# WFIRST/AFTA Surveys of the Epoch of Reionization

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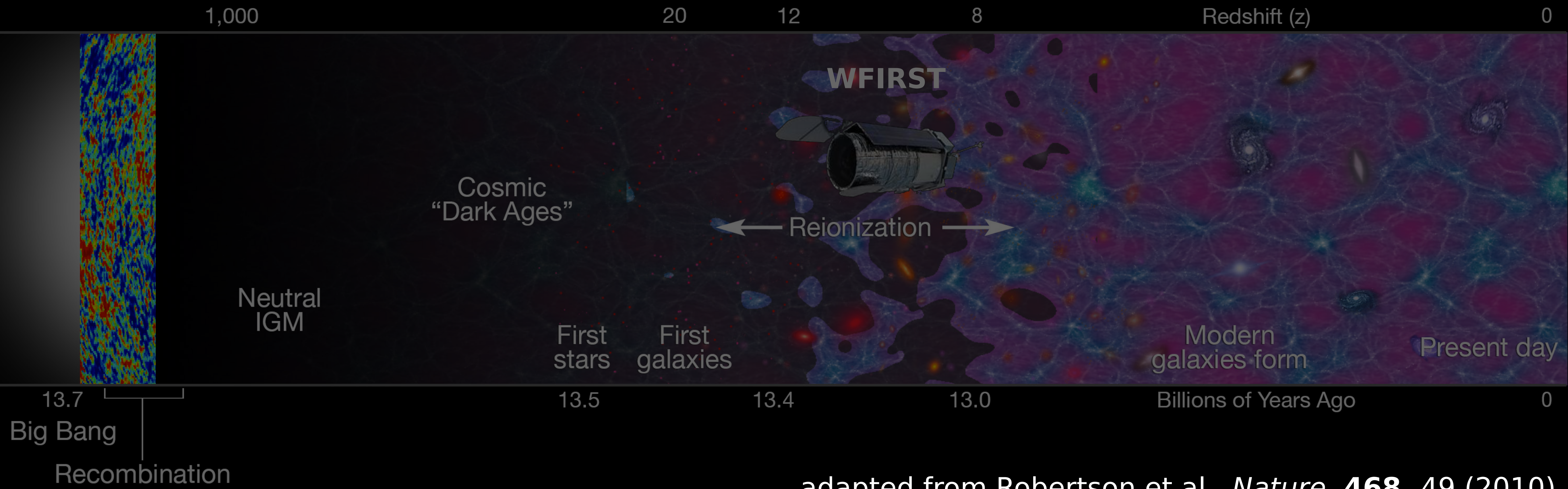
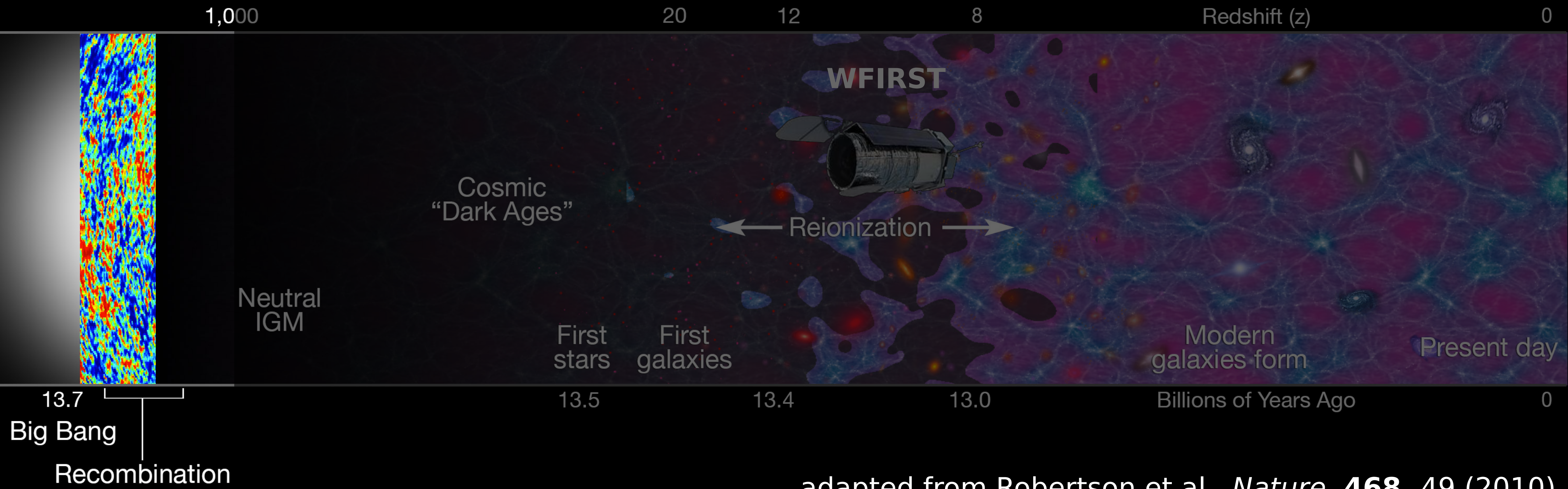
# Observable Cosmological History

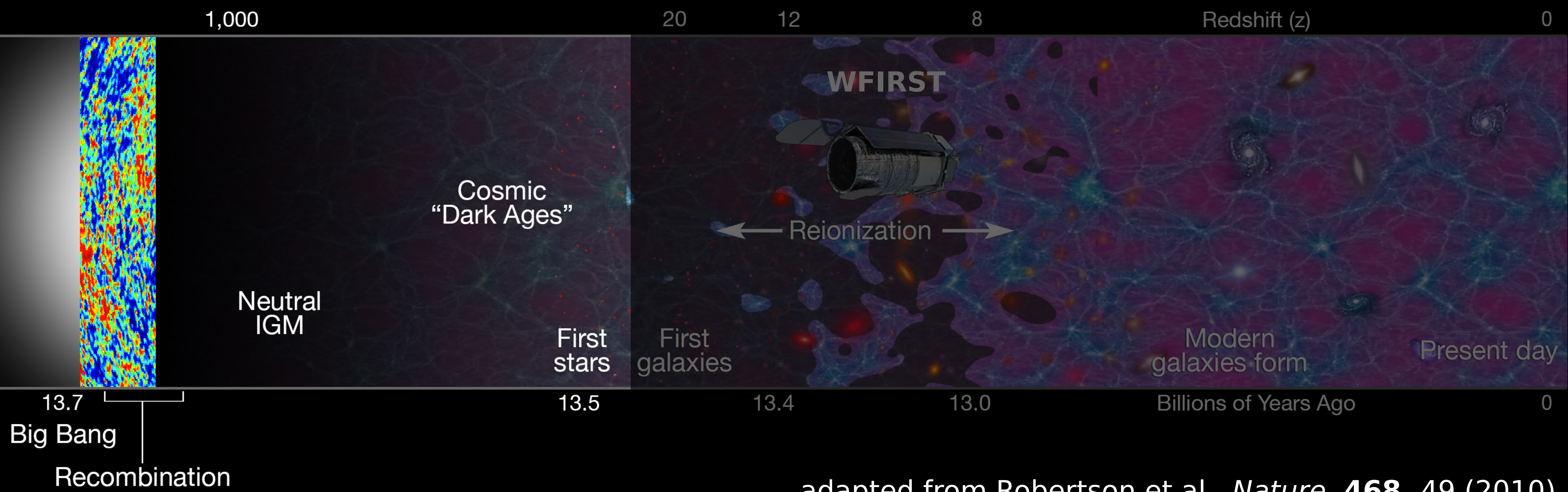



adapted from Robertson et al., *Nature*, **468,** 49 (2010)



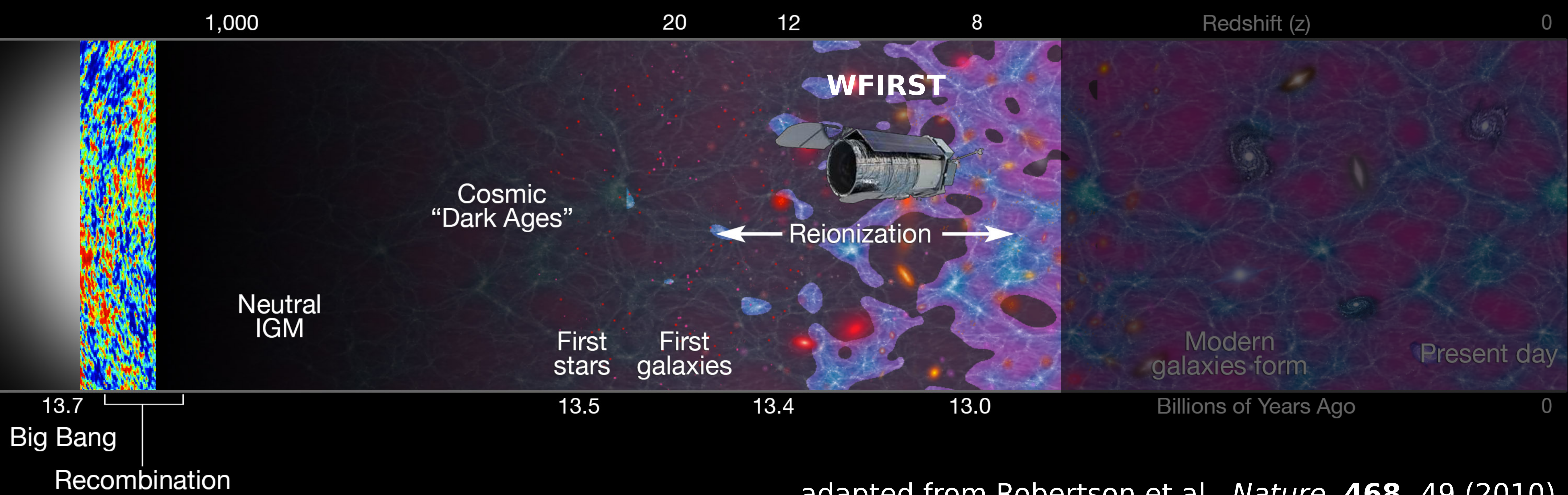

adapted from Robertson et al., *Nature*, **468,** 49 (2010)

# Recombination (z~1100)



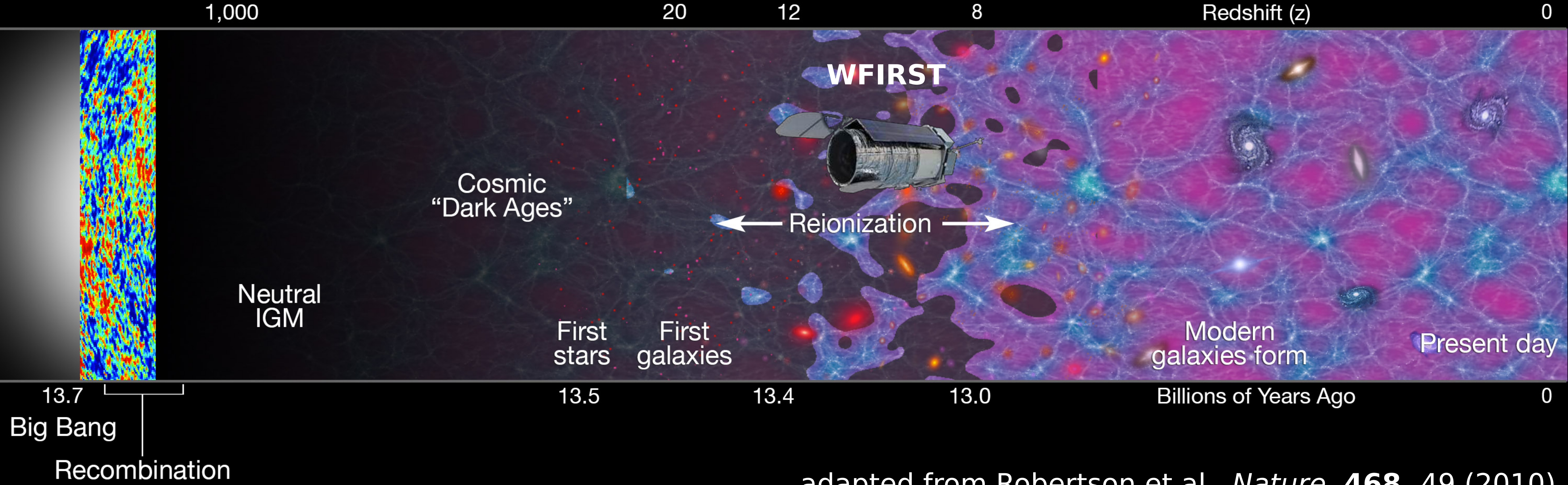

adapted from Robertson et al., *Nature*, **468,** 49 (2010)

# First Light (z~30-50)



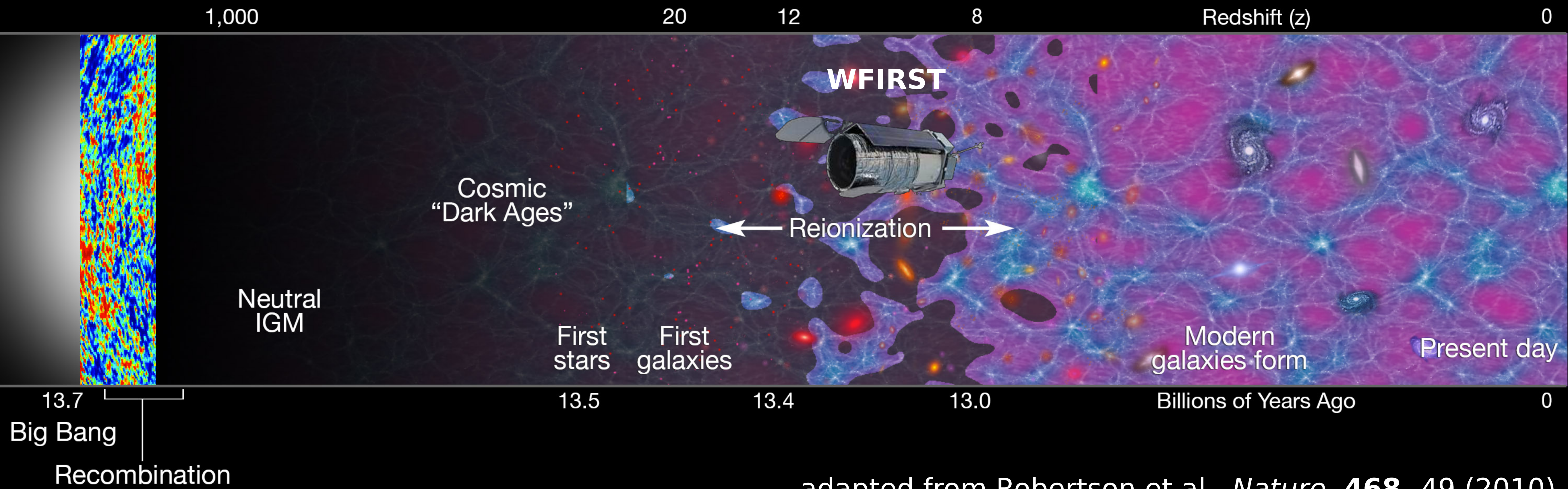

adapted from Robertson et al., *Nature*, **468,** 49 (2010)

# Reionization (z~6-15)




adapted from Robertson et al., *Nature*, **468,** 49 (2010)

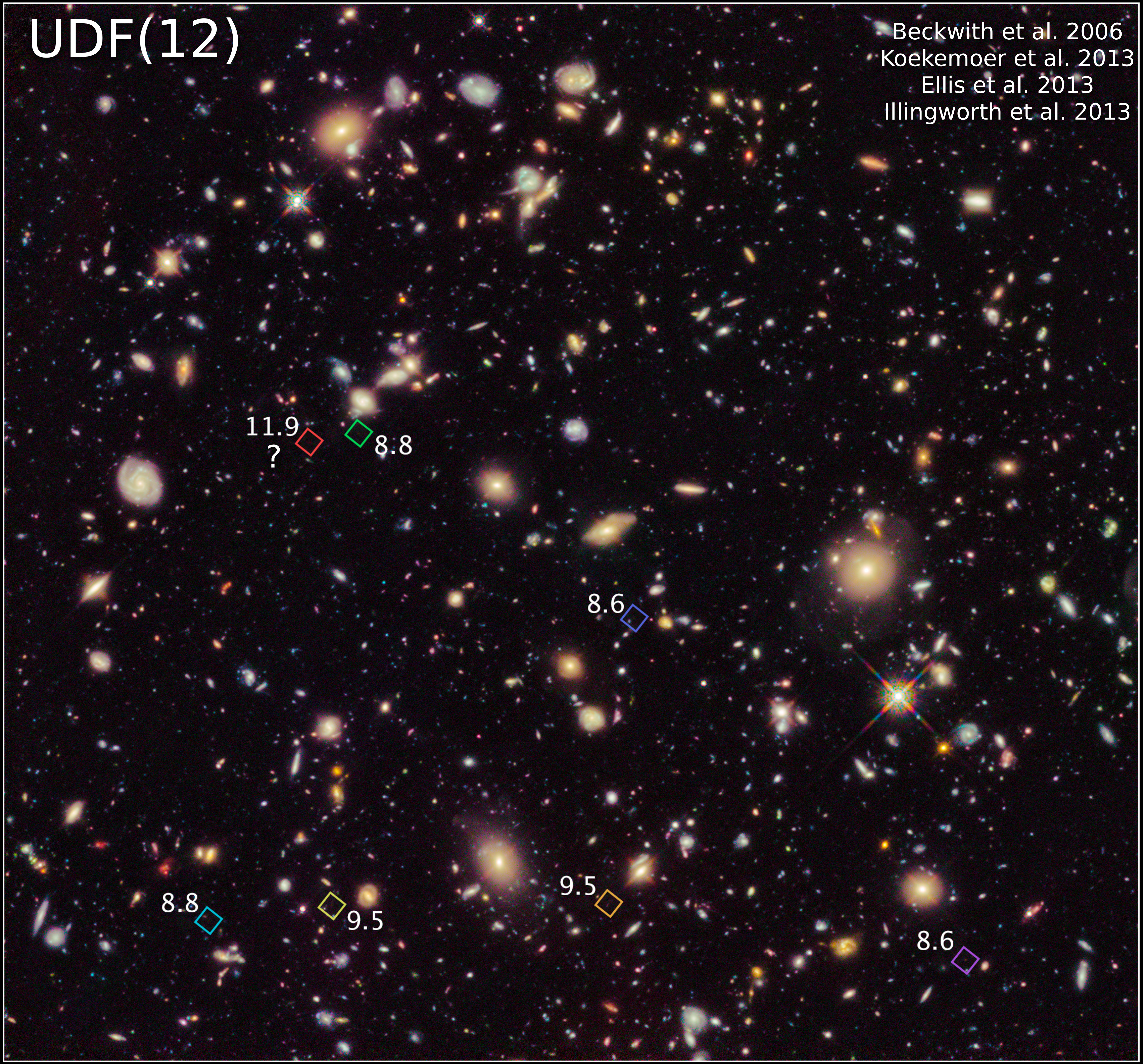
# Modern Galaxies Form (z<3)




adapted from Robertson et al., *Nature*, **468,** 49 (2010)

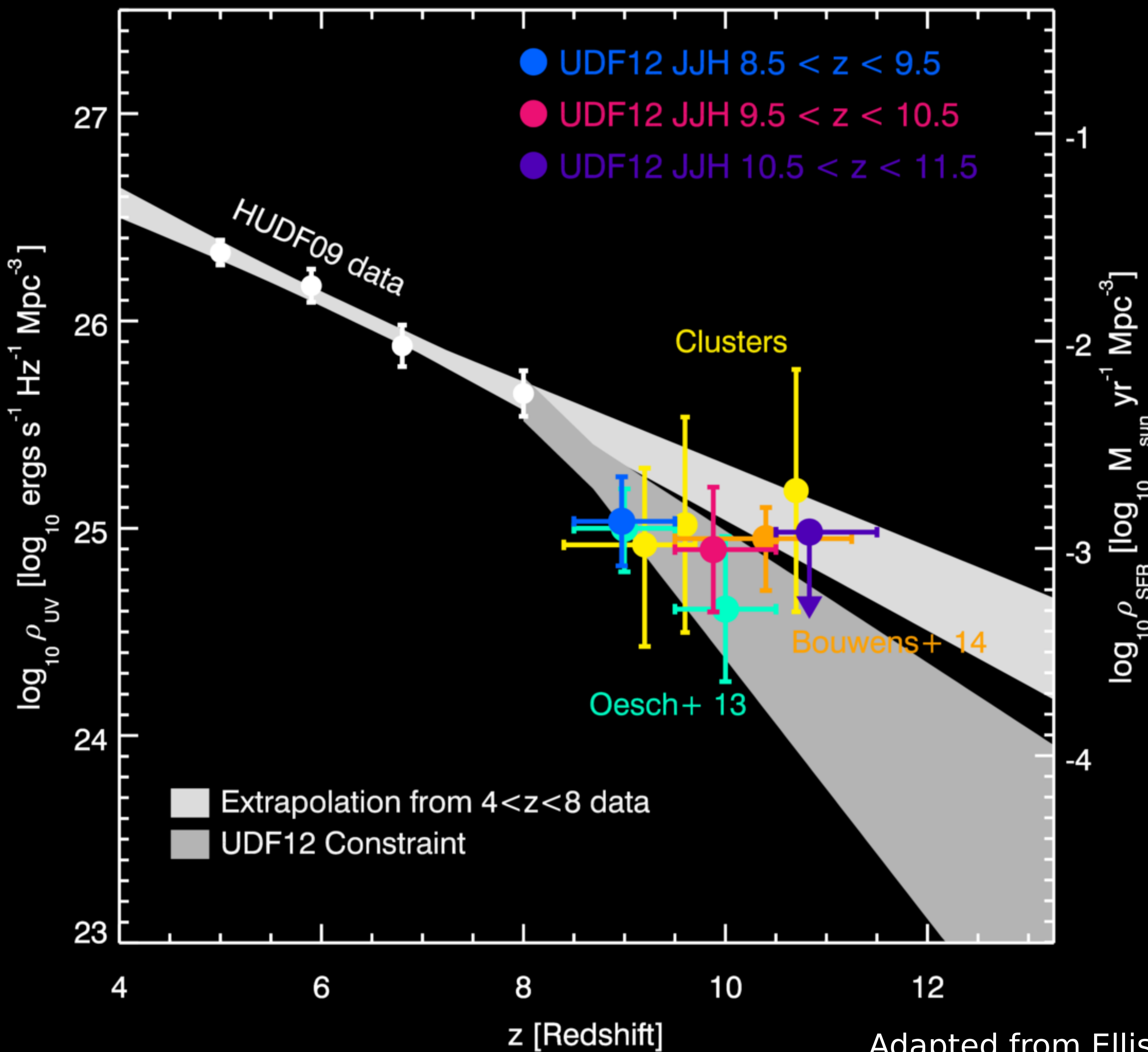
# Important Questions About the High-z Universe

- When did galaxies first become abundant?
- Were galaxies collectively abundant and luminous enough to cause Reionization by z~6?
- Were there enough early galaxies to partially ionize the IGM at z>10 long enough to account for the CMB Thomson optical depth?


UDF(12)
Beckwith et al. 2006
Koekemoer et al. 2013
Ellis et al. 2013
Illingworth et al. 2013
11.9
?
8.8
8.6
8.8
9.5
9.5
8.6

| Existing Surveys of Reionization Epoch Galaxies | | | | |
|---|---|---|---|---|
| **Survey** | **Area [deg$^2$]** | ***H*-band Depth [5-σ AB]** | **Instrument** | **Reference** |
| **UltraVISTA** | 1.5 | 24 | VISTA VIRCAM | McCracken et al. 2012<br>Bowler et al. 2014 |
| **CANDELS Wide (+ GOODS ERS)** | 0.29 | 26.7-27.3 | HST WFC3 | Grogin et al. 2011<br>Koekemoer et al. 2011<br>Windhorst et al. 2011 |
| **BoRG** | >0.1 (71 fields) | 25.6-27.0 | HST WFC3 | Trenti et al. 2011<br>Schmidt et al. 2014 |
| **HIPPIES** | 0.034 (26 fields) | 26.7 (median) | HST WFC3 | Yan et al. 2011 |
| **CLASH** | 25 Lensing Clusters | 27.5 | HST WFC3 | Postman et al. 2012 |
| **CANDELS Deep** | 0.038 | 27.6-27.8 | HST WFC3 | Grogin et al. 2011<br>Koekemoer et al. 2011 |
| **Frontier Fields** | 4-6 Cluster / Blank Field pairs | 28.7 | HST WFC3 | — |
| **Ultra Deep Field** | 0.0013 | 29.5 | HST WFC3 | Beckwith et al. 2006<br>Koekemoer et al. 2013<br>Ellis et al. 2013<br>Illingworth et al. 2013 |

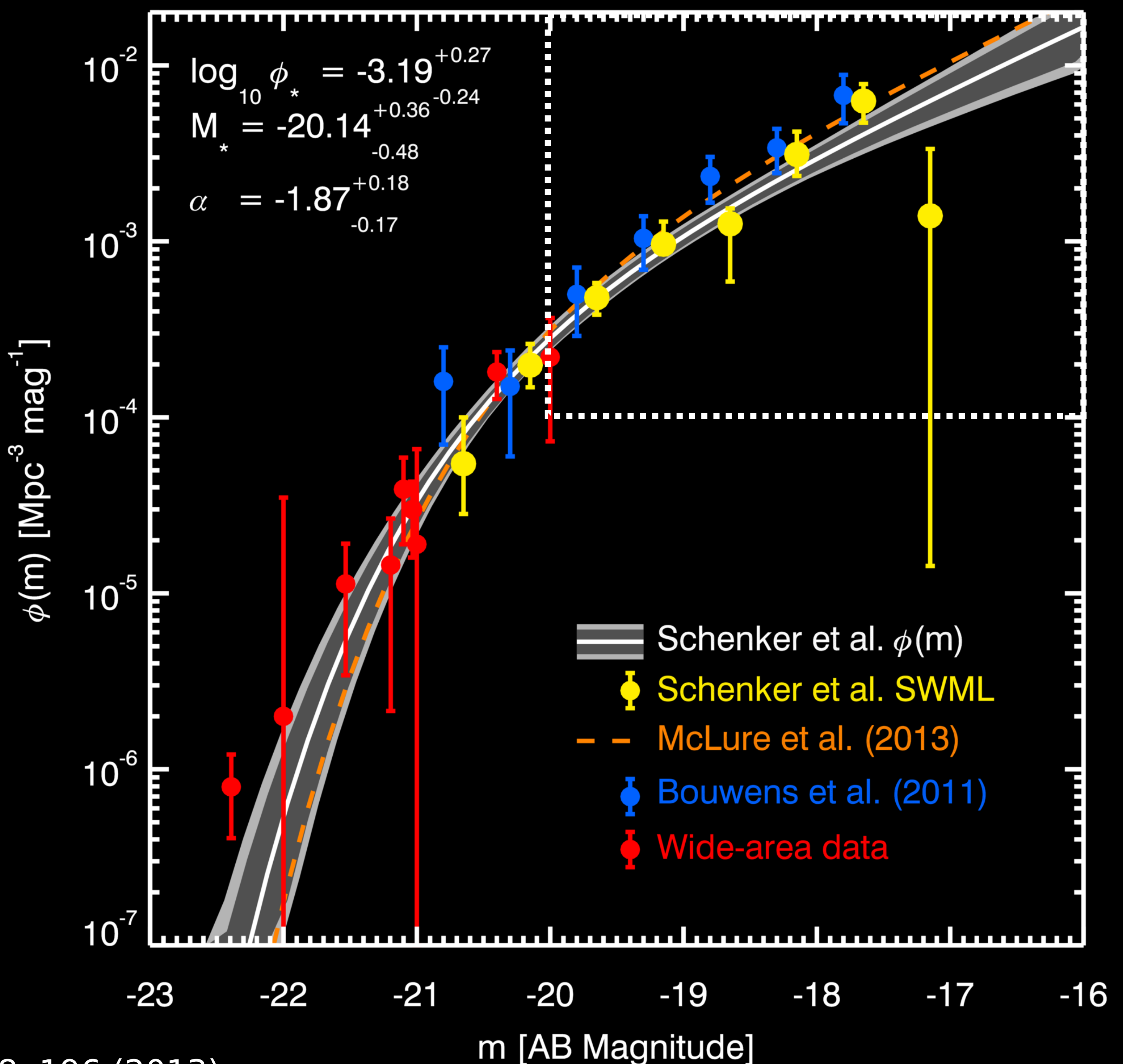
Rest-Frame UV
Luminosity Density




Global Star Formation
Rate Density

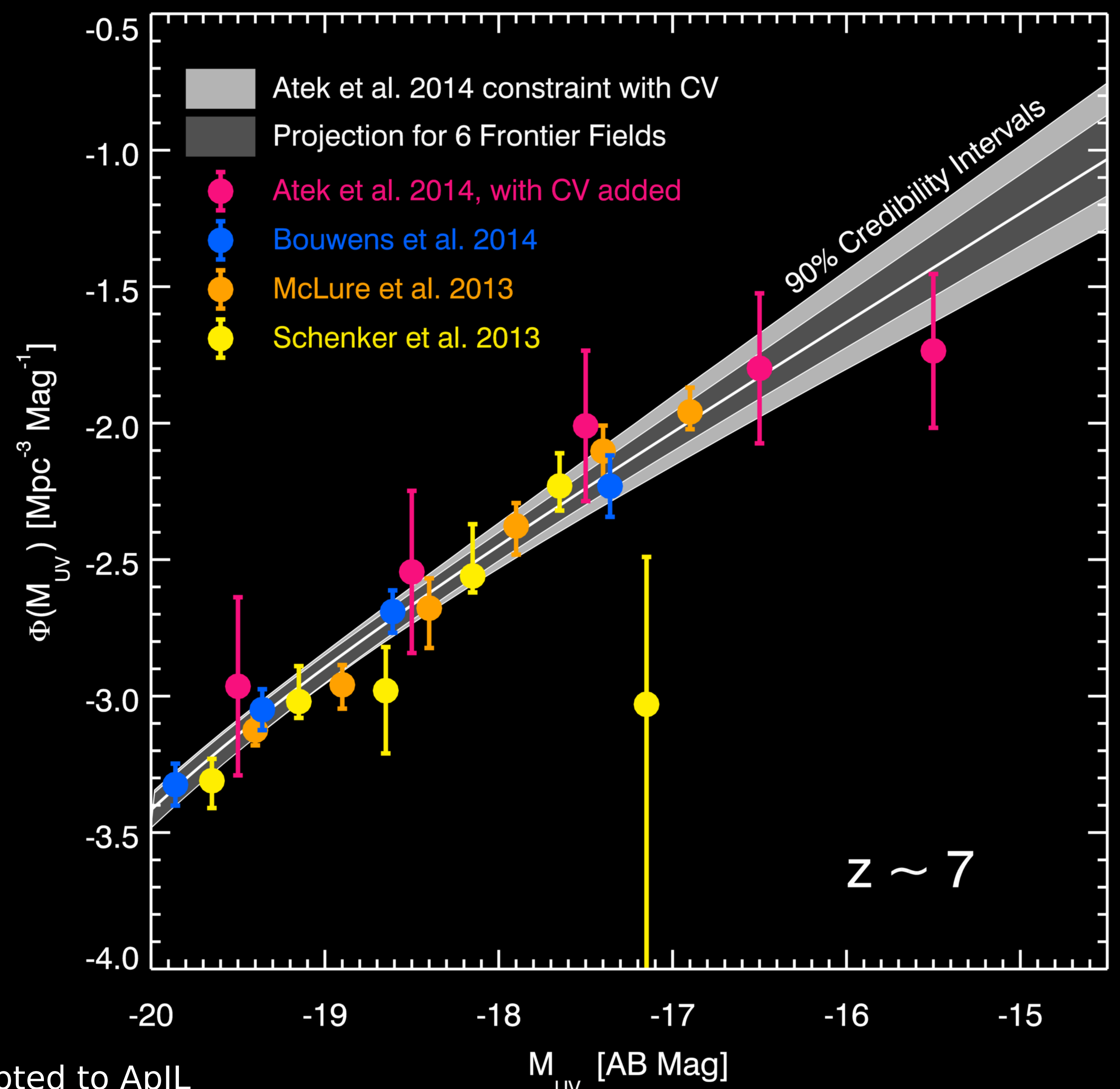
Adapted from Ellis et al., ApJL, 763, L7 (2013)

# Redshift z~7 Luminosity Function



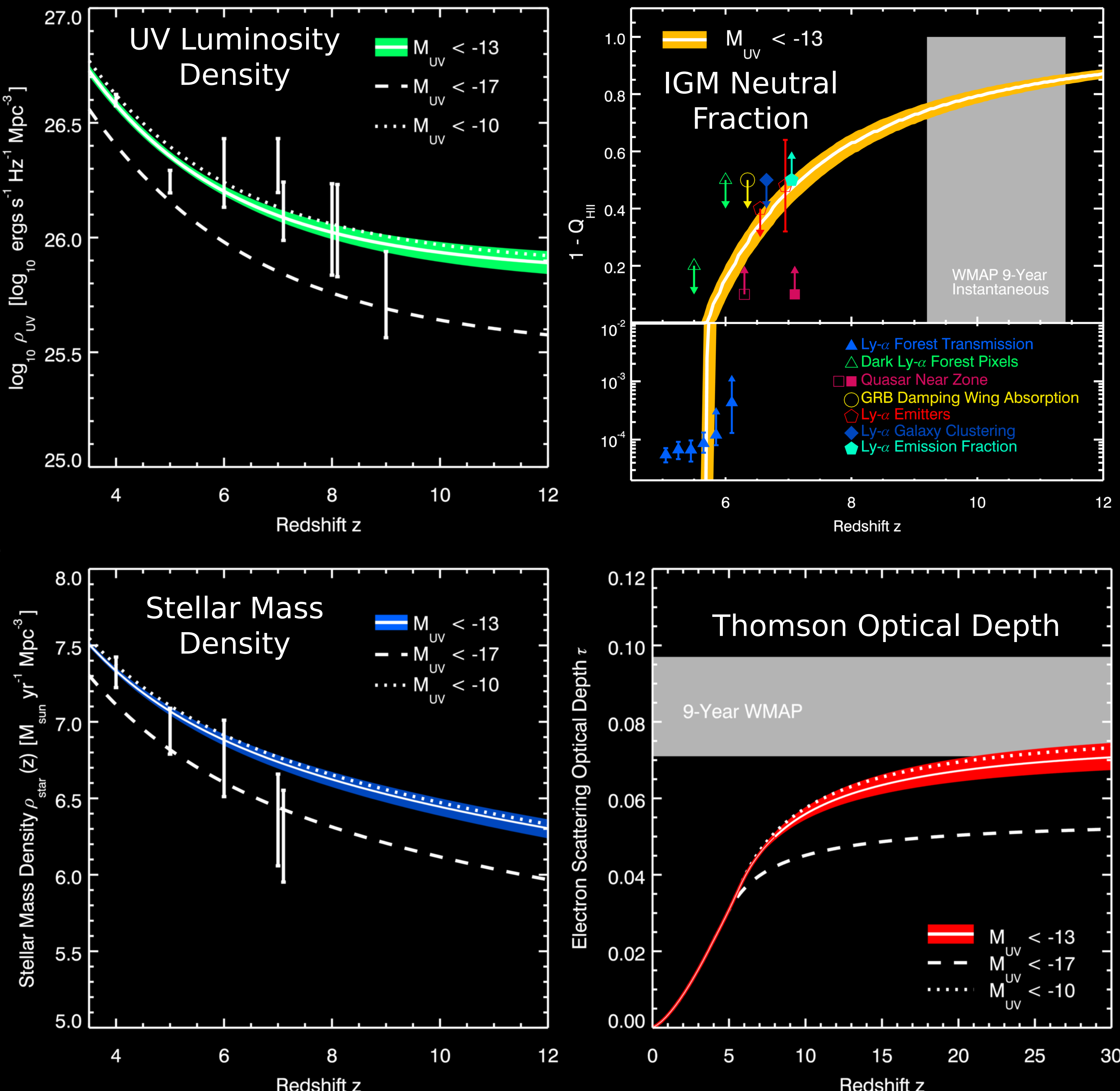

Schenker, BER, et al., ApJ, 768, 196 (2013)

Redshift z~7 Luminosity Function

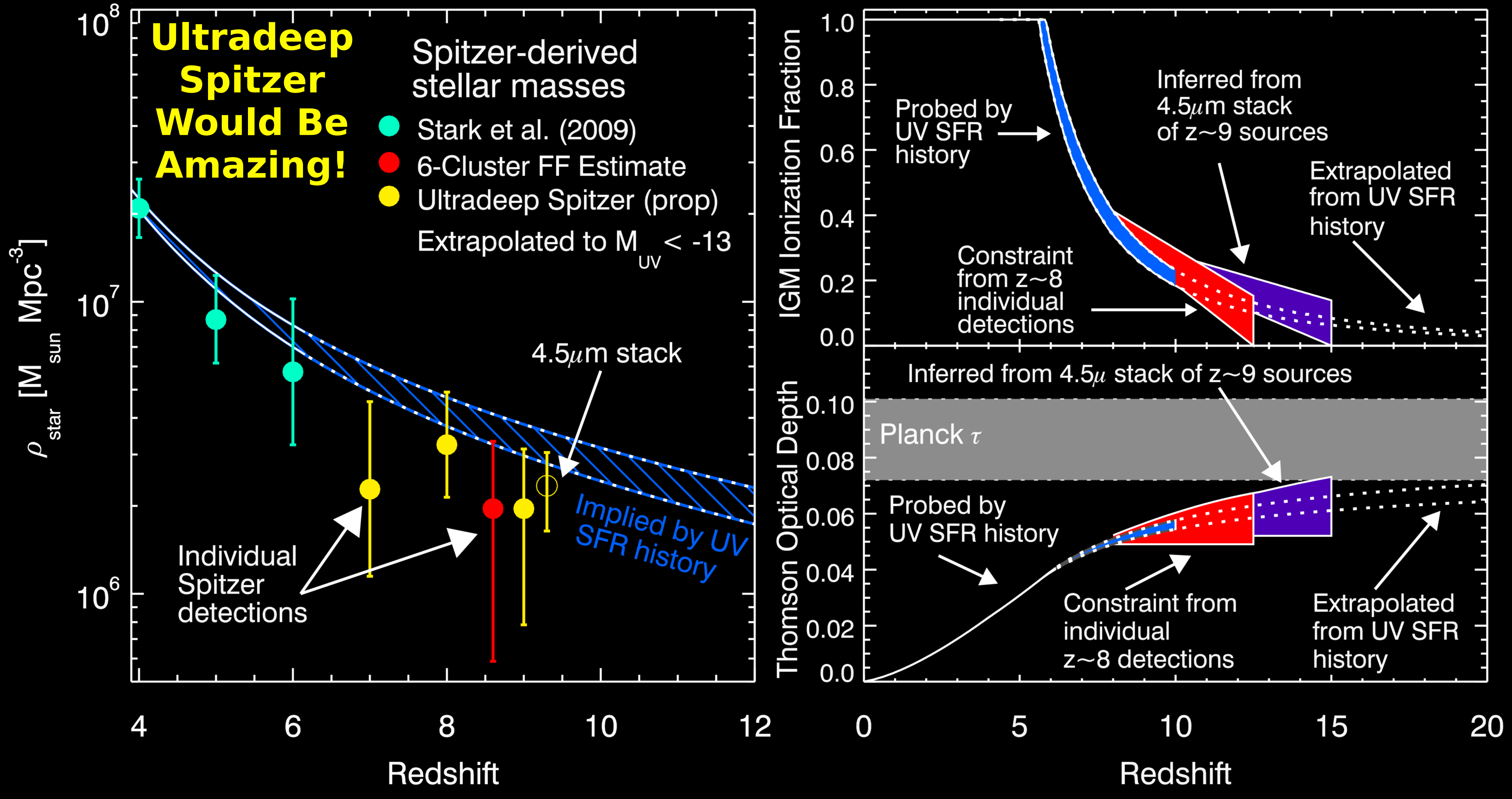



Faint-End Including Frontier Fields

BER, arXiv:1410.0962, accepted to ApJL



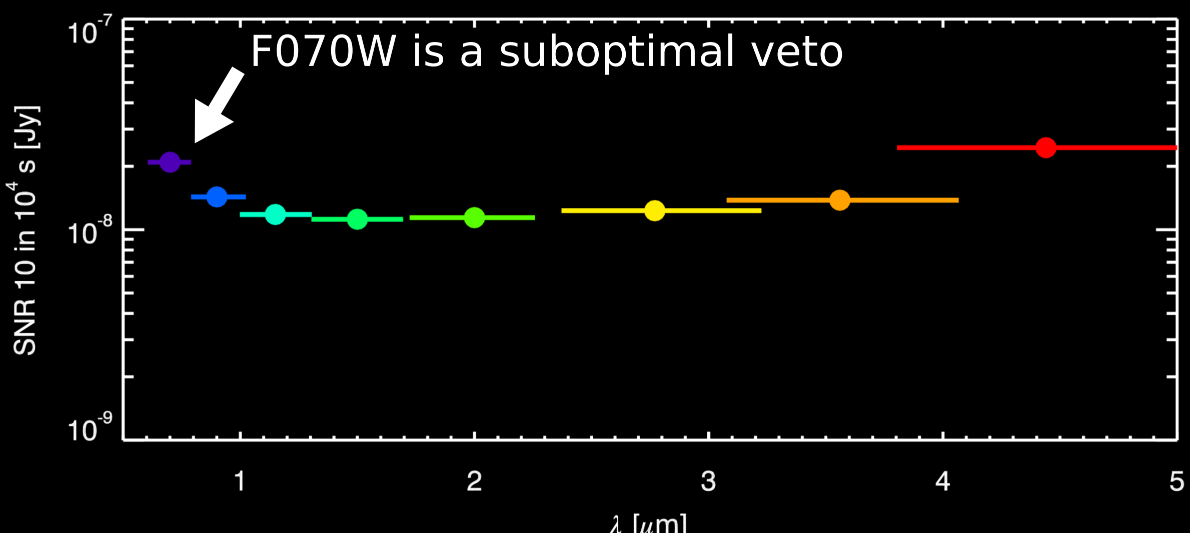

BER et al., ApJ, 768, 71 (2013)

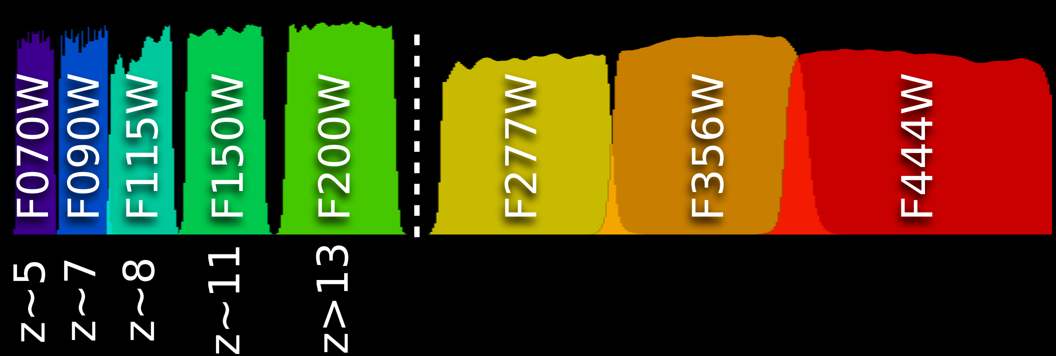

Ultradeep Spitzer Would Be Amazing!
Spitzer-derived stellar masses
Stark et al. (2009)
6-Cluster FF Estimate
Ultradeep Spitzer (prop)
Extrapolated to $M_{UV} < -13$
4.5μm stack
Implied by UV SFR history
Individual Spitzer detections
$\rho_{star}$ [$M_{sun}$ $Mpc^{-3}$]
Redshift
IGM Ionization Fraction
Probed by UV SFR history
Inferred from 4.5μm stack of z~9 sources
Extrapolated from UV SFR history
Constraint from z~8 individual detections
Thomson Optical Depth
Inferred from 4.5μ stack of z~9 sources
Planck τ
Probed by UV SFR history
Constraint from individual z~8 detections
Extrapolated from UV SFR history
Redshift

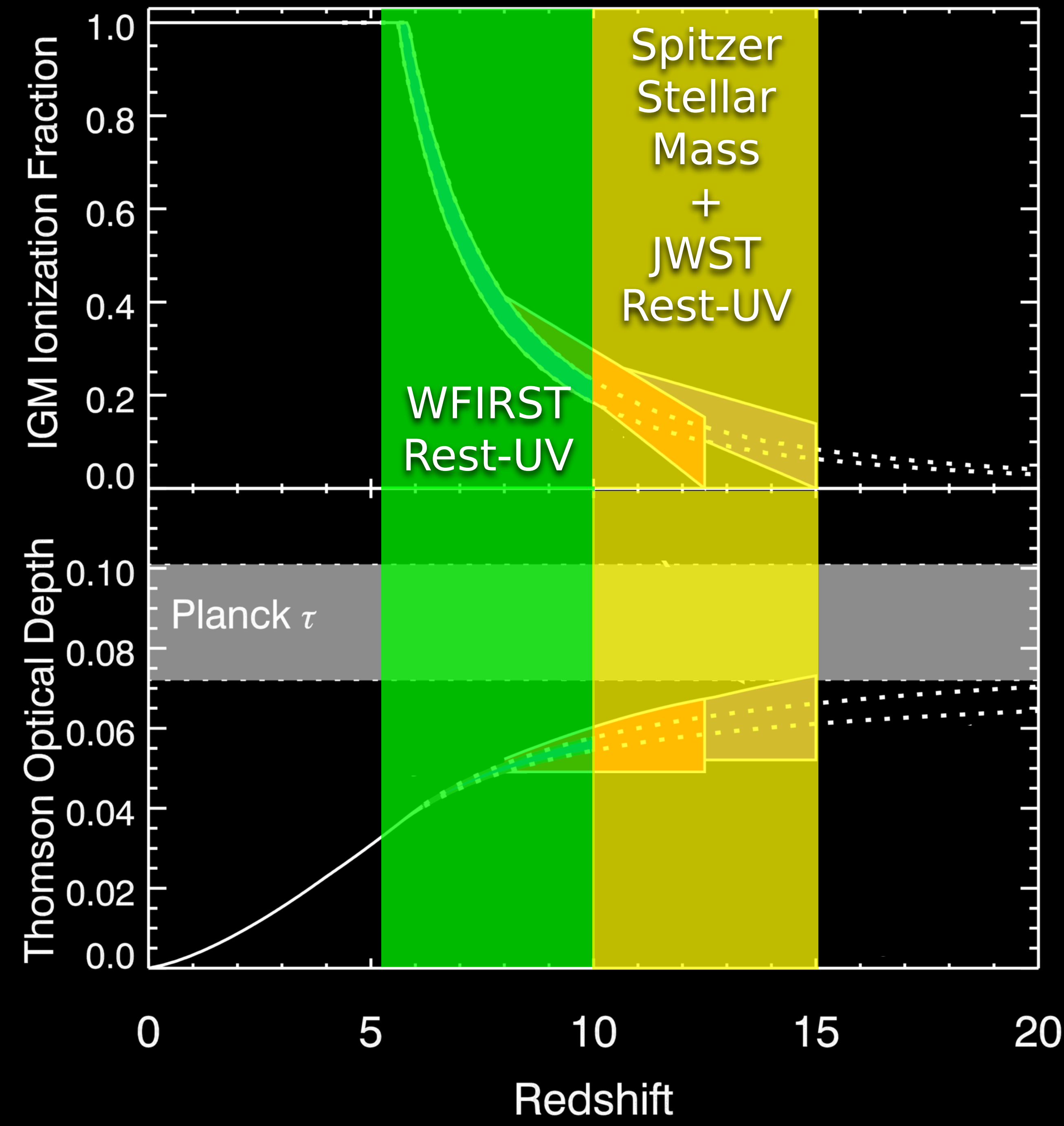
# JWST is Optimized for:

Rest-Frame Optical at z<10

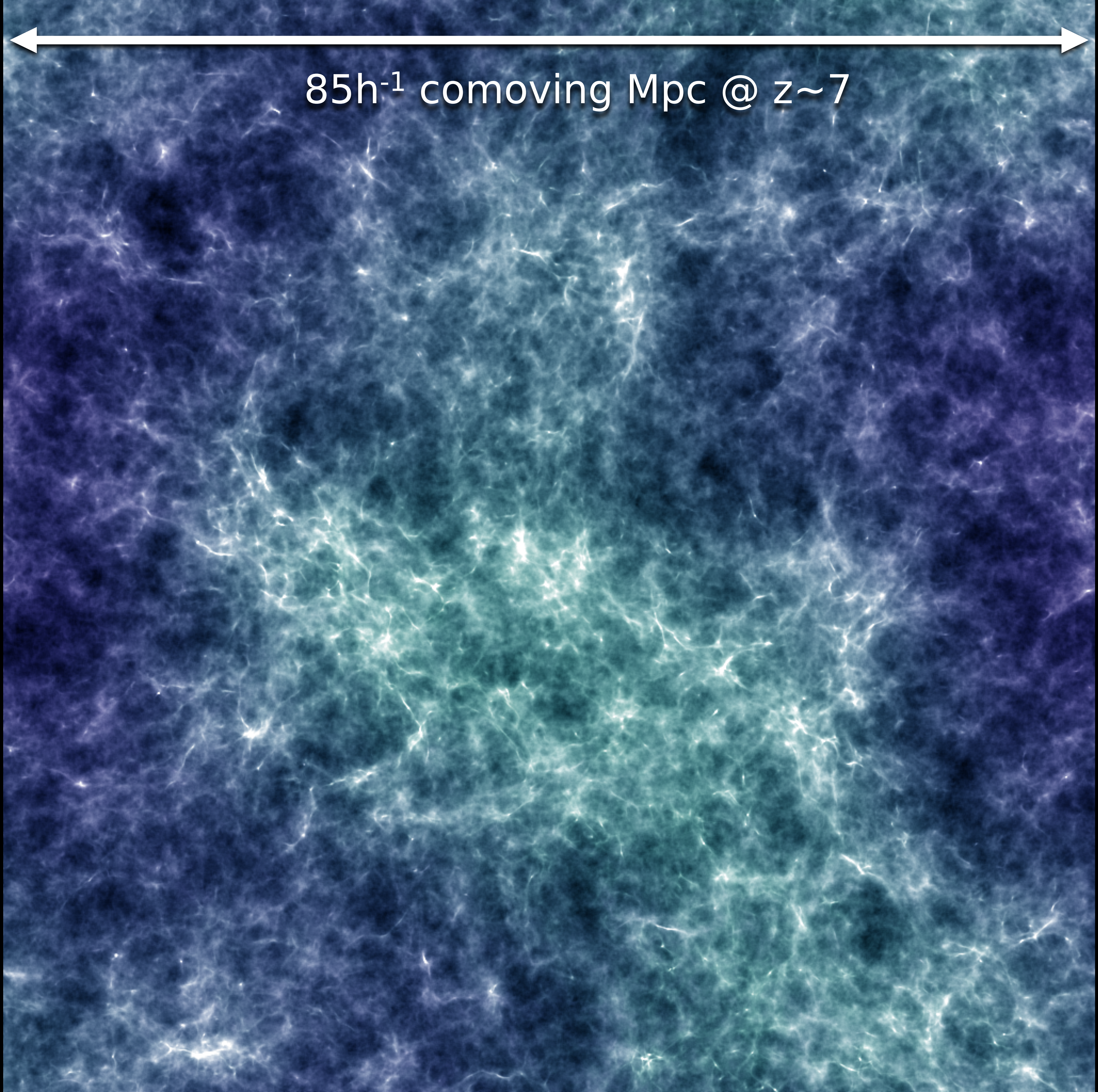
Rest-Frame UV at z>8.5

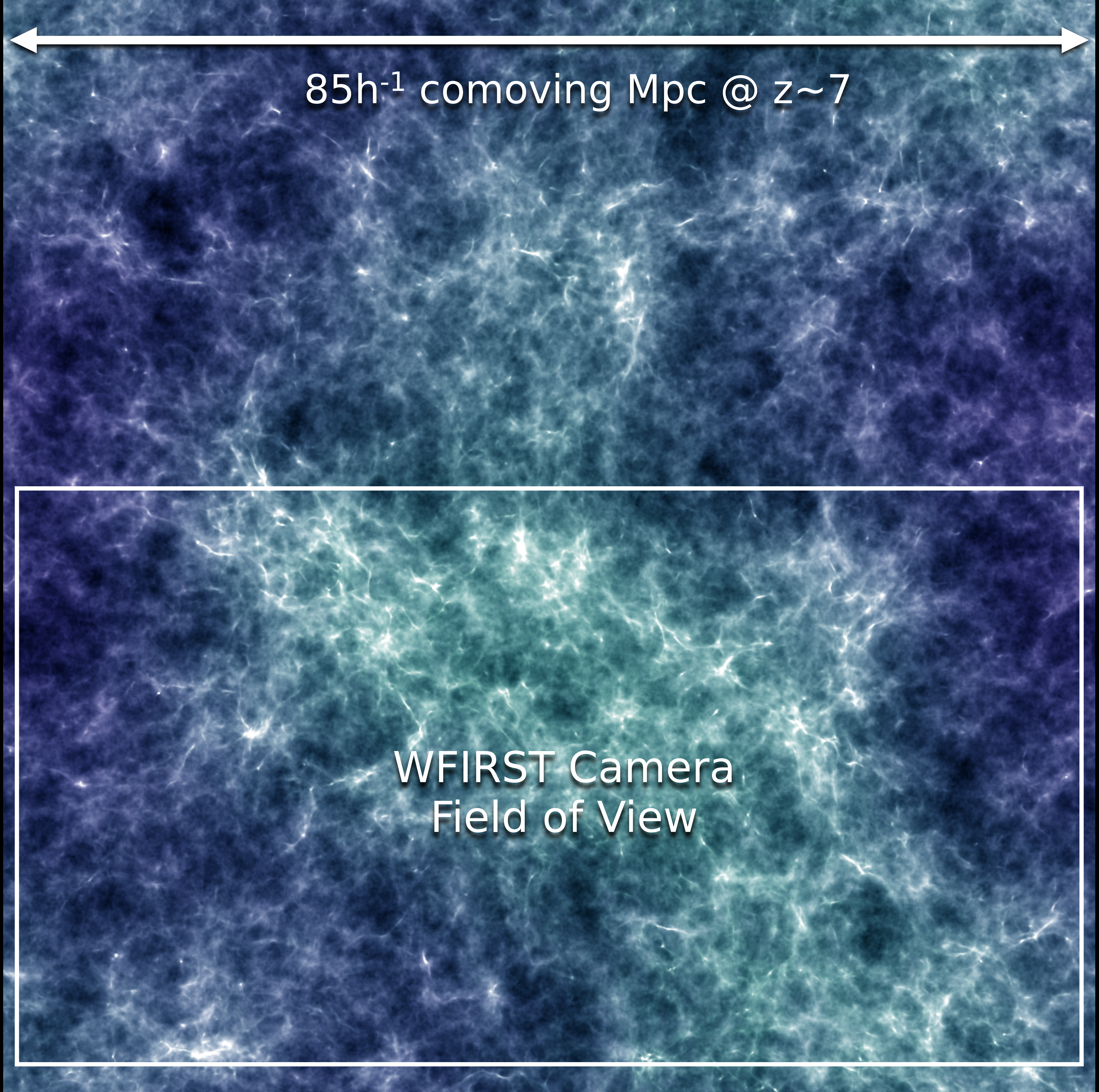


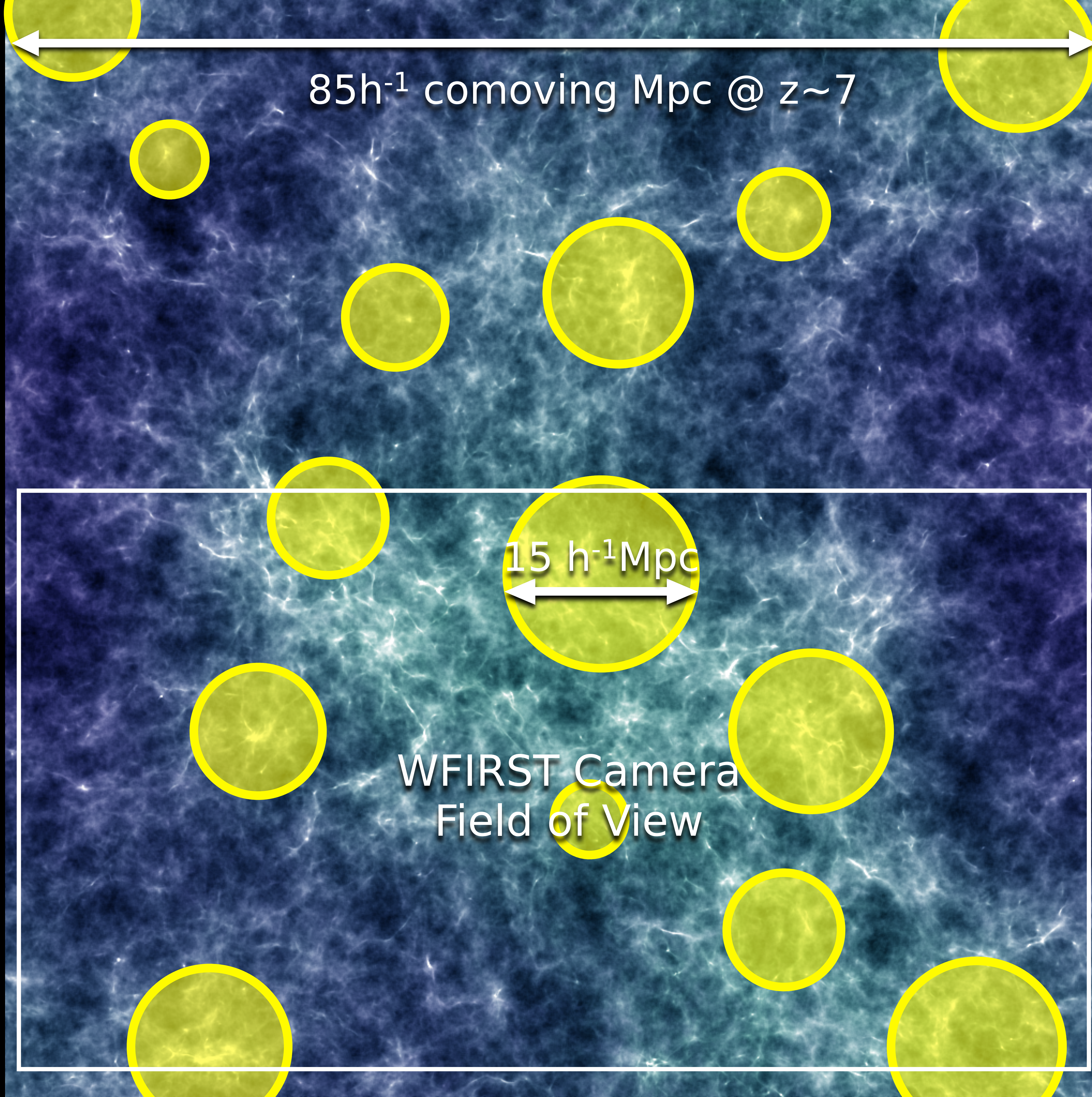




 *WFIRS Meeting, Nov. 17, 2014* Brant Robertson, UA

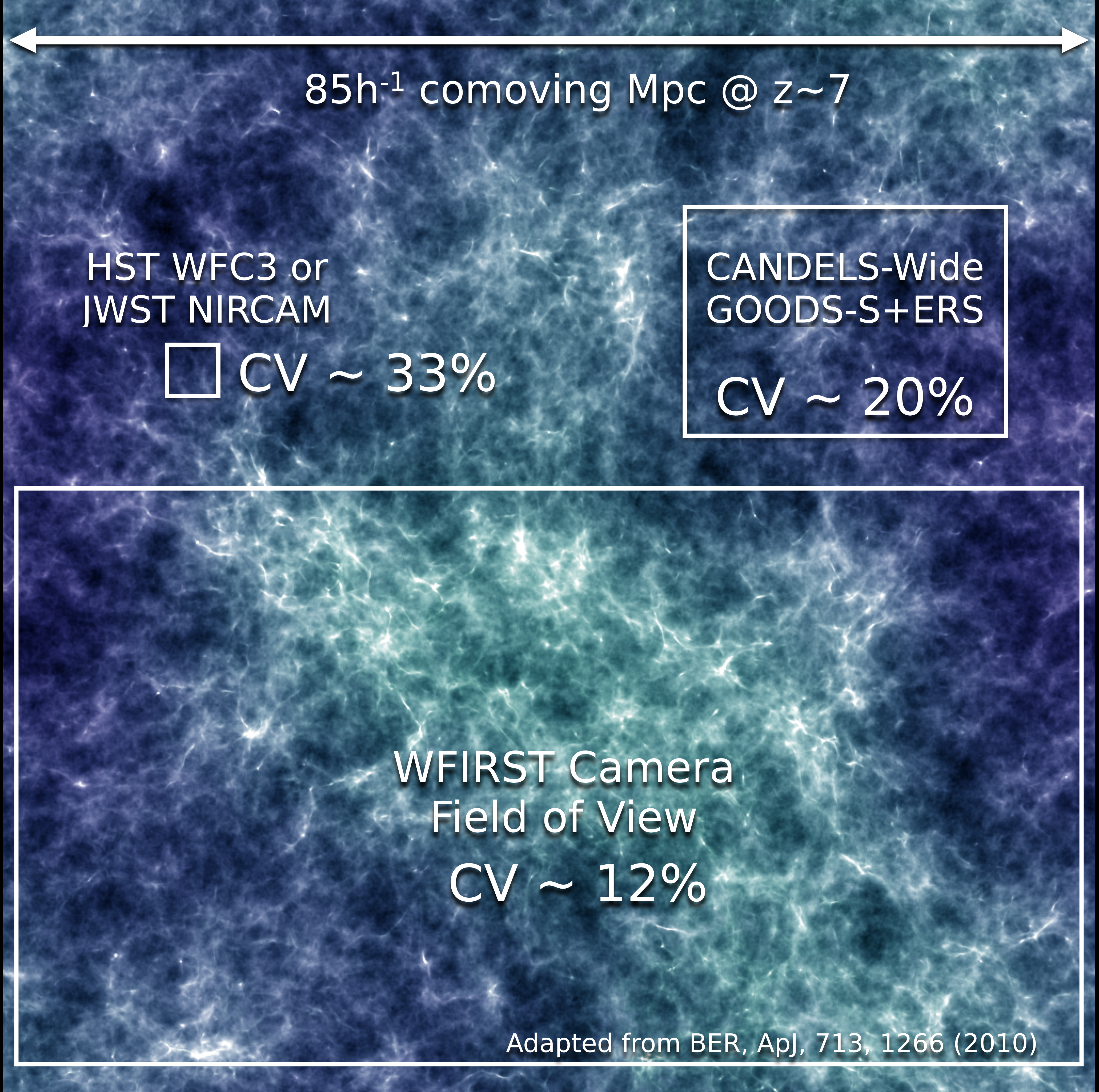

85h-1 comoving Mpc @ z~7


85h-1 comoving Mpc @ z~7
WFIRST Camera
Field of View

# Reionized Bubbles



# Cosmic Variance



## Power of WFIRST Surveys (Fisher Forecasts)

| Survey | Area [deg$^2$] | Depth [5-σ AB] | N Galaxies | Uncertainty on M* | Uncertainty on Φ* (x10$^{-4}$) | Uncertainty on α |
|---|---|---|---|---|---|---|
| **Current (Bouwens et al. 2014)** | 0.0013-0.21 | $H$=26.3-29.5 | 481 (z~7)<br>217 (z~8)<br>6 (z~10) | 0.26 (z~7)<br>0.36 (z~8) | 0.2 (z~7)<br>0.2 (z~8) | 0.13 (z~7)<br>0.23 (z~8) |
| **Supernova Wide** | 27.44 | $J$=27.5 | 1.6x10$^5$ (z~7)*<br>7.1x10$^4$ (z~8) | 0.027 (z~7)*<br>0.039 (z~8) | 0.145 (z~7)*<br>0.149 (z~8) | 0.015 (z~7)*<br>0.026 (z~8) |
| **Supernova Medium** | 8.96 | $H$=28.1 | 1.1x10$^5$ (z~7)*<br>5.0x10$^4$ (z~8) | 0.037 (z~7)*<br>0.050 (z~8) | 0.185 (z~7)*<br>0.194 (z~8) | 0.014 (z~7)*<br>0.023 (z~8) |
| **Supernova Deep** | 5.04 | $H$=29.4 | 1.5x10$^5$ (z~7)*<br>7.1x10$^4$ (z~8) | 0.040 (z~7)*<br>0.051 (z~8) | 0.168 (z~7)*<br>0.170 (z~8) | 0.009 (z~7)*<br>0.015 (z~8) |
| **Single WFIRST Field of View (z~7)** | 0.281 | $H$=29.5 | 8.6x10$^3$ (z~7)<br>3.97x10$^3$ (z~8)<br>3.48x10$^2$ (z~10) | 0.16 (z~7)<br>0.21 (z~8)<br>0.97 (z~10) | 0.775 (z~7)<br>0.588 (z~8)<br>0.362 (z~10) | 0.039 (z~7)<br>0.061 (z~8)<br>0.22 (z~10) |

*if color selection is possible

see formalism in BER, ApJ, 713, 1266 (2010)

**N-body Cosmological Simulation Requirements to Model WFIRST Observations of the Epoch of Reionization**

| Survey | Area [$deg^2$] | Depth [5-σ AB] | Box Size [comoving $h^{-1}$ Mpc] | Halo Mass for UV Mag. Limit [$h^{-1}$ $M_{sun}$] | Required N |
|---|---|---|---|---|---|
| **High Latitude Survey** | 2000 | $H$=26.7 | 6766 | $2.2 \times 10^{10}$ | $65536^3$ |
| **Supernova Wide** | 27.44 | $J$=27.5 | 530 | $6.5 \times 10^9$ | $8192^3$ |
| **Supernova Medium** | 8.96 | $H$=28.1 | 310 | $4.4 \times 10^9$ | $4096^3$ |
| **Supernova Deep** | 5.04 | $H$=29.4 | 235 | $6.5 \times 10^8$ | $8192^3$ |
| **Single WFIRST Field of View** | 0.281 | $H$=29.5 | 85 | $6.5 \times 10^8$ | $2048^3$ |

# Summary


- WFIRST will be transformative for reionization epoch science, especially at z~7.
- To realize its full promise for high-redshift science, deep *z*-band is essential for all WFIRST imaging surveys.
- WFIRST will make tremendous progress for the z~7 luminosity function, where JWST is suboptimal.
- Fisher forecasts for LF parameters suggest dramatic improvement owing to WFIRST area, with 100,000 z~8 galaxies and ~350 candidates at z~10.