WFIRST/AFTA Surveys of the Epoch of Reionization

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Observable Cosmological History

adapted from Robertson et al., *Nature*, **468**, 49 (2010)
Recombination ($z \sim 1100$)

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 $z \sim 6$?
- Were there enough early galaxies to partially ionize the IGM at $z>10$ long enough to account for the CMB Thomson optical depth?

adapted from Robertson et al., *Nature*, **468**, 49 (2010)
## Existing Surveys of Reionization Epoch Galaxies

<table>
<thead>
<tr>
<th>Survey</th>
<th>Area [deg$^2$]</th>
<th>$H$-band Depth [5-σ AB]</th>
<th>Instrument</th>
<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td>UltraVISTA</td>
<td>1.5</td>
<td>24</td>
<td>VISTA VIRCAM</td>
<td>McCracken et al. 2012, Bowler et al. 2014</td>
</tr>
<tr>
<td>CANDELS Wide (+ GOODS ERS)</td>
<td>0.29</td>
<td>26.7-27.3</td>
<td>HST WFC3</td>
<td>Grogin et al. 2011, Koekemoer et al. 2011, Windhorst et al. 2011</td>
</tr>
<tr>
<td>BoRG</td>
<td>&gt;0.1 (71 fields)</td>
<td>25.6-27.0</td>
<td>HST WFC3</td>
<td>Trenti et al. 2011, Schmidt et al. 2014</td>
</tr>
<tr>
<td>HIPPIES</td>
<td>0.034 (26 fields)</td>
<td>26.7 (median)</td>
<td>HST WFC3</td>
<td>Yan et al. 2011</td>
</tr>
<tr>
<td>CLASH</td>
<td>25 Lensing Clusters</td>
<td>27.5</td>
<td>HST WFC3</td>
<td>Postman et al. 2012</td>
</tr>
<tr>
<td>CANDELS Deep</td>
<td>0.038</td>
<td>27.6-27.8</td>
<td>HST WFC3</td>
<td>Grogin et al. 2011, Koekemoer et al. 2011</td>
</tr>
<tr>
<td>Frontier Fields</td>
<td>4-6 Cluster / Blank Field pairs</td>
<td>28.7</td>
<td>HST WFC3</td>
<td>—</td>
</tr>
<tr>
<td>Ultra Deep Field</td>
<td>0.0013</td>
<td>29.5</td>
<td>HST WFC3</td>
<td>Beckwith et al. 2006, Koekemoer et al. 2013, Ellis et al. 2013, Illingworth et al. 2013</td>
</tr>
</tbody>
</table>
Adapted from Ellis et al., ApJL, 763, L7 (2013)
Redshift $z \sim 7$

Luminosity Function

\begin{align*}
\log_{10} \phi_* &= -3.19^{+0.27}_{-0.48} \\
M_* &= -20.14^{+0.36}_{-0.48} \\
\alpha &= -1.87^{+0.18}_{-0.17}
\end{align*}

Redshift $z \sim 7$
Luminosity Function

BER, arXiv:1410.0962, accepted to ApJL
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

- 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
- Planck $\tau$
- Probed by UV SFR history

**WFIRS Meeting, Nov. 17, 2014**
JWST is Optimized for:

Rest-Frame Optical at $z<10$

Rest-Frame UV at $z>8.5$

F070W is a suboptimal veto

Rest-Frame Optical at $z<10$

Rest-Frame UV at $z>8.5$
$85h^{-1}$ comoving Mpc @ $z \approx 7$
85h$^{-1}$ comoving Mpc @ z~7

WFIRST Camera
Field of View
Reionized Bubbles

WFIRST Camera Field of View

85$h^{-1}$ comoving Mpc @ $z\sim 7$

15$h^{-1}$ Mpc
85h⁻¹ comoving Mpc @ z~7

HST WFC3 or JWST NIRCAM

CV ~ 33%

CANDELS-Wide GOODS-S+ERS

CV ~ 20%

WFIRST Camera Field of View

CV ~ 12%

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

*if color selection is possible

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</thead>
<tbody>
<tr>
<td>High Latitude Survey</td>
<td>2000</td>
<td>H=26.7</td>
<td>6766</td>
<td>2.2 x 10⁻¹⁰</td>
<td>65536³</td>
</tr>
<tr>
<td>Supernova Wide</td>
<td>27.44</td>
<td>J=27.5</td>
<td>530</td>
<td>6.5 x 10⁹</td>
<td>8192³</td>
</tr>
<tr>
<td>Supernova Medium</td>
<td>8.96</td>
<td>H=28.1</td>
<td>310</td>
<td>4.4 x 10⁹</td>
<td>4096³</td>
</tr>
<tr>
<td>Supernova Deep</td>
<td>5.04</td>
<td>H=29.4</td>
<td>235</td>
<td>6.5 x 10⁸</td>
<td>8192³</td>
</tr>
<tr>
<td>Single WFIRST Field of View</td>
<td>0.281</td>
<td>H=29.5</td>
<td>85</td>
<td>6.5 x 10⁸</td>
<td>2048³</td>
</tr>
</tbody>
</table>
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.