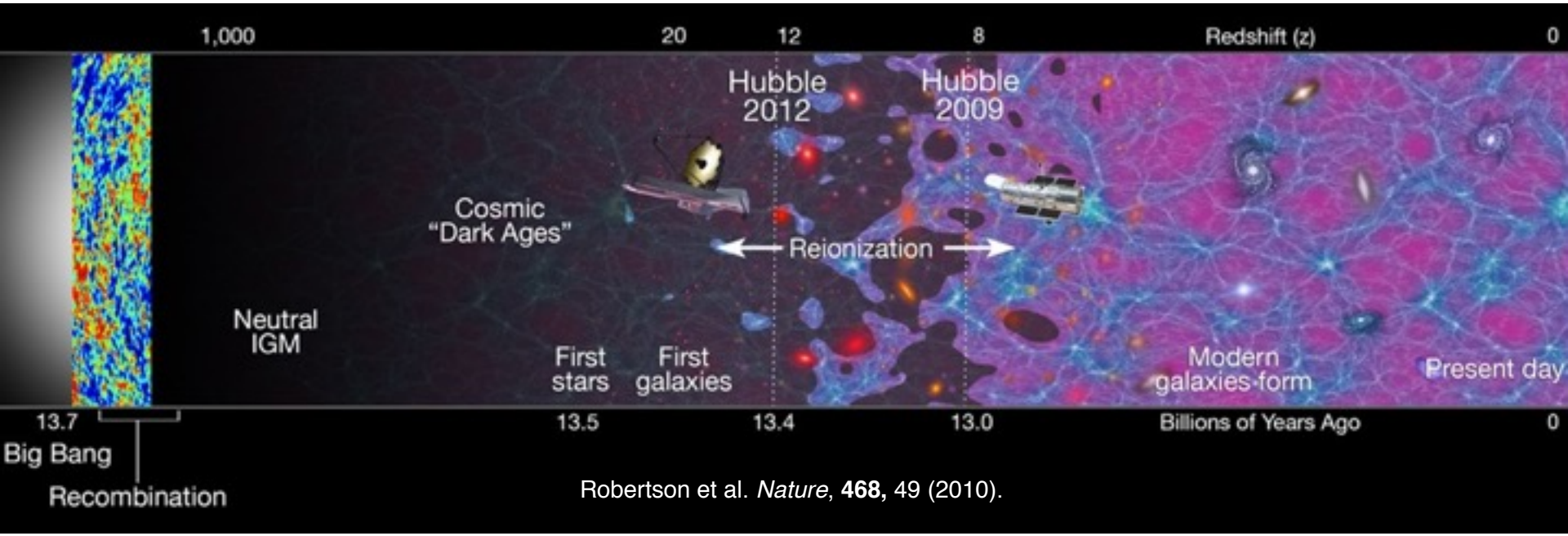
Near-Field Constraints on Deep-Field Science: Did faint galaxies reionize the universe?



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

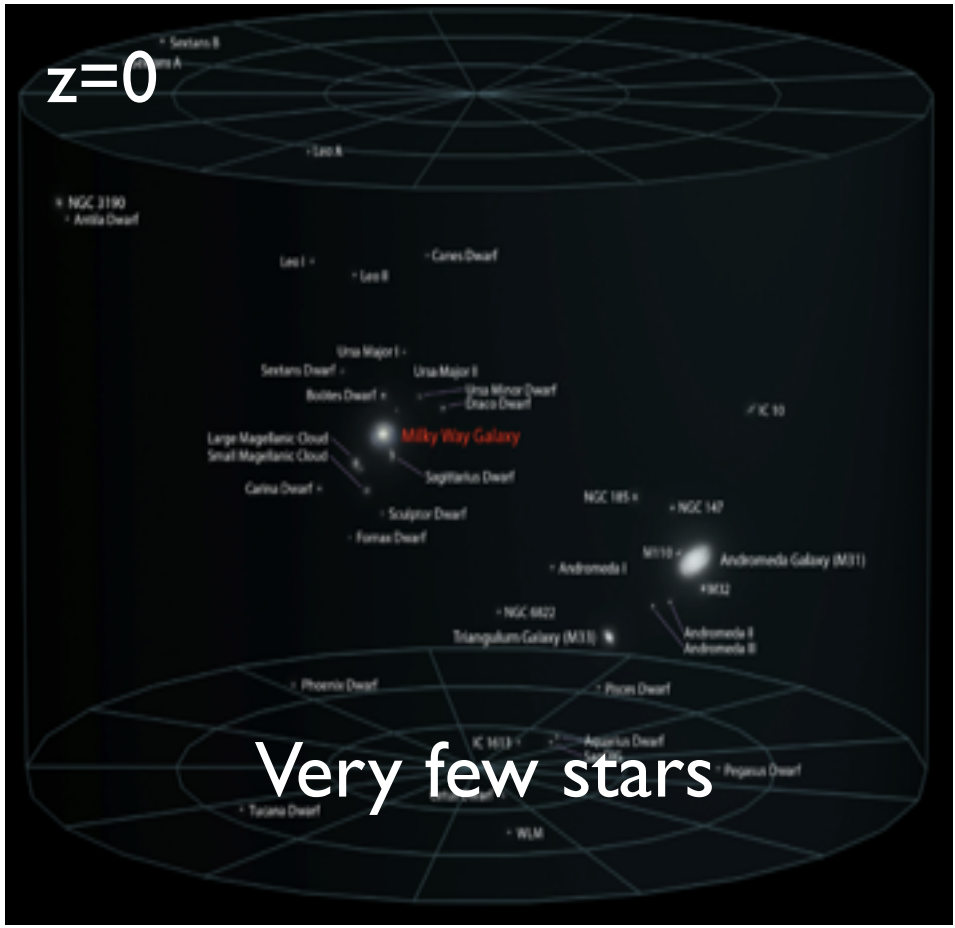
James Bullock (UC Irvine)

Mike Boylan-Kolchin; Shea Garrison-Kimmel
Andrew Graus

A basic tension for small halos (M_{dm} ~10^8 M_{sun})

Early Universe

Local Universe

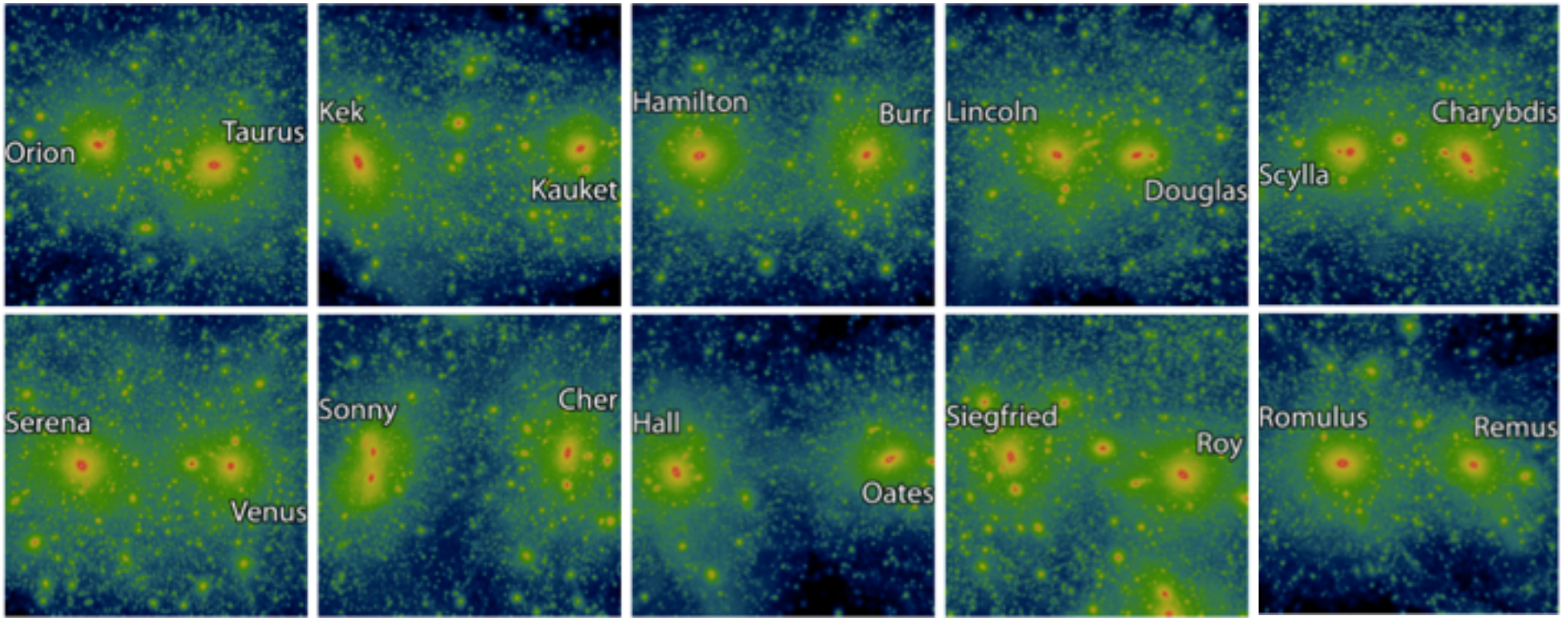


ELVIS

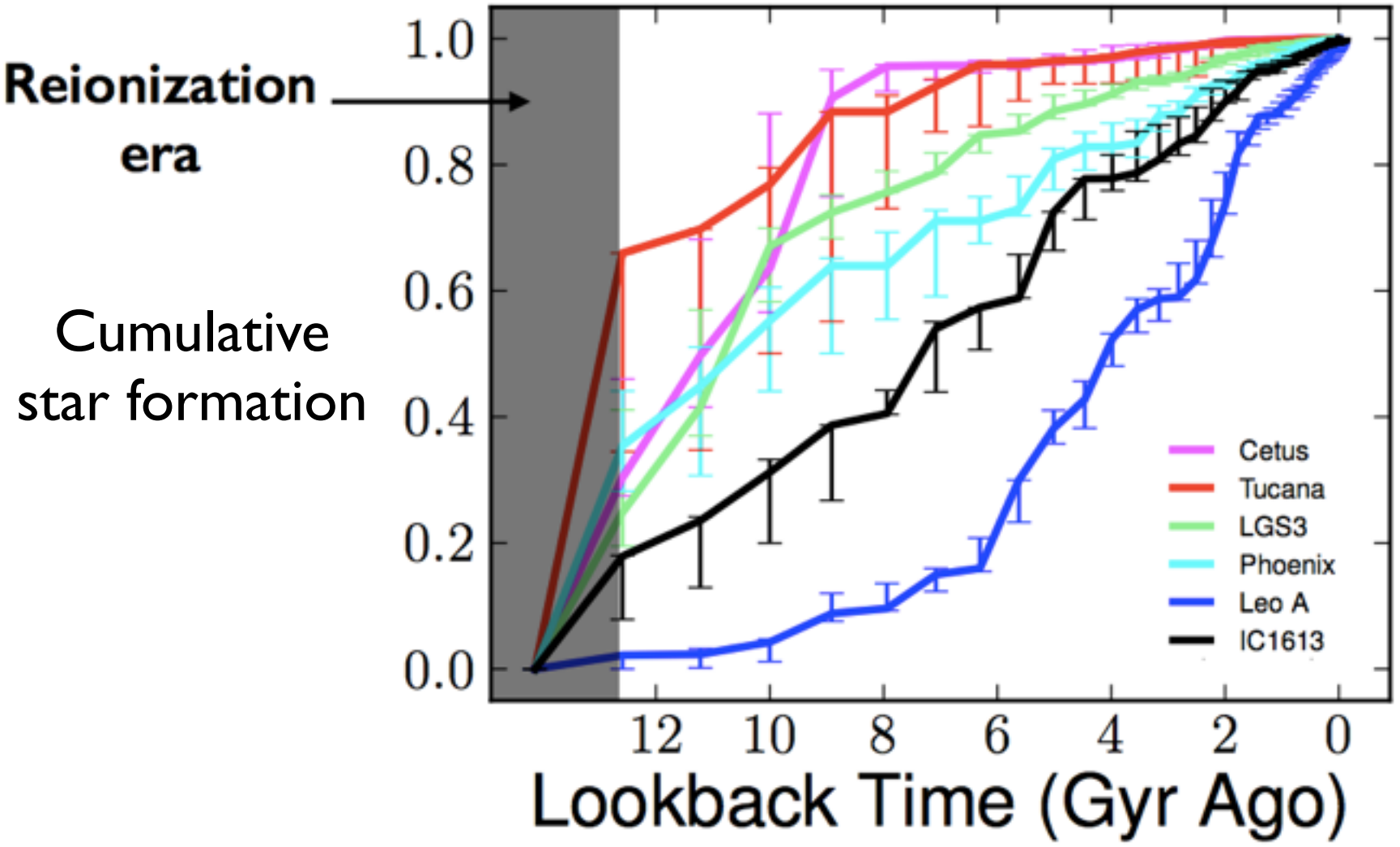
[Exploring the Local Volume In Simulations]

Garrison-Kimmel, Boylan-Kolchin, JSB
(2014, MNRAS)

http://localgroup.ps.uci.edu/elvis/

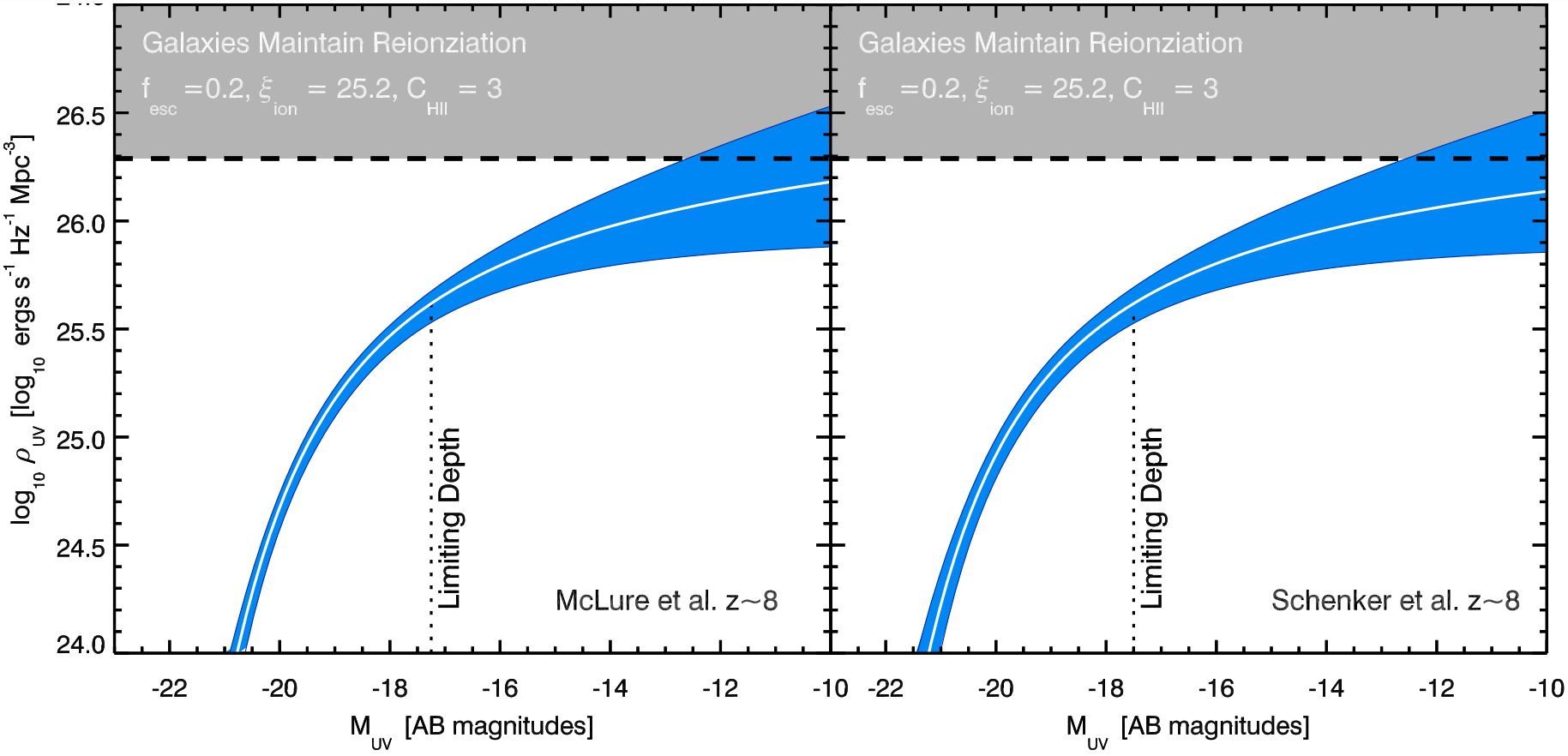


Local Group Dwarf Star Formation Histories



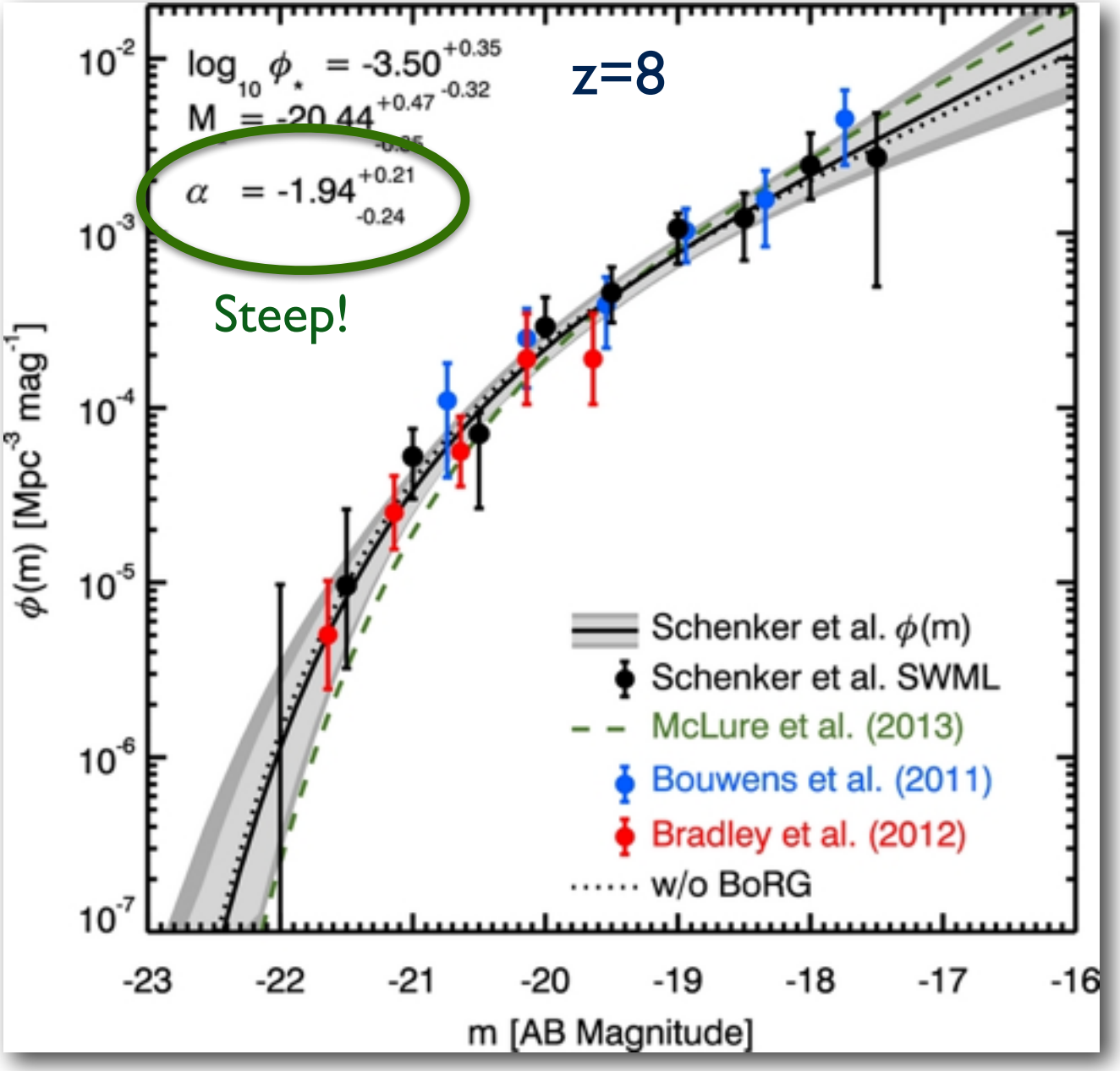
Skillman et al. 2014 (ACS LCID project); **Weisz et al. 2014**

Faint galaxies (M_{uv} ~ -10) drive reionization?



Robertson et al. 2013

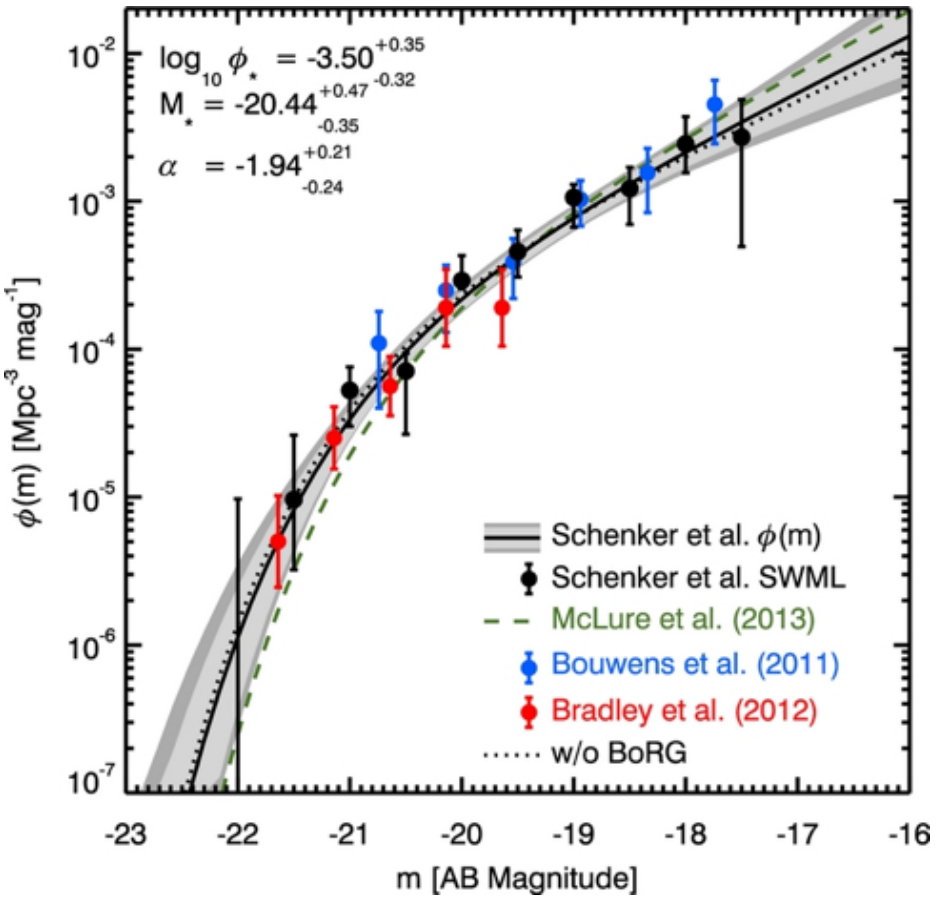
Also: Finkelstein et al. 2012, Kuhlen & Faucer-Giguere 2012

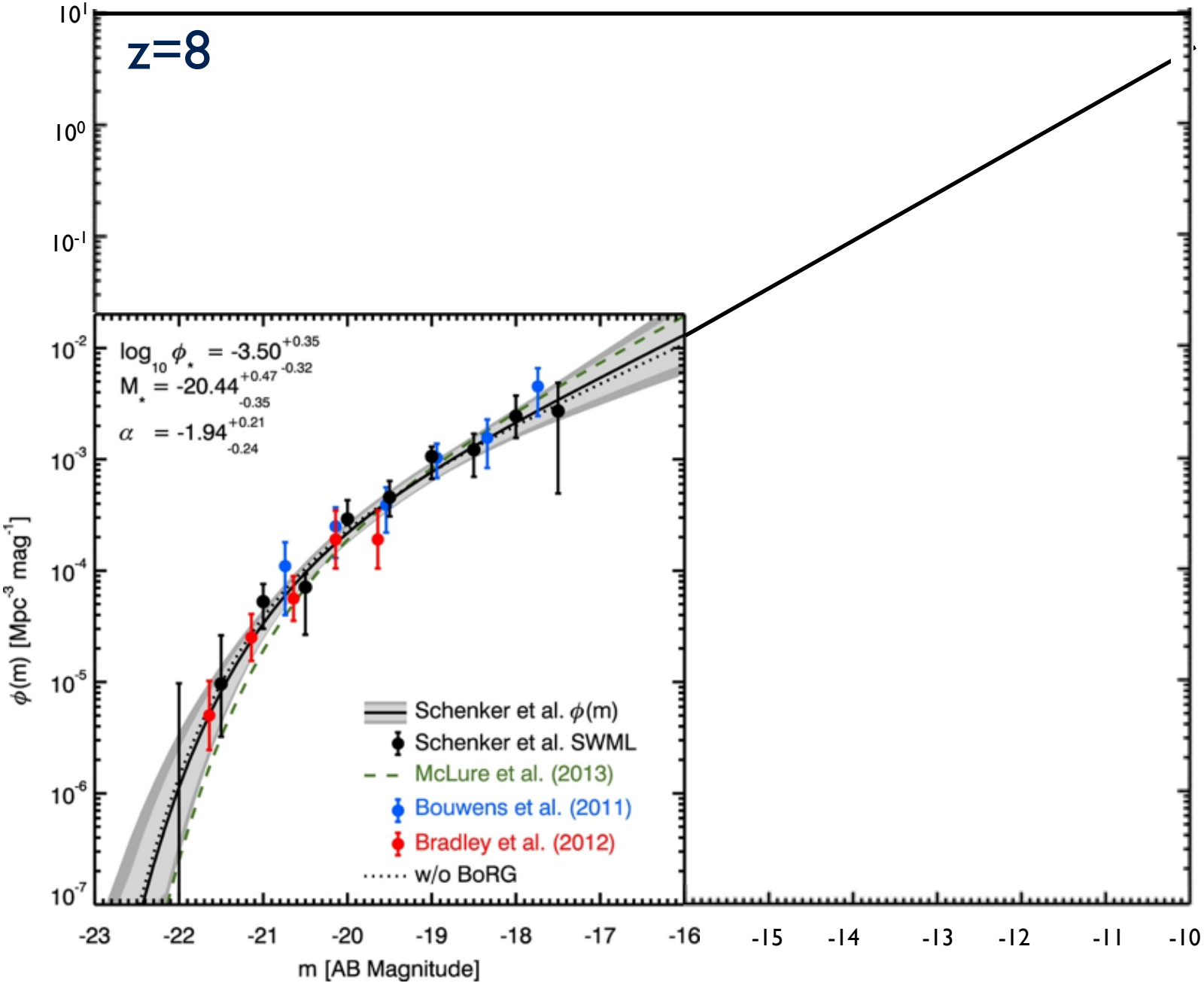


Also:

Oesch et al. 2013;
Illingworth et al. 2013;
Bouwens et al. 2014;

z=8


$\log_{10}\phi_* = -3.50^{+0.35}_{-0.32}$
$M_* = -20.44^{+0.47}_{-0.35}$
$\alpha = -1.94^{+0.21}_{-0.24}$
Schenker et al. ϕ(m)
Schenker et al. SWML
McLure et al. (2013)
Bouwens et al. (2011)
Bradley et al. (2012)
w/o BoRG
ϕ(m) [Mpc^{-3} mag^{-1}]
m [AB Magnitude]
10^{-2}
10^{-3}
10^{-4}
10^{-5}
10^{-6}
10^{-7}
-23
-22
-21
-20
-19
-18
-17
-16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10^{1}
10^{0}
10^{-1}
10^{-2}
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10^{-5}
10^{-6}
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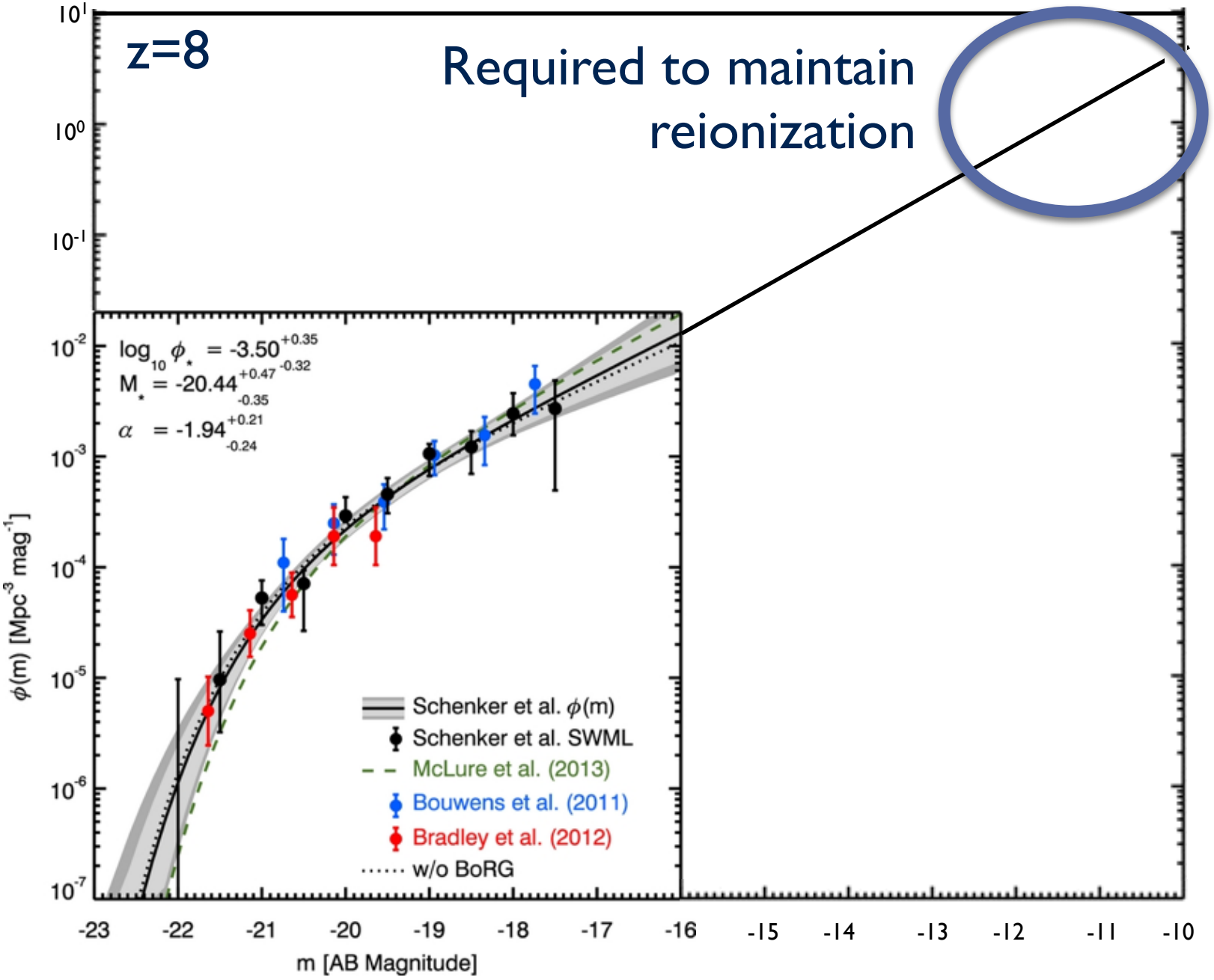
z=8
Required to maintain reionization
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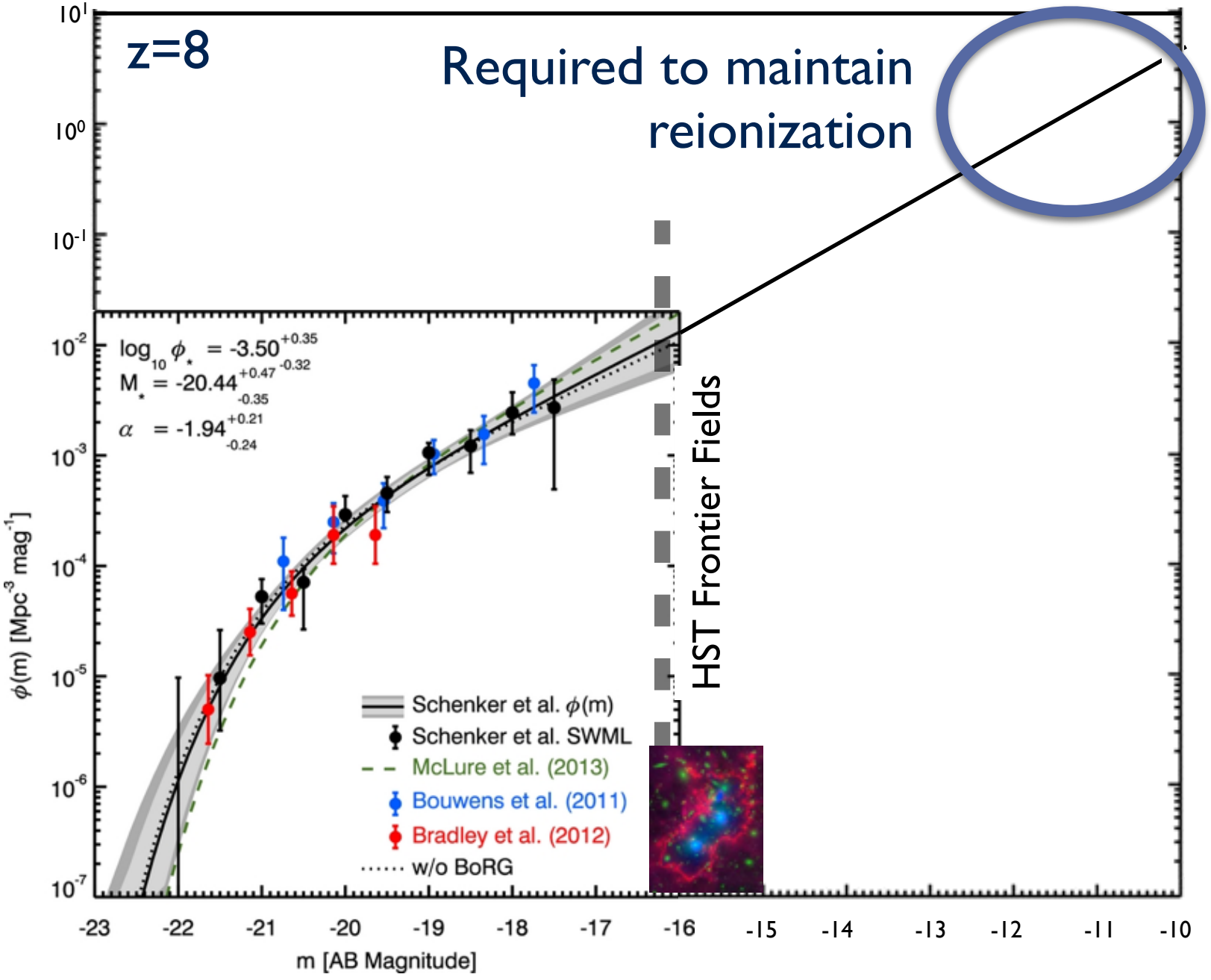
z=8
Required to maintain reionization
HST Frontier Fields
$\log_{10}\phi_* = -3.50^{+0.35}_{-0.32}$
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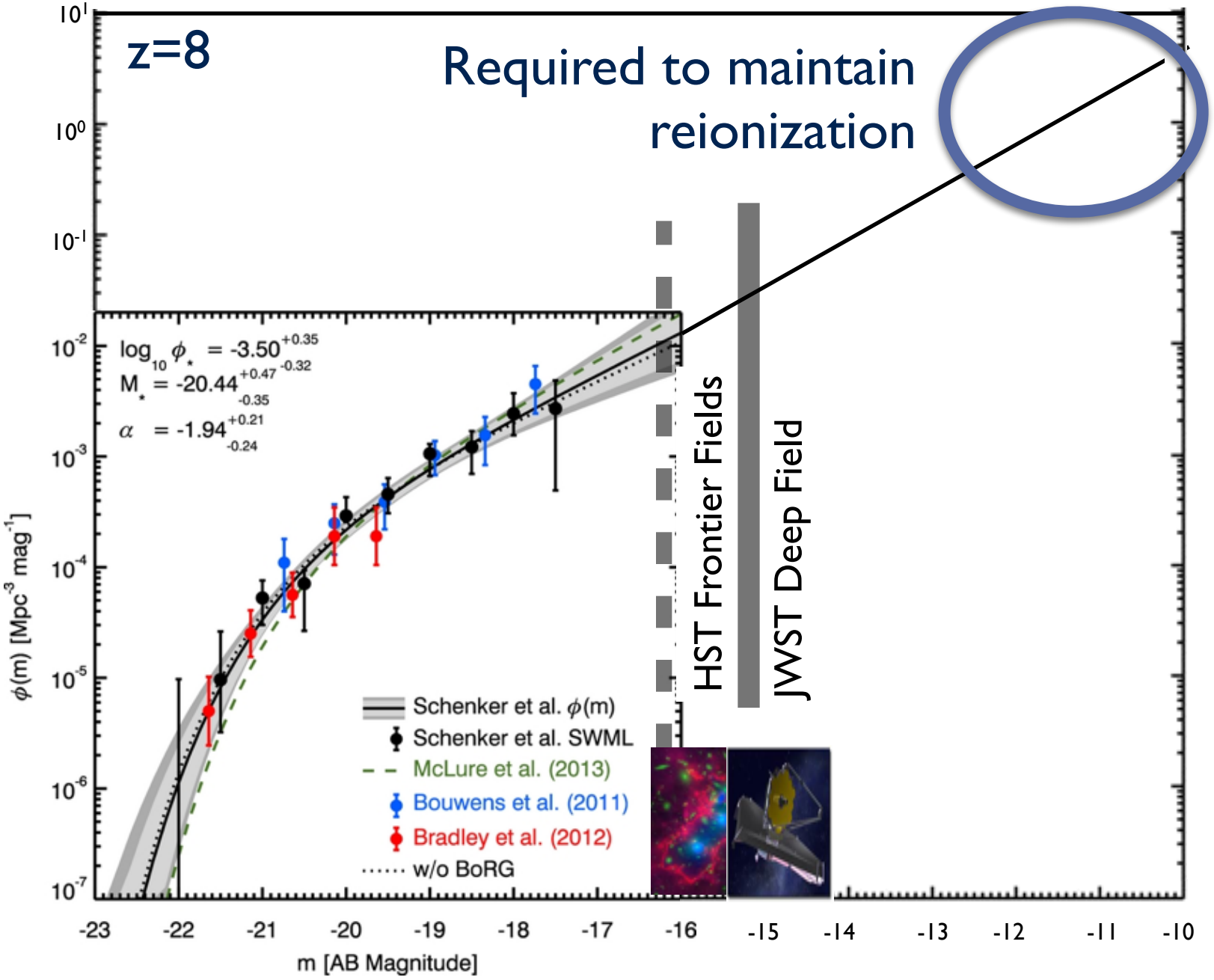
z=8
Required to maintain reionization
HST Frontier Fields
JWST Deep Field
$\log_{10}\phi_* = -3.50^{+0.35}_{-0.32}$
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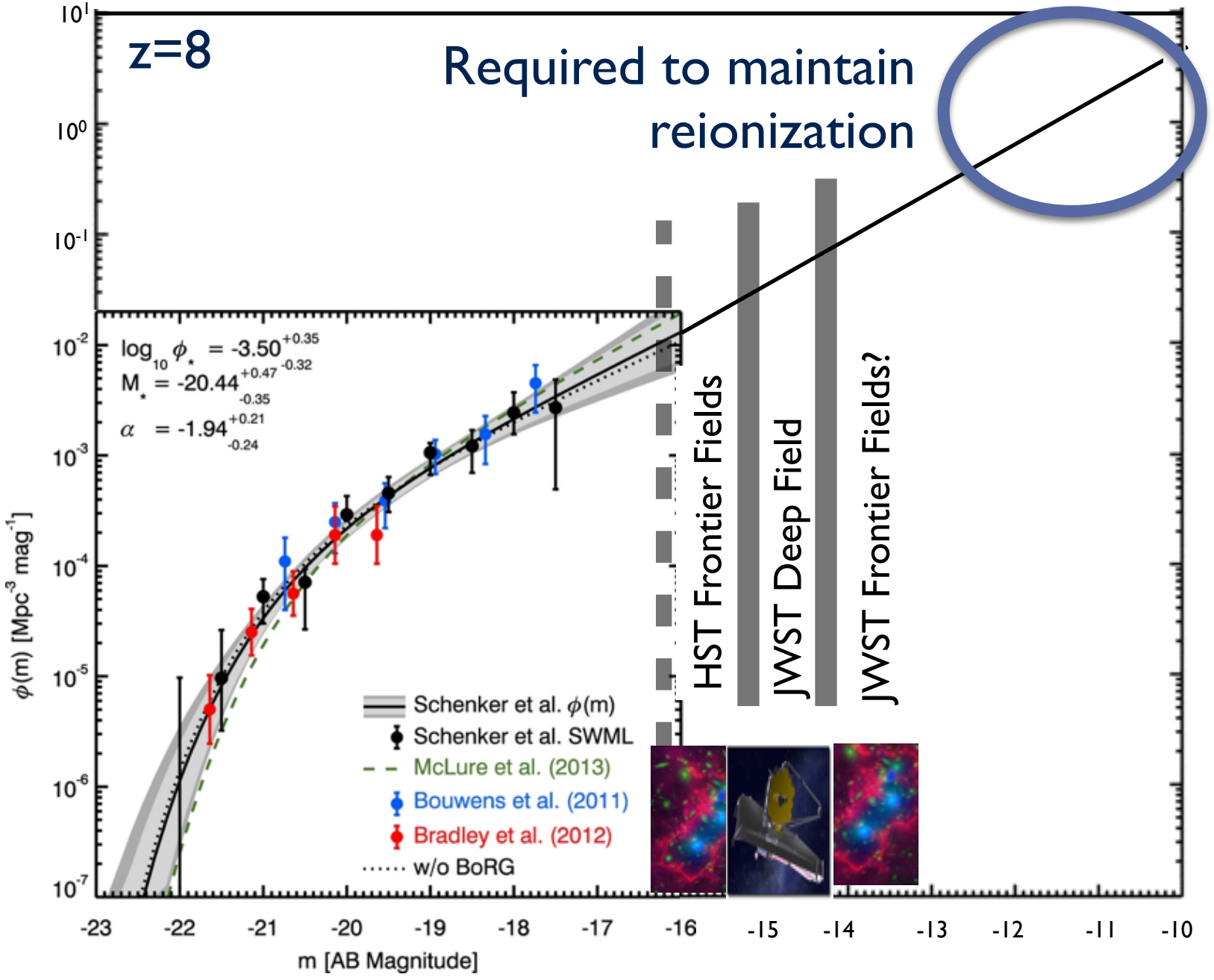
z=8
Required to maintain reionization
HST Frontier Fields
JWST Deep Field
JWST Frontier Fields?
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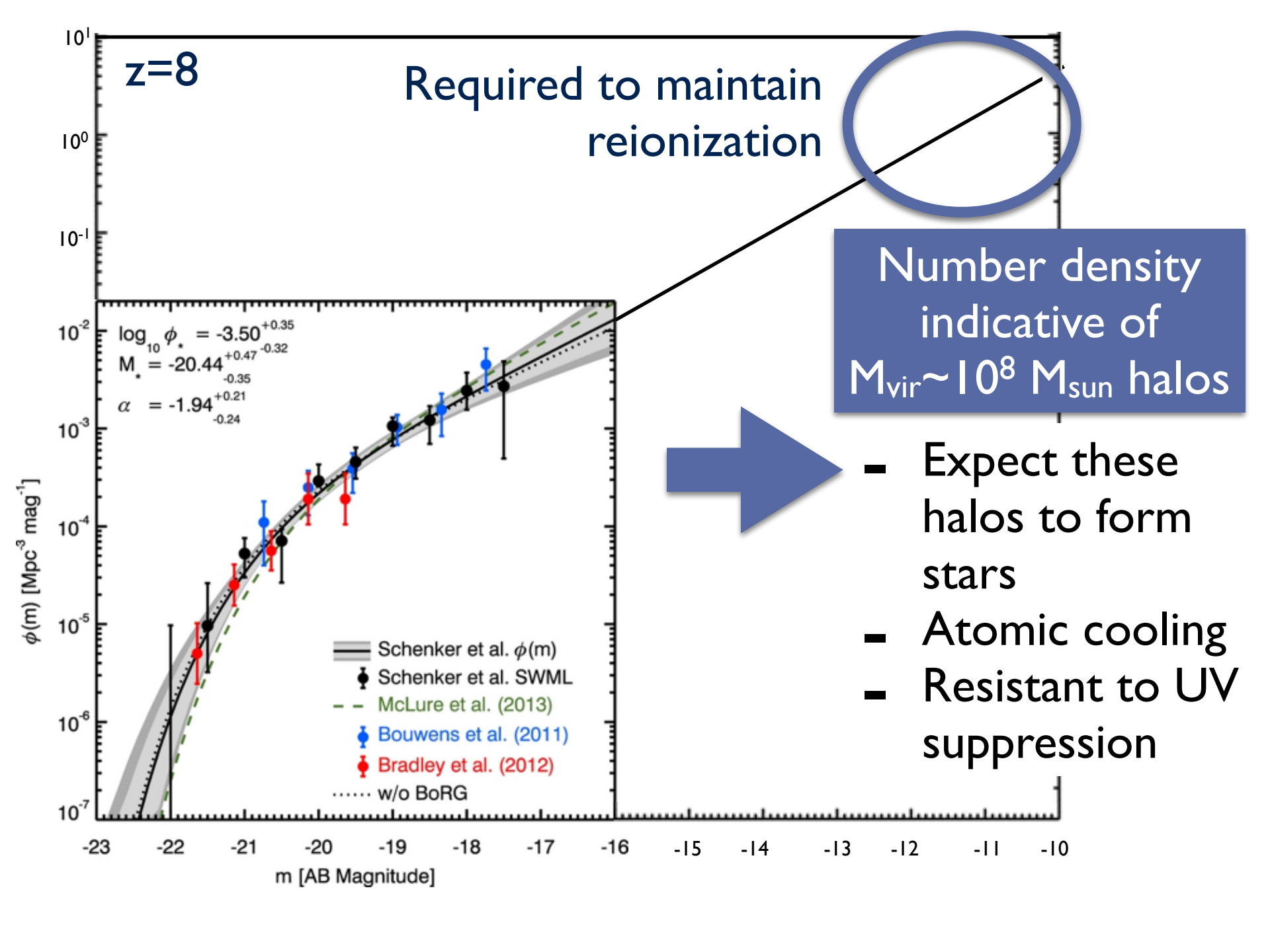
z=8
Required to maintain reionization
Number density indicative of $M_{vir} \sim 10^8 M_{sun}$ halos
- Expect these halos to form stars
- Atomic cooling
- Resistant to UV suppression
$\log_{10}\phi_* = -3.50^{+0.35}_{-0.32}$
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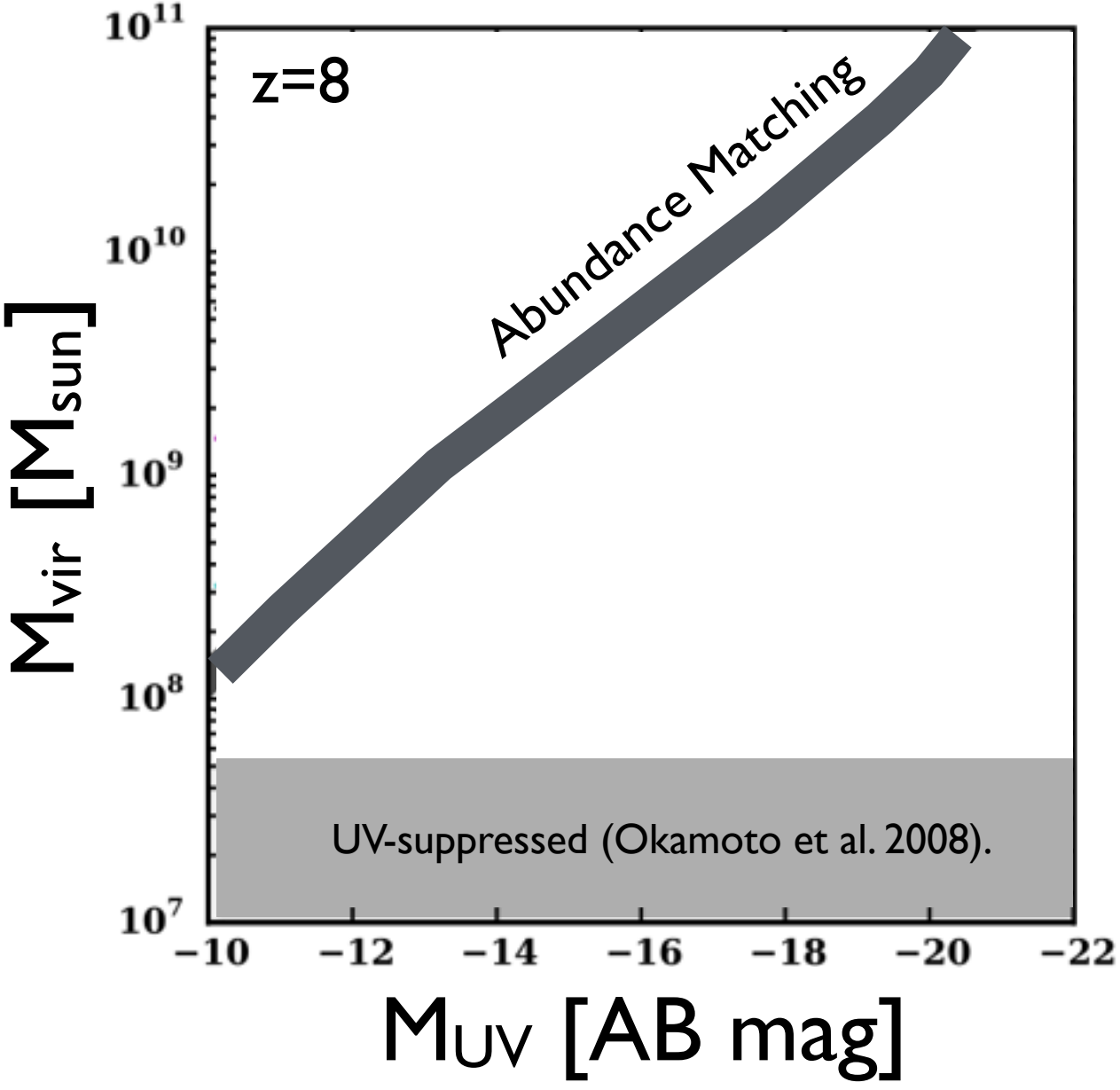
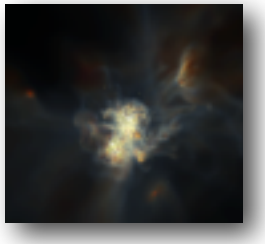
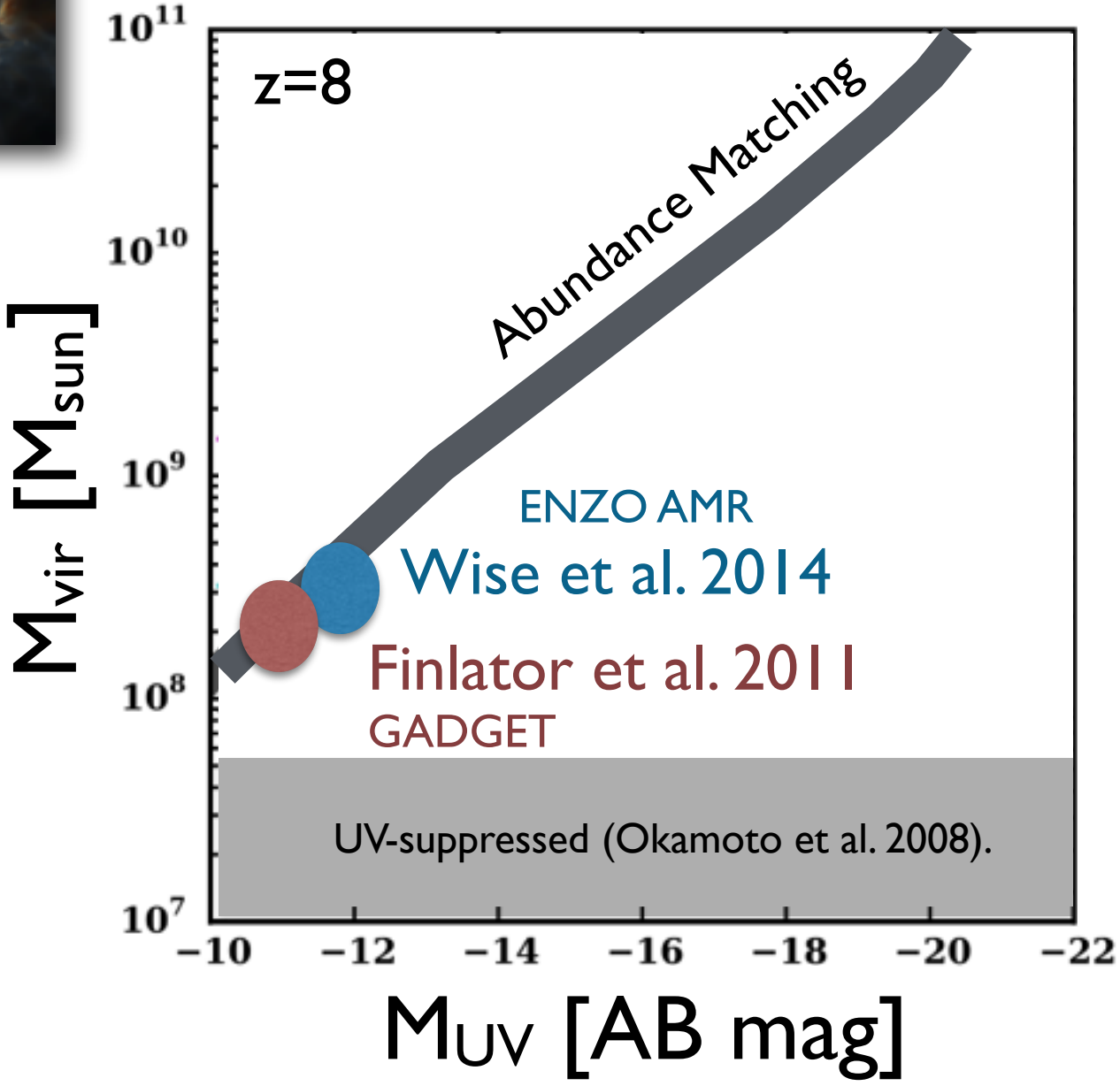
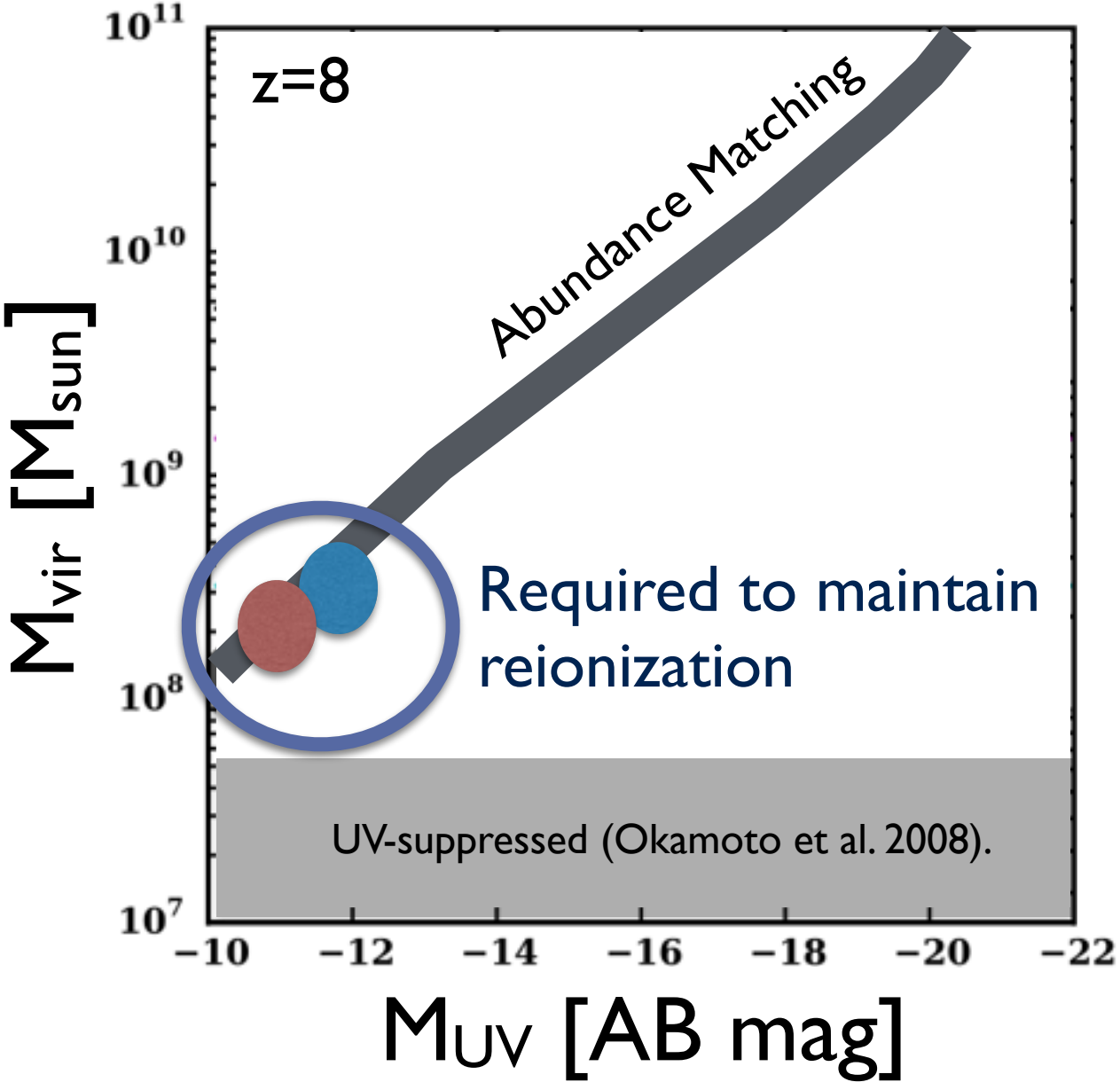
ϕ(m) [Mpc^{-3} mag^{-1}]
m [AB Magnitude]


z=8
Abundance Matching
UV-suppressed (Okamoto et al. 2008).
10^{11}
10^{10}
10^{9}
10^{8}
10^{7}
−10
−12
−14
−16
−18
−20
−22
M_{vir} [M_{sun}]
M_{UV} [AB mag]




z=8
Abundance Matching
ENZO AMR
Wise et al. 2014
Finlator et al. 2011
GADGET
UV-suppressed (Okamoto et al. 2008).
10^{11}
10^{10}
10^{9}
10^{8}
10^{7}
M_{vir} [M_{sun}]
−10
−12
−14
−16
−18
−20
−22
M_{UV} [AB mag]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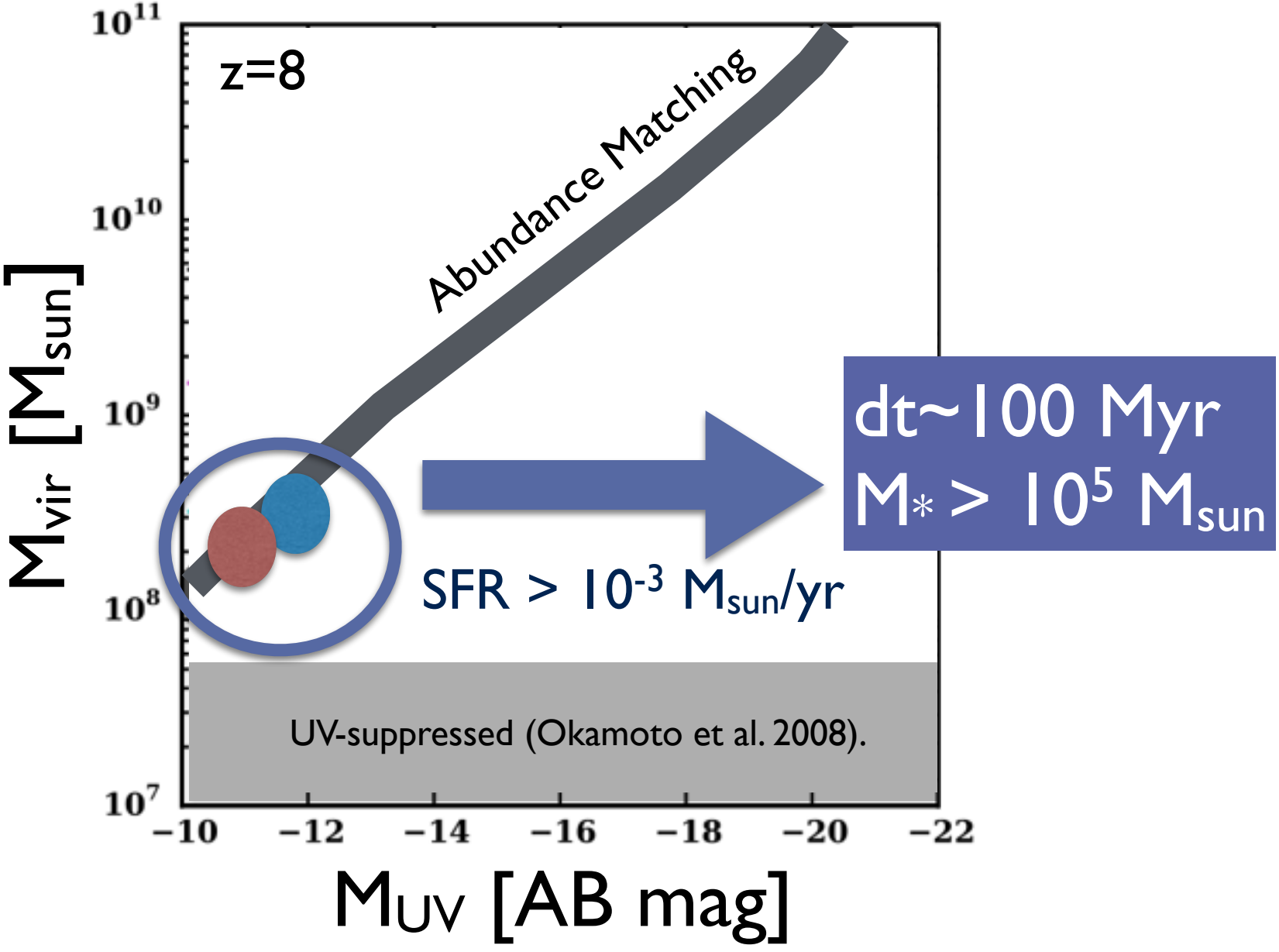
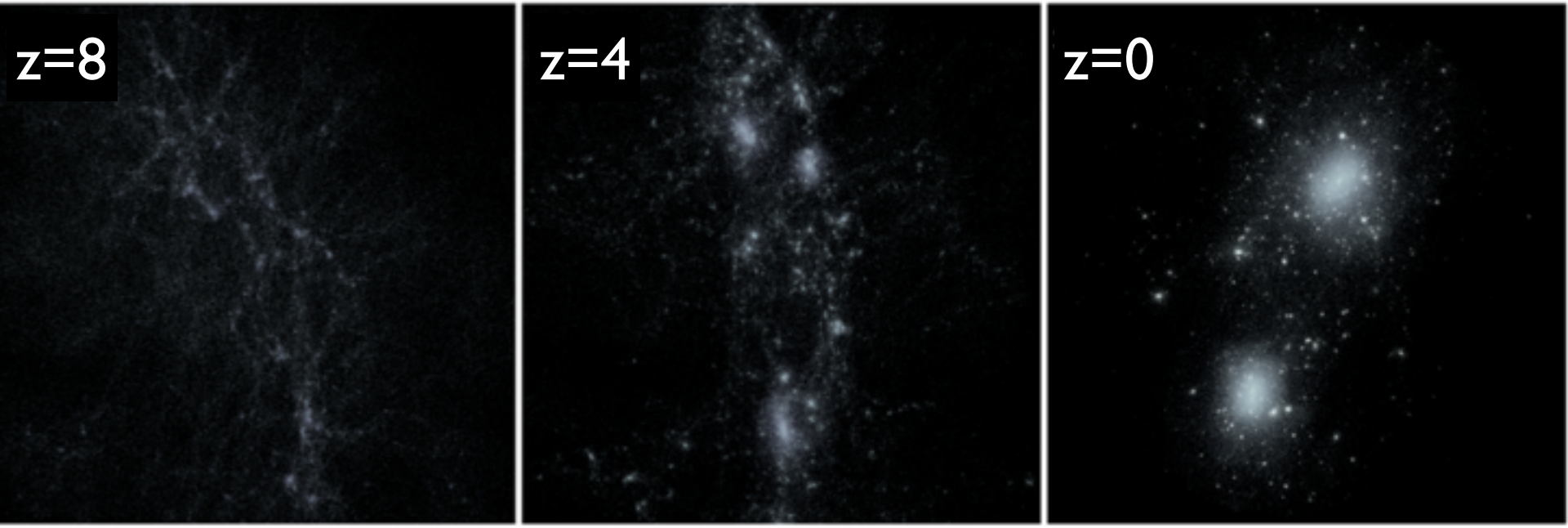
Abundance Matching
Required to maintain reionization
UV-suppressed (Okamoto et al. 2008).
10^{11}
10^{10}
10^{9}
10^{8}
10^{7}
M_{vir} [M_{sun}]
−10
−12
−14
−16
−18
−20
−22
M_{UV} [AB mag]


z=8
Abundance Matching
dt~100 Myr
M* > 10^5 M_sun
SFR > 10^-3 M_sun/yr
UV-suppressed (Okamoto et al. 2008).
M_vir [M_sun]
M_UV [AB mag]
10^11
10^10
10^9
10^8
10^7
−10
−12
−14
−16
−18
−20
−22

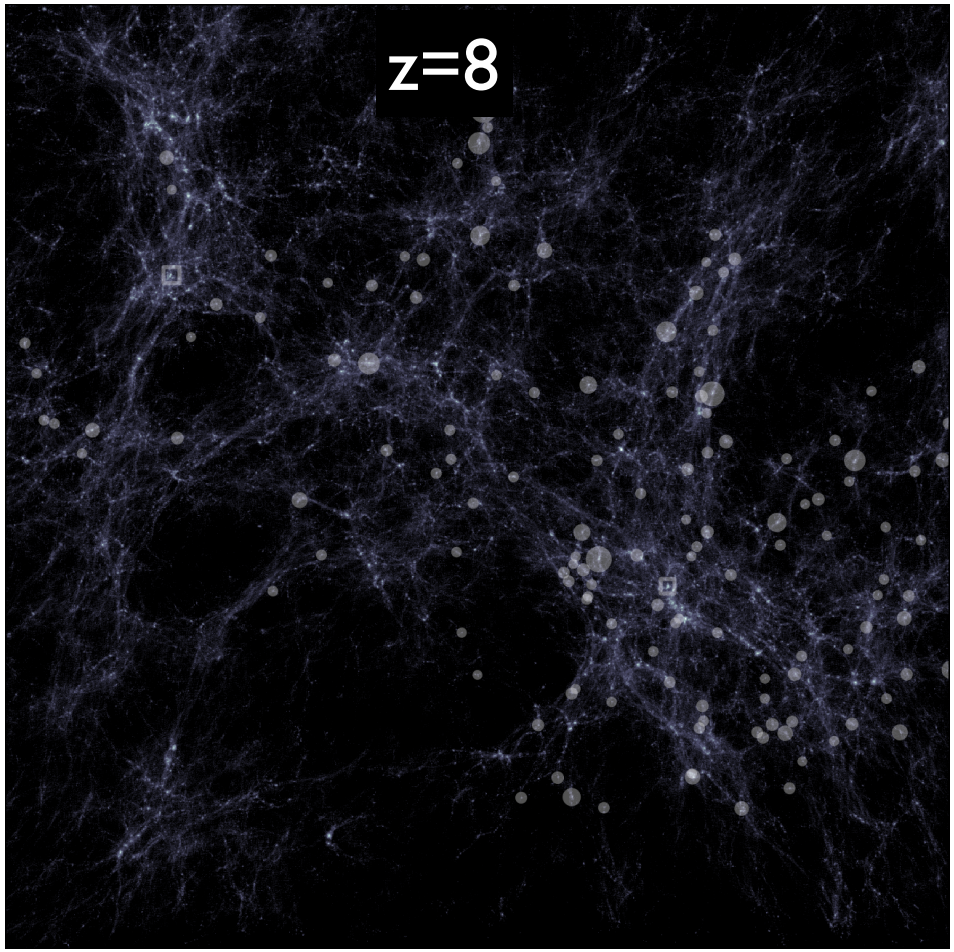
Connecting Galaxies Over Cosmic Time

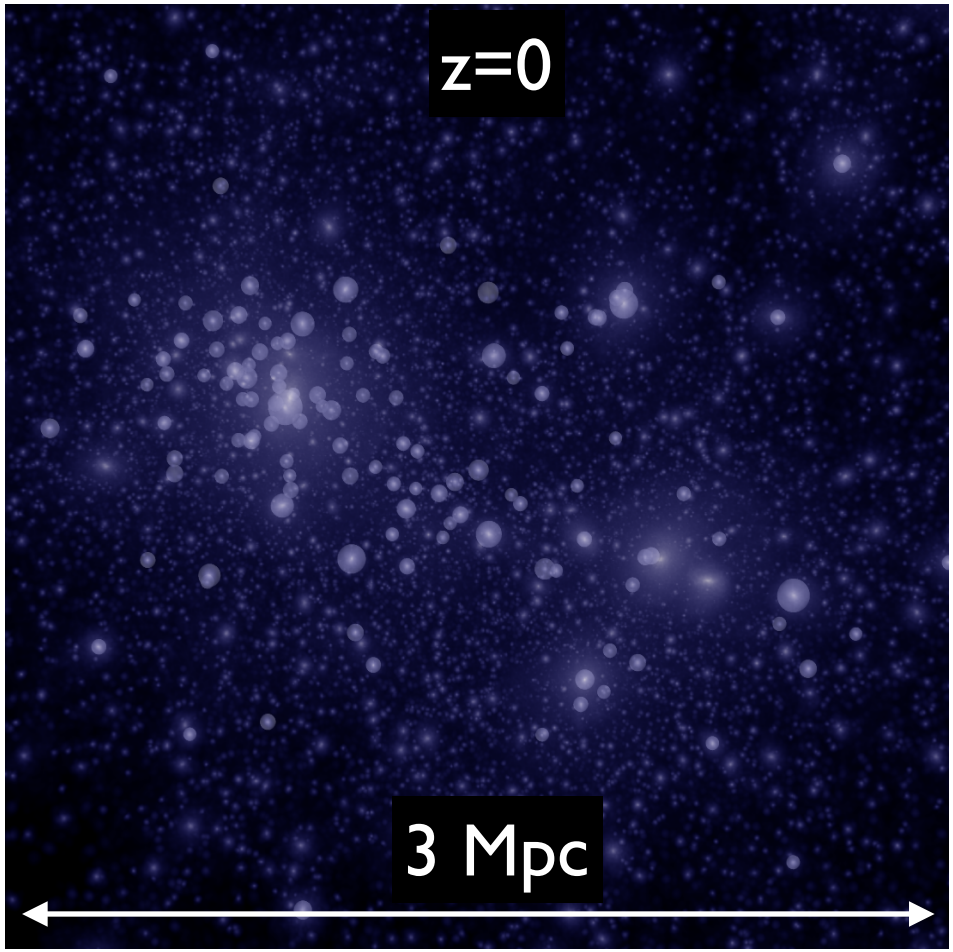


ID systems with $M_v > 10^8 M_{sun}$

Bound progenitors at z=8

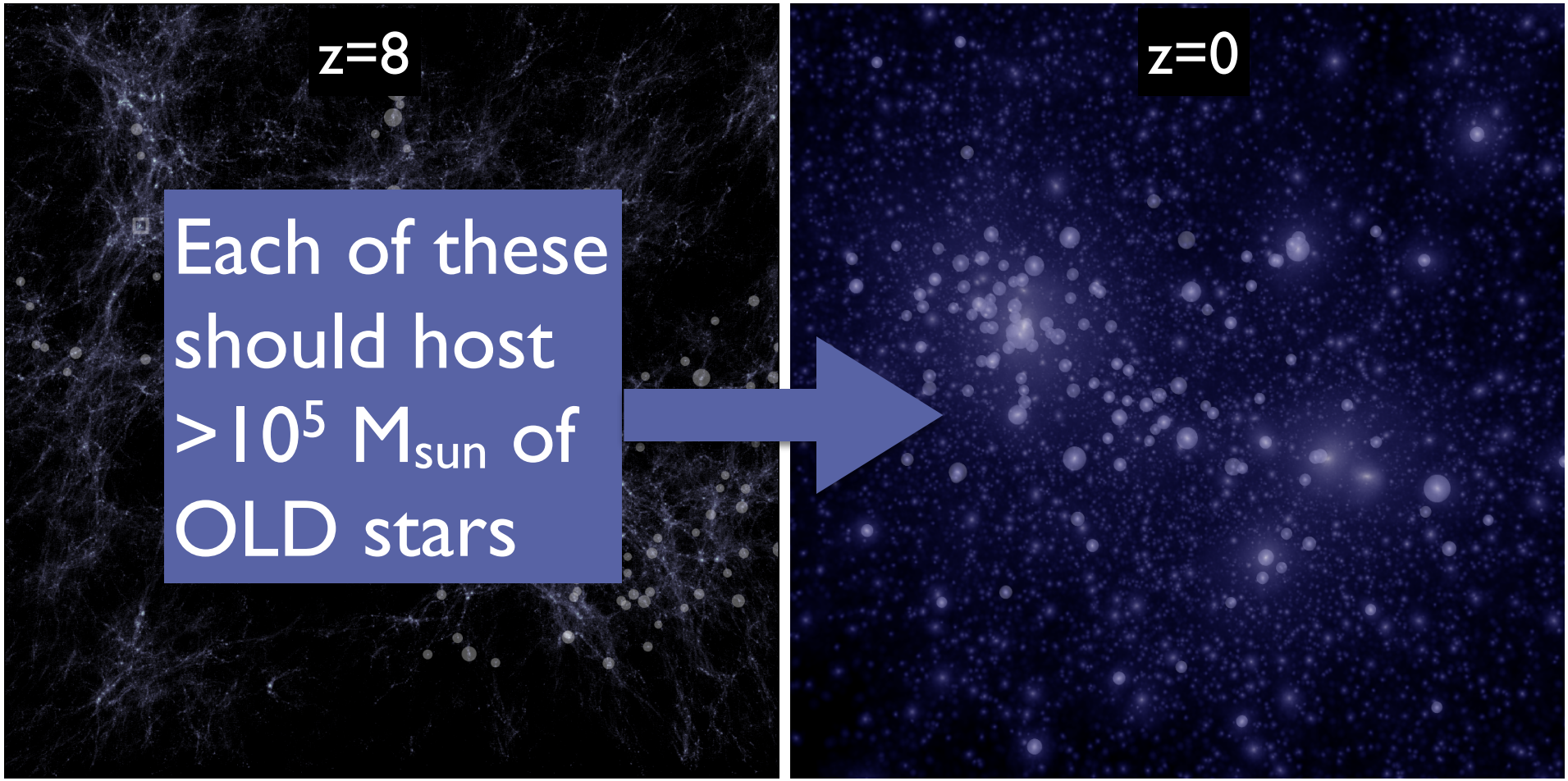
Descendants of Reionization in the Local Group





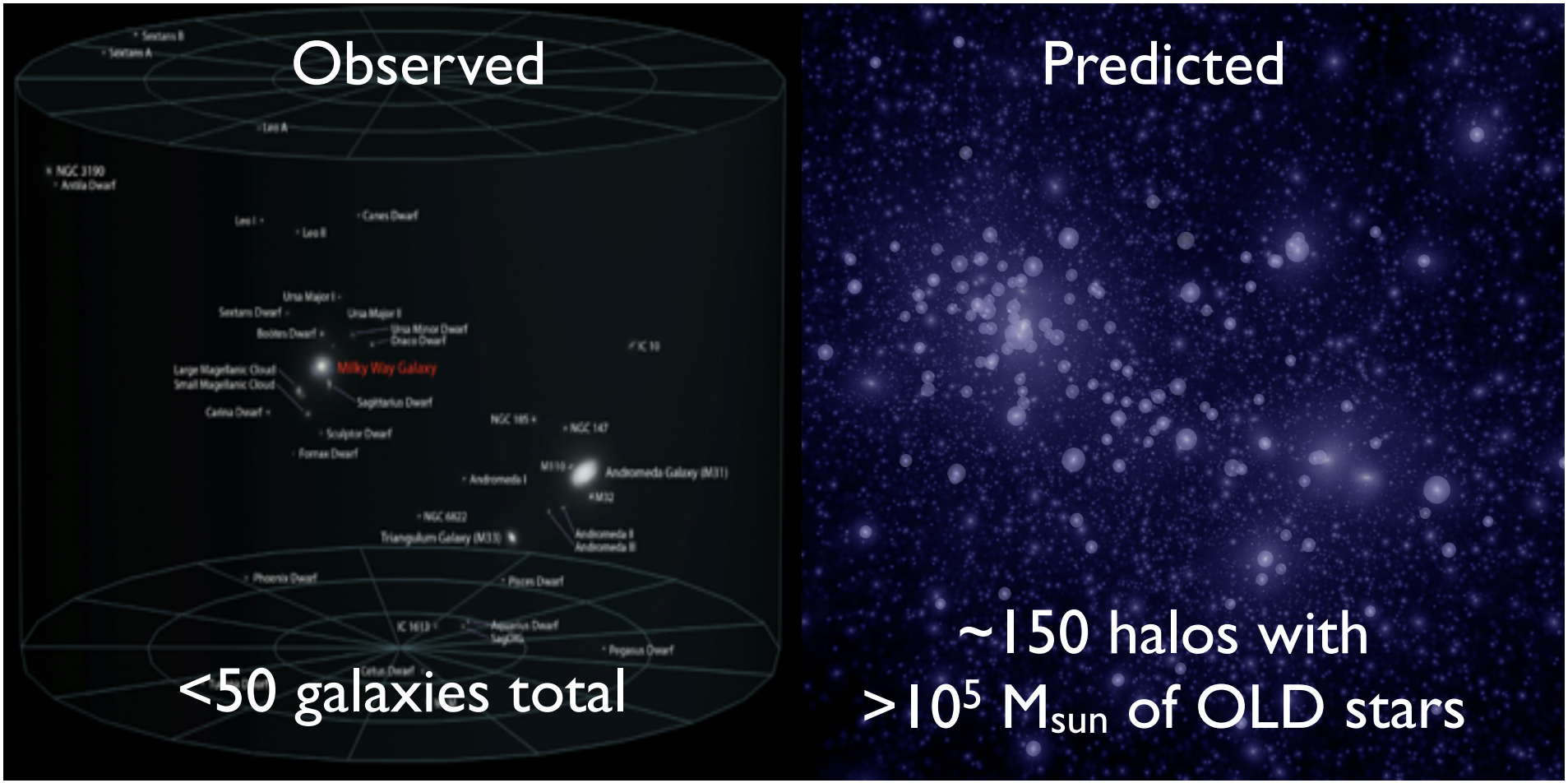
~150 bound descendants of halos atomic cooling halos z=8

Descendants of Reionization in the Local Group

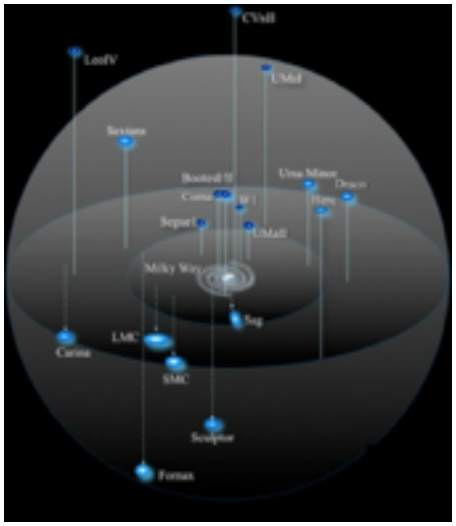


~150 bound descendants of halos atomic cooling halos z=8

Descendants of Reionization in the Local Group

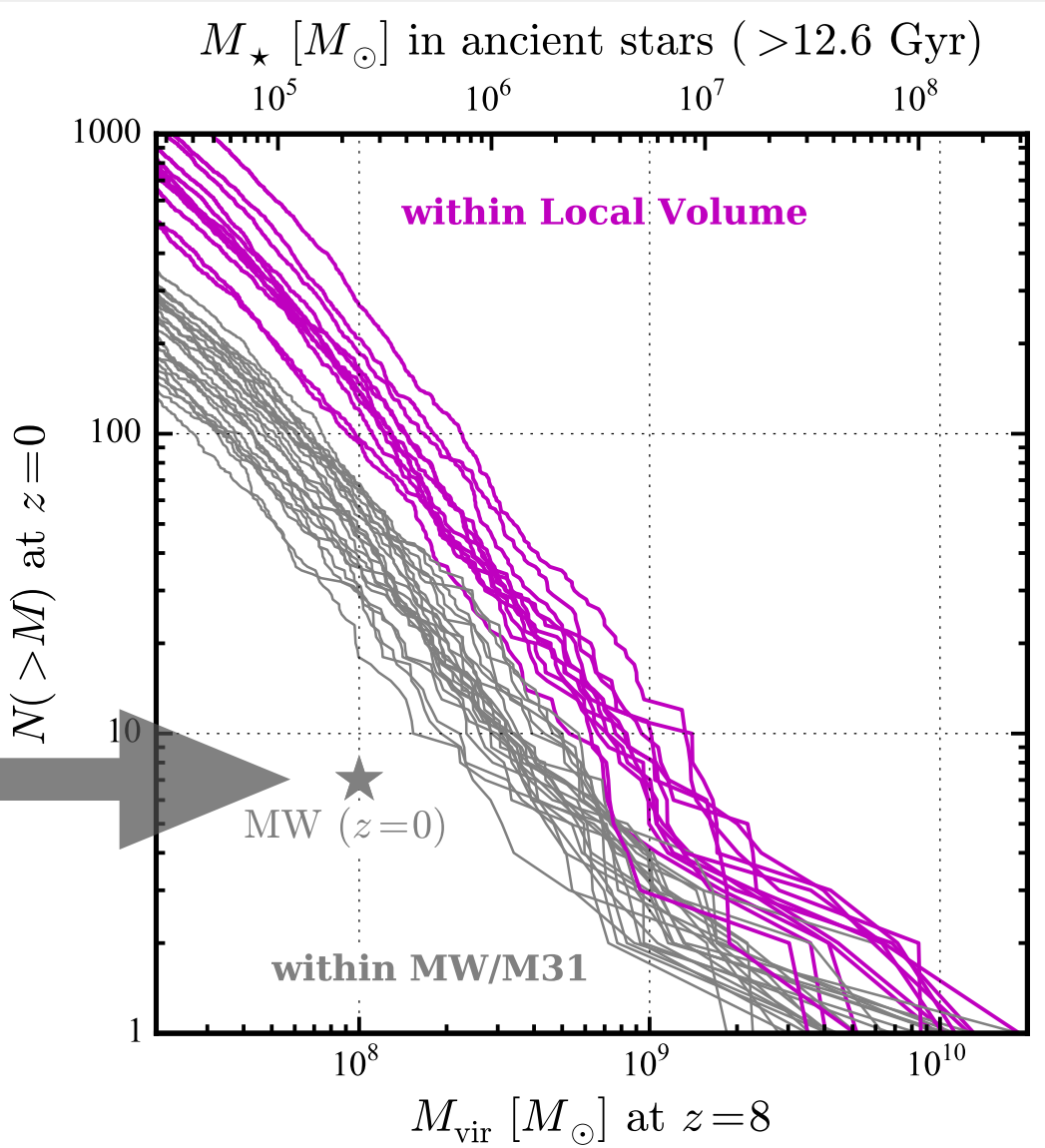


Where are the “first light” halos?



MW has only 7 satellites with >2.10^{5}M$_{sun}$ in ancient stars

Weisz et al. 2014



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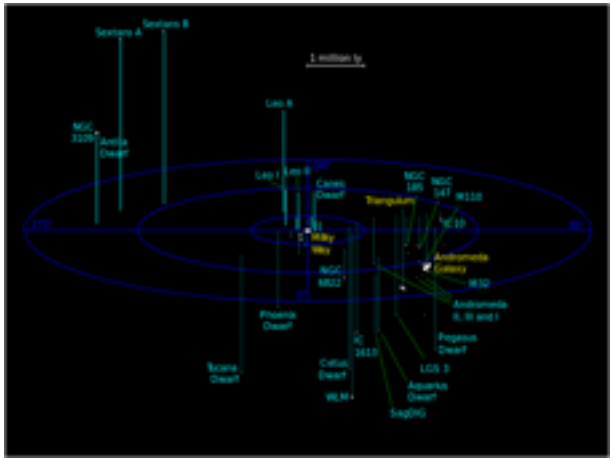
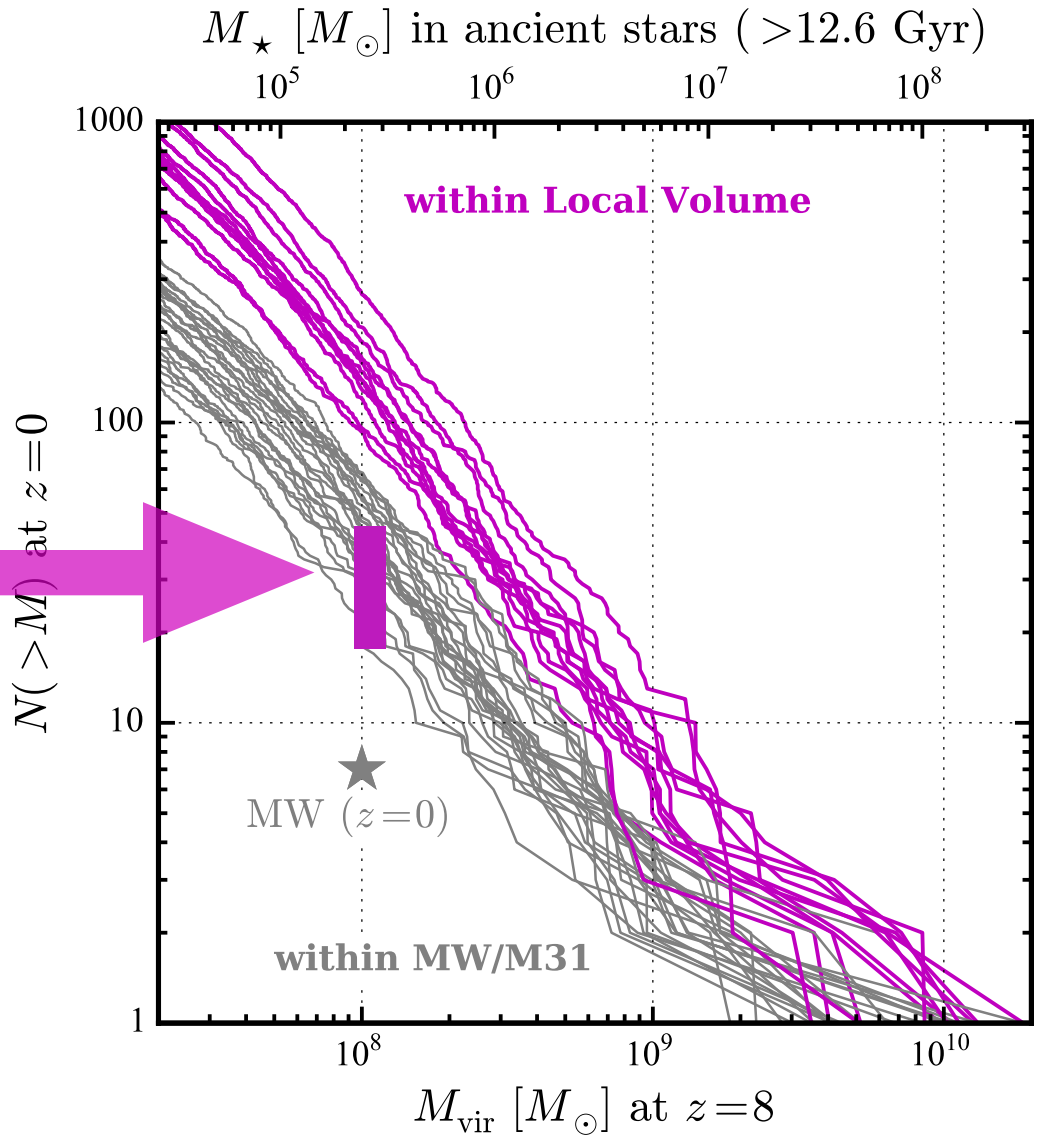
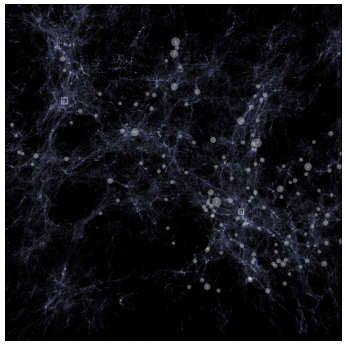


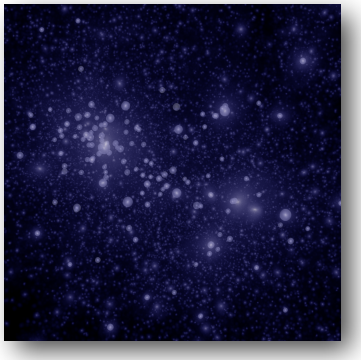
Local group has ~30 galaxies w/ > 2.10^5 M_{sun} of ancient stars

Weisz et al. 2014





Summary

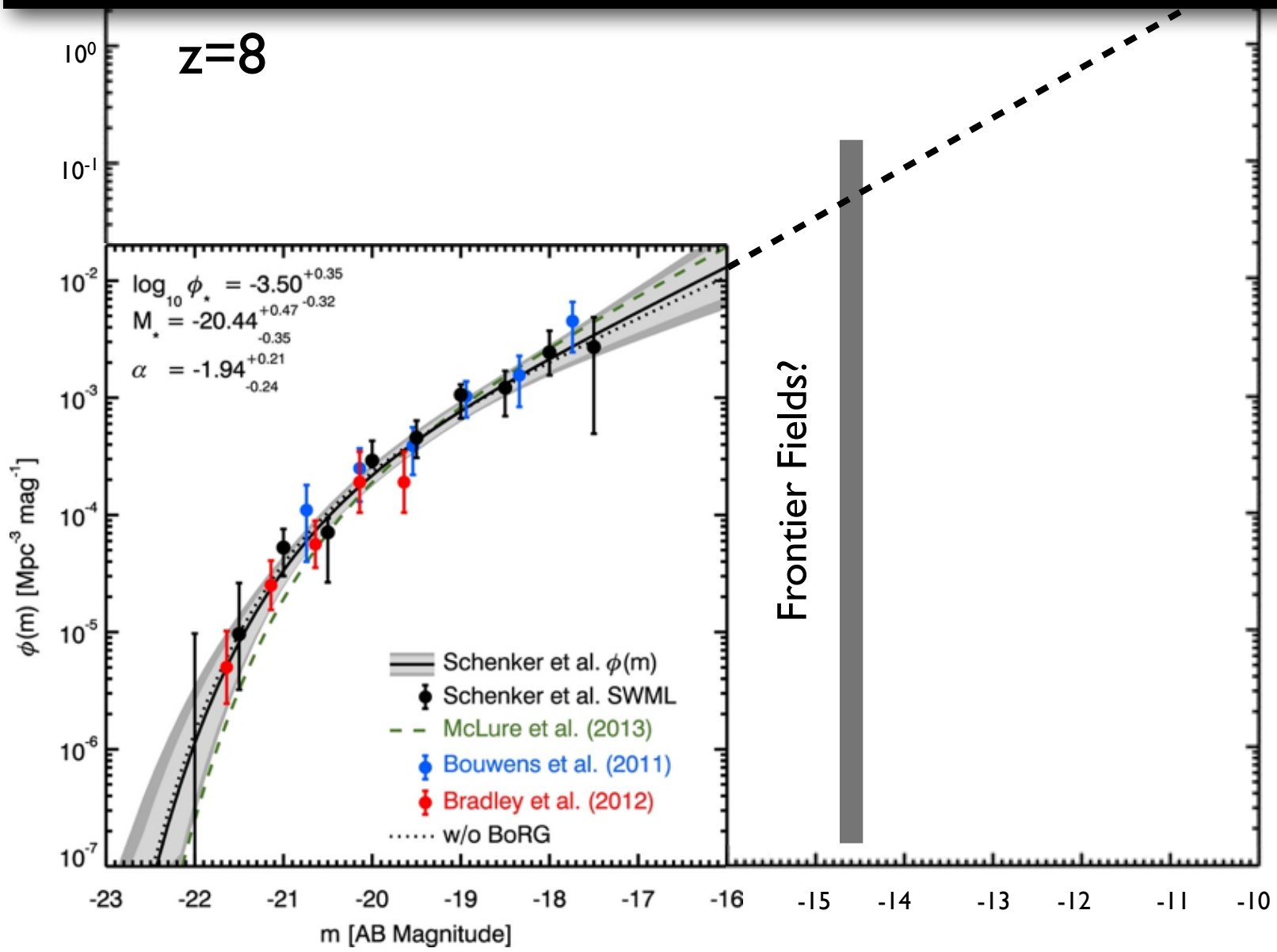


- The Local Group should have ~150 bound descendants of z~8 atomic cooling halos (M_v~10^8 M_{sun} at z~8)

- Local galaxy counts strongly suggest that these small halos (M_v~10^8 M_{sun}) are NOT forming stars significantly at z~8 and do **not** contribute significantly to reionization.

Need to shut off galaxy formation in M_v<~$10^9 M_{sun}$ halos at z~8. HOW?

How could we evade this bound + stars reionize universe?



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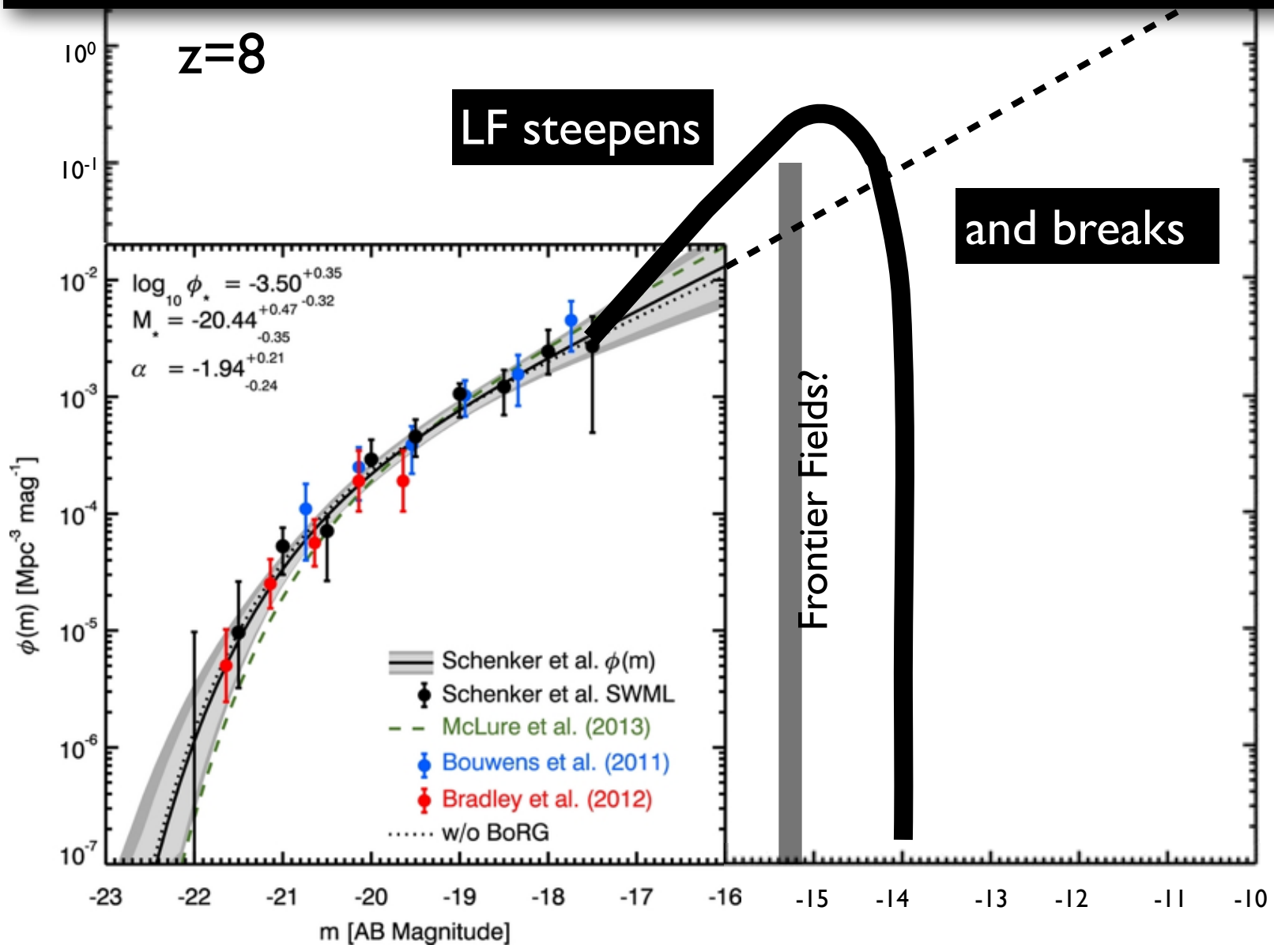

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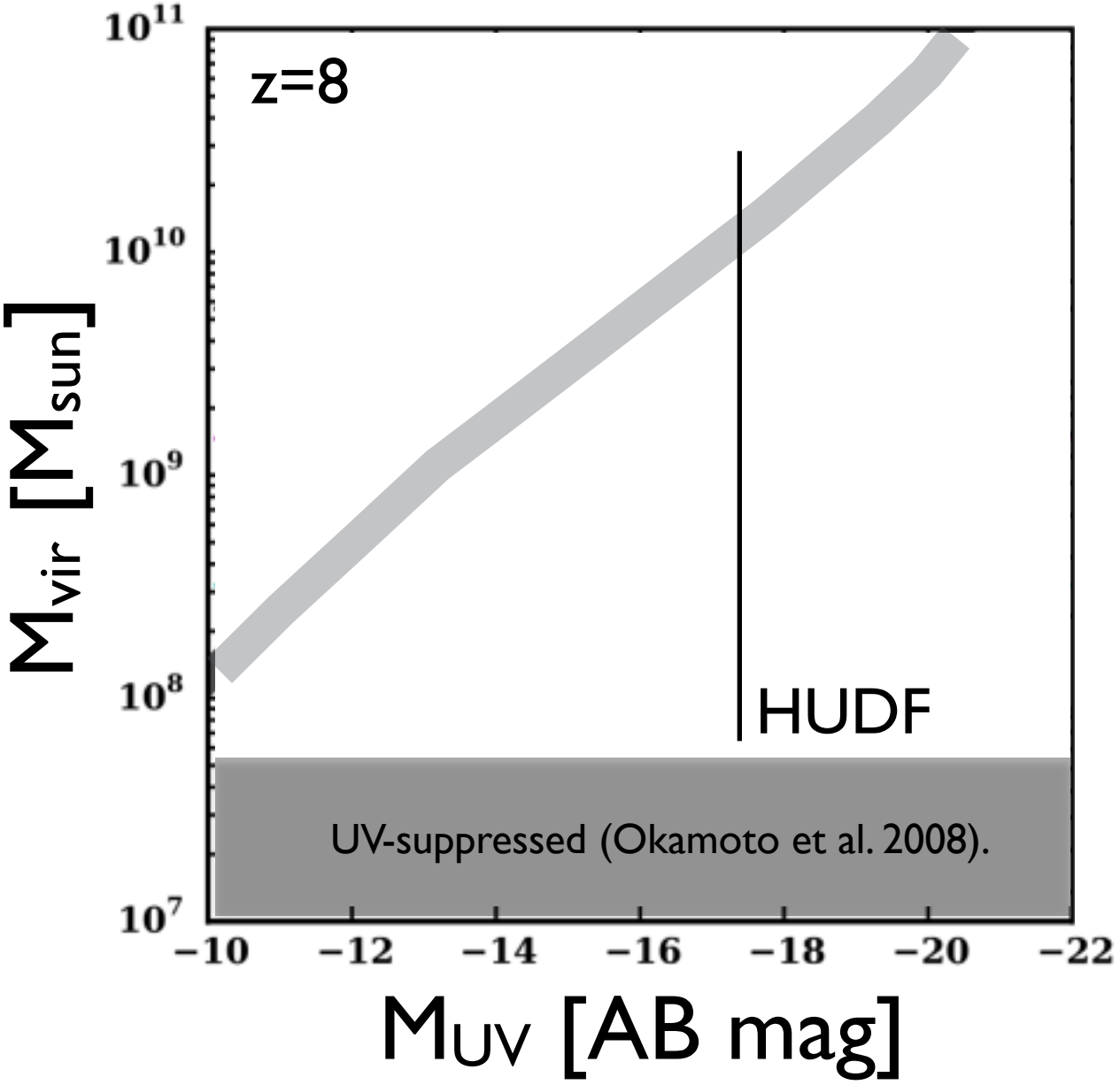

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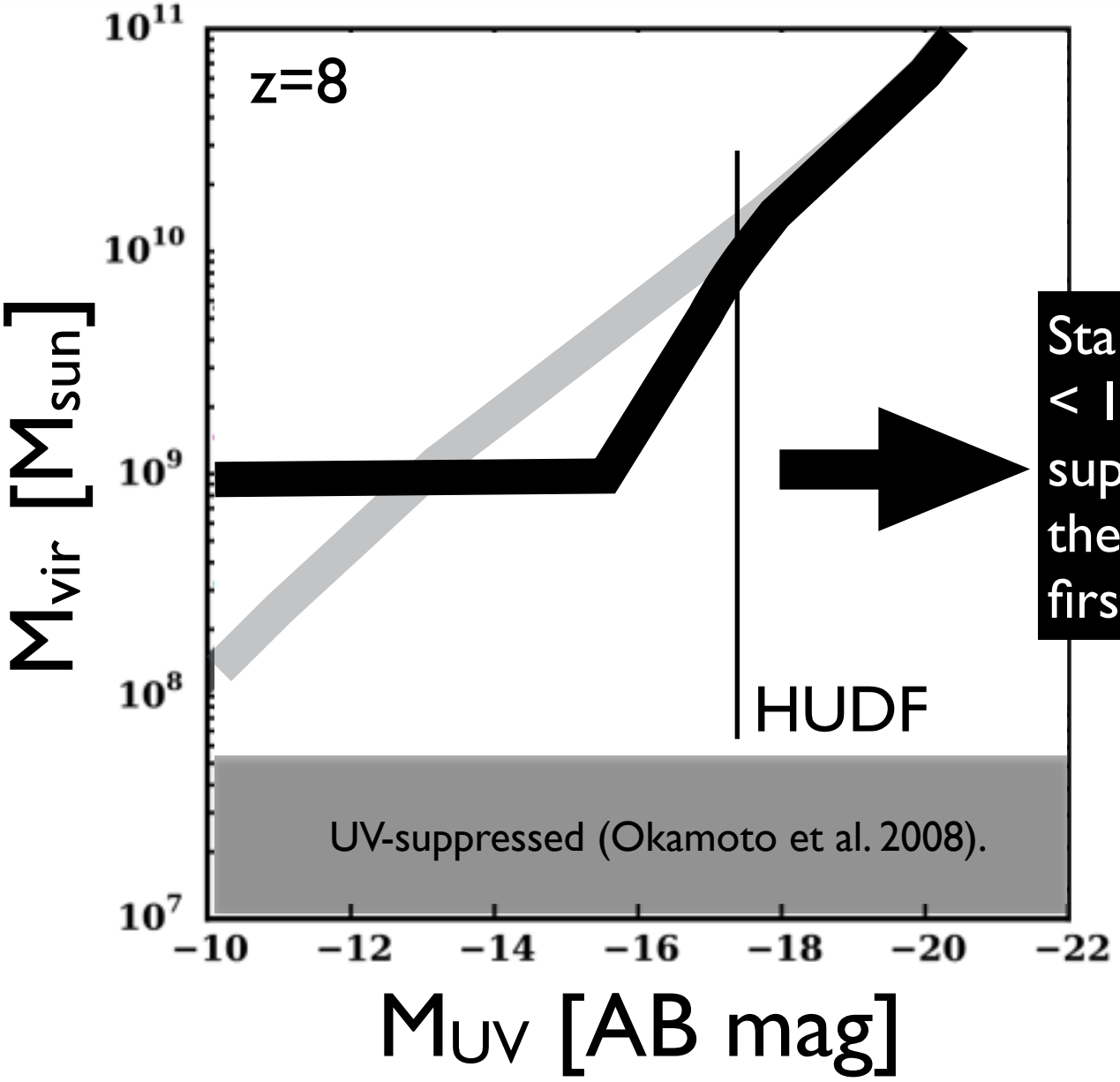
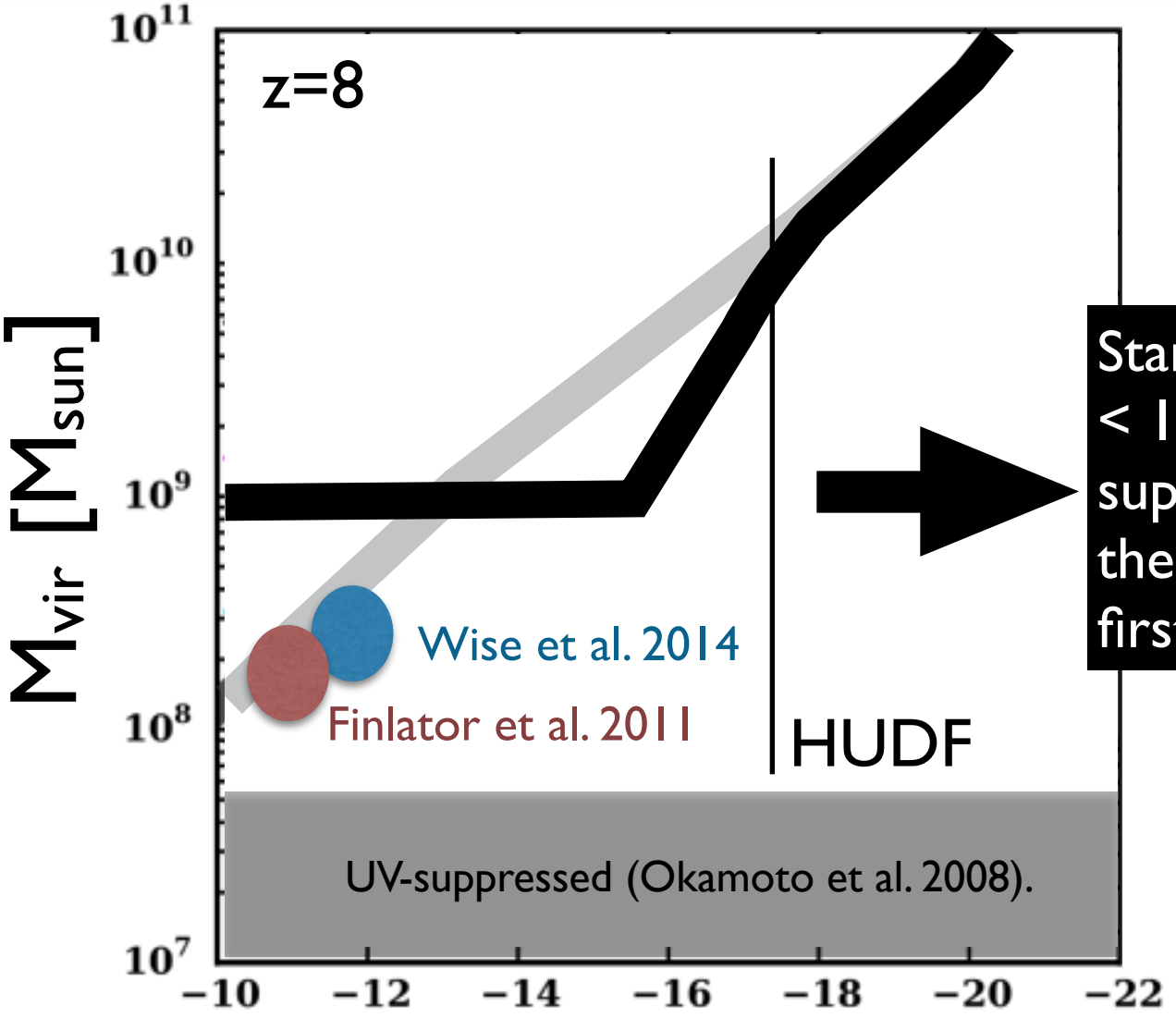


Star formation in $< 10^9$ M_{sun} halos suppressed at the epoch of first light.

How could we evade this bound + stars reionize universe?

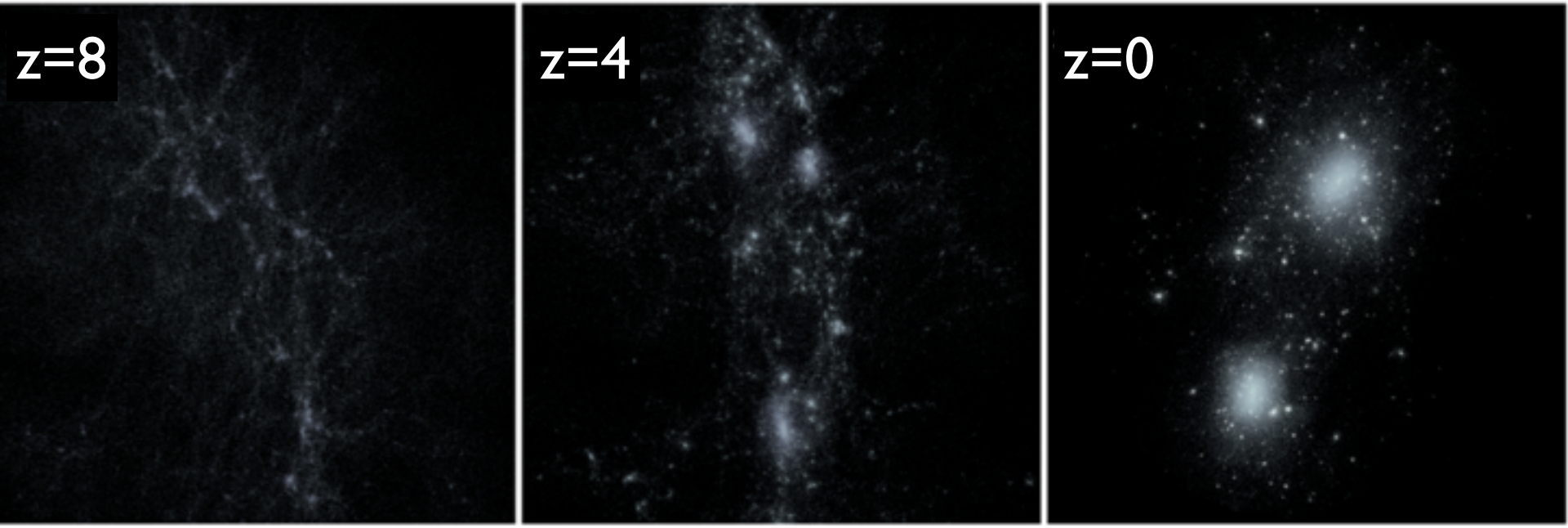


Star formation in $< 10^9$ M_{sun} halos suppressed at the epoch of first light.

WHY?

- The most sophisticated simulations to date don't see this…

Connecting Galaxies Over 13.5 Billion Years

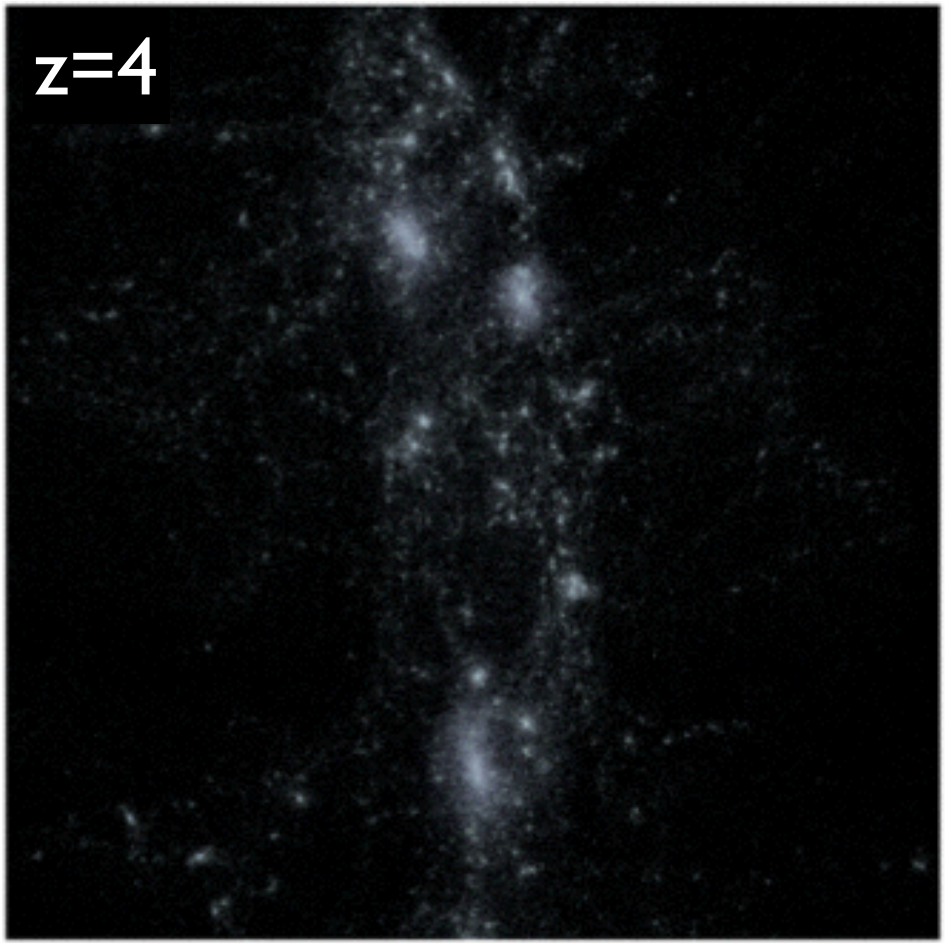


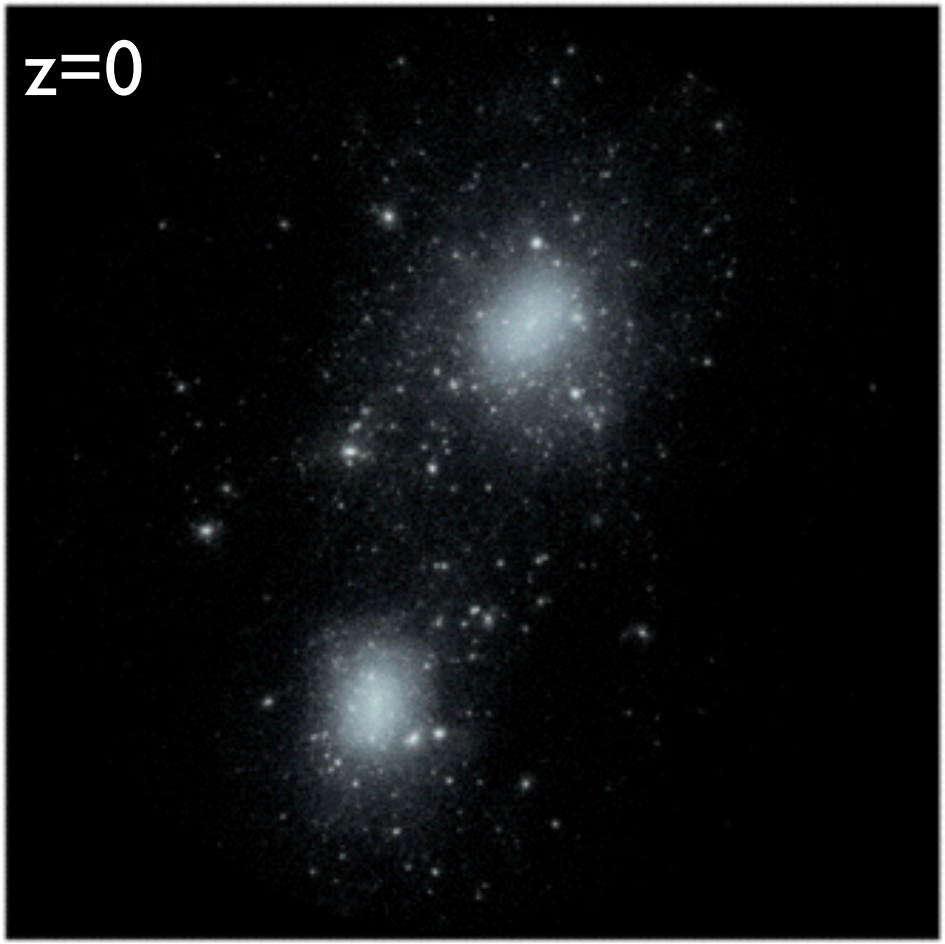
ID systems with $M_v > 10^8 M_{sun}$

Bound progenitors at z=8

Suggests conventional wisdom re reionization is wrong…

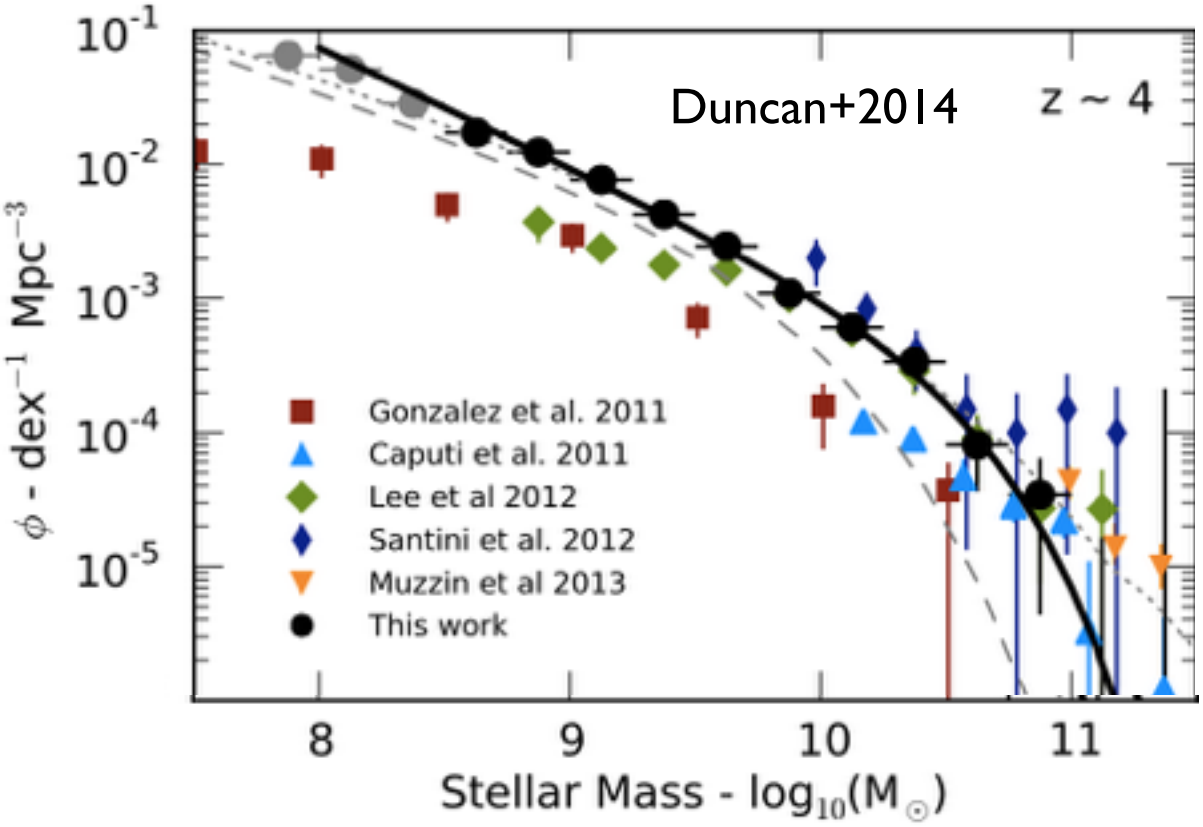
Connecting Galaxies Over 12 Billion Years





Stellar mass function (z=4; CANDELS)

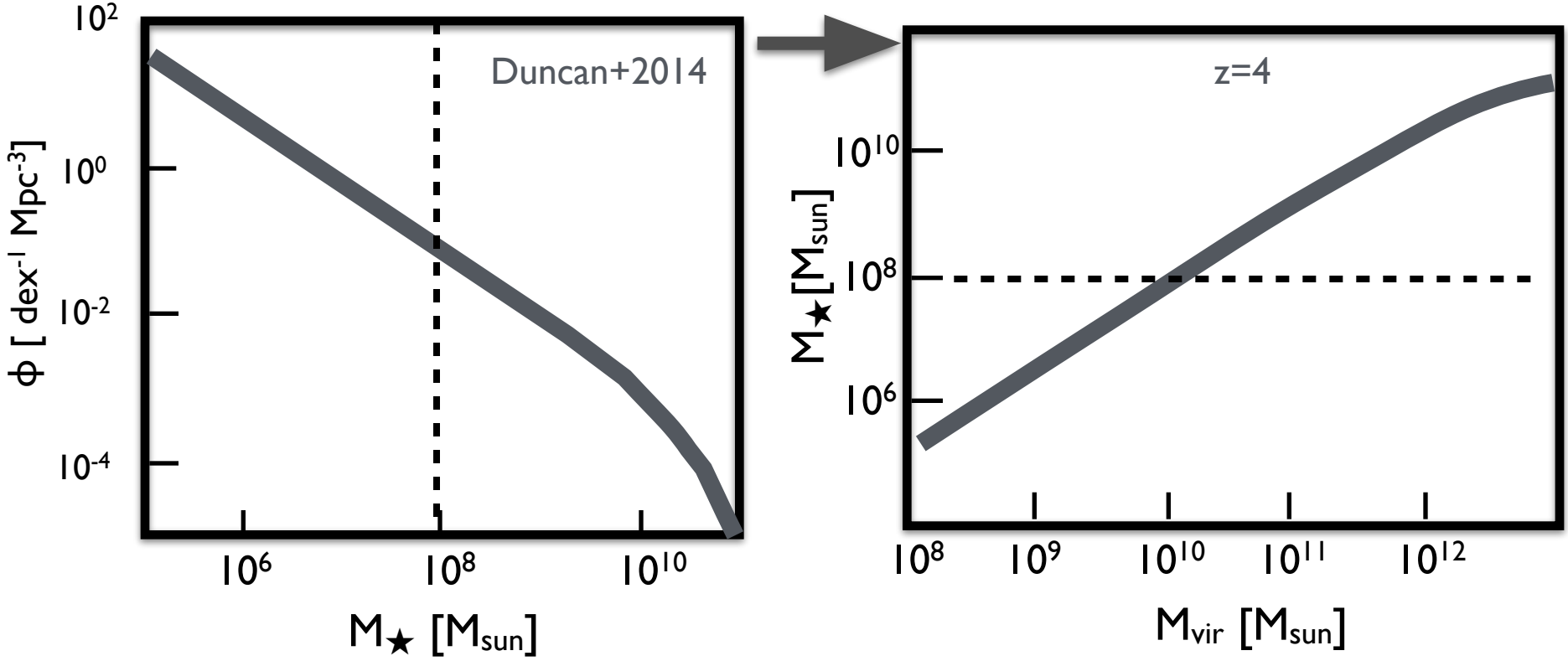
GOODS-South field

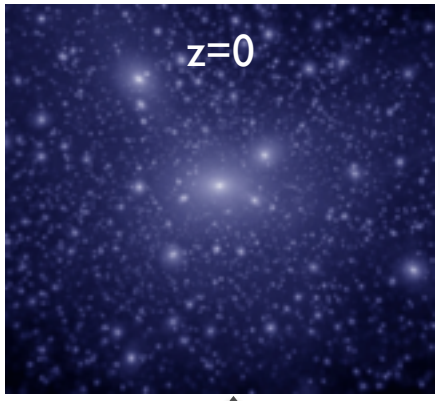


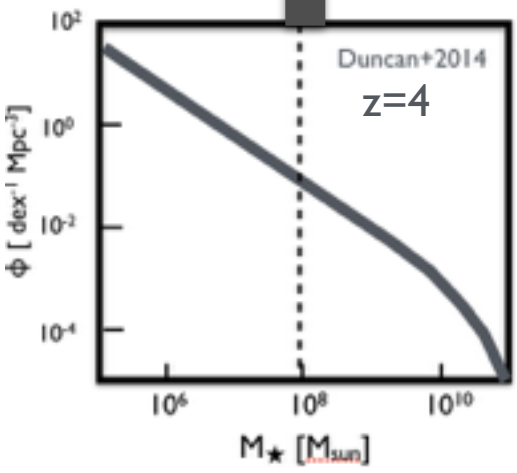
faint slope $\alpha \sim -2$

Steep!

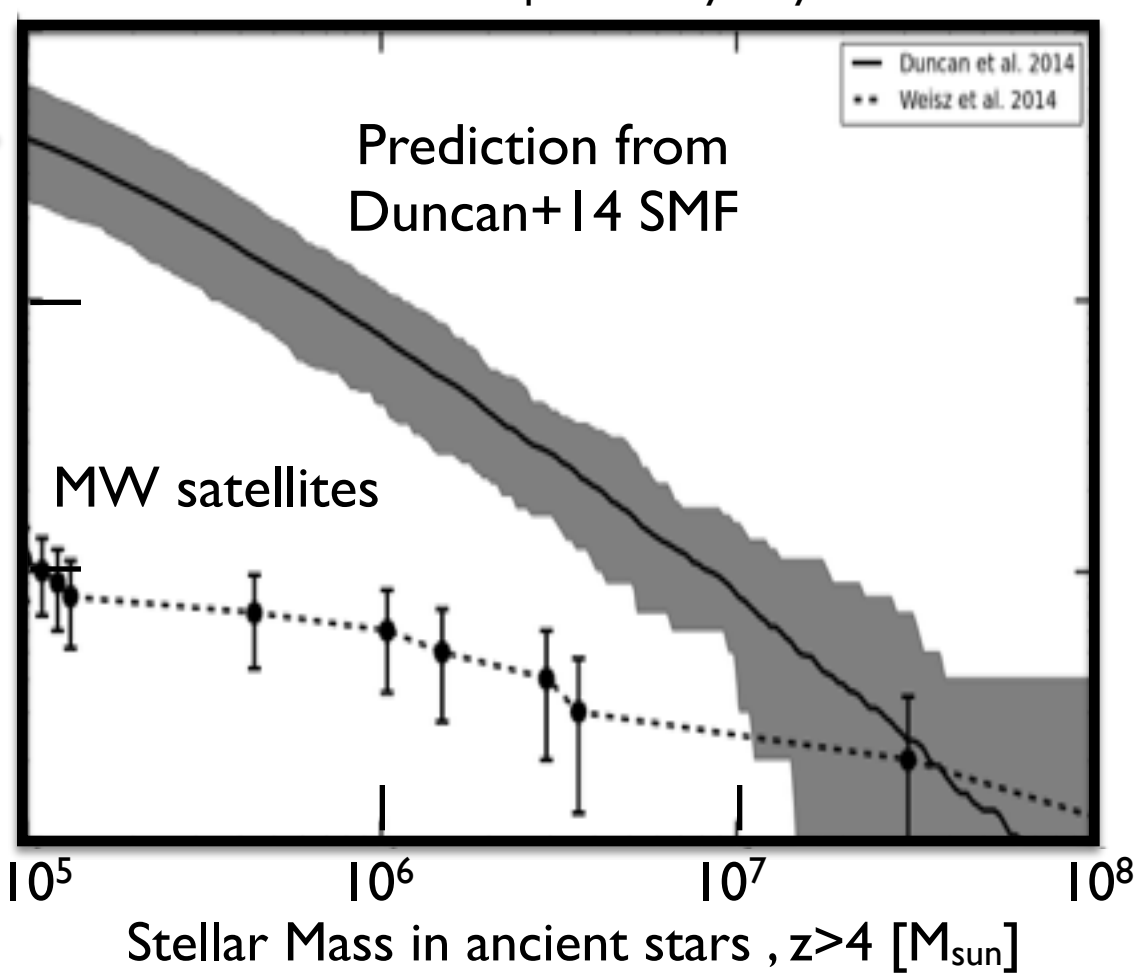
Abundance Matching: z=4





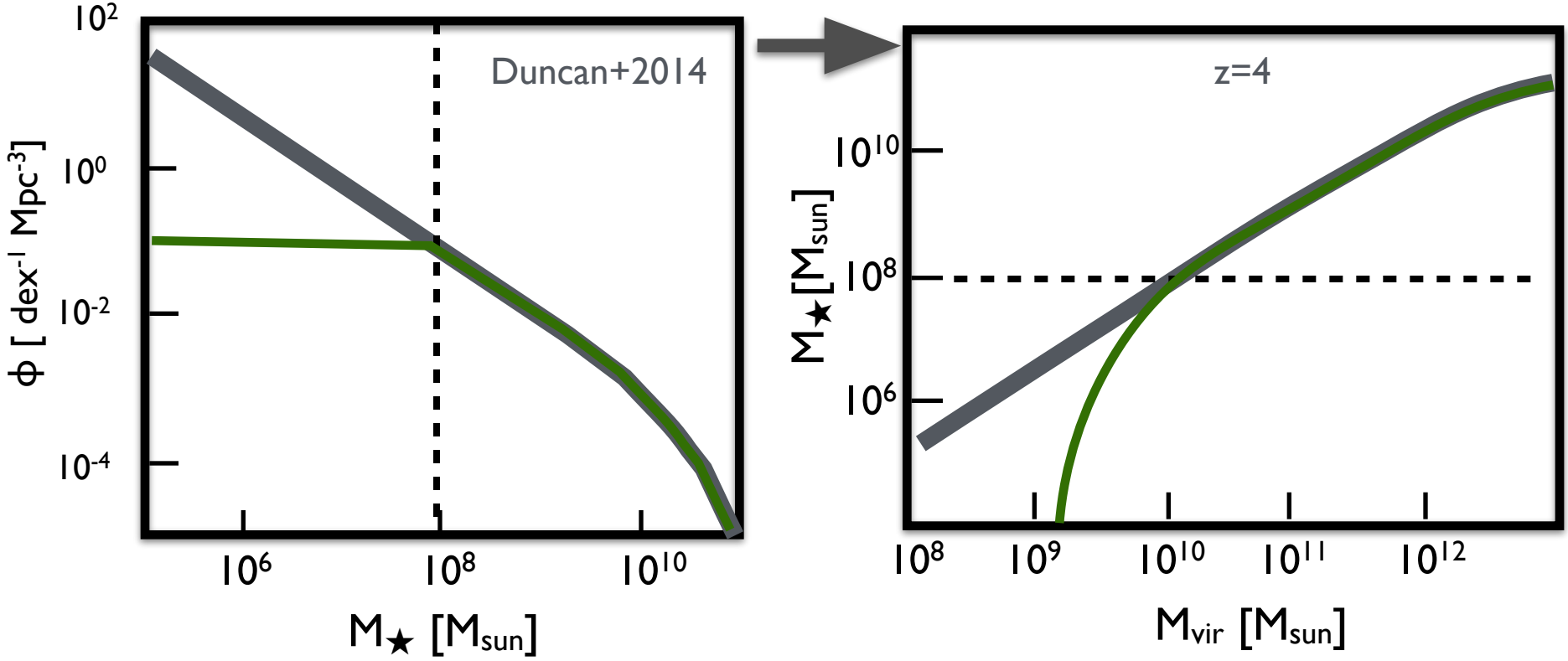


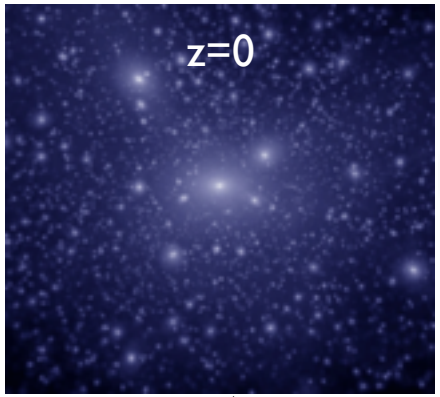
R < 300 kpc of Milky Way

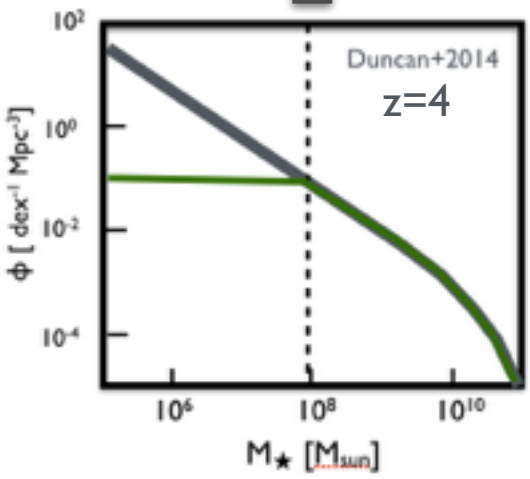


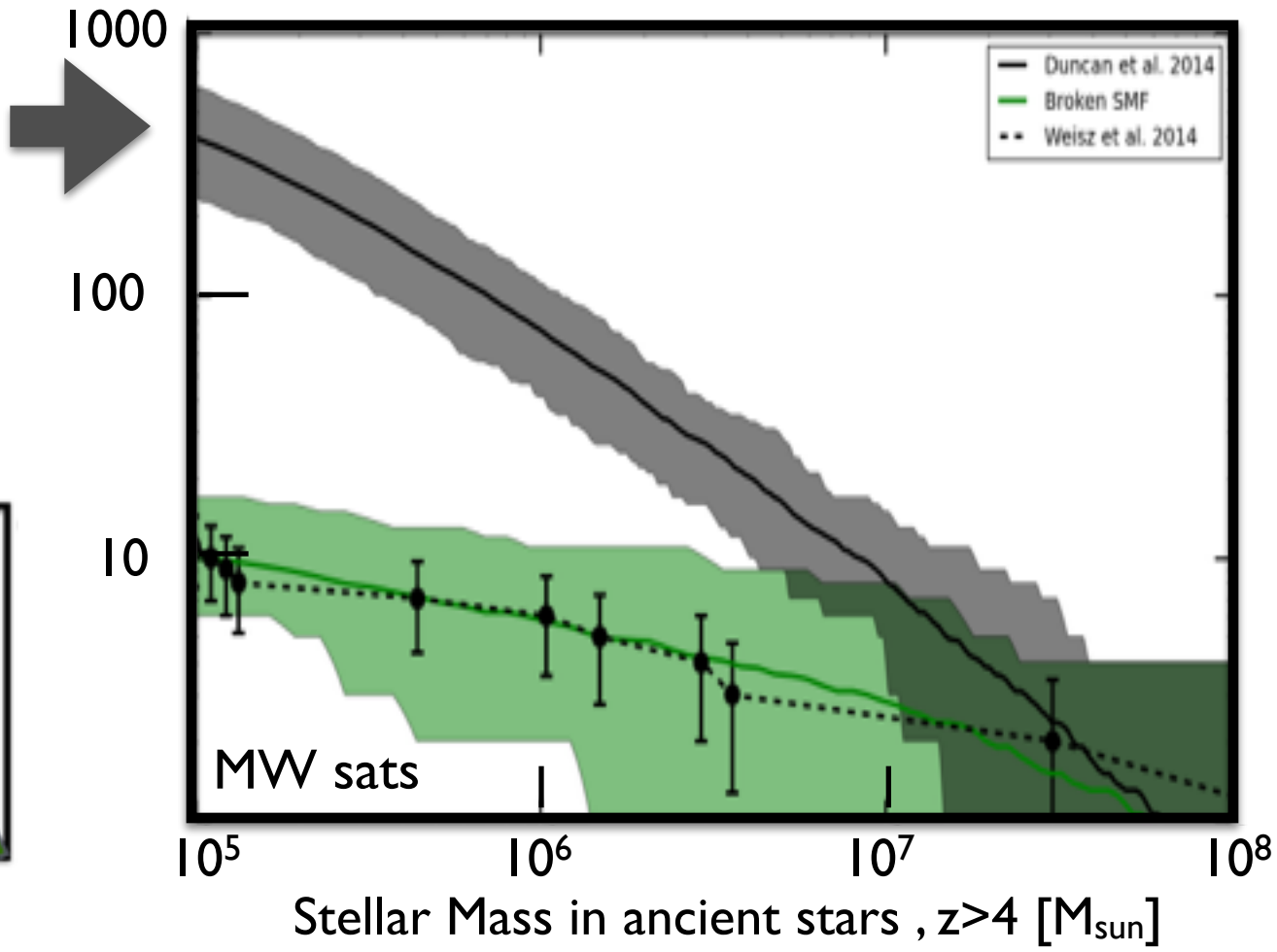
Graus et al. 2014

Abundance Matching: z=4



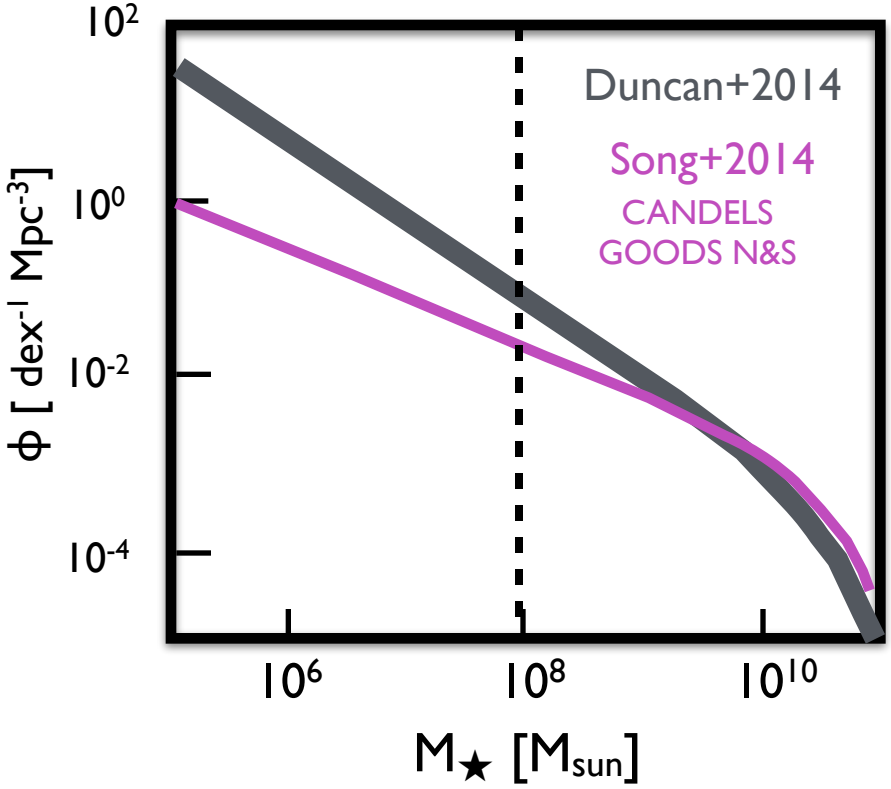


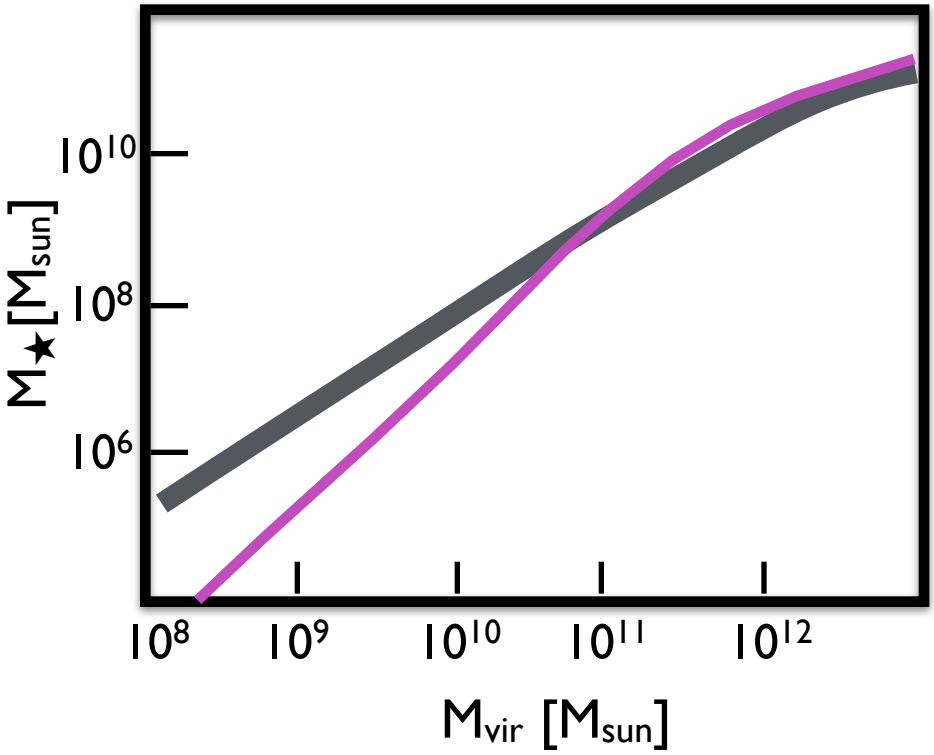


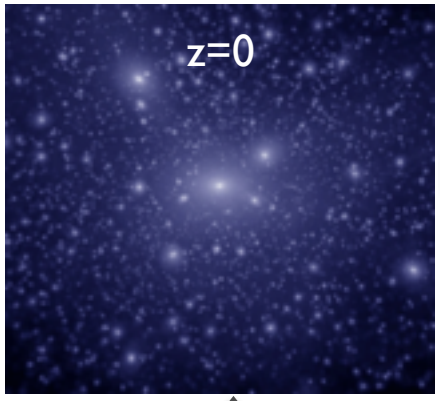


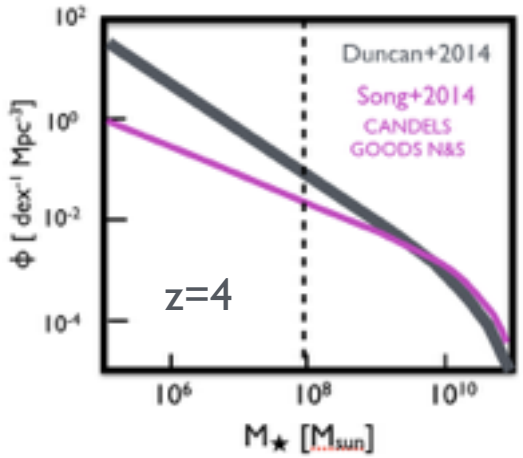
Graus et al. 2014

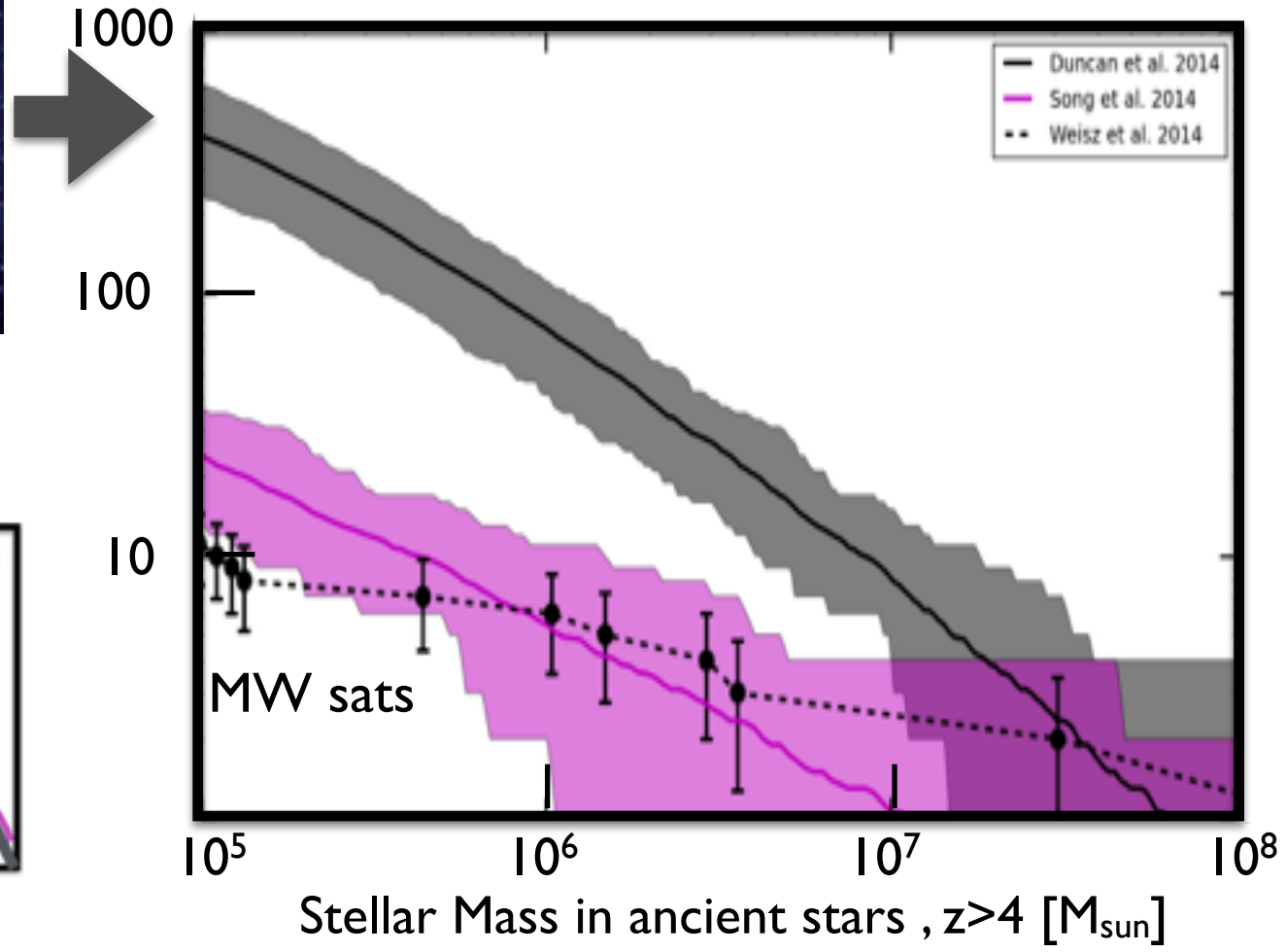
Abundance Matching: z=4



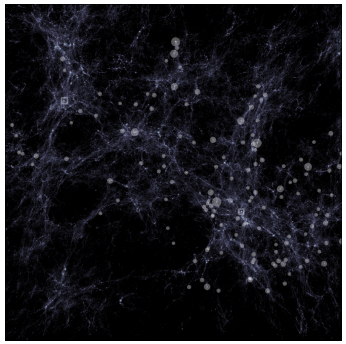




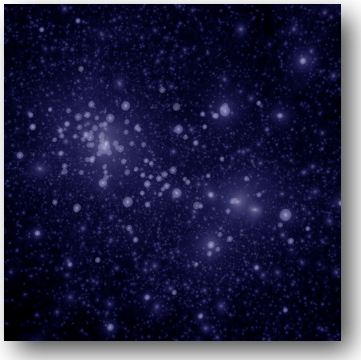




Graus et al. 2014

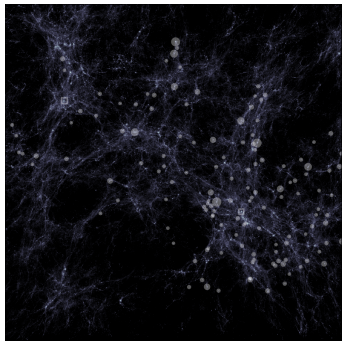


Summary: z~4

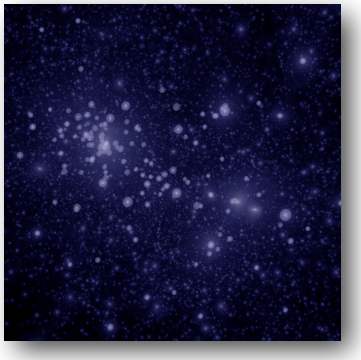


- A steeply rising mass function ($\alpha \sim -2$) cannot continue without break much beyond current limits without over-populating Local Group.

- A faint slope $\alpha \sim -1.6$ much more consistent.



Summary: z~8

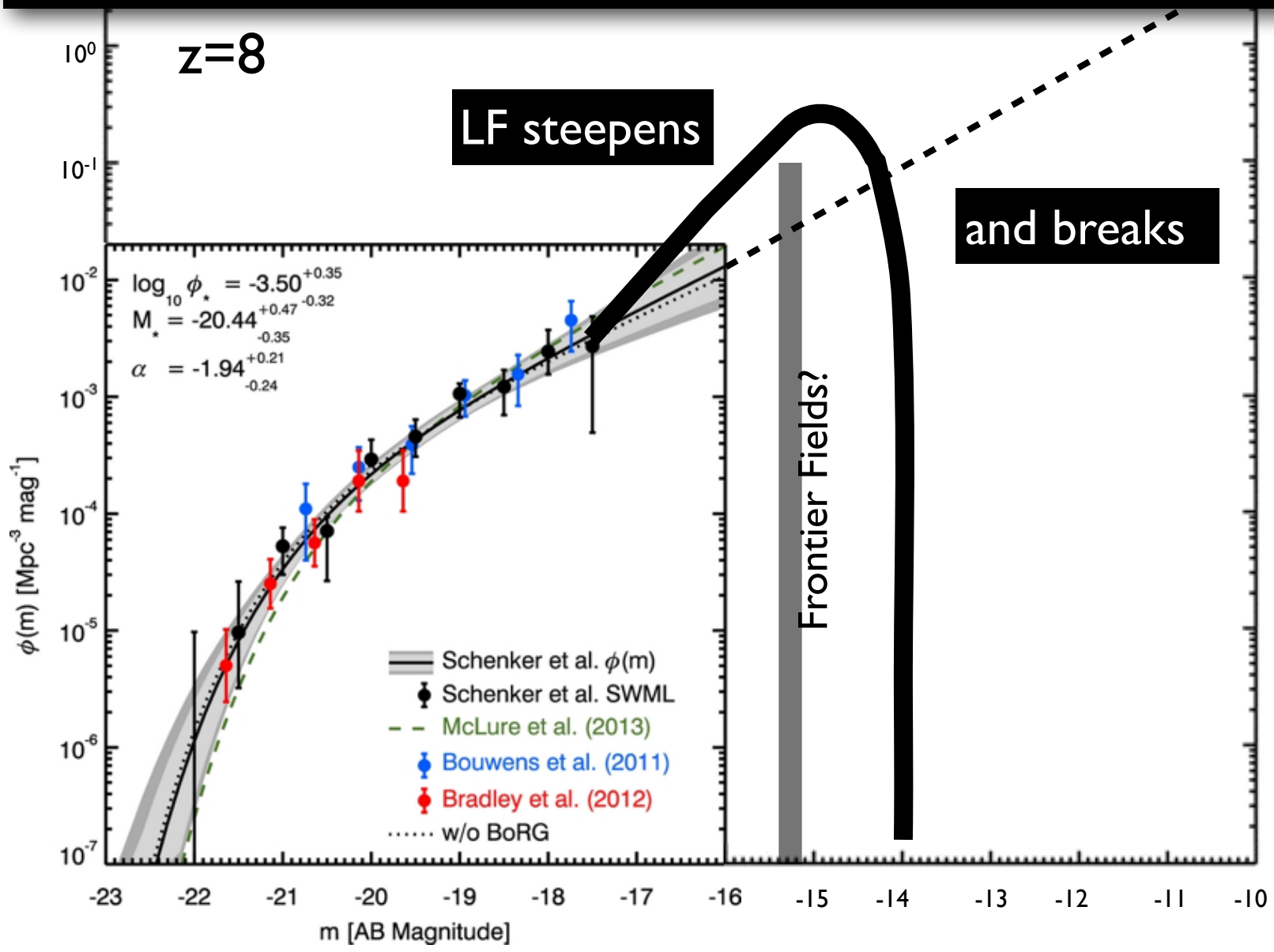


- The Local Group should have ~150 bound descendants of z~8 atomic cooling halos (M_v~10^8 M_{sun} at z~8)

- Local galaxy counts strongly suggest that these small halos (M_v~10^8 M_{sun}) are NOT forming stars significantly at z~8 and do **not** contribute significantly to reionization.

Need to shut off galaxy formation in M_v<~$10^9 M_{sun}$ halos at z~8. HOW?

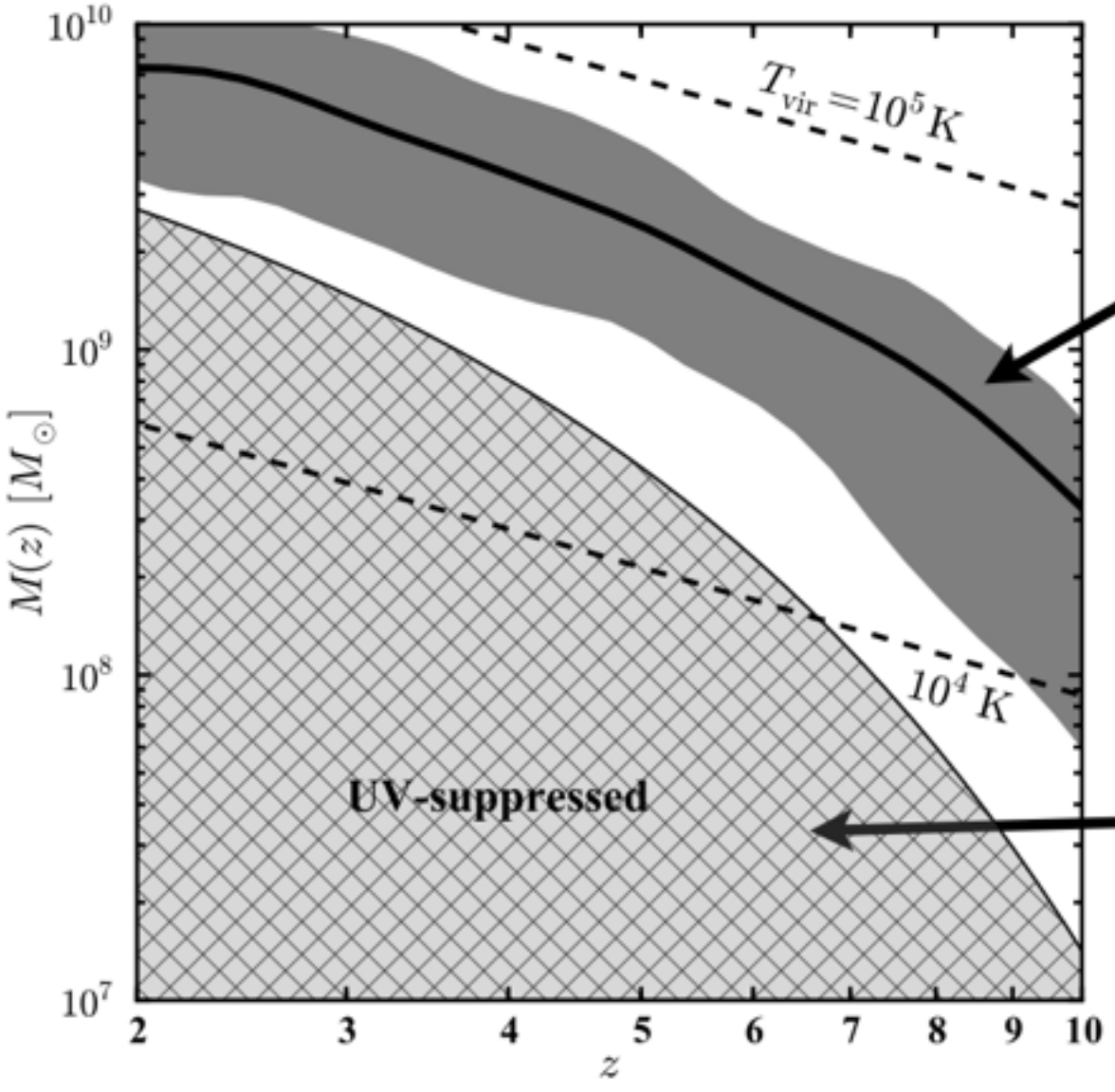
How could we evade this bound + stars reionize universe?



Questions

- Do galaxies really maintain reionization by themselves?
- How do we shut down star formation in ~10^9 M_{sun} halos at early times? (Most simulations do not!)

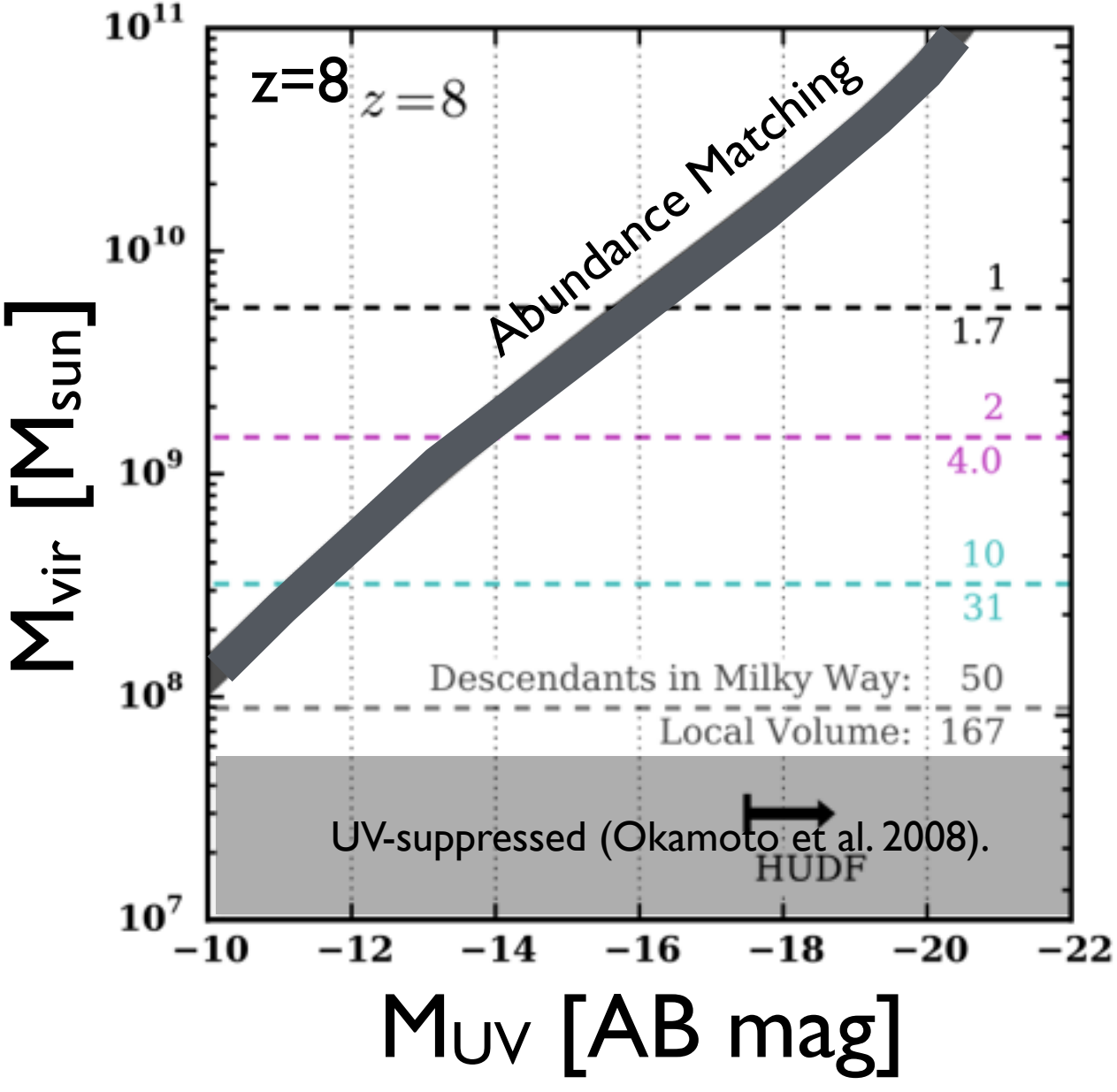
http://localgroup.ps.uci.edu/elvis/



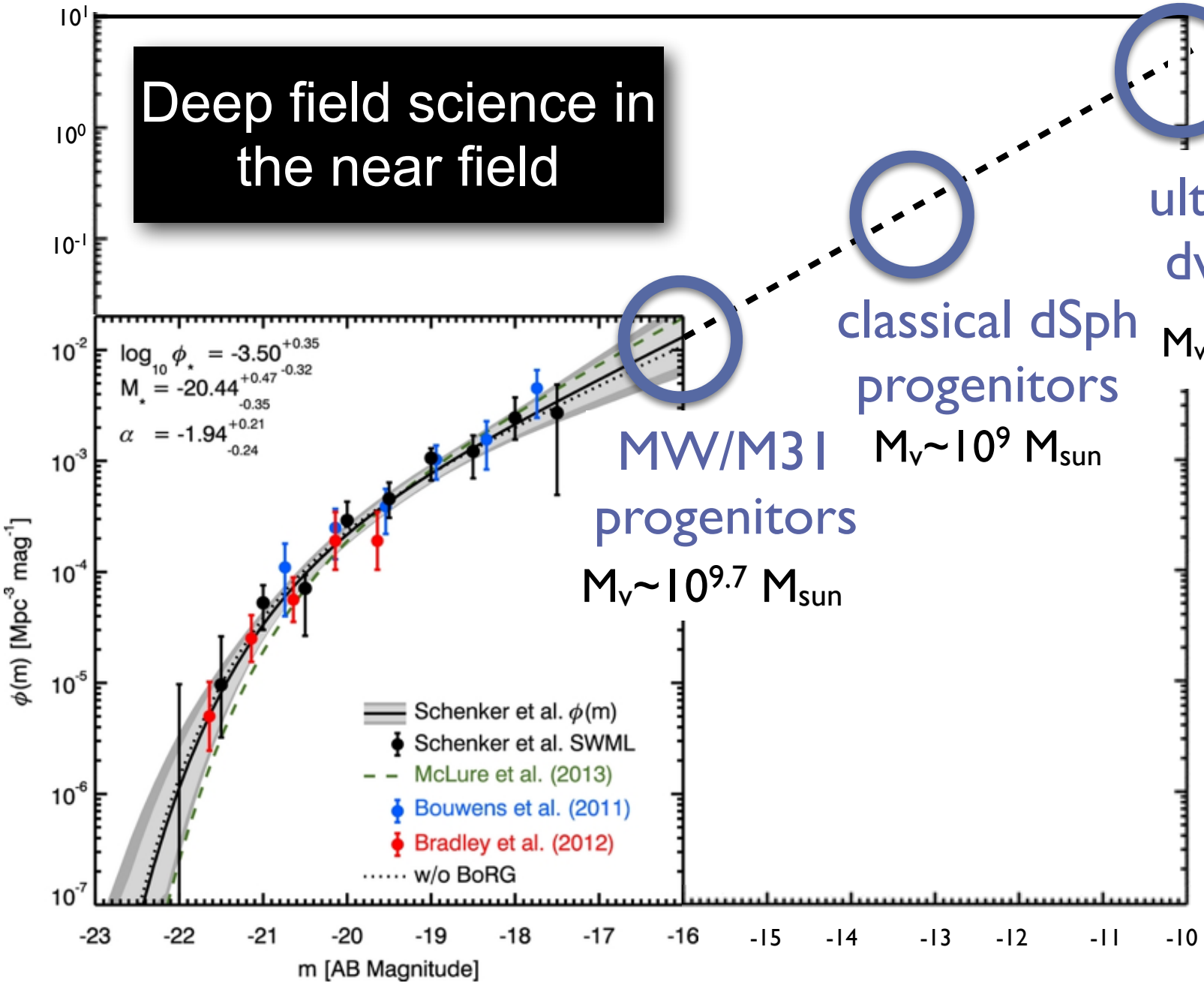
Median mass for subhalos with V_{peak} > 30 km/s

Suppressed by UV background (Okamoto et al. 2008)

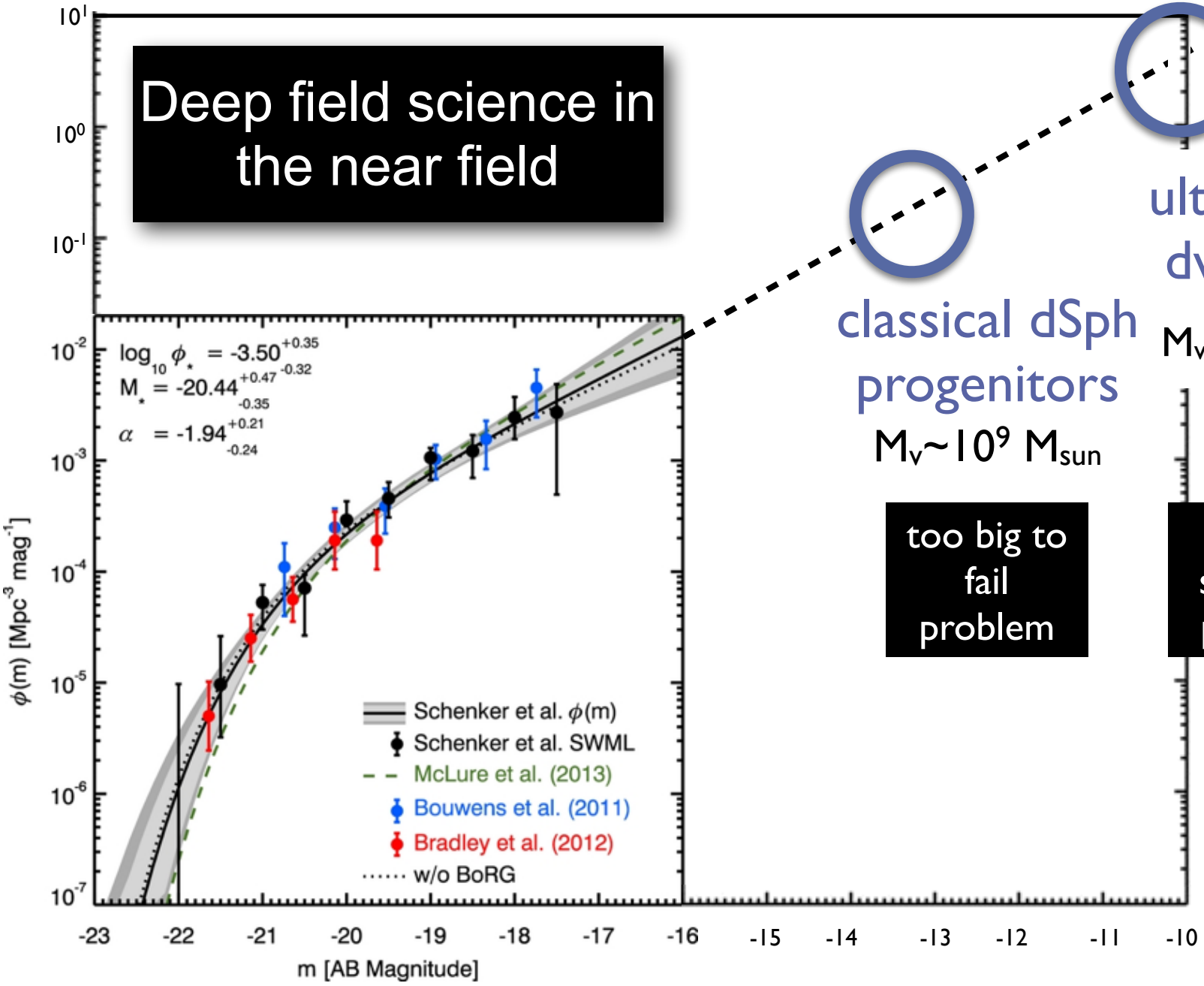
Boylan-Kolchin, JSB, Kaplinghat 2012


z=8
$z=8$
Abundance Matching
1
1.7
2
4.0
10
31
Descendants in Milky Way: 50
Local Volume: 167
UV-suppressed (Okamoto et al. 2008).
HUDF
10^{11}
10^{10}
10^{9}
10^{8}
10^{7}
−10
−12
−14
−16
−18
−20
−22
M_{vir} [M_{sun}]
M_{UV} [AB mag]

Deep field science in the near field



Deep field science in the near field



z=8

ultrafaint dwarfs?

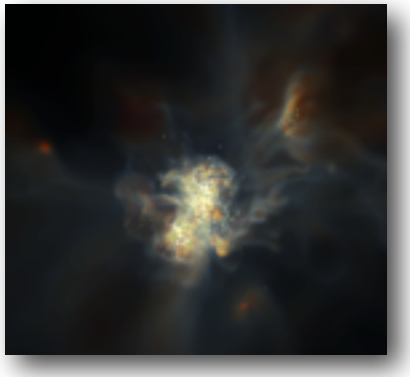
$M_v \sim 10^8 M_{sun}$

classical dSph progenitors

$M_v \sim 10^9 M_{sun}$

too big to fail problem

missing satellites problem



Wise et al. 2014

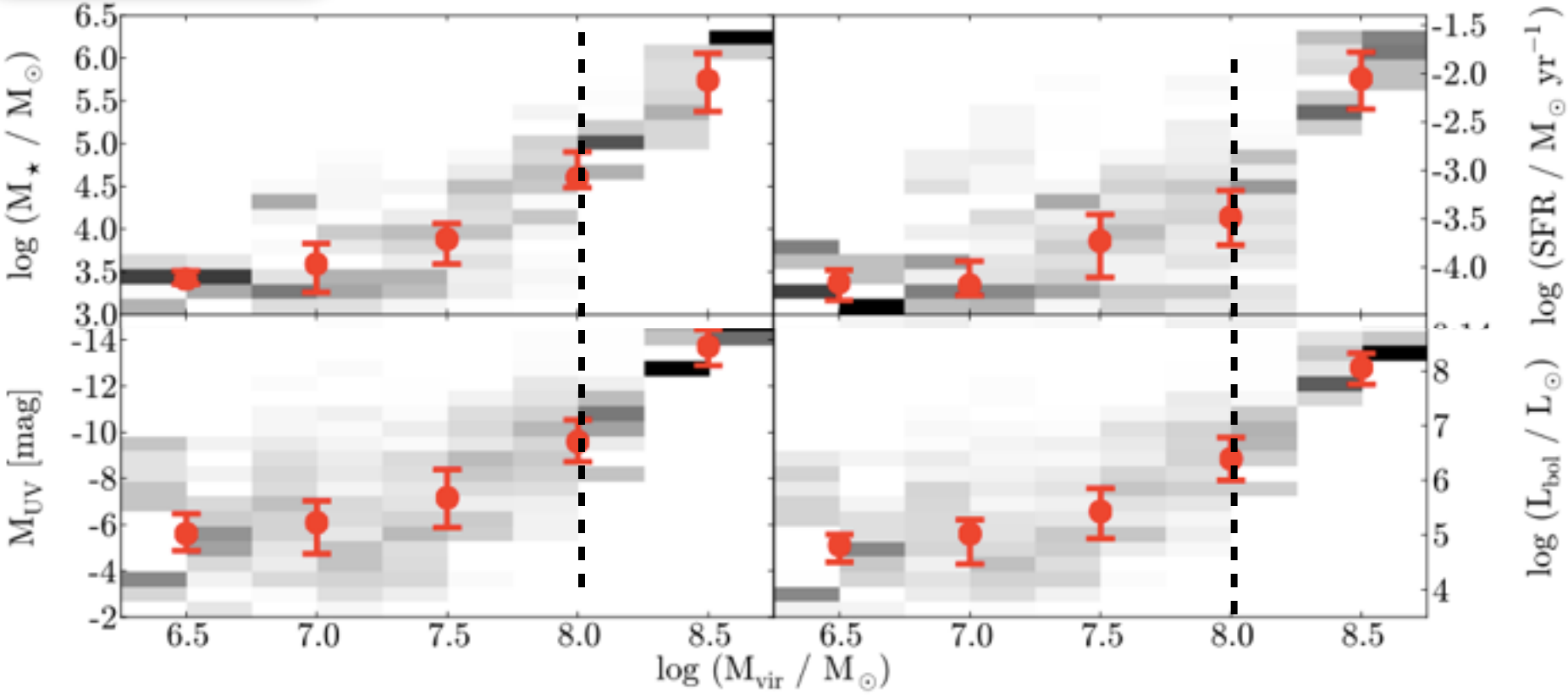
ENZO AMR

M_{vir} ~ 10^8 M_{sun} halos at z=8

M_{UV} ~ -10

SFR ~ 10^{-3} Msun/yr

M_* ~ 10^5 M_{sun}



Also: Finlator et al. 2011, Simpson et al. 2013