The First Galaxies Frontier

Hubble's BoRG survey and a WISH for the future

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WFC3: Exploring the first 700Myr

★New discovery space for galaxies at z>7

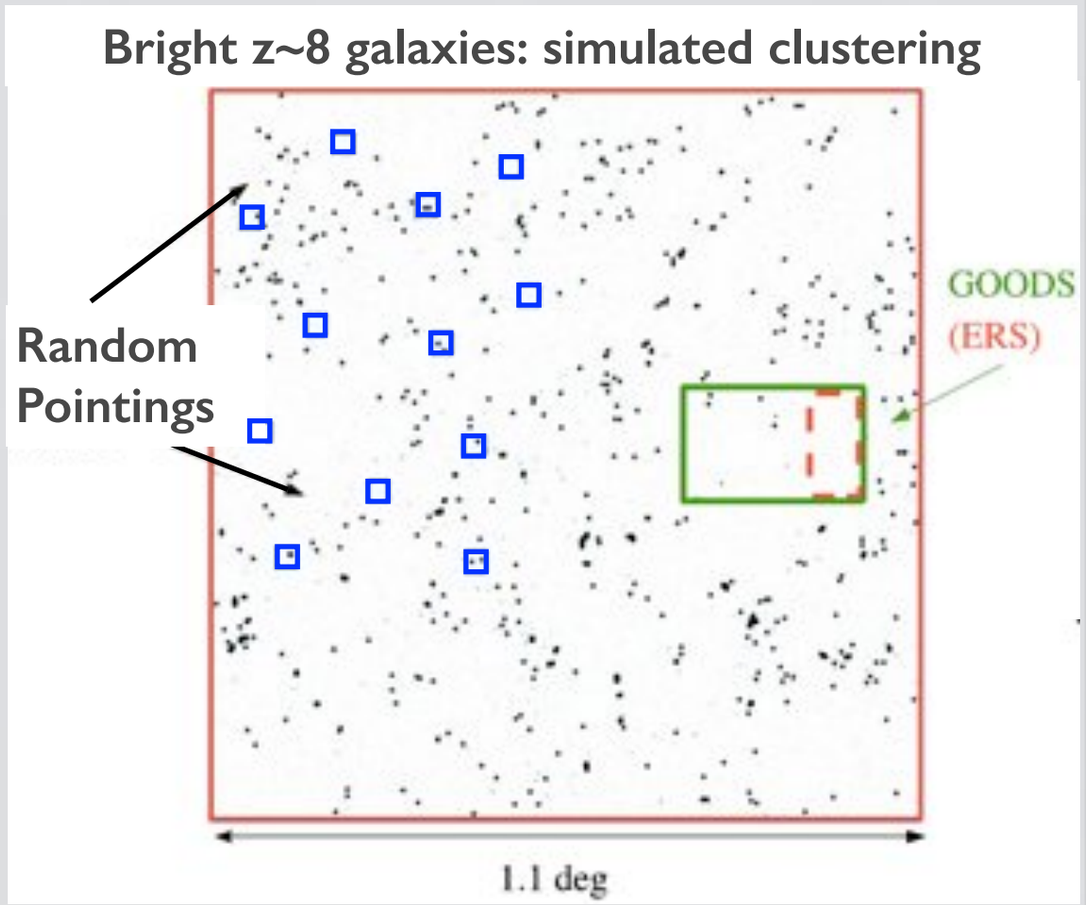
- Exciting results from Hubble legacy fields

  [Talk by Rychard earlier today]

★Legacy fields challenges:

★(Ultra)Deep, small area:
Mostly faint galaxies (L<L*)

★ Few lines of sight:
Results affected by
galaxy clustering



The Brightest of Reionizing Galaxies Survey

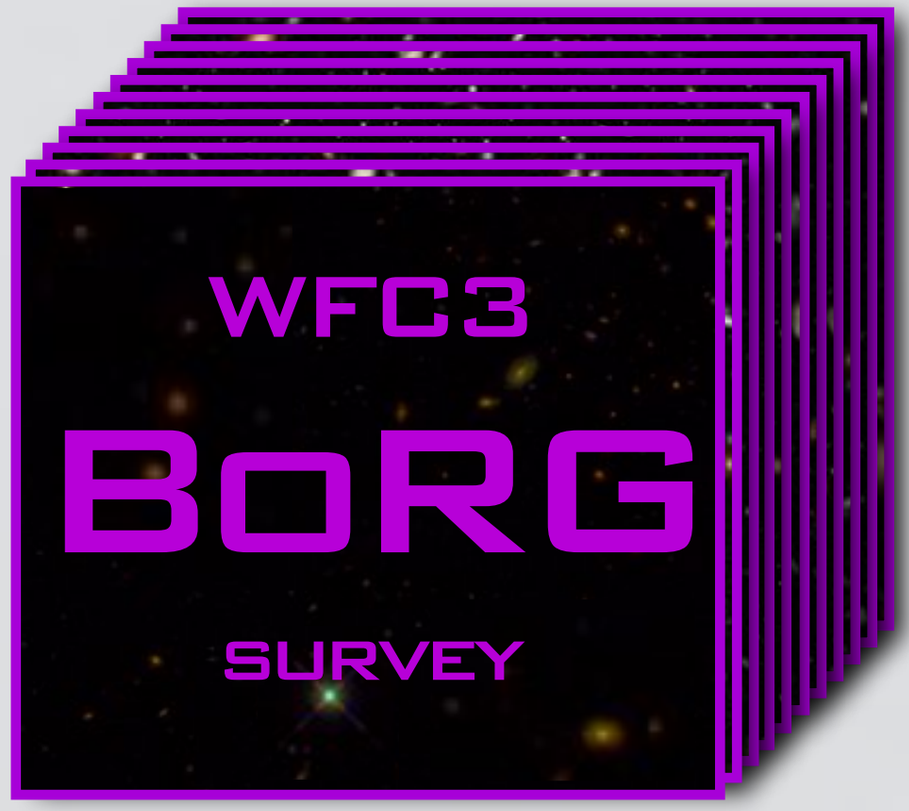
<2014

- Primary goal: photometric identification of rare galaxies at z~8 (~650Myr after Big Bang)

- 74 WFC3 independent pointings
  ~350 arcmin^2, >400 orbits
  (PI Trenti, Cycles 17+19+20)

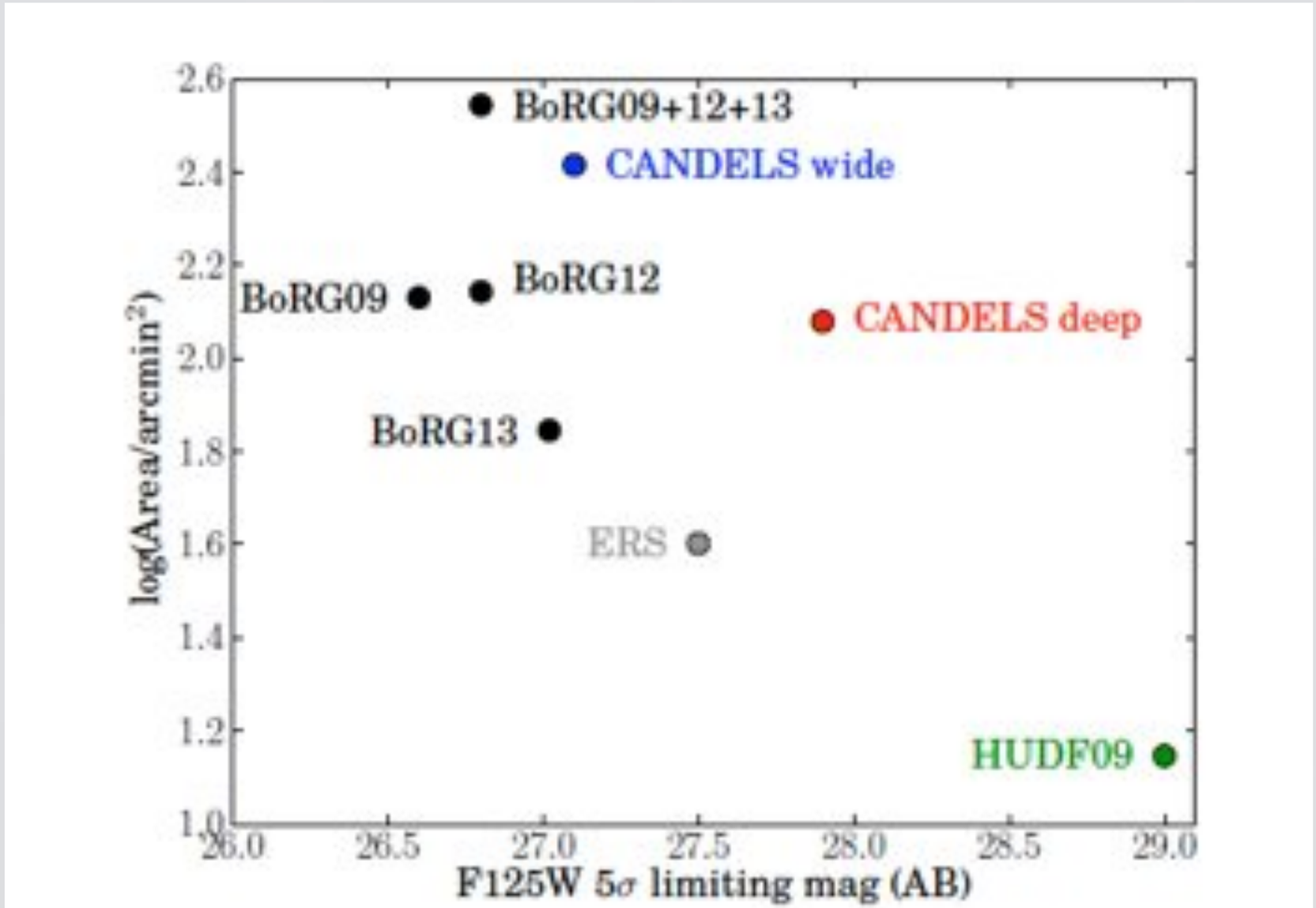
- 4 filters (optical+near-IR):
  V, Y, J, H

- 4-6 hours/field:
  5σ sensitivity: m_{lim}~27



BoRG compared to legacy fields

- Largest area available to find z~8 galaxies

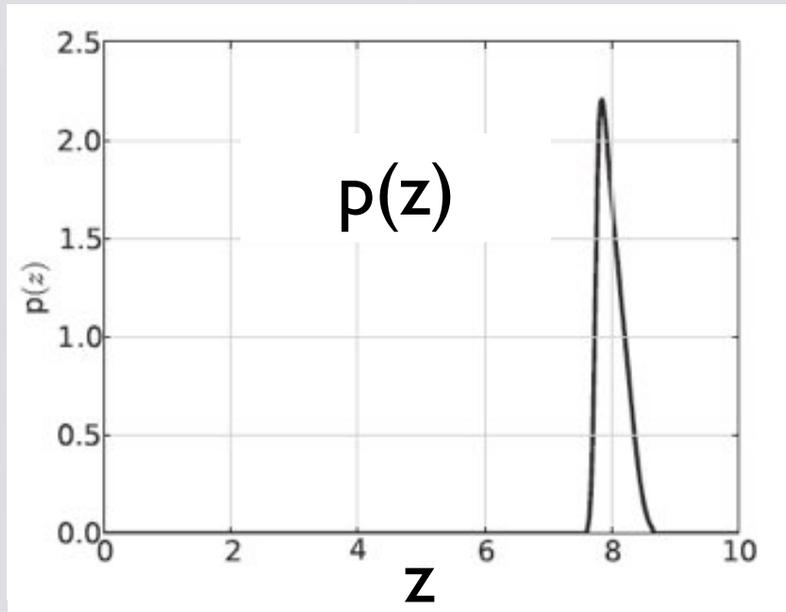


Schmidt et al. (2014)

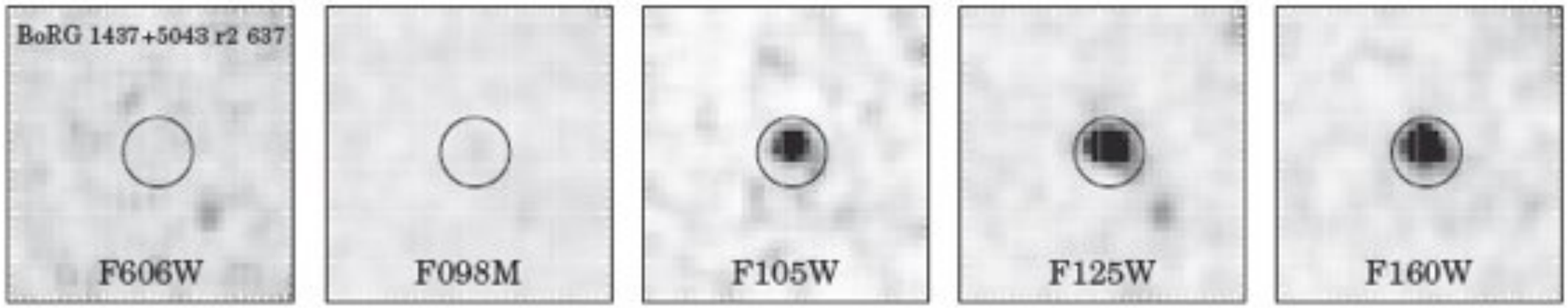
Some z~8 galaxies from BoRG

★ BoRG finds most luminous z~8 galaxies (~650 Myr after Big Bang):

- n=10 at S/N>8 (m<26.5)
- n=28 at S/N>5 (m~27)

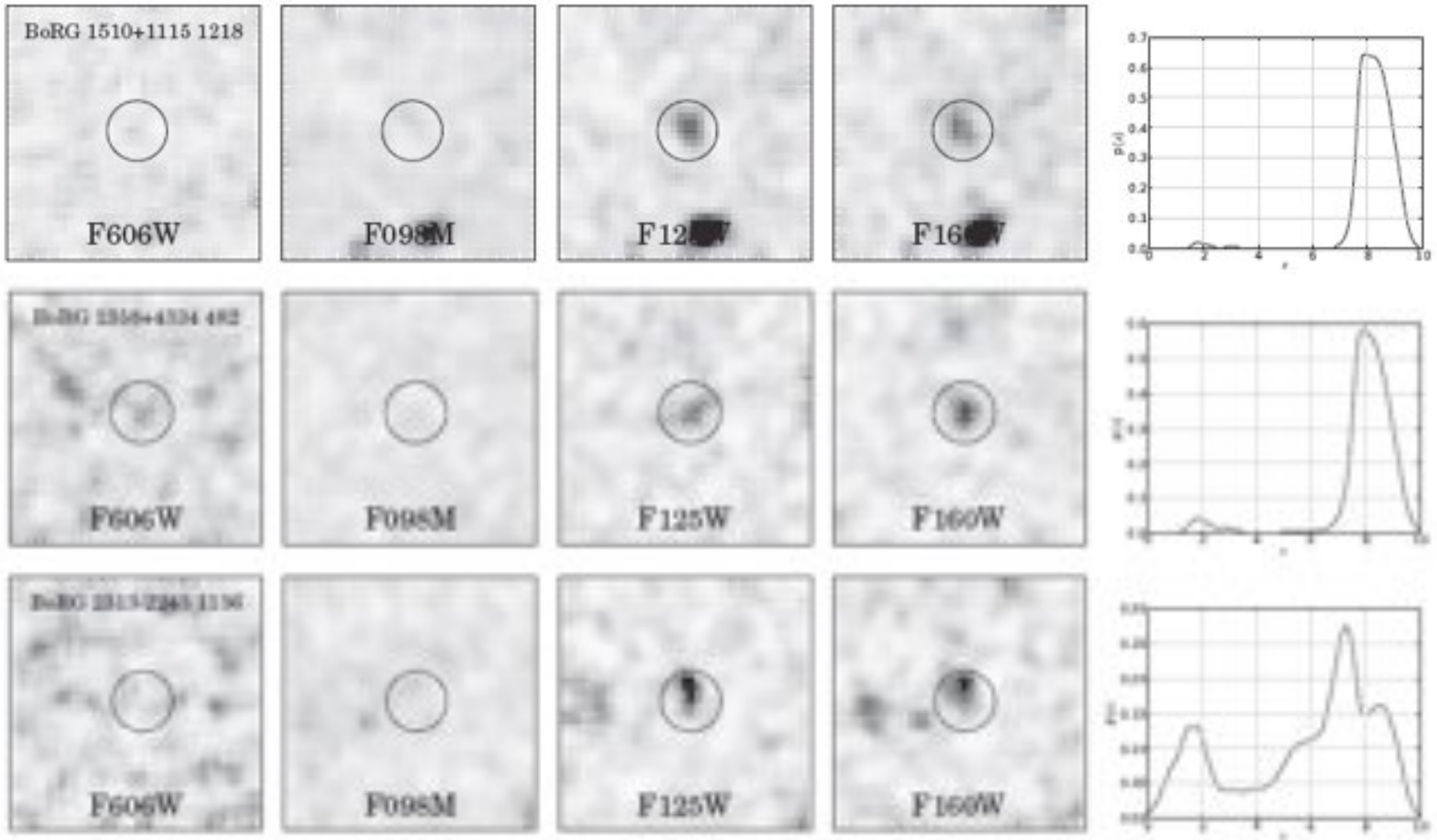


Best BoRG source: m_J=25.9 (S/N>20)



Trenti et al. (2011, 2012); Bradley et al. (2012); Schmidt et al. (2014)

Some z~8 galaxies from BoRG



Schmidt et al. (2014)

The luminosity function at z~8

Large area (~350 arcmin^2) determination

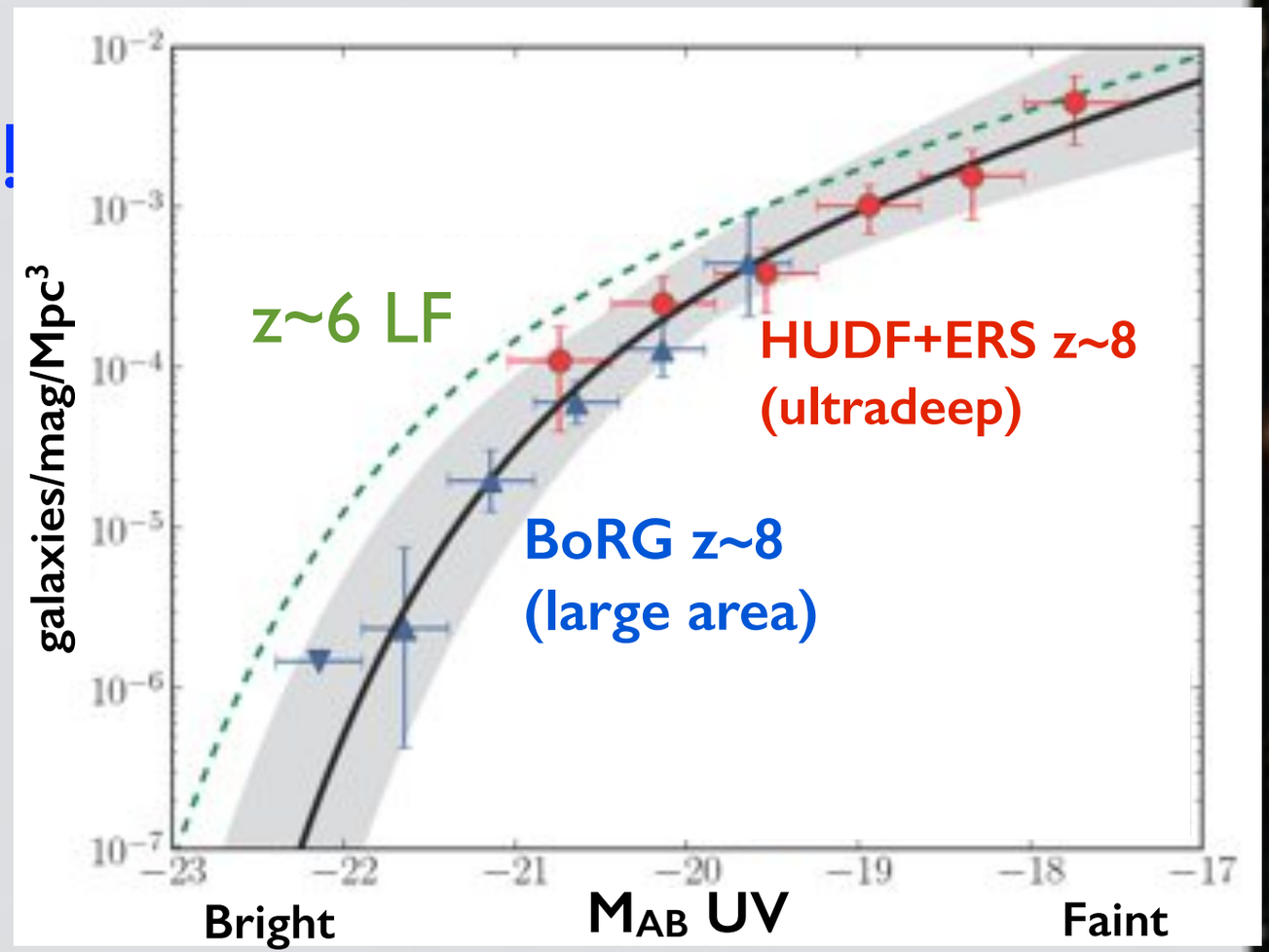
★ BoRG+HUDF/ERS:
97 Y-dropout galaxies

★ None known preWFC3!

★ LF well described by Schechter form

★ Less sources at high-z:
Galaxy density evolution from z~6 to z~8 at 99.995% confidence

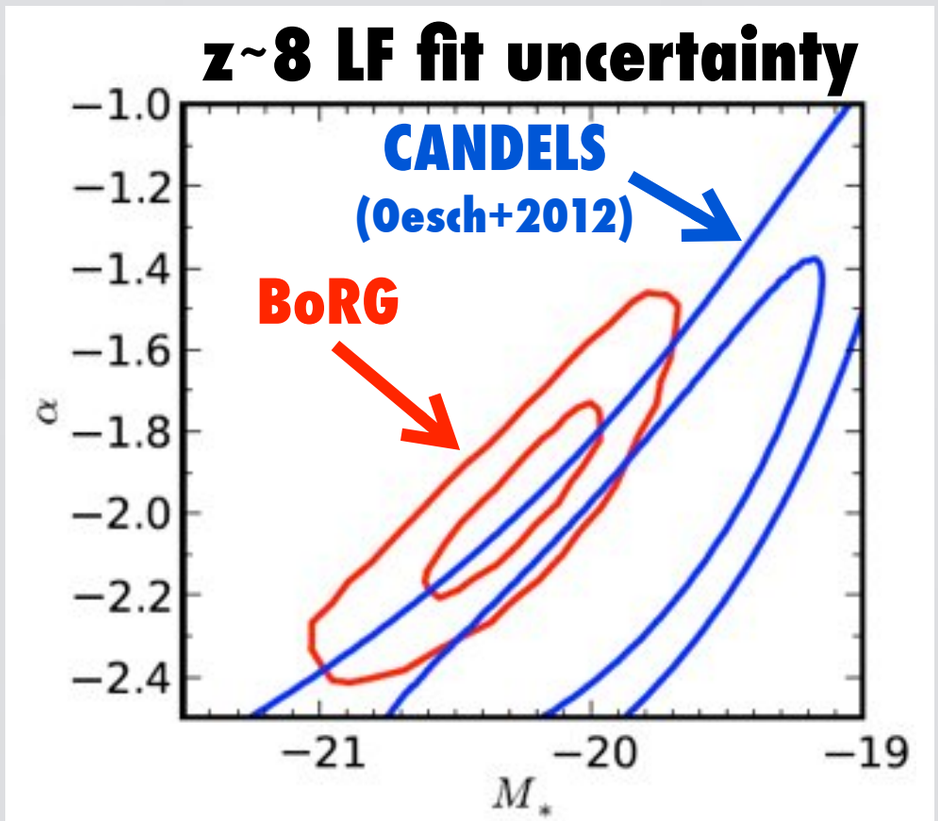
$$\phi(L) = \phi_0 (L/L_*)^{\alpha} \exp(-L/L_*)$$



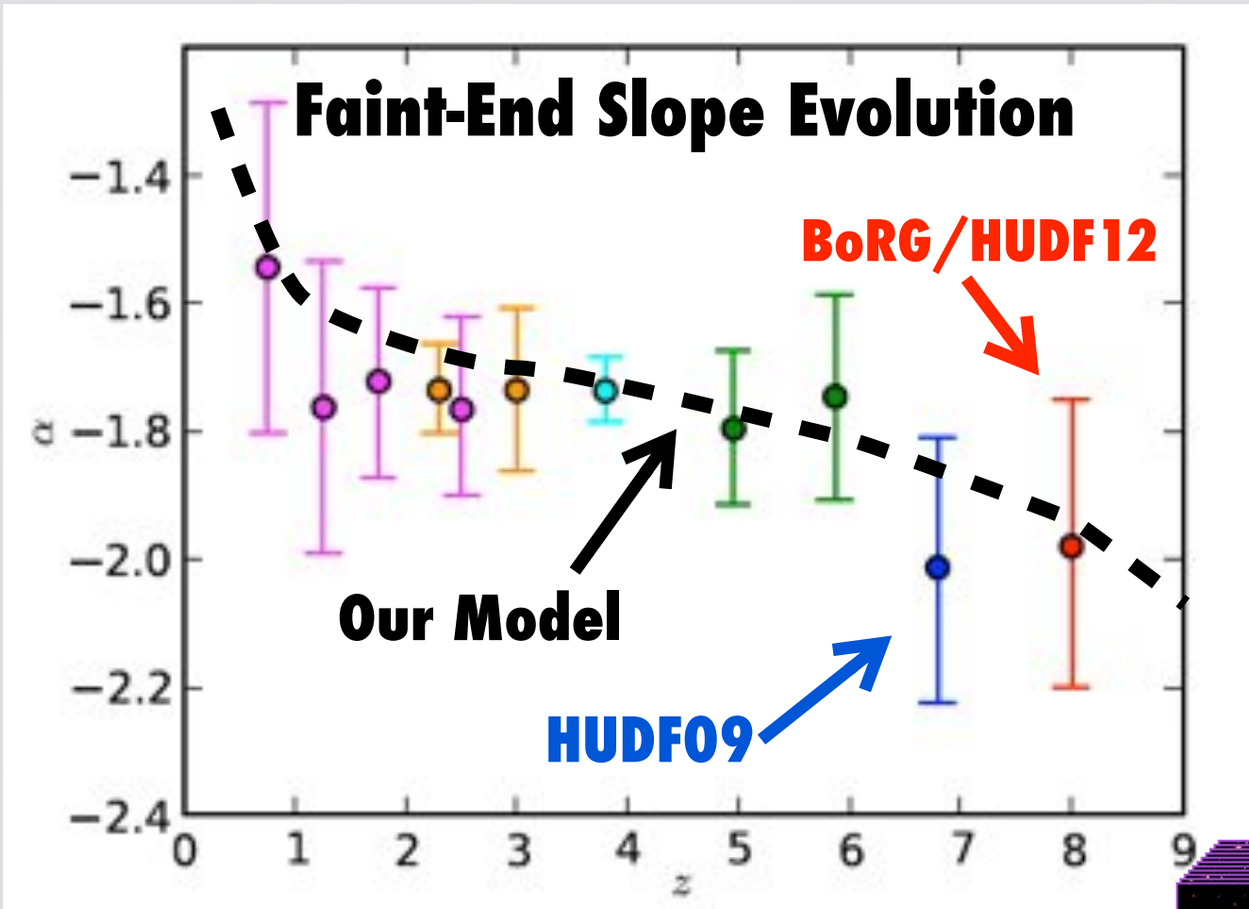
Bradley, Trenti et al. (2012); Schmidt et al. (2014)

Very steep z~8 luminosity function

- Best fit gives $\alpha = -1.98 \pm 0.2$ (log divergent!)
- Steepening of the LF at z>7:
  Abundance of faint reionizing sources



Bradley, Trenti et al. (2012)



from Tacchella, Trenti & Carollo (2013)

Luminosity function extrapolation

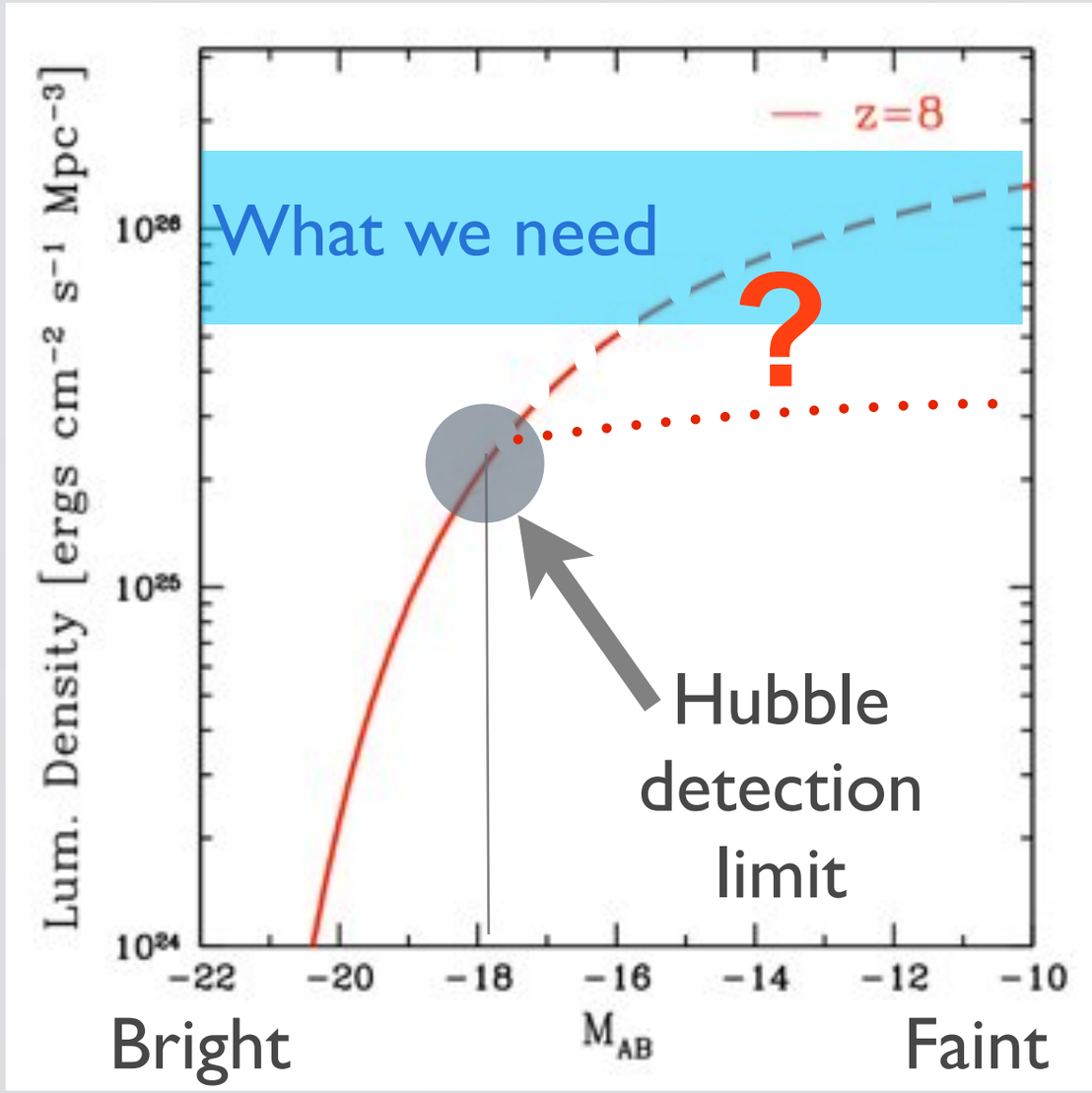
★ How to characterize luminosity density of faint ionizing sources?

★ Modeling (Trenti et al. 2010, Tacchella, Trenti & Carollo 2013)

★ Indirect tracers: GRBs (Trenti et al. 2012b,2013, 2014)

★ Gravitational telescopes: Frontier Fields Initiative (Hakim Atek & Masami Ouchi talks next)

Luminosity density and reionization



Trenti et al. (2012b)

High-z galaxies: Extending the frontier

★ WFC3/HST: Galaxies found at z~7-10 (2010-2013)

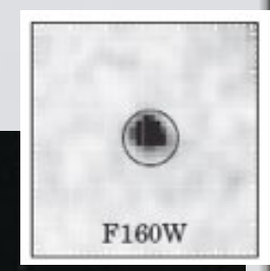
★Next step: Characterize their properties

★ Brightest z>8 galaxies: *rare but ideal targets*

★Easiest to follow-up!

★Earlier assembly expected: z>13 [~300 Myr!!]

Probes of earliest star formation and reionization



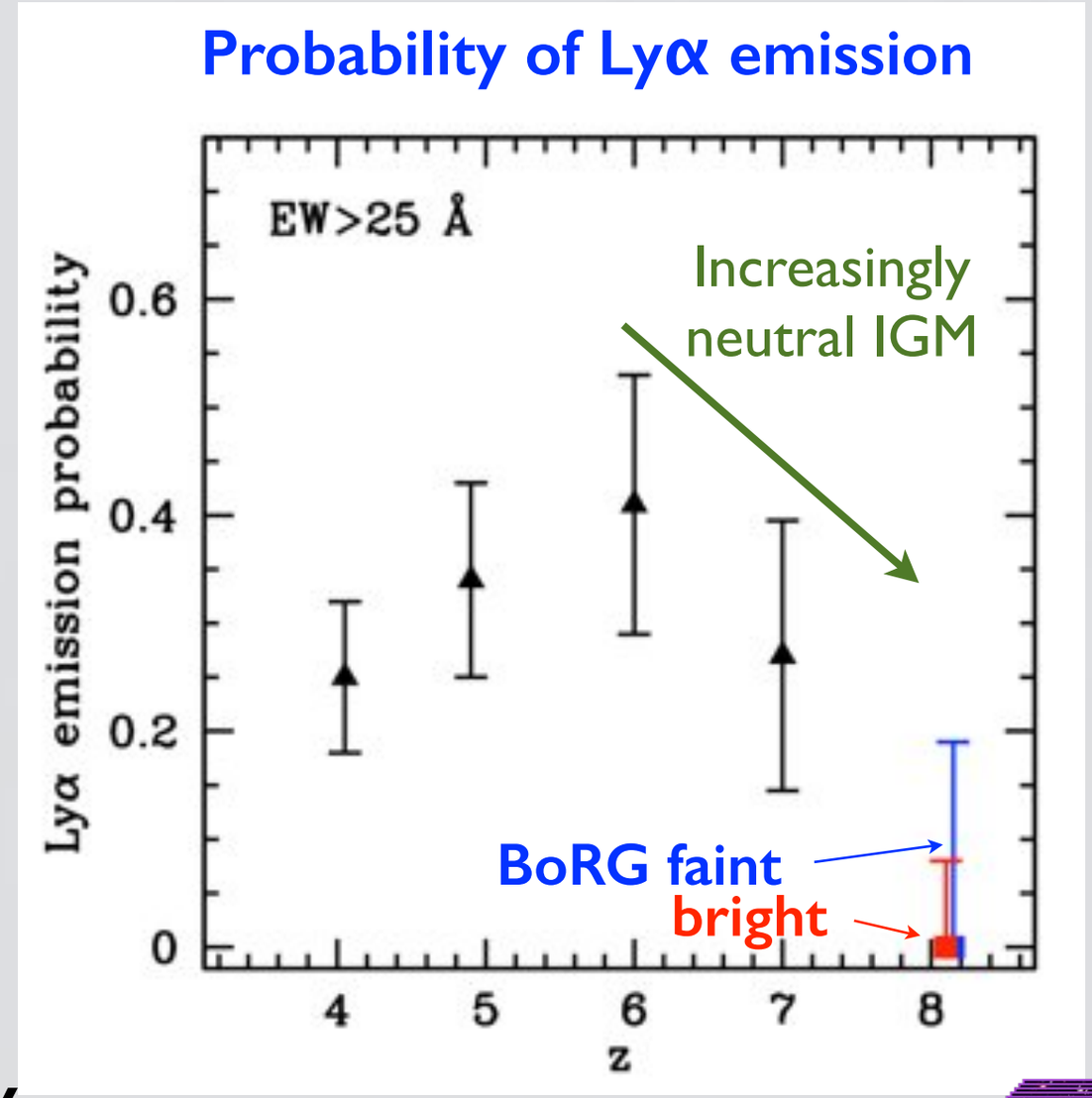
Galaxy properties: Lyα emission

★ BoRG follow-up: Keck (~32h) & VLT (~12h)

★ 15 galaxies observed, no Lyα emission detected (EW>25A)

★ Dramatic evolution of intergalactic medium from z~8 to z~6: Reionization in progress

★ BoRG z~8 limits crucial to establish trend previously hinted by z~7 spectroscopy



Treu, Trenti et al. (2012, 2013)

Galaxy properties: Clustering

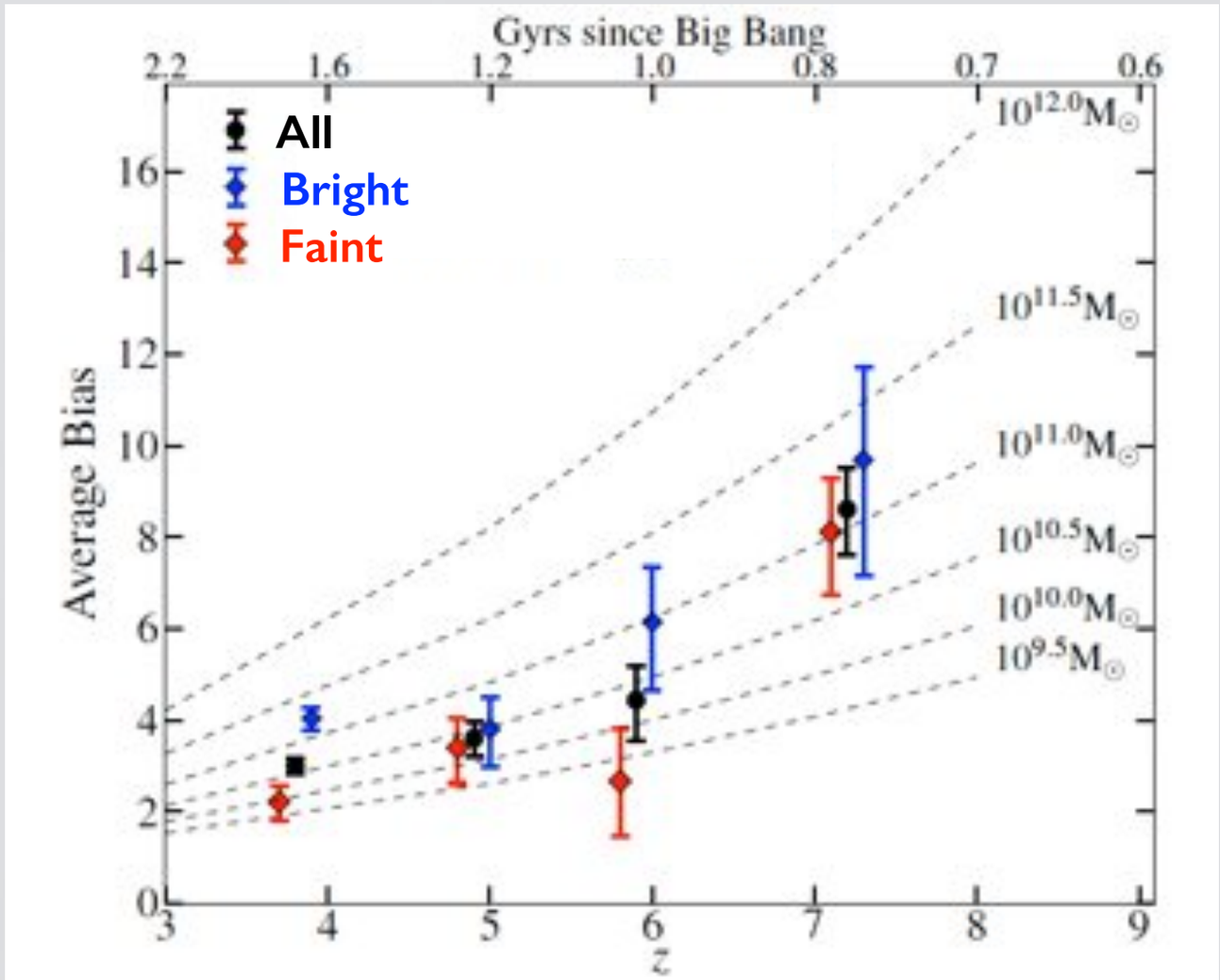
Clustering analysis constraints the dark matter halo masses of galaxies

★First measure of clustering at z>7!

★Derived DM halos ~10^{11} M_{sun}

★Galaxies at z>7 expected in more abundant halos with 10^{8}-10^{10} Msun!

Bias: galaxies vs. DM halos



Barone-Nugent, Trenti et al. (2014)
[Melbourne PhD student]

Outlook for the future

Hubble Space Telescope

★HST is photon and wavelength limited to z~10 but key facility for short-term progress:

★"Frontier Fields" [public survey] is using gravitational lenses to identify intrinsically fainter sources

★GLASS survey [Treu PI, Trenti CoI] will provide spectra of faint z≲8 sources (synergic with BoRG)

★BoRG-like survey targeted at z~9-10 to find rare bright catches (easiest to follow-up)

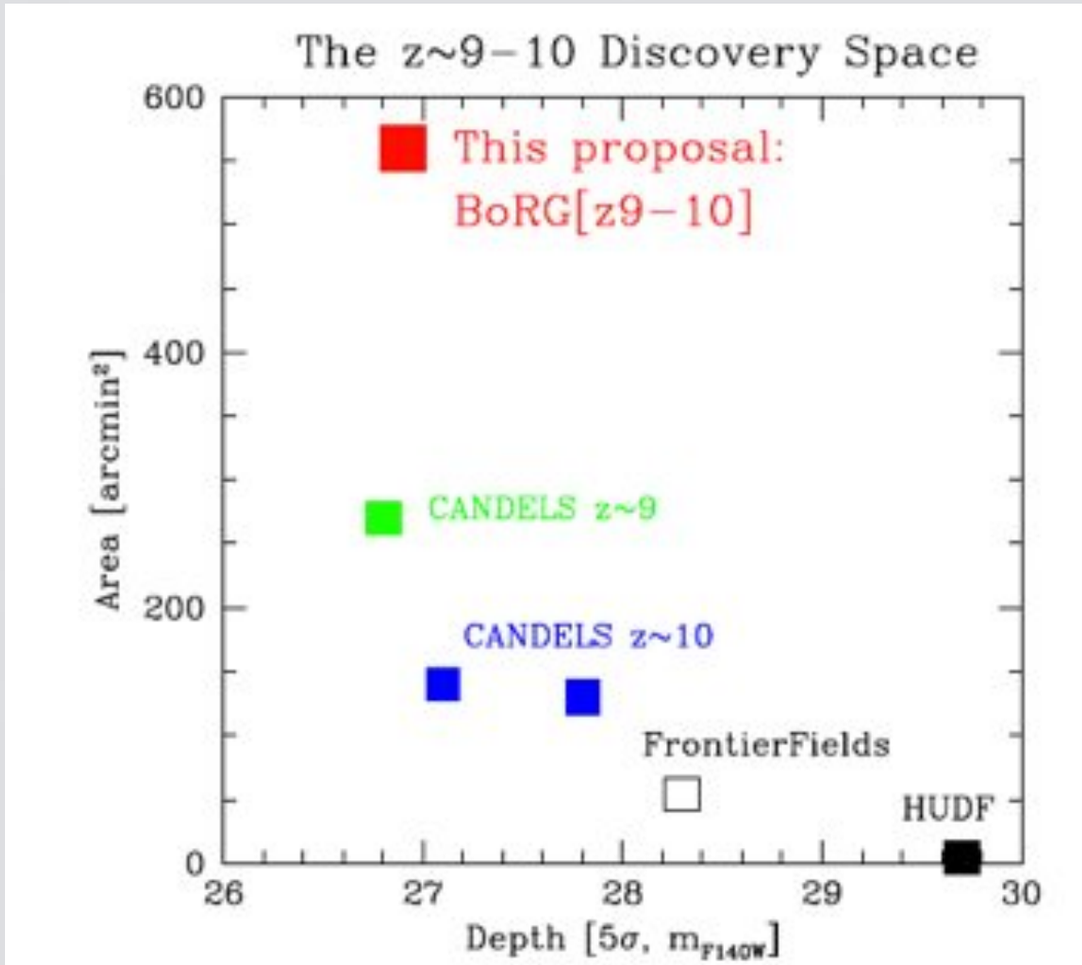
The future at z~9-10

Bright Galaxies at Hubble's Detection Frontier (PI Trenti)

★ Largest Cycle 22 HST program (32 days!)

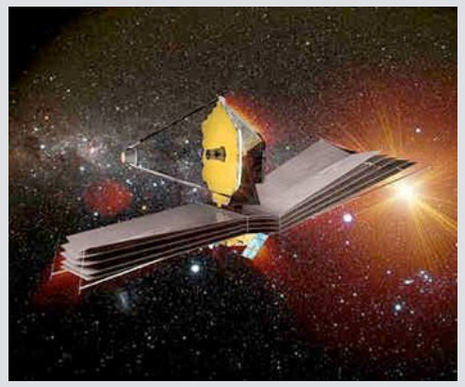
★ Wide area, near-IR: 550 arcmin^2; 120 sight-lines

★ ~20 galaxies at z~9-10; ~200 at z~7-8; [m_{AB}<27]



Aim: Investigate star formation in rare, massive halos (n~10^{-6} Mpc^3)

Beyond Hubble: JWST (2018)



★James Webb next giant leap

- Better sensitivity, resolution, IR coverage
- Detection of first generation of galaxies out to ~300 million years after Big Bang (z~15)
- Parallels have ground-breaking potential *(1h reaches m_{AB}=29 with S/N=5 at 2μm)*

Hubble
H band

JWST
H band

image simulation by
M. Stiavelli, STScI

WISH es for the future

★**WISH mission concept is amazing for truly wide area search of first galaxies**

★Some exciting science on galaxies **before reionization:**

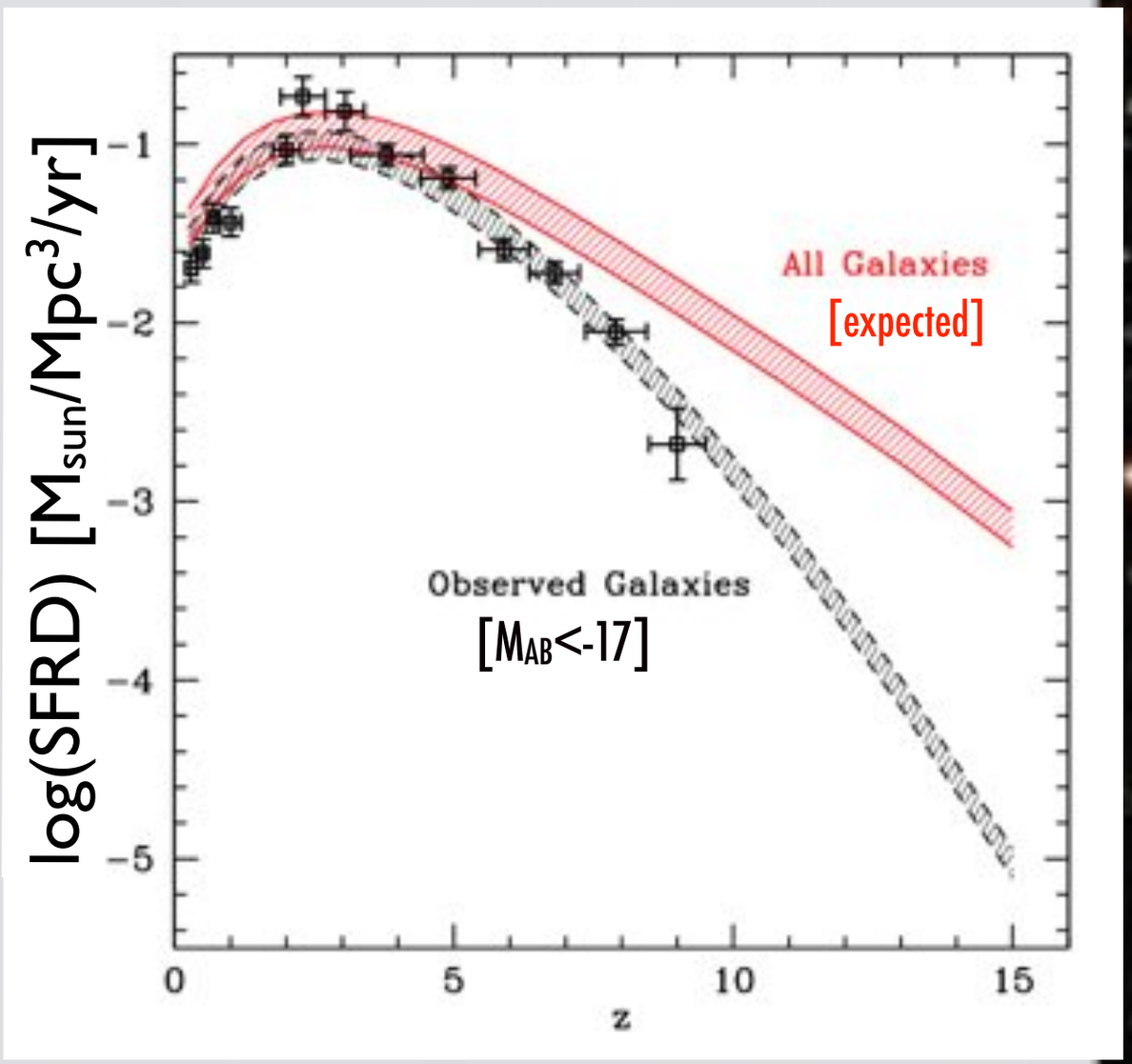
- Large Scale Structure
- Efficiency of metal enrichment
- Detection of Population III supernovae?

WISH es for the future

★Rapid redshift evolution of the luminosity density

- Early structure formation shifts toward smaller scales
  - **Bright galaxies rarer**
- **Large area of WISH critically needed for detection out to z~15**

Star formation rate predictions



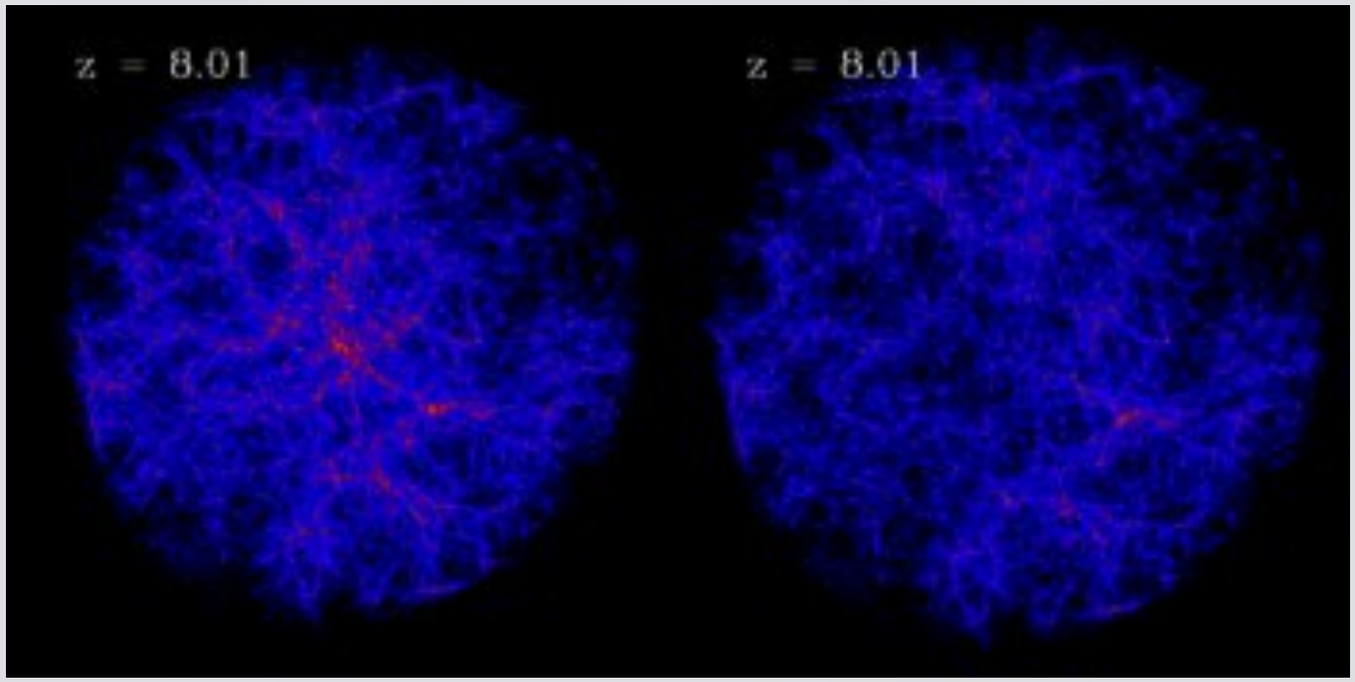
Trenti et al. (2013), Tacchella, Trenti & Carollo (2013)

Large Scale Structure

★*Puzzling result*: No excess of LBGs around SDSS QSOs at z~6 defying DM modeling expectations [Kim et al. 2009]

Cluster region

25 Mpc



Average Region

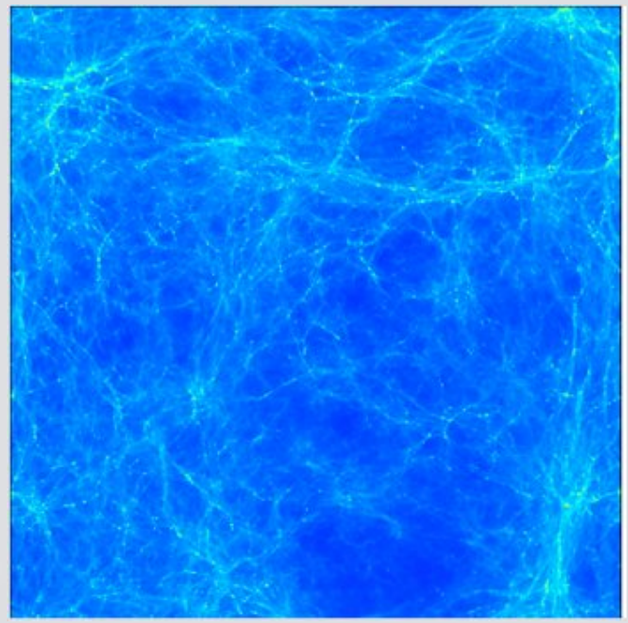
Trenti et al. (2012)

★What is DM halo - light connection for rare objects?

★How do SMBHs and galaxy clusters grow?

★WISH uniquely suited to investigate earliest assembly!

Metal Enrichment



★ **Metals in & around high-z galaxies: How much and how far?**

★ Metal pollution in biased regions starts early: At z>40 from PopIII (metal-free) stars (Trenti & Stiavelli 2007)

★ Stellar Populations of rare, bright galaxies at z>10-15 ideal probes of PopIII to PopII transition

★ **WISH can detect best sources for spectroscopic follow-up**

PopIII supernovae?

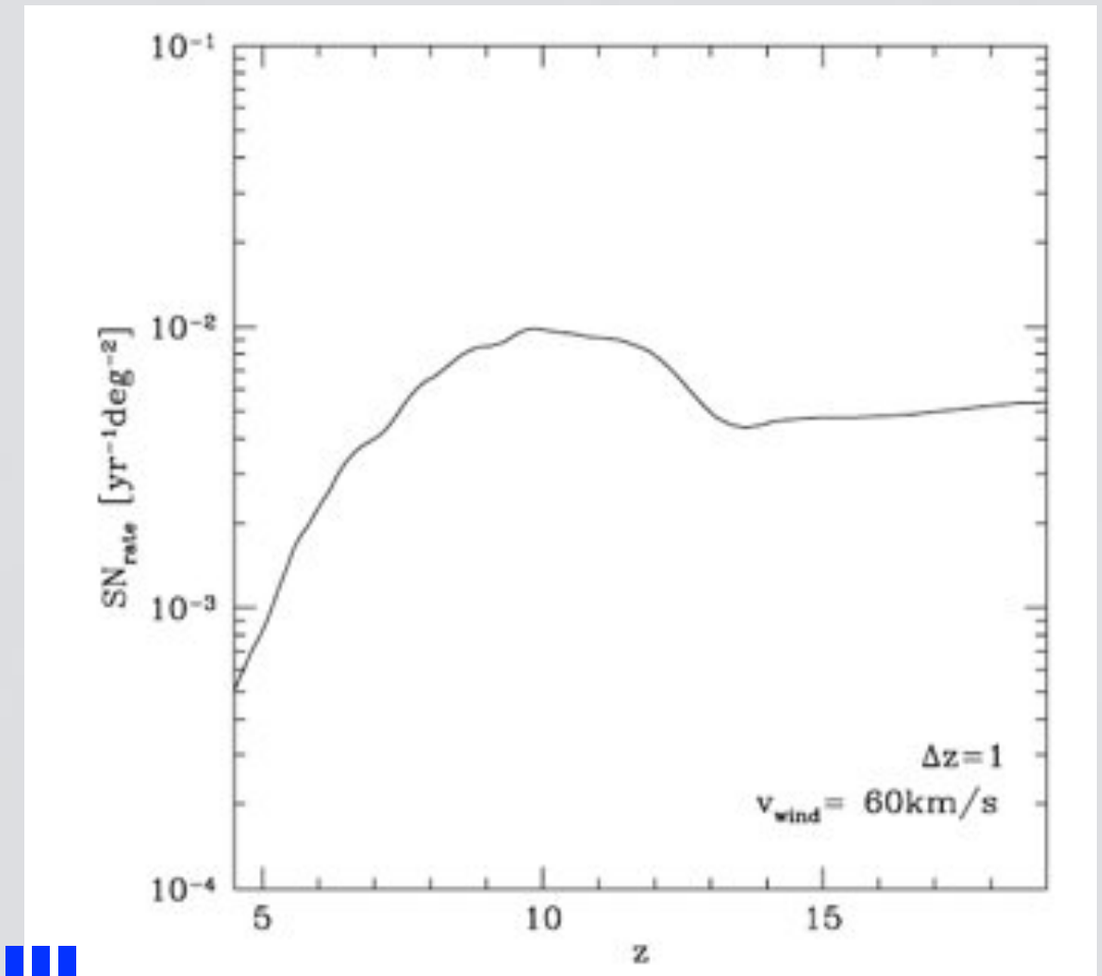
★ **Non-homogenous chemical enrichment implies PopIII supernovae at z<10**

★ Rate ~10^{-2} deg^2/yr

★ Slowly varying sources (year timescale)

★ **WISH has potential to find evidence of PISNe from PopIII stars!**

PopIII Supernova Rate [Observer Frame]



Trenti et al. (2009)

Summary

- Hubble's WFC3/IR transformed our view of galaxy evolution in the first 700 Myr
  - BoRG parallel imaging, and our spectroscopic followup, is playing a key role in this revolution
- BoRG[z9-10] survey will explore a new discovery space at z~9-10 in the short term
- Combination of WISH+JWST is an amazing opportunity for unprecedented wide&deep observations in the infrared!

Star formation beacons

★ Gamma Ray Bursts [~10^{52} ergs s^{-1}] emitted by dying massive stars rare but detectable at all redshifts

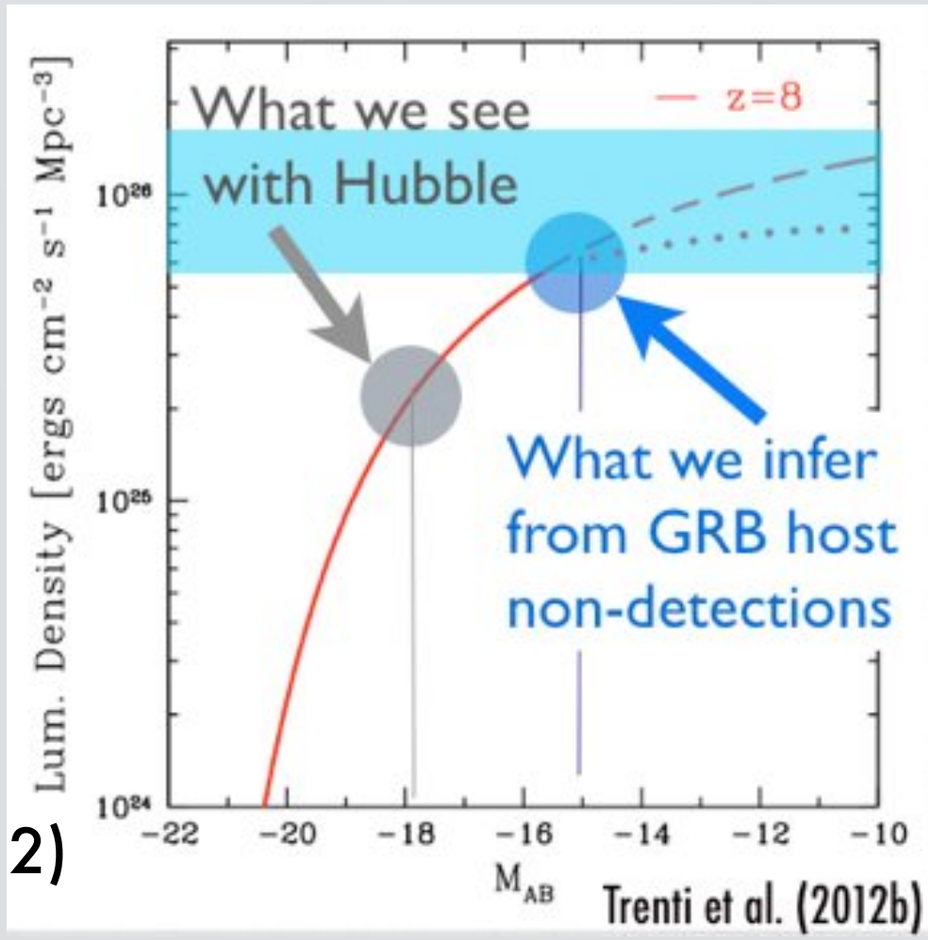
★ *Pinpoint sky locations with star formation (from bright optical/IR afterglow)*

★ Follow-up to probe host galaxy

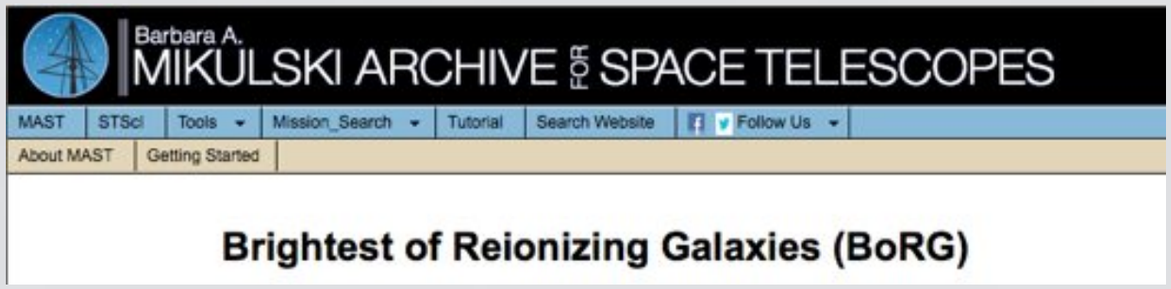
★ Upper limits only from HST ultra-deep data on 6 GRBs at z>5

★ Galaxy LF extends to 10x fainter than observed

(Trenti et al. 2012b,2013, Tanvir et al. 2012)



Legacy Value



IR-data from space have clear legacy value

★ 350 arcmin^2 of medium-depth near-IR data released through Hubble's archive

★ Core Science:

★ BoRG key dataset for bright-end of z~8 galaxy luminosity: Used by several independent teams
(Yan et al. 2011, McLure et al. 2013, Bouwens et al. 2014)

★ Legacy Science:

★ Milky Way Galactic Structure
(Ryan et al. 2011, Holwerda et al. 2014)