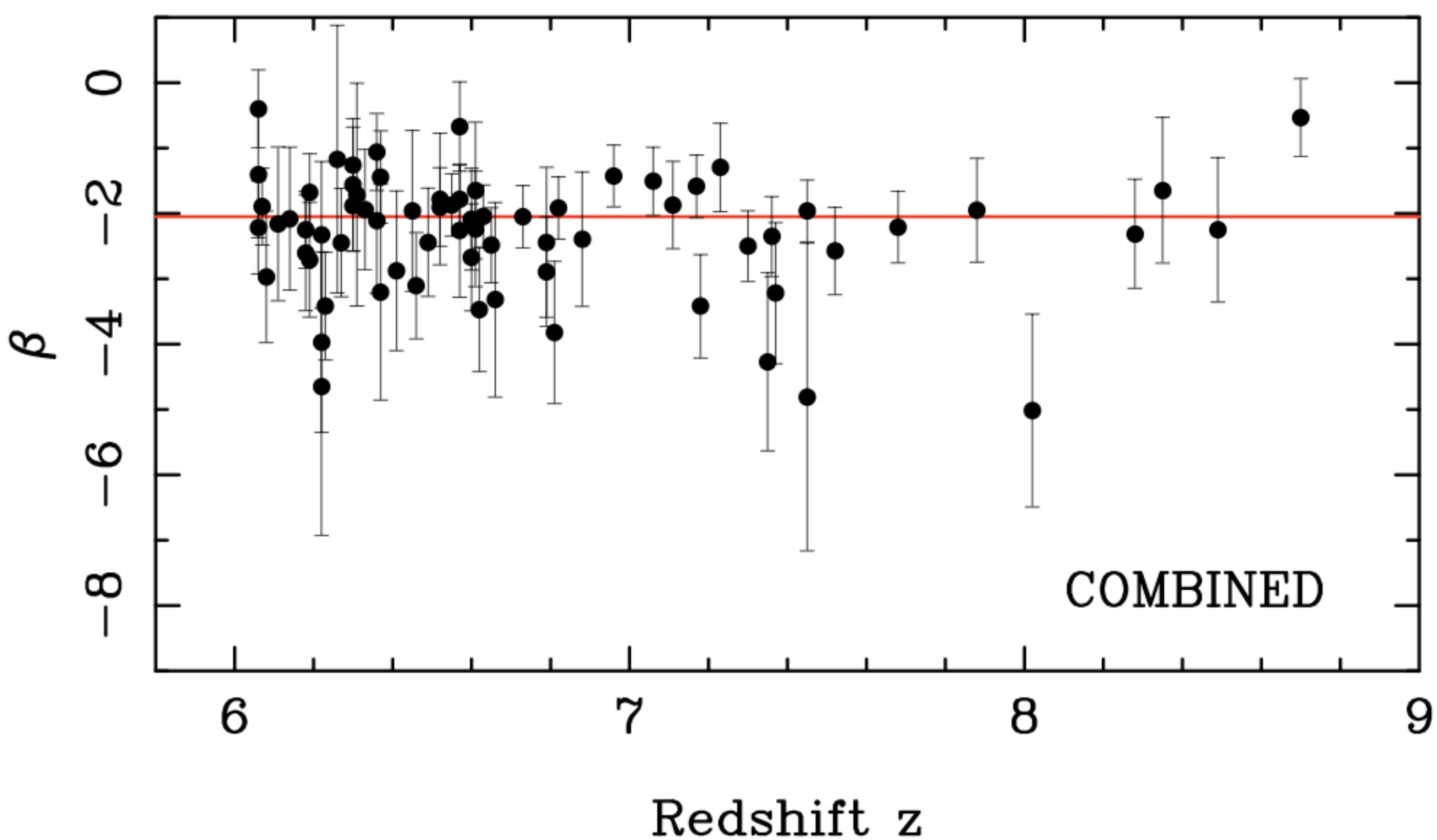


But β can be <-2 without extremely metal poor stellar populations

(Schaerer and de Barros 2010, A&A 515, A73)

McLure et al. 2011 MNRAS 418, 2074

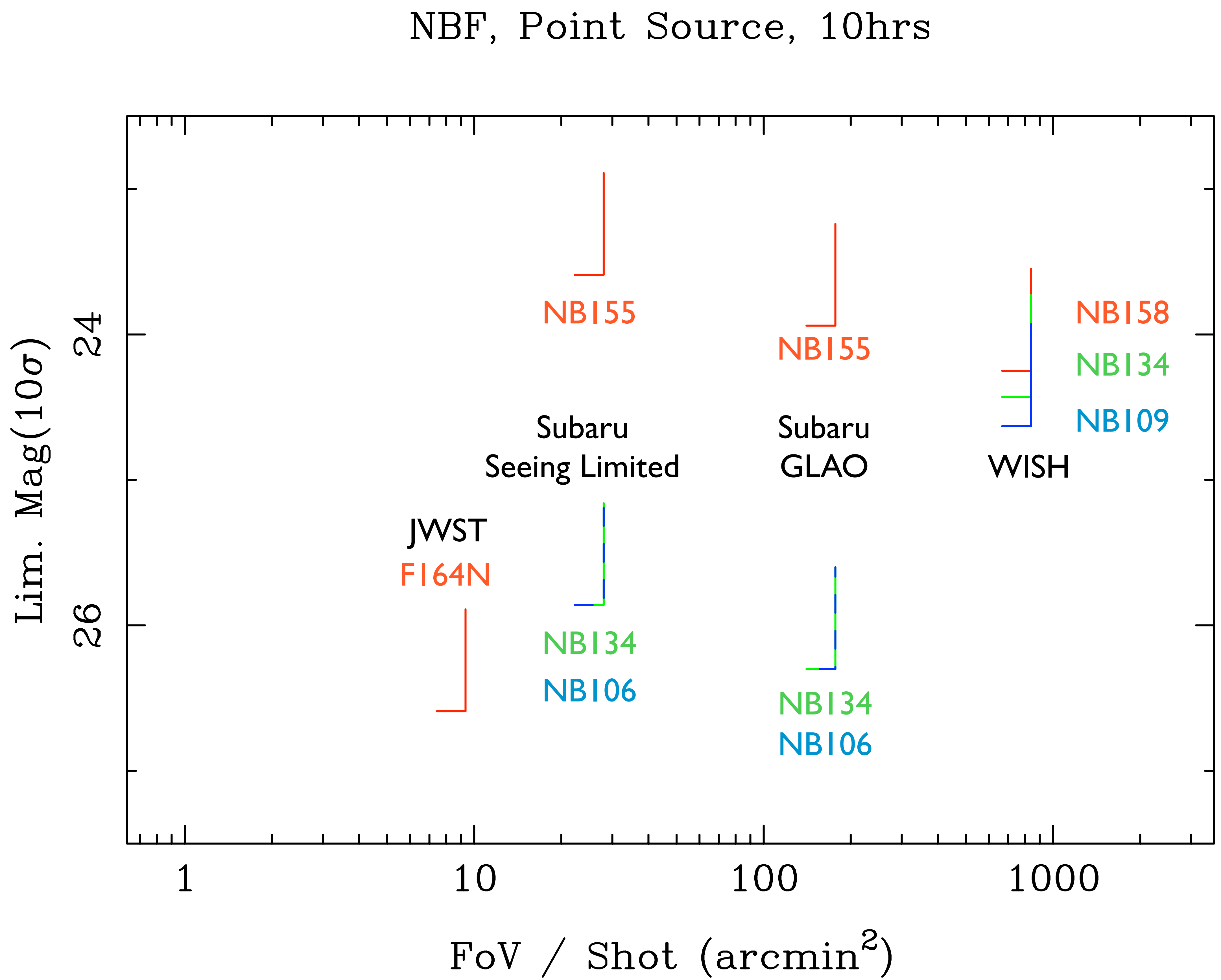
- McLure et al. 2011, MNRAS 418, 2074:
  - HUDF + ERS 6.0 < phot-z < 8.7
  - 70 objects
  - UV Slope β Mean: -2.05 ↔ β < -2.5 (Bouwens et al. 2010, Labbe et al. 2010)



WISH UDS for Exploration of Epoch of Reionization

- Discovery of Bright LBGs at $8 < z < 15$
  - Feed Spectroscopy Targets to ELTs
- Bright-End of UV Luminosity Function
  - We would need to quantify how it is critically important to constrain the bright-end of UVLF at $z>8$
- UV Slope of Bright LBGs
  - Constraint on stellar populations

2. Narrow-band Filter Search for LAEs


NBF, Point Source, 10hrs
Lim. Mag(10σ)
24
26
FoV / Shot (arcmin²)
1
10
100
1000
NB155
Subaru
Seeing Limited
NB134
NB106
JWST
F164N
NB155
Subaru
GLAO
NB134
NB106
NB158
NB134
NB109
WISH

Summary of Limiting Magnitudes and Expected Number of Detections for WISH

Limits are for 3σ

		R=50		R=100	
redshift	Exp Time	Lim Mag.	N/deg^2	Lim Mag.	N/deg^2
z=8	10h	26.0	52.9	25.3	9.1
	50h	26.9	91.3	26.2	71.1
z=10	10h	26.1	9.3	25.4	0.96
	50h	27.0	18.8	26.3	9.7
z=12	10h	26.0	2.40E-02	25.3	2.20E-02
	50h	26.9	0.40	26.2	0.42

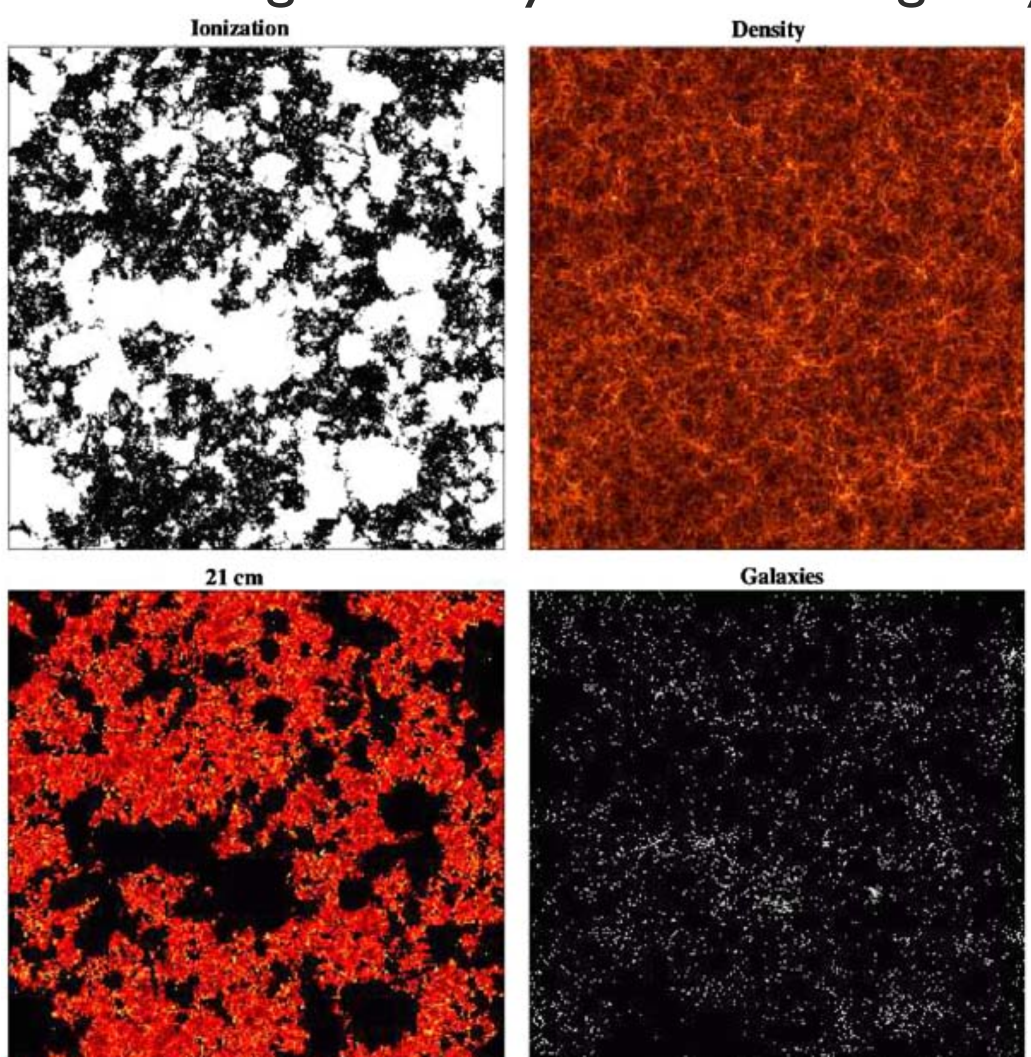
WISH Can Detect

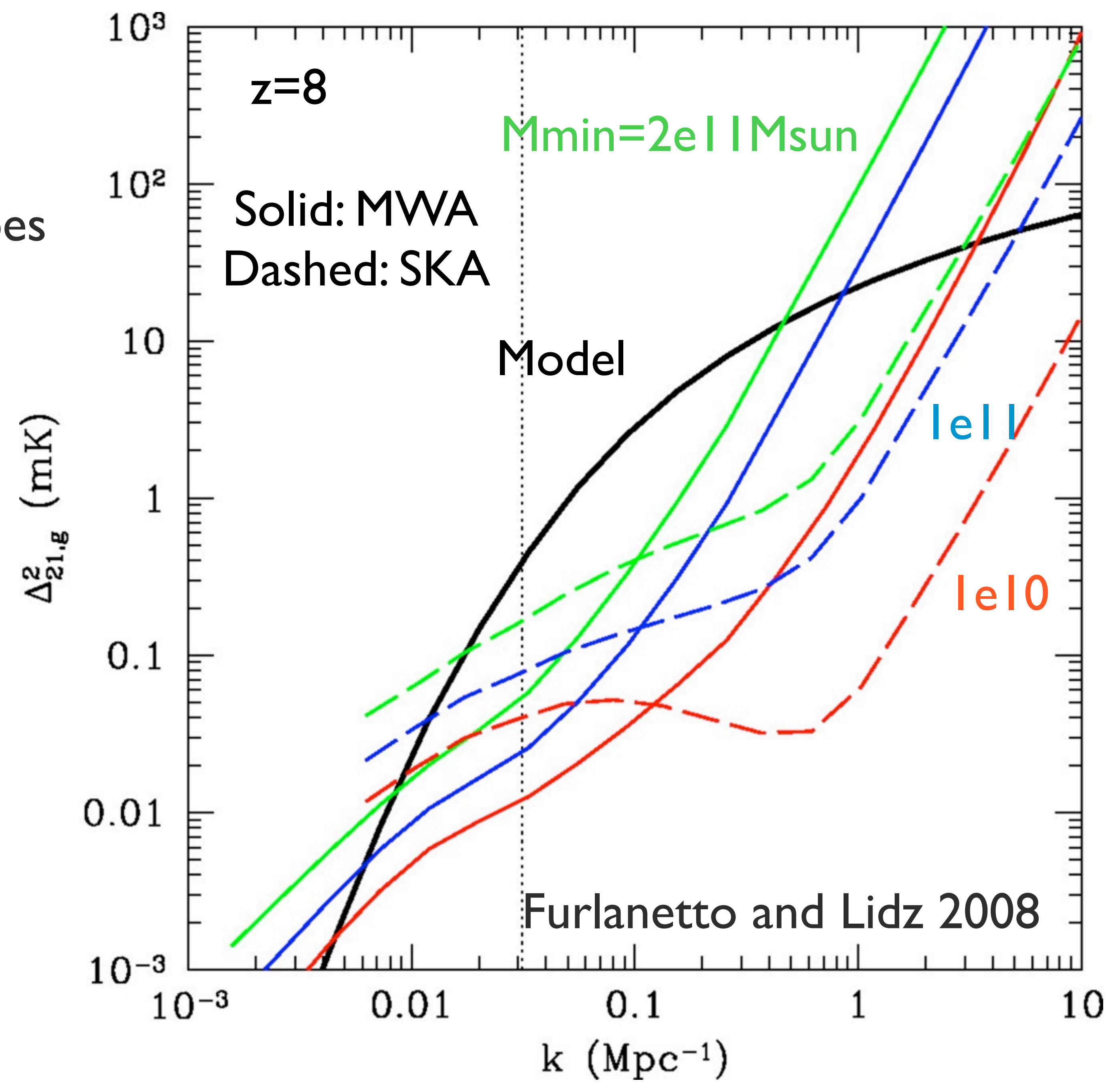
Large Sample of LAEs at z=8-10

Cross-Correlation of Galaxies and IGM 21cm Emission

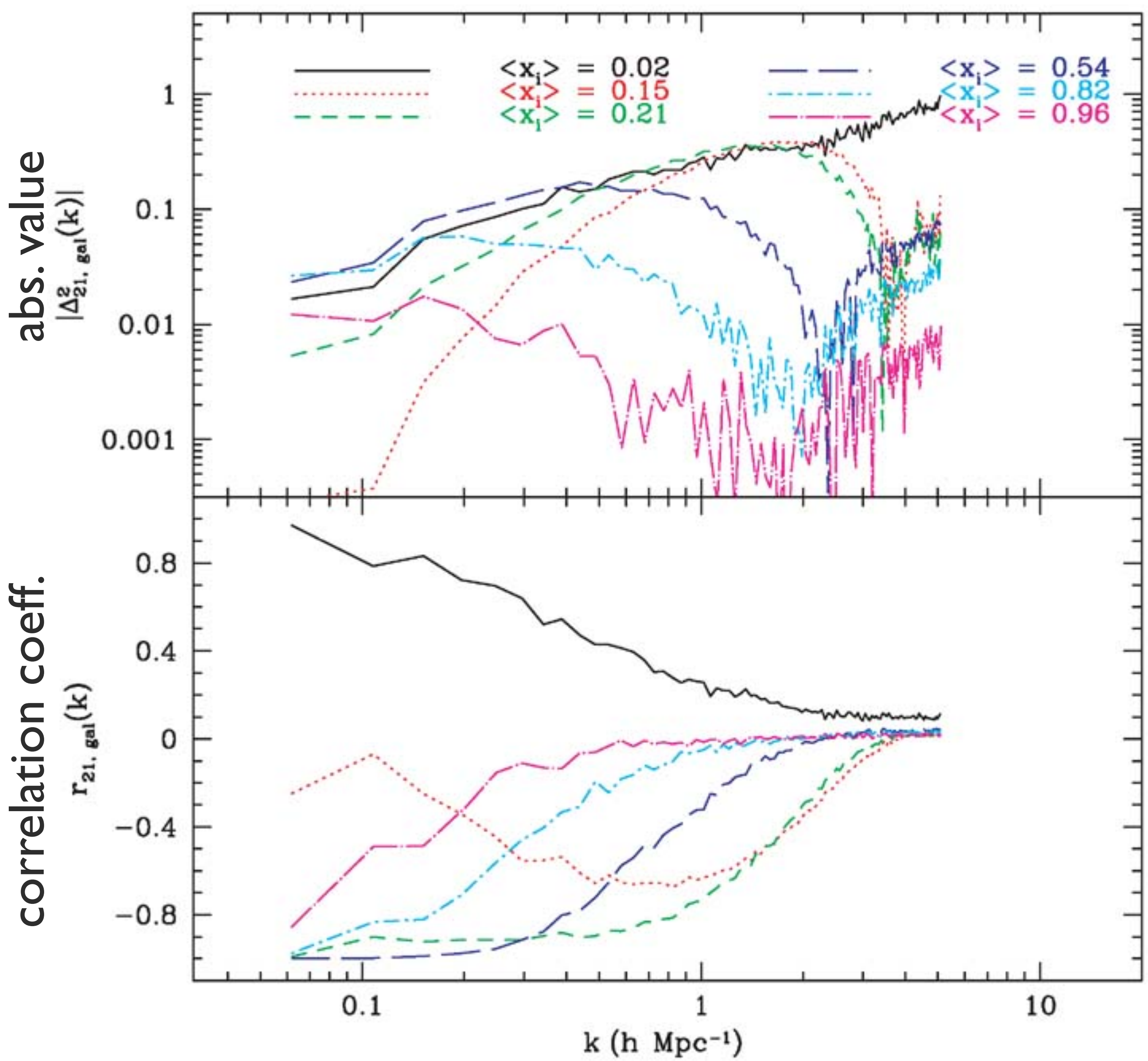
Cross-Correlation of HI 21cm Emission and Galaxies

- Wyithe and Loeb 2007, MNRAS 375, 1034; Furlanetto and Lidz 2008, ApJ 660, 1030
- Advantage of Galaxy - 21cm line cross correlation over 21cm signal alone:
    - Eliminates foreground contaminations
    - Possible S/N improvement
    - Ionizing efficiency for different galaxy types





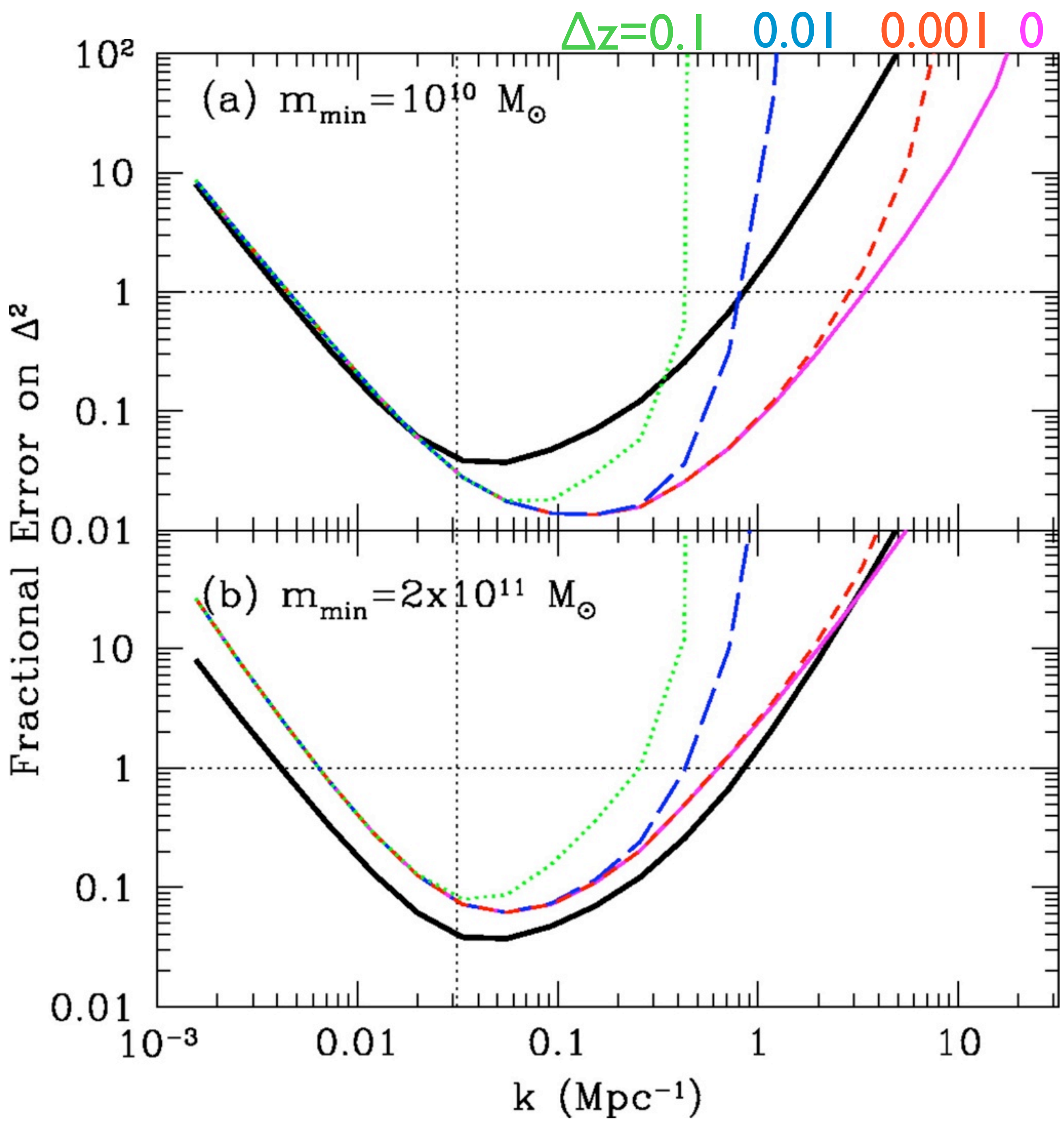
Resolving History of Reionization



Lidz et al. 2009, ApJ 690, 252

- Beginning: galaxy and 21cm are positively correlated
- Galaxies ionize overdense regions. Underdense regions remain neutral - Brief period of low amplitude cross-correlation (Xi=0.15 in the left model)
- Galaxy and 21cm quickly become anticorrelated

Requirements on the Galaxy Survey



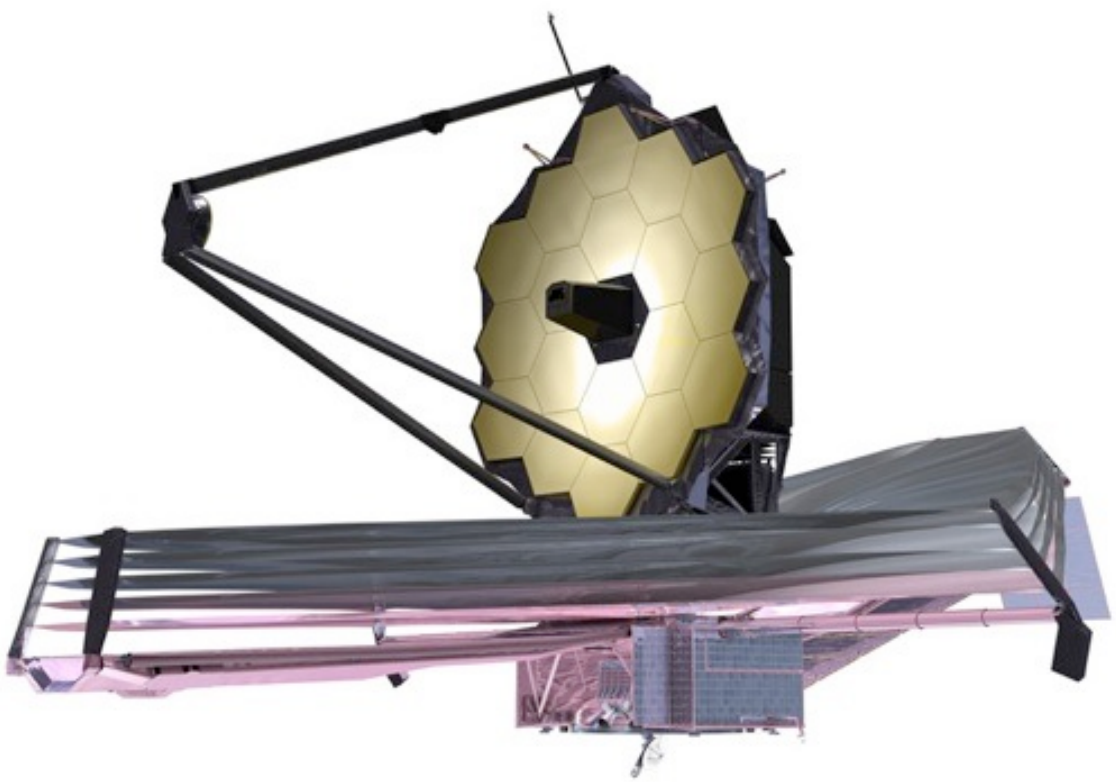
Furlanetto and Lidz 2008

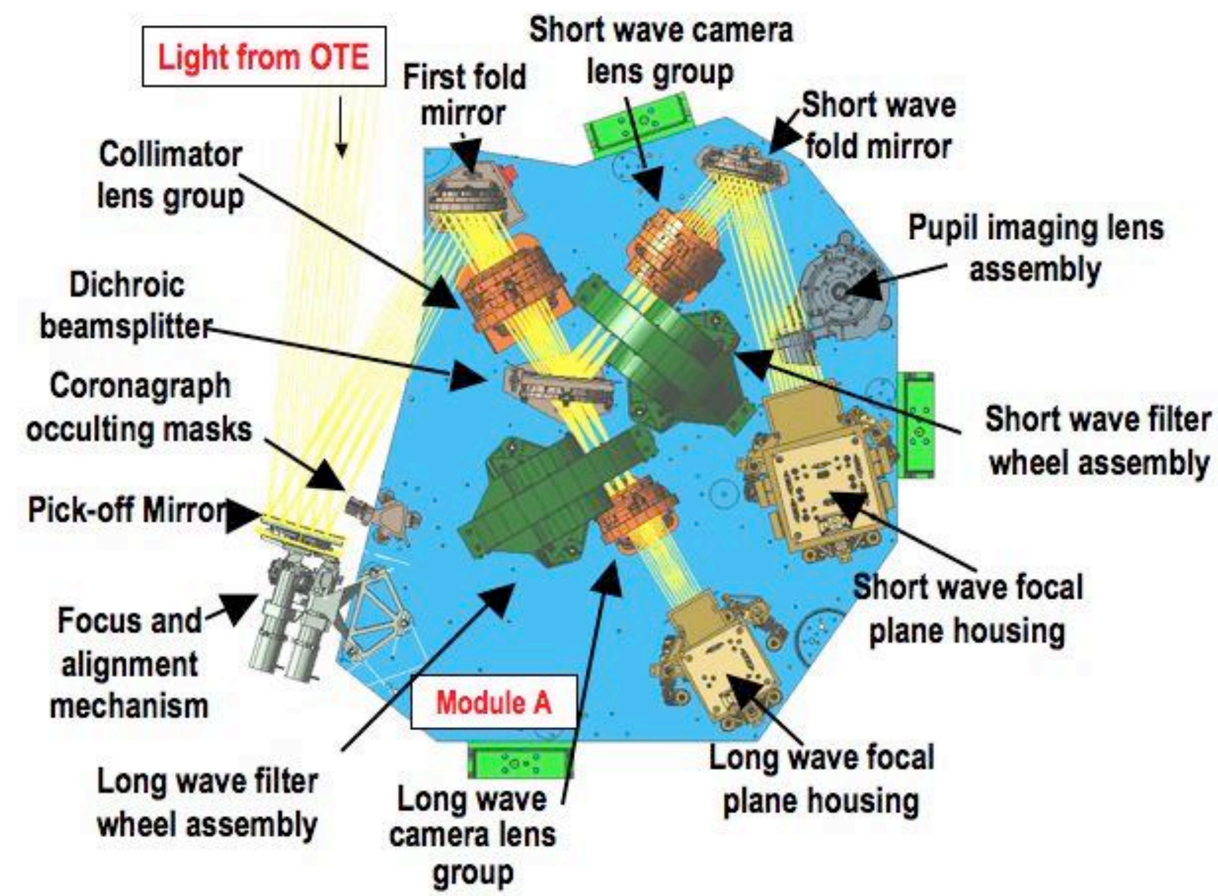
- Accurate redshifts
  - LAE survey would be good
- Large area coverage
  - to improve S/N
  - >100 deg^2 survey area, coordinated with 21cm line obs.

3. Comparisons with JWST etc.

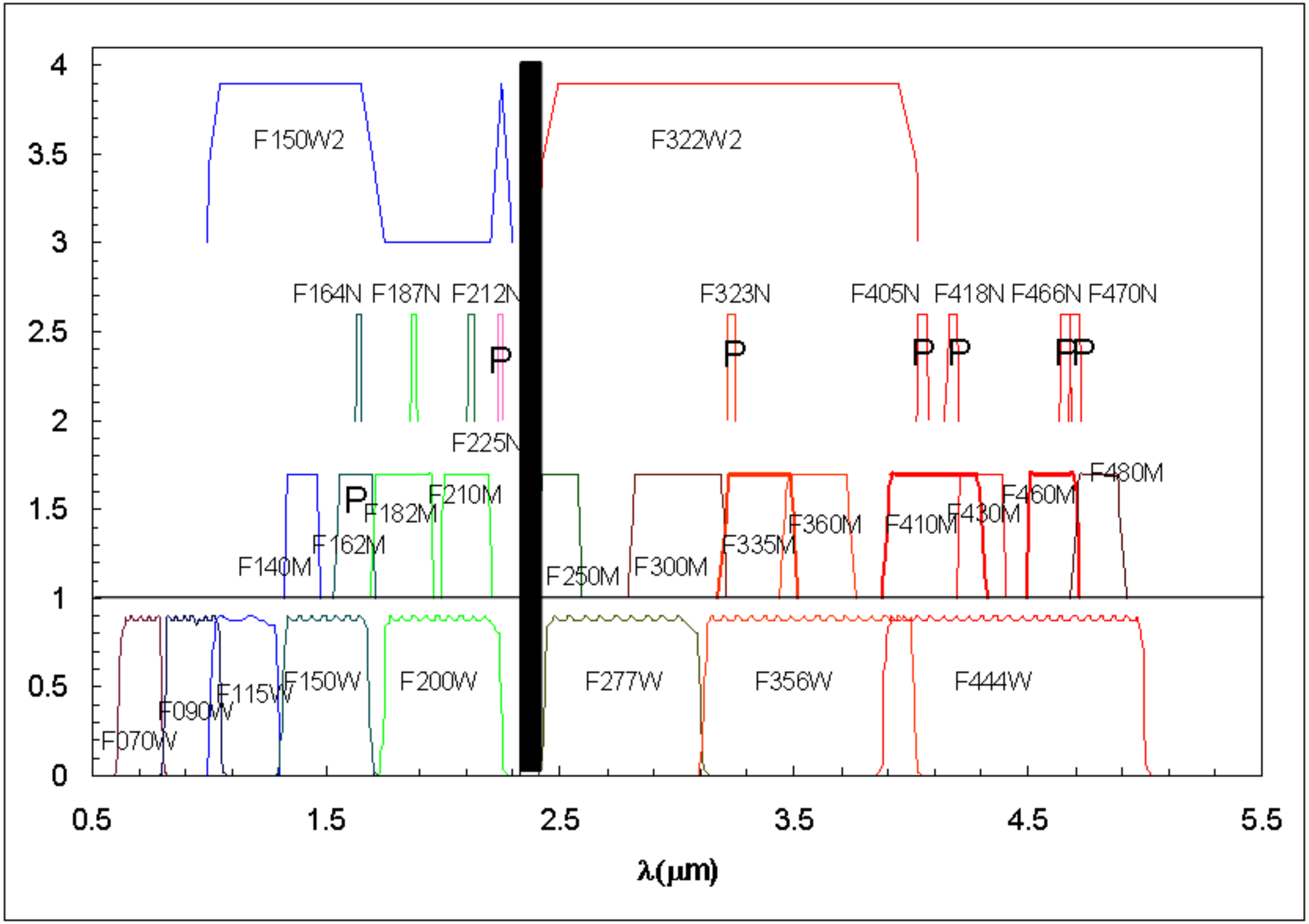
JWST NIRCam

- Two Channels, both 2.2’ x 4.4’
  - Short: 0.5 - 2.3 µm, 32 mas (8 H2RGs)
  - Long: 2.5 - 5.0 µm, 64 mas (2 H2RGs)
- Coronagraphic High Contrast Imaging
- Slitless Grism Spectroscopy R~1800





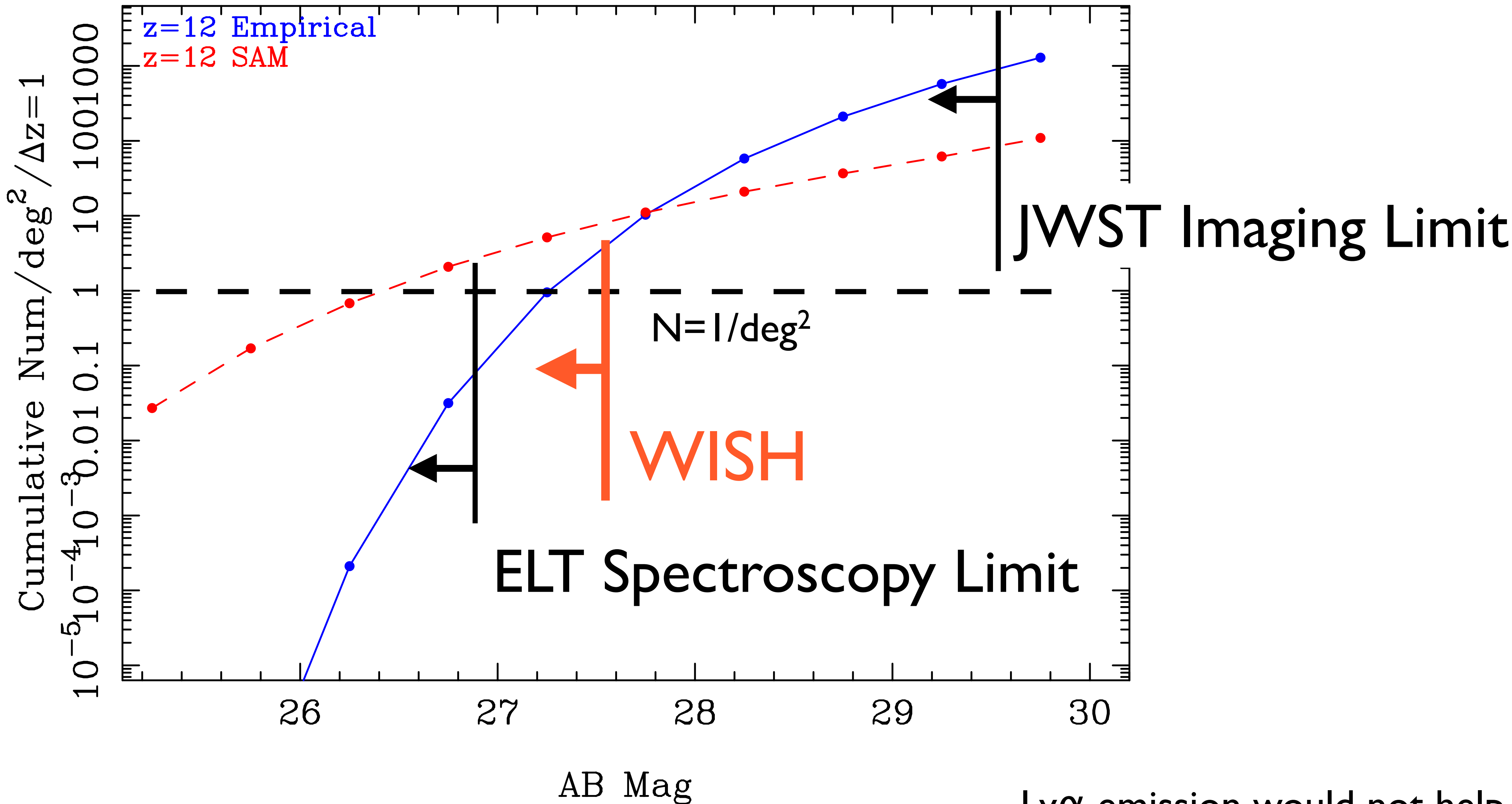
NIRCam Filters



JWST / NIRCam Expected Surveys

- Assume operation similar to HST
- Mirror size: x 2.6, Field of View: x 2.0
- HST WFC3/IR Deep Surveys: ~300 $arcmin^2$ in a few years
- NIRCam Surveys with Depth Similar to Current WFC3/IR Surveys (~29 AB mag.)
- → ~1 deg^2 in a few years. Several deg^2 in 5-10 years.

Number Density of z=12 Galaxies



Lyα emission would not help improving the detection limit with ELTs for extended sources

WISH and JWST for Exploration of EoR

- WISH:
  - Discovery of Bright LBGs at $8 < z < 15$
    - Feed Spectroscopy Targets to ELTs
  - Bright-End of UV Luminosity Function
  - UV Slope of Bright LBGs
  - LAEs at z=8 and 10
    - Feed to ELTs
    - Cross-correlation with HI 21cm Line Surveys?
- JWST:
  - Determination of Faint-End of UV Luminosity Function
    - Contribution of Faint Galaxies to the Cosmic Reionization
  - Discovery of Galaxies at z>8 (up to z~20?)
    - Spectroscopy with NIRSpec
  - Limited Survey Area

Euclid, WFIRST, and WISH

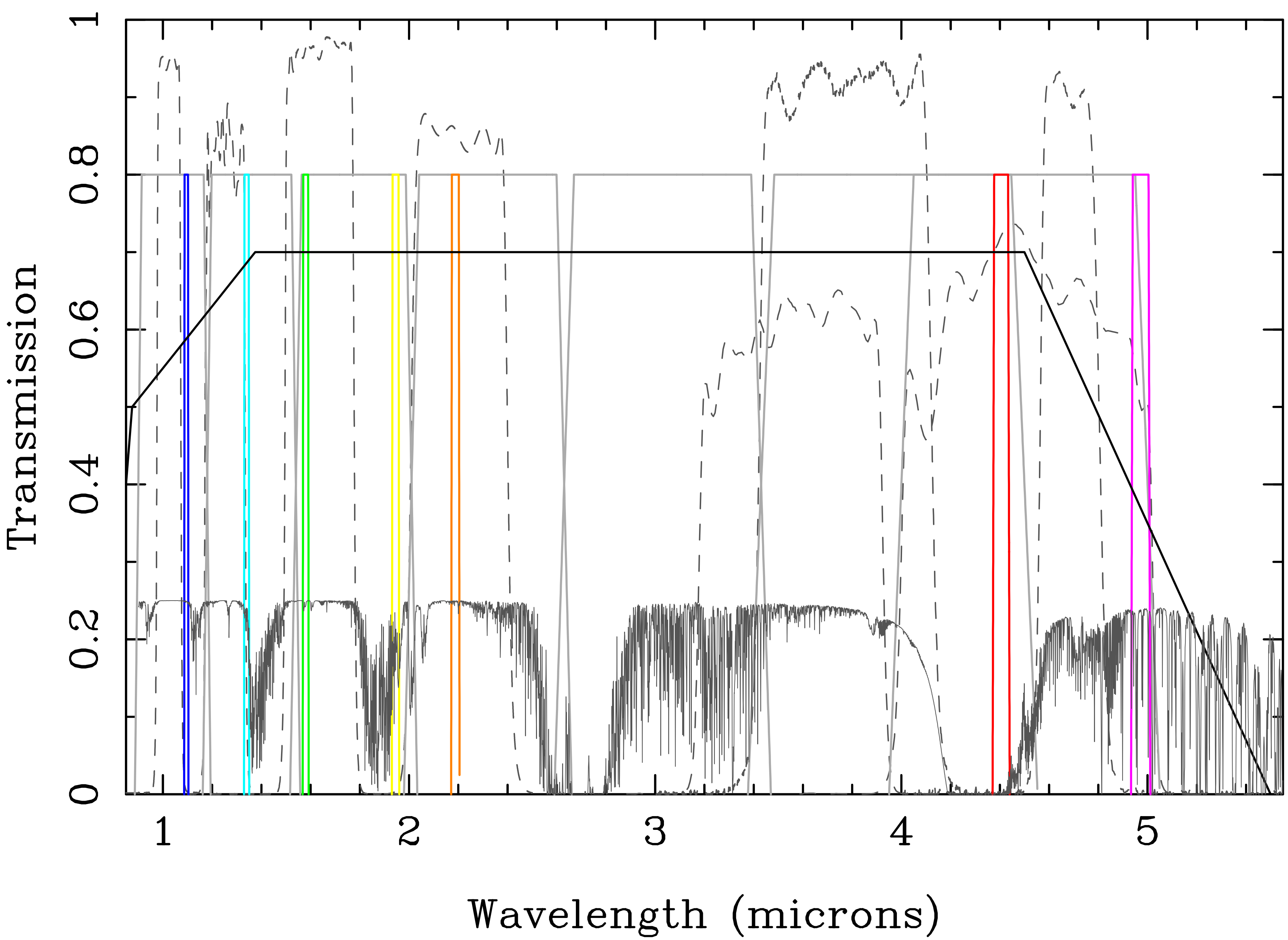
	Euclid	WFIRST	WISH
Mirror	1.2m	1.3m?	1.5m
FoV	0.5 deg^2	0.3deg^2?	0.23deg^2
Visual Imager	RIz	↓	--
NIR Imager	YJH	0.6-2.0μm	0.9-5.0μm
Lim. Mag.	24AB	25.9AB	28AB
Survey Area	20,000 deg^2	>11,000 deg^2	100 deg^2
Primary Science	Dark Energy	DE, Exoplanet, QSO	First Galaxies

Summary

1. What will we know with WISH Ultra-Deep Survey?
   - Evolution of UVLF
   - UV slope
   - Re-check depth and area
2. Narrow-band Survey
   - Cross-correlation with HI 21cm?
3. Comparisons with JWST, Euclid, and WFIRST
   - Complimentary to JWST
   - Unique λ, depth + area against Euclid and WFIRST

Backup Slides

NBF Set 01

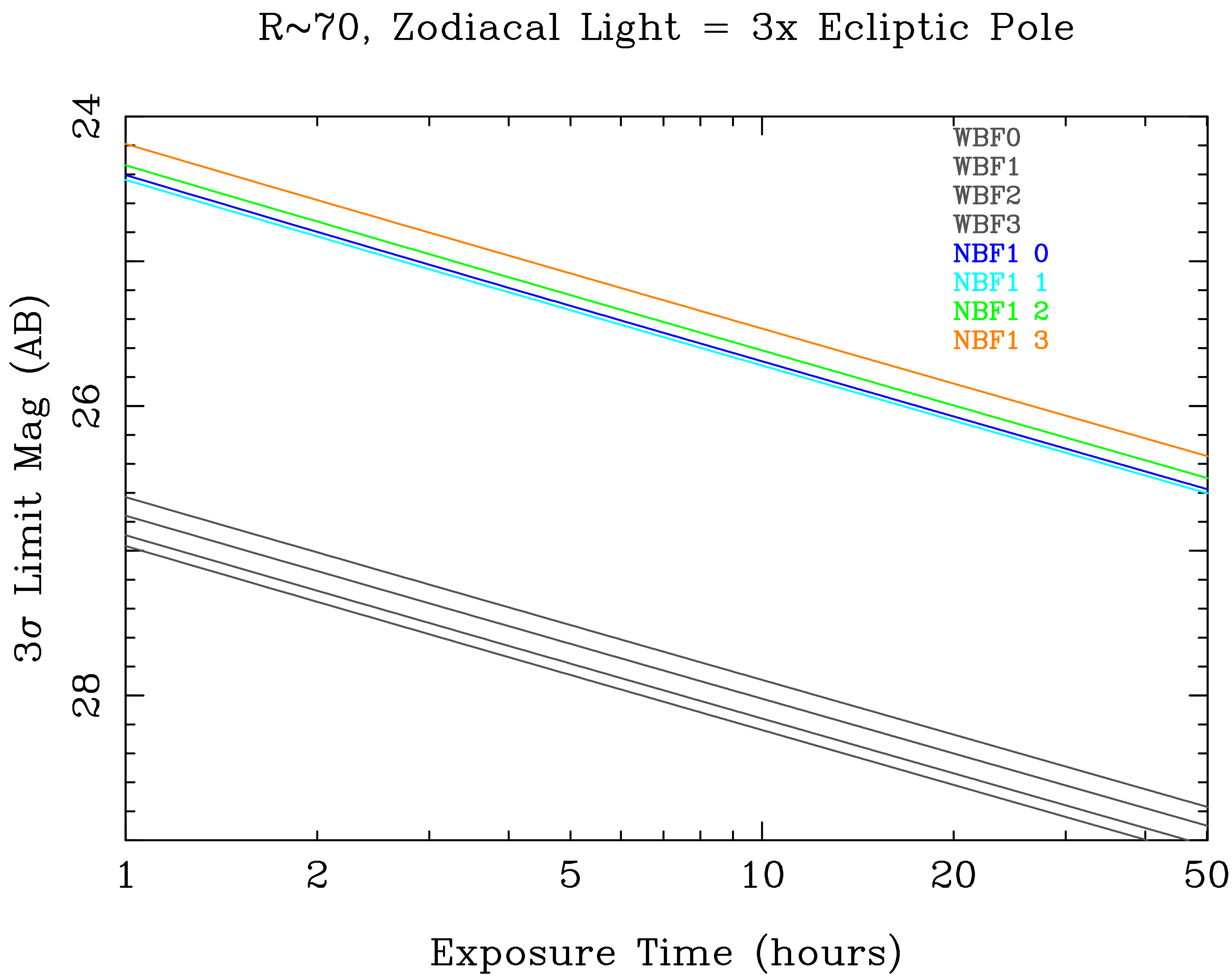


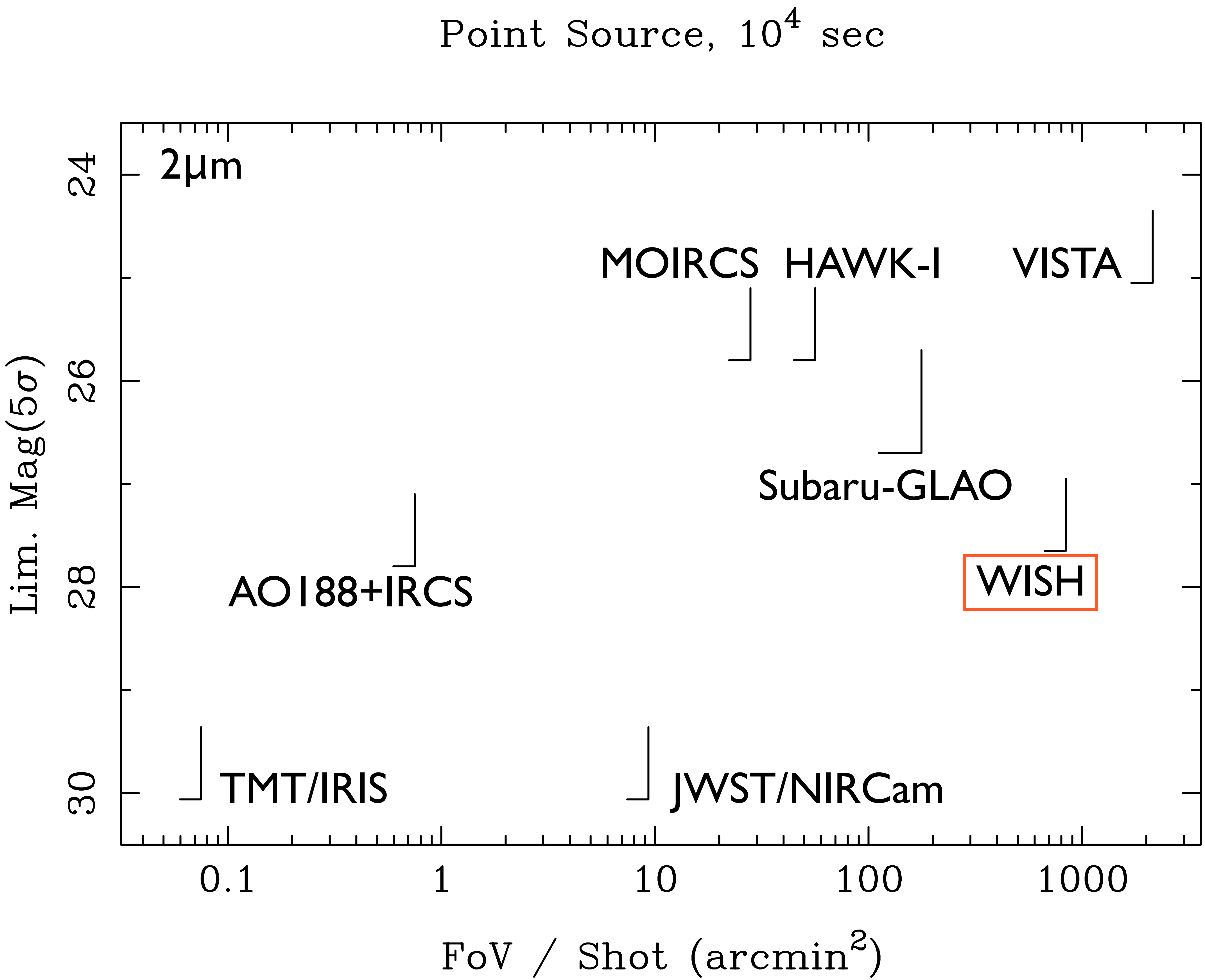
NBF Set 01 (R~70)

Name	λc	z	FWHM	R
0100_00	1.095	8.0	0.015	73.0
0100_01	1.340	10.0	0.019	70.5
0100_02	1.580	12.0	0.022	71.8
0100_03	1.945	15.0	0.027	72.0
0100_04	2.188	17.0	0.031	70.6
0100_05	4.4052	5.71*	0.063	69.9
0100_06	4.9720	6.58*	0.071	70.0

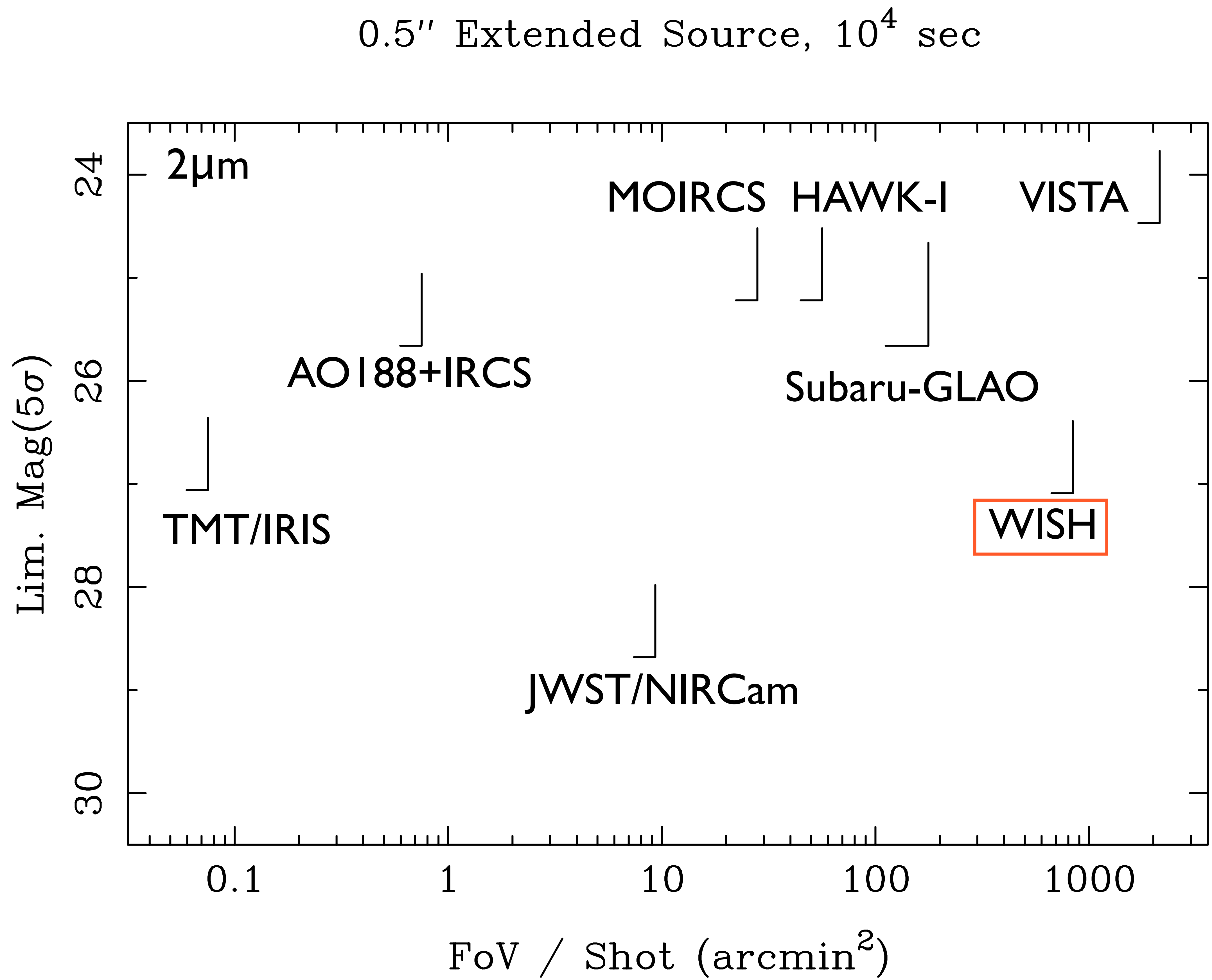
* redshift for Hα

NBF Set 01, Limiting Mag.





Point Source, 10^4 sec
2μm
MOIRCS
HAWK-I
VISTA
Subaru-GLAO
WISH
AO188+IRCS
TMT/IRIS
JWST/NIRCam
24
26
28
30
Lim. Mag(5σ)
0.1
1
10
100
1000
FoV / Shot (arcmin^2)


0.5″ Extended Source, 10^4 sec
2μm
MOIRCS
HAWK-I
VISTA
AO188+IRCS
Subaru-GLAO
TMT/IRIS
WISH
JWST/NIRCam
Lim. Mag(5σ)
24
26
28
30
0.1
1
10
100
1000
FoV / Shot (arcmin^2)

Comparison: Imaging

	Subaru MOIRCS	Subaru GLAO	TMT IRIS	HST WFC3/IR	JWST NIRCam
Mirror Size	8.2m	8.2m	30m	2.4m	6.5m
Wavelength	0.9-2.5μm	0.9-2.5μm	0.84-2.4μm	0.9-1.7μm	0.9-2.3μm / 2.4-5.0μm
Spatial Sampling	0.117”/pix 0.4”@2μm	~0.1”/pix 0.2”@2μm	4 mas 10mas@1μm	0.13”/pix FWHM~ 0.25”	32 mas / 64 mas
FoV	28 □’	~120 □’	0.075 □’	4.65 □’	9.7 □’

Comparison: Spectroscopy

	Subaru MOIRCS	Subaru GLAO	TMT IRIS	HST WFC3/IR	JWST NIRSpec
Wavelength	0.9-2.5μm	0.9-2.5μm	0.84-2.4μm	0.9-1.7μm	0.6-5μm
Spatial Sampling	0.117”/pix 0.4”@2μm	~0.1”/pix 0.2”@2μm	4 - 50 mas	0.13”/pix FWHM~ 0.25”	0.2”x0.45”
FoV	~25 □’	~120 □’	0.2-10 □”	4.65 □’	12.24 □’(MSA) 3”x3”(IFS)
Spectroscopic Capability	Single-Slit MOS IFS	Multi-IFS	IFS	Slitless	Slits Microshutters IFS
Spectral Resolution	600-3000	-3000?	4000-10000	TBW	100, 1000, 2700