Dark Cosmology Centre

Understanding Galaxies and Reionization Together

http://arxiv.org/abs/1305.4768

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Observational Constraints on Hydrogen Reionization

Emissivity

$\tau_{Ly\alpha}$; UV luminosity function; absorber abundance; GRB rate; IR background fluctuations; X-ray background

Opacity

LAEs (clustering, line profile, luminosity function); QSO damping wing; 21cm fluctuations

History

τ_{CMB}; IGM temperature; Kinetic S-Z effect

Observational Constraints on Hydrogen Reionization ...that are invoked in models

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Observational Constraints on Hydrogen Reionization ...that are invoked in models

Emissivity

$\tau_{Ly\alpha}$; UV luminosity function; absorber abundance; GRB

In order to interpret more observations,
a model must include more physics.

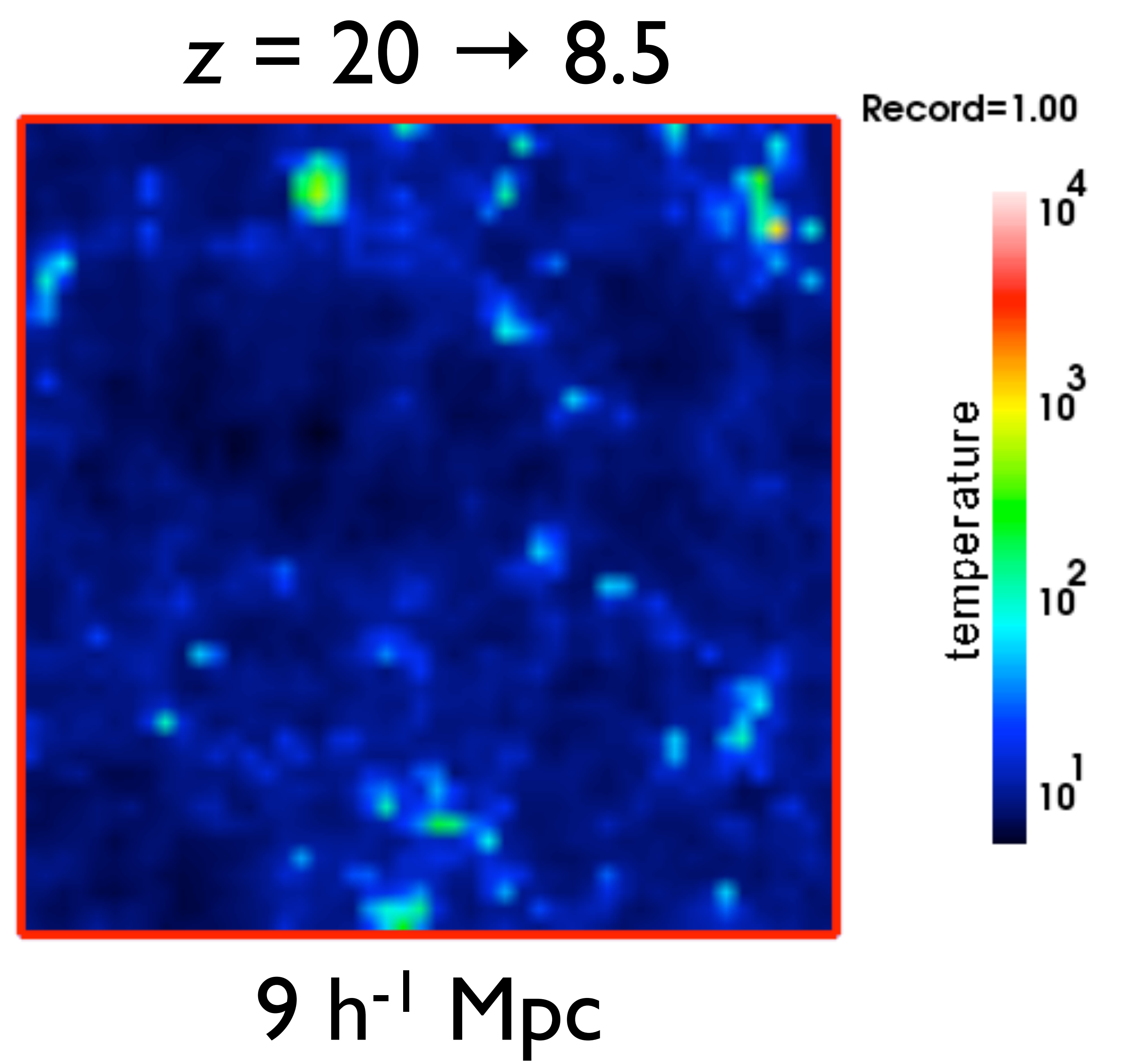
(see also talks by A. Pawlik, H. Kim; poster by K. Hasegawa)

damping wing; 21cm fluctuations

History

τ_{CMB}; IGM temperature; Kinetic S-Z effect

Cosmological Radiation Hydrodynamic Simulations



Observational tests

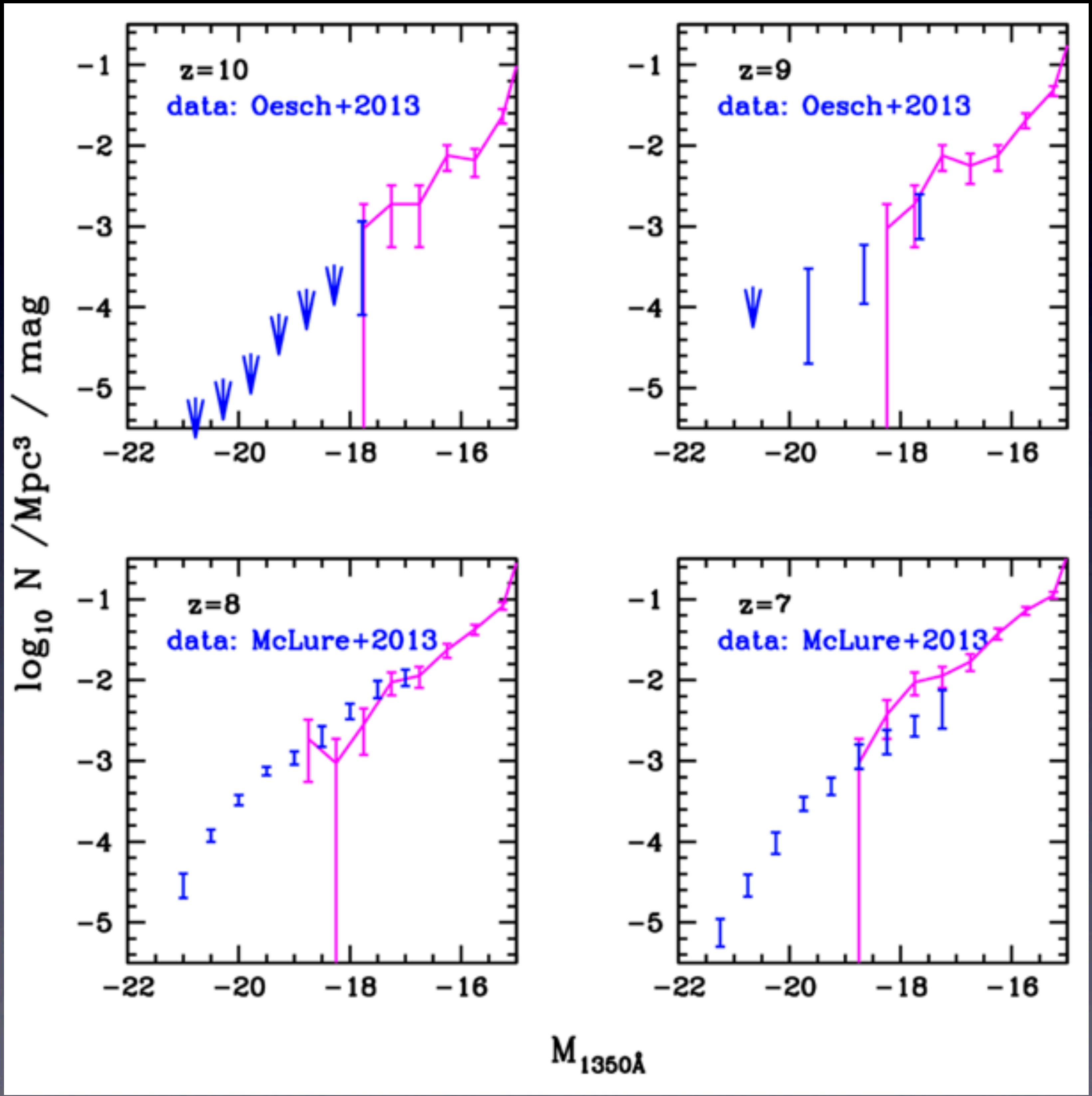
- UV LF
- τ_{CMB}
- $\tau_{Ly\alpha}$
- T_{IGM}
- abundance of absorbers

Ingredients

- GADGET-2 + on-the-fly ionizing radiation transport (KF+2011b)
- nonequilibrium ionization (processes/rates from Katz, Weinberg, & Hernquist 1996)
- outflow, star formation models have been tested extensively against UV LF, IGM metal absorbers, galaxy metallicities (Davé+; Oppenheimer+; KF+; Ford+)

Modeling the UV LF

Predicted LF Evolution is Reasonable



See also:

Schenker+2013; Ellis+2013; Bouwens+

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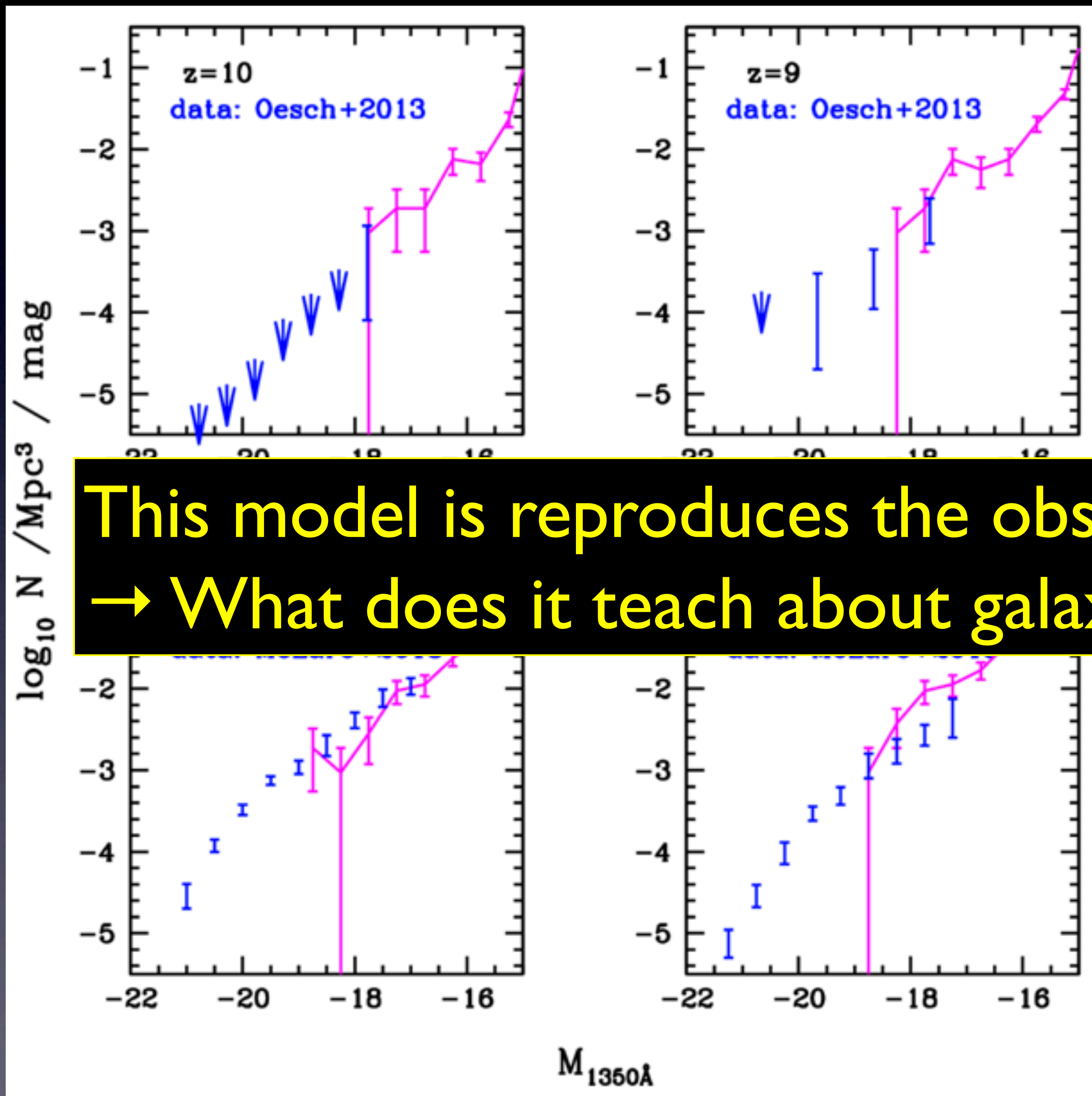

See also:
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This model is reproduces the observed UV LF.
→ What does it teach about galaxy evolution?

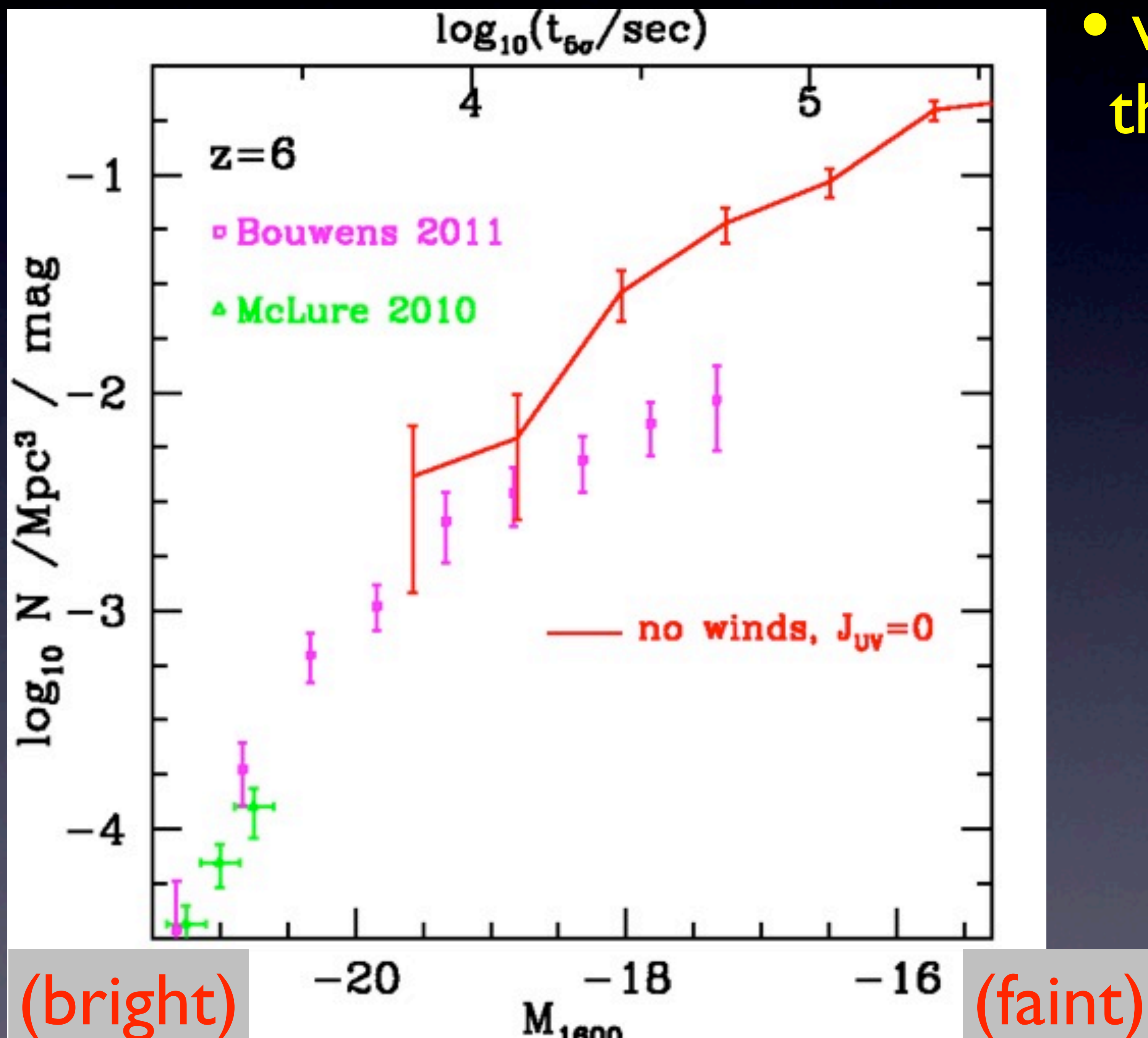
Outflows versus Photoionization Heating

Outflows vs Photoevaporation

credit: Mark Westmoquette (University College London), Jay Gallagher (University of Wisconsin-Madison), Linda Smith (University College London), WIYN//NSF, NASA/ESA

credit: NASA/NSSDC

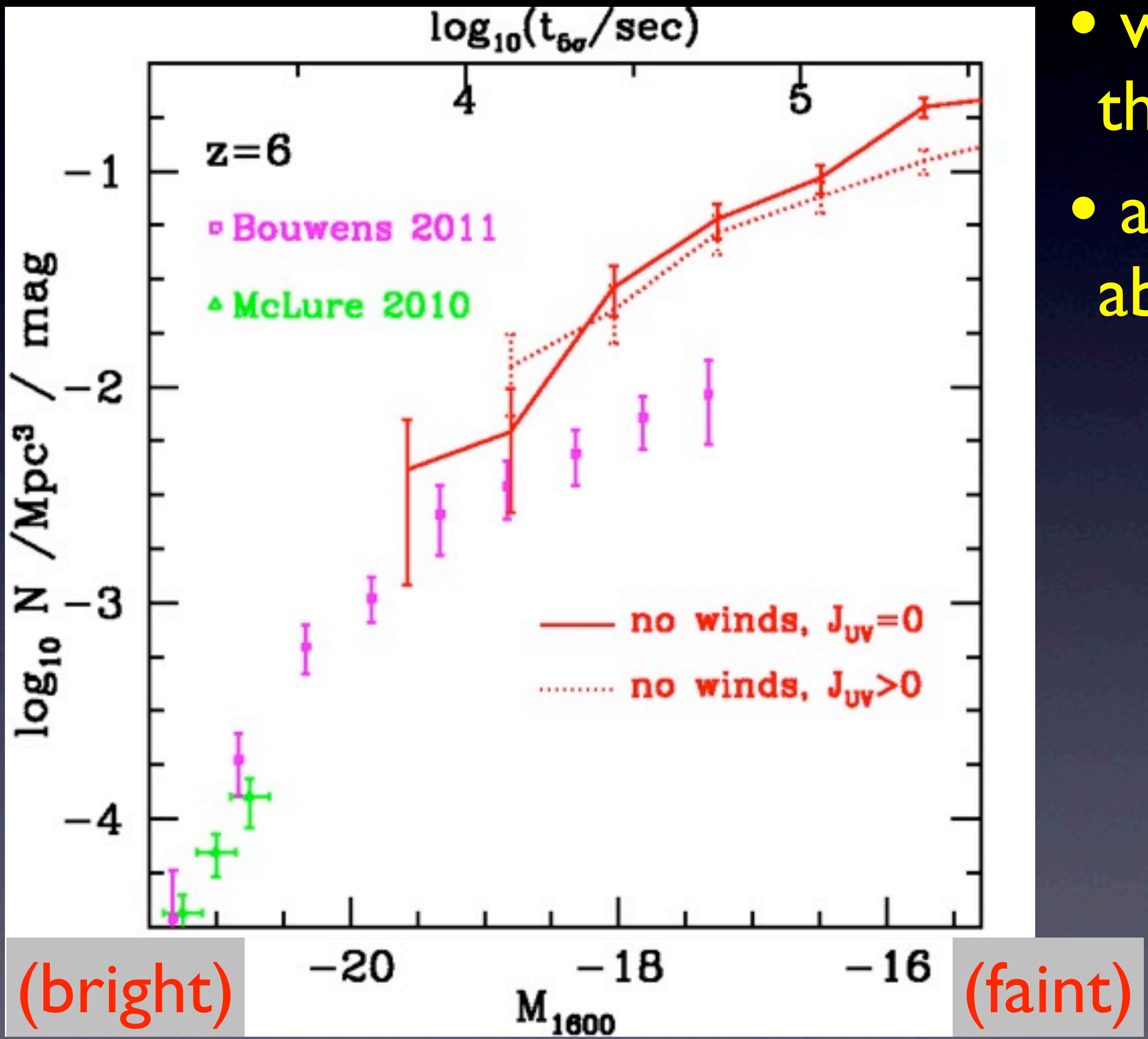
Photoheating vs. Outflows



KF, Davé, & Özel 2011

- without any feedback, the LF is overproduced

Photoheating vs. Outflows



KF, Davé, & Özel 2011

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- an EUVB reduces galaxy abundance by < 50%

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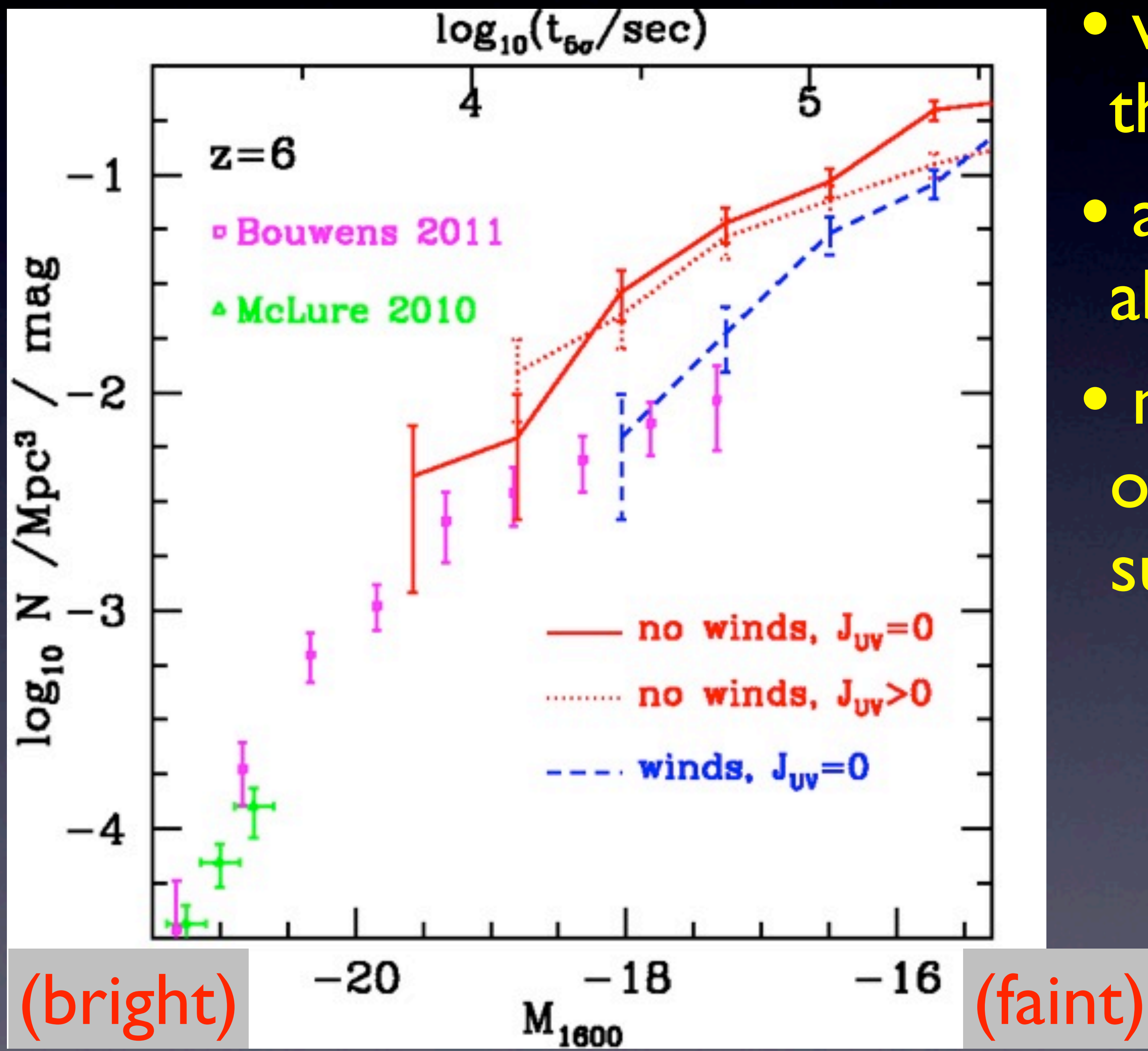

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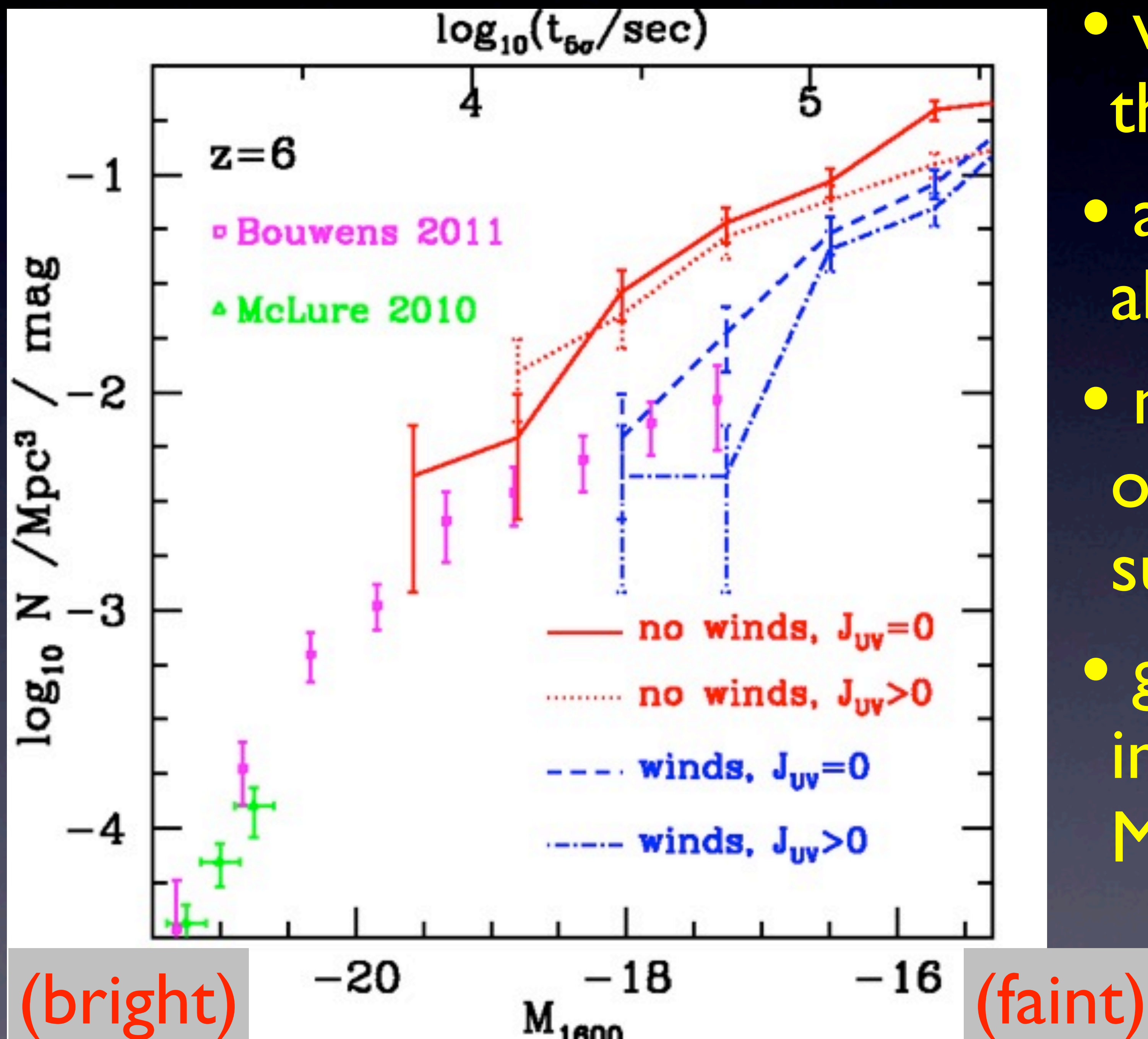

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see also: Davé, KF, & Oppenheimer 2006; KF+2006;

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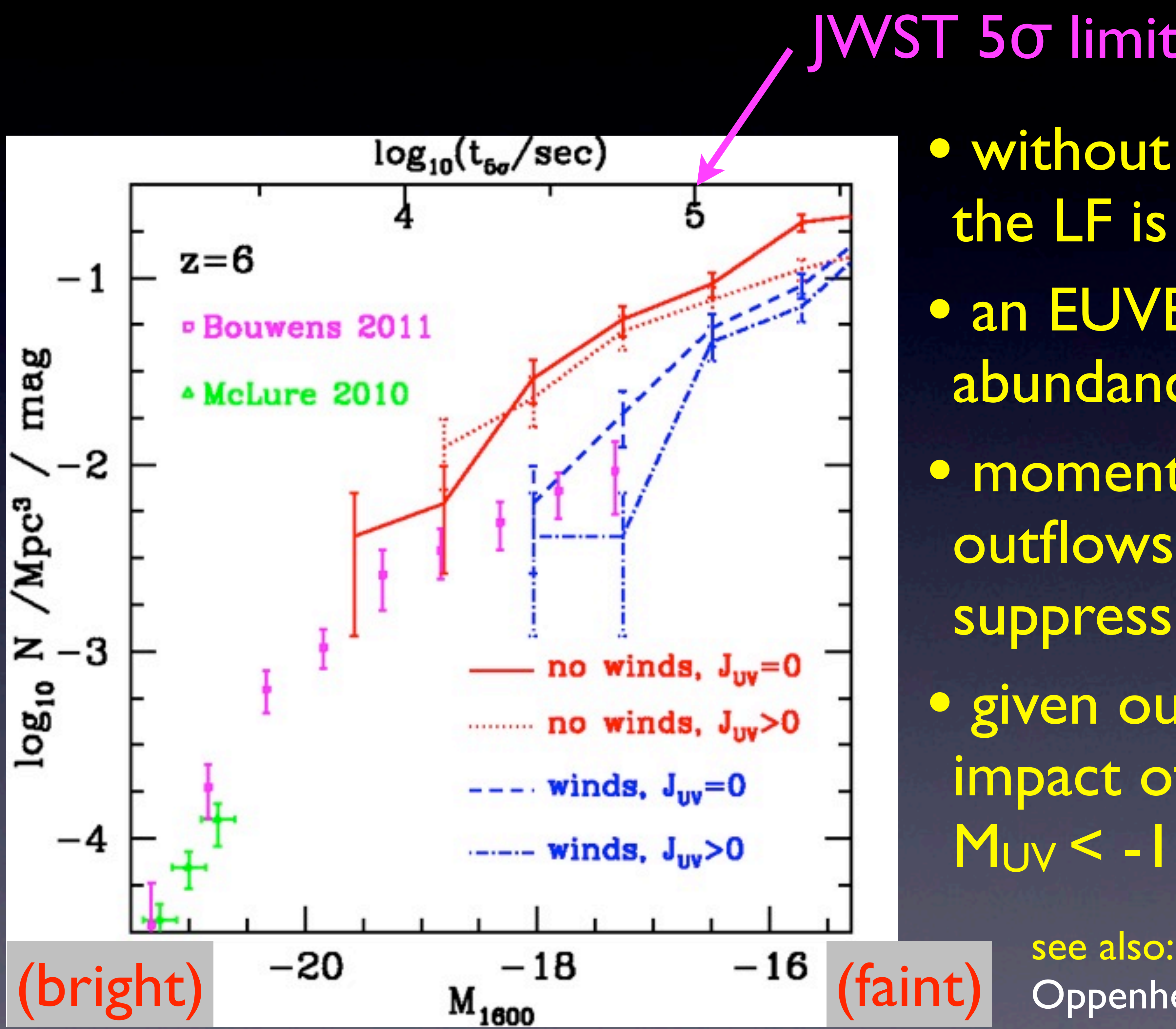

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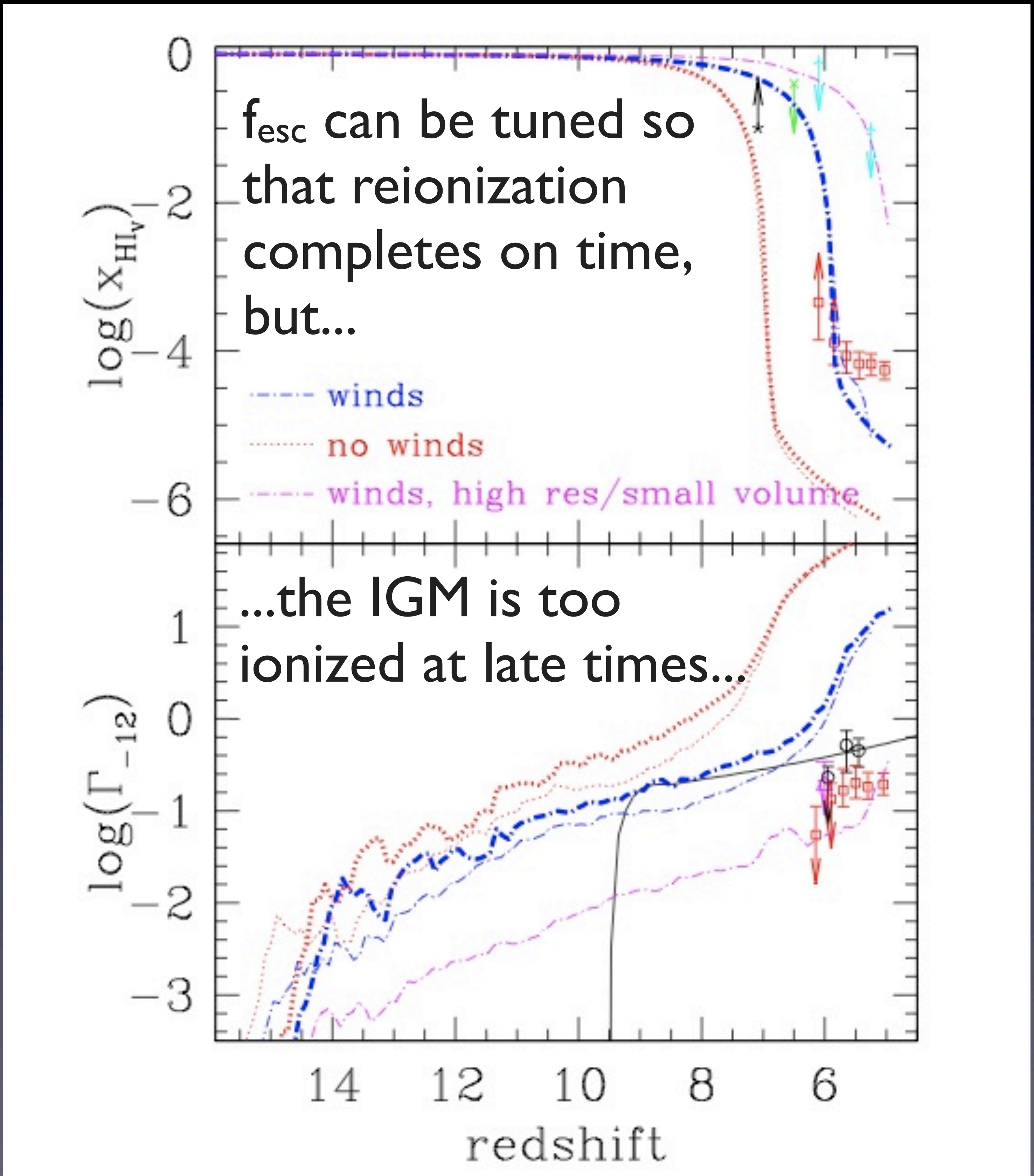
see also: Davé, KF, & Oppenheimer 2006; KF+2006;

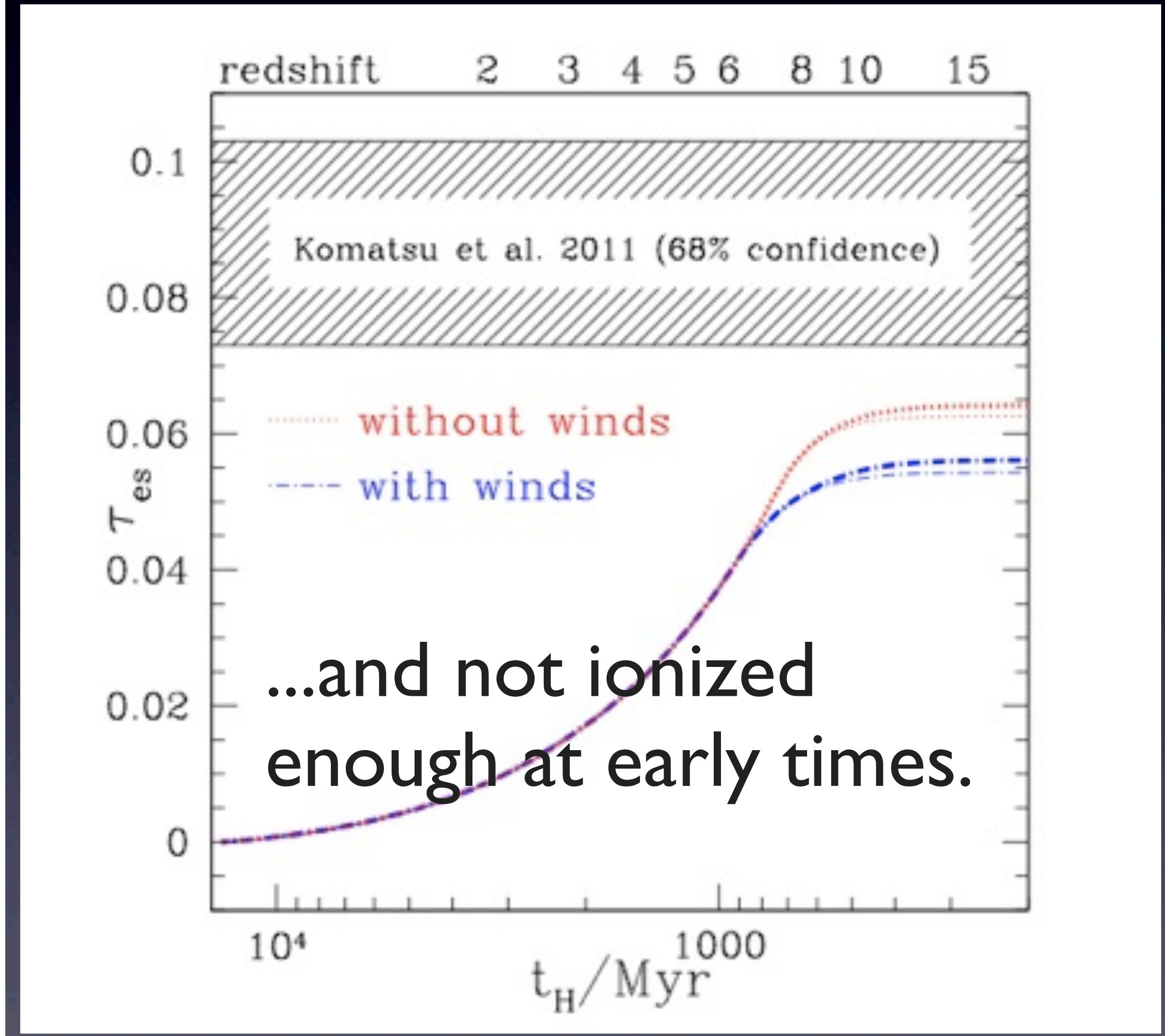
Takeaways: UV LF

- If $M_{wind}/M_* \propto M_h^{-1}$ (momentum-conserving outflows), then outflows dominate feedback for all $M_h > 10^9 M_0$, $z \geq 6$
- If SN feedback is energy-driven, then outflows dominate wherever AGN don't (Wyithe & Loeb 2012; Kim+2013)

Modeling $\tau_{Ly\alpha}$ and τ_{CMB}

For fixed f_{esc}, τ_{CMB} and $\tau_{Ly\alpha}$ in tension





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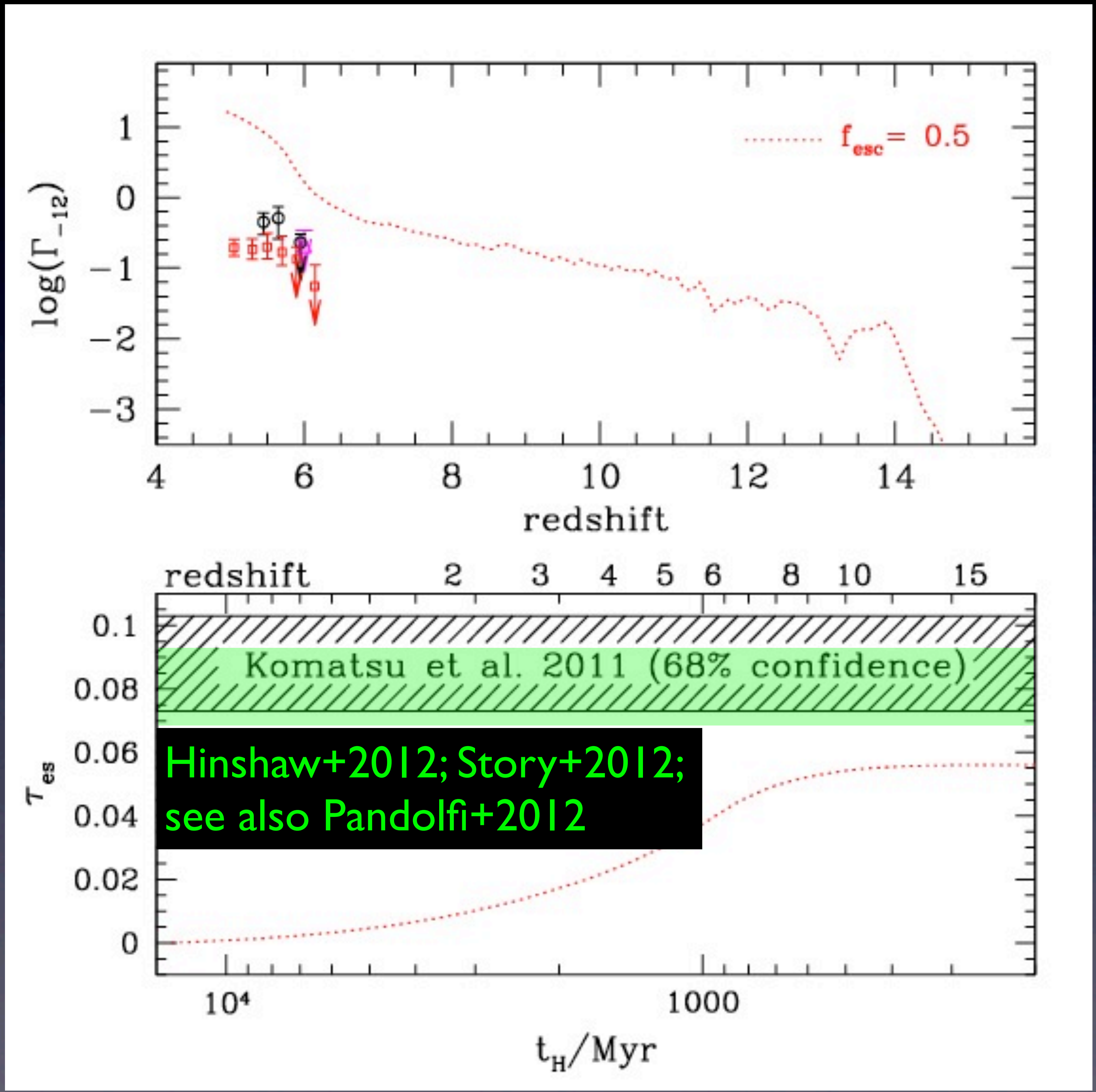
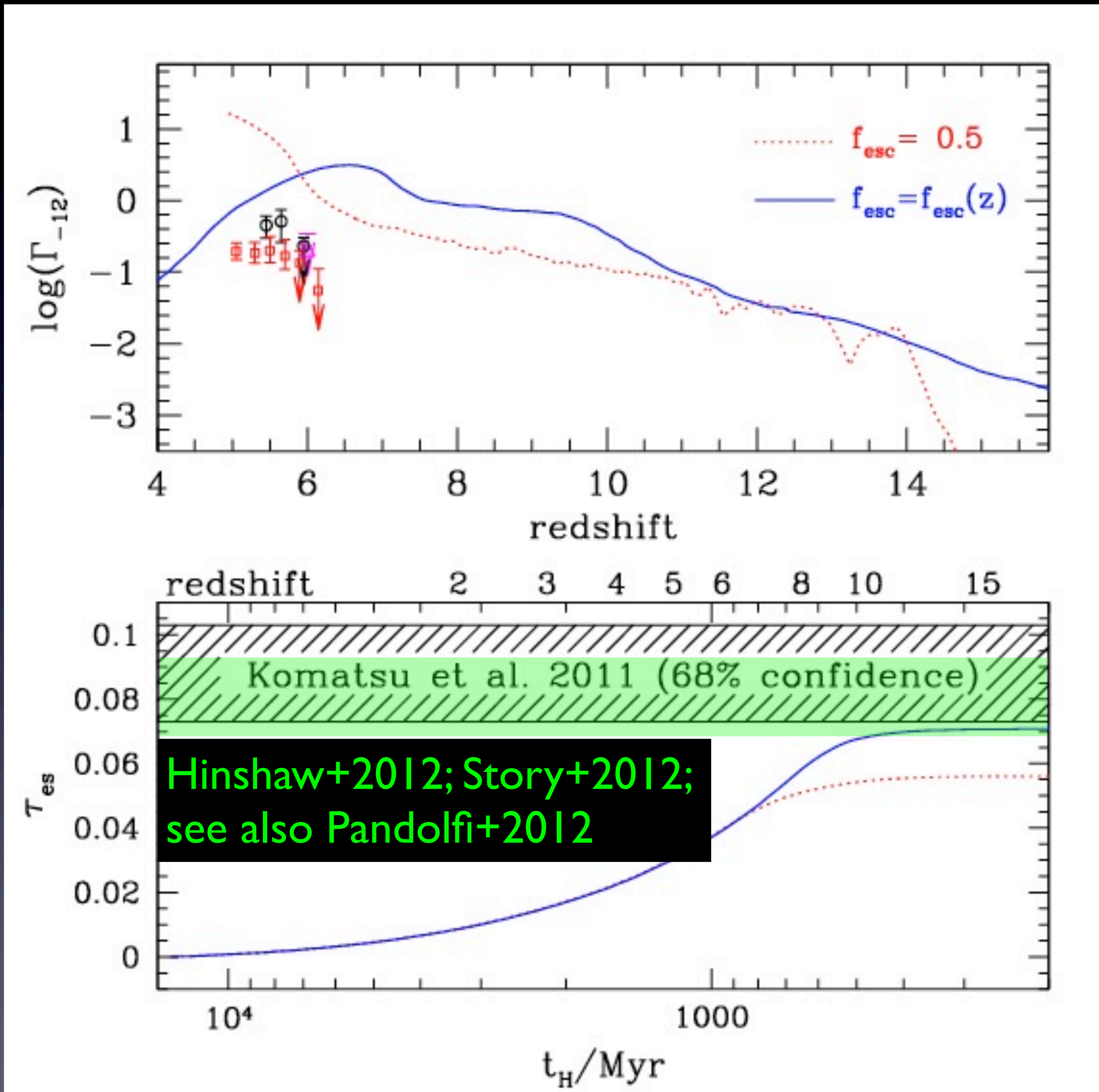


KF, Oh, Özel, & Davé 2011

Evolving $f_{esc}(z)$ Performs Better



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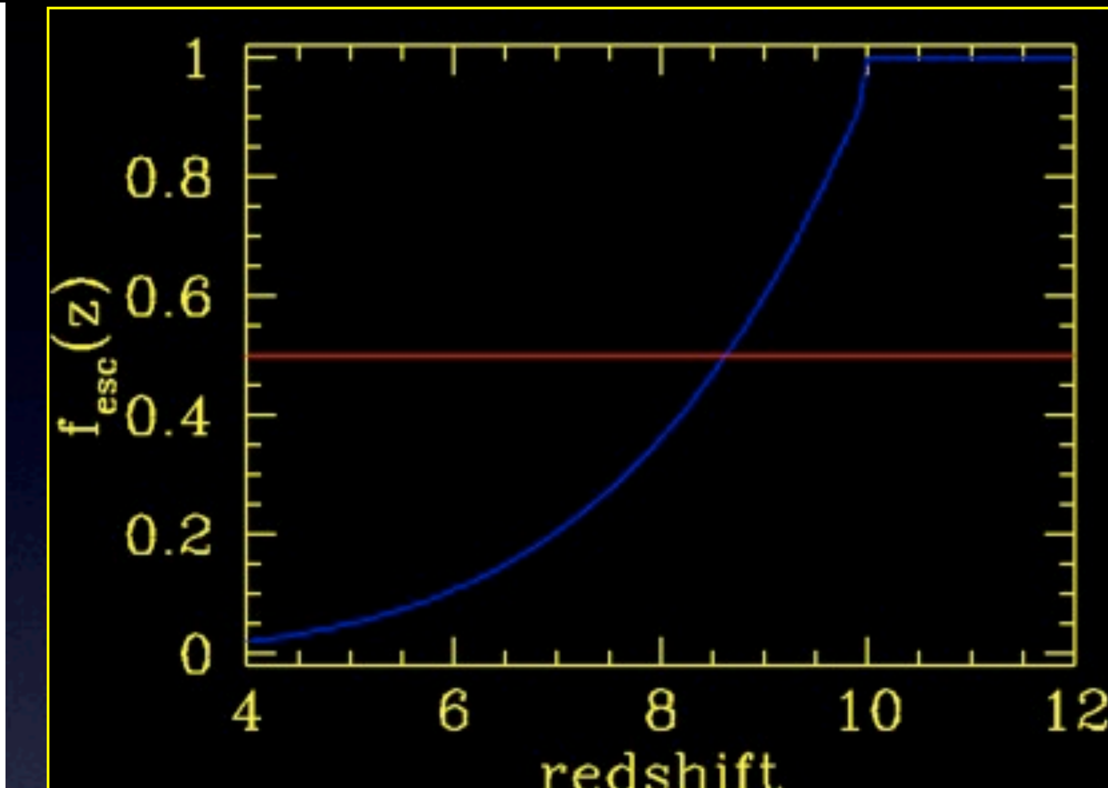

see also:

Inoue+2006;
Kuhlen & Faucher-Giguere 2012;
Mitra+2011, 2012;
Ferrara & Loeb 2012;
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Raskutti, Bolton, Wyithe, & Becker 2012

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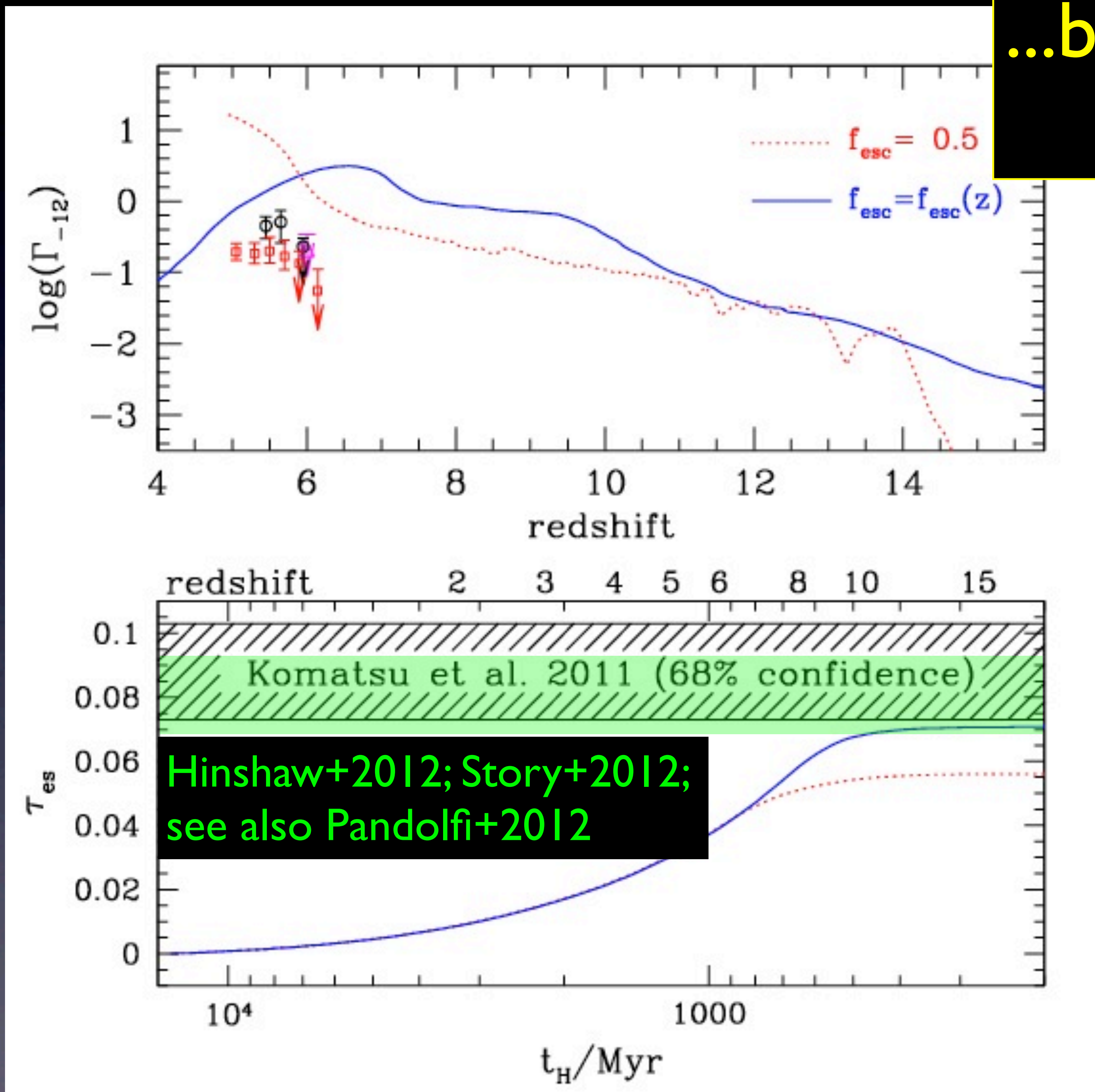
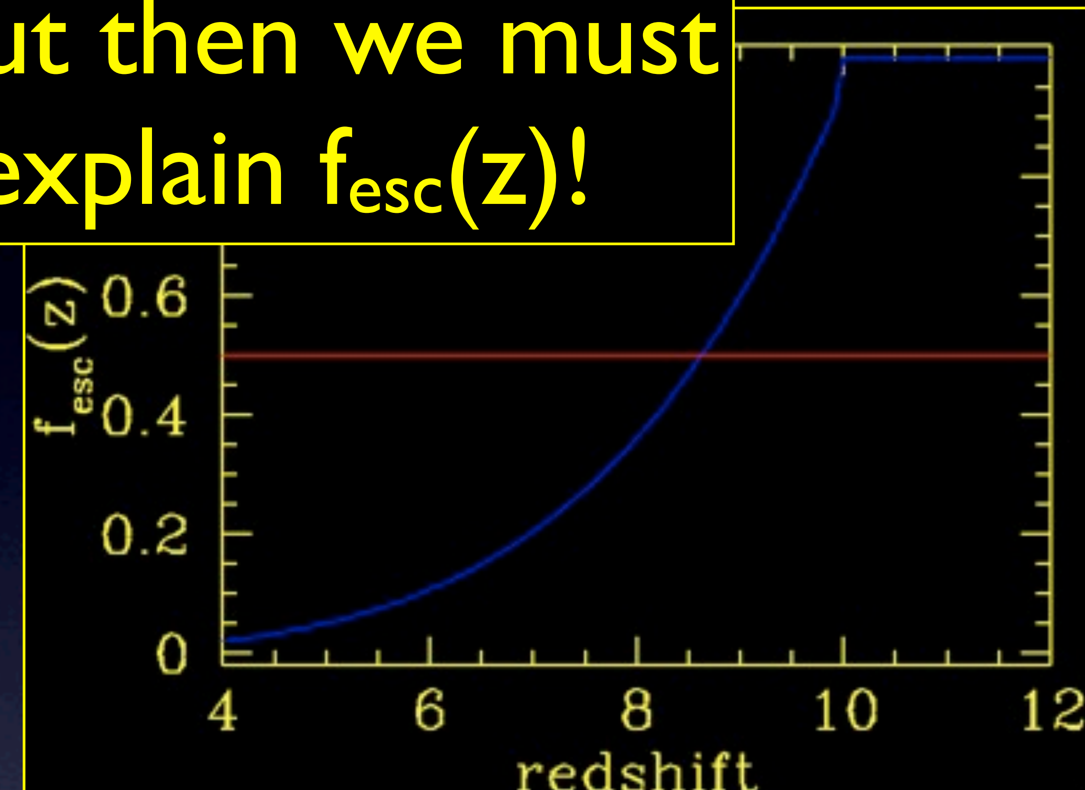


Hinshaw+2012; Story+2012; see also Pandolfi+2012

KF, Oh, Özel, & Davé 2011

...but then we must explain $f_{esc}(z)$!



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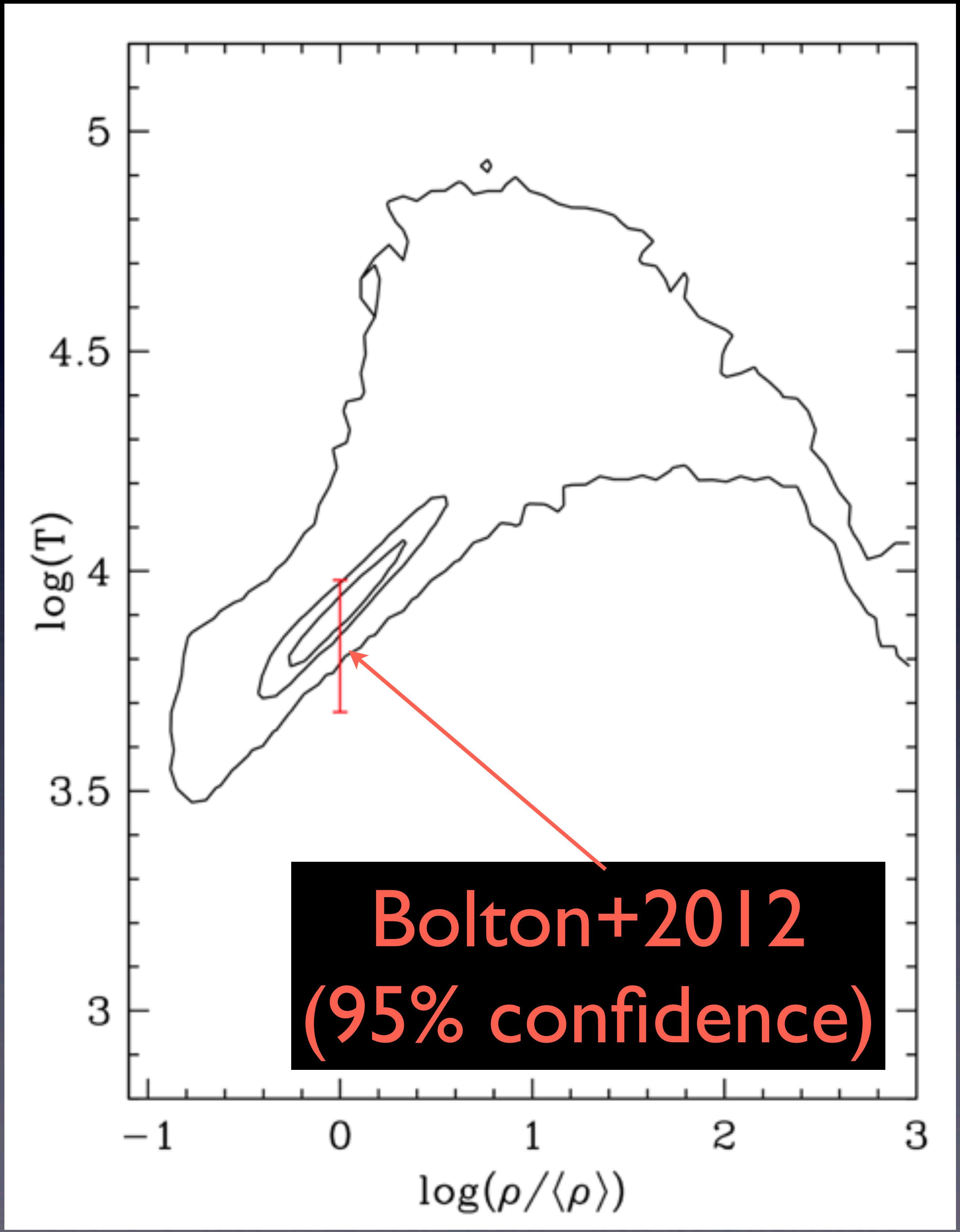
Takeaways: $\tau_{Ly\alpha}$ and τ_{CMB}

(1) Matching $\tau_{Ly\alpha}$ and τ_{CMB} simultaneously within a galaxy-driven reionization scenario requires either a strongly evolving $f_{esc}(z)$ or self-regulation (Alvarez, KF, & Trenti 2012).

(2) Outflows are in tension with self-regulated scenarios (Wyithe & Loeb 2012; Kim+2013)

Modeling T_{IGM}

Testing Models Using T_{IGM} at z = 6



Comparing the temperature log(T/K) of gas at the mean density at z=6:

Simulation: 3.8 - 4.2
Bolton+2012: 3.68 - 3.98

⇒ excellent agreement suggests that the reionization history is realistic.

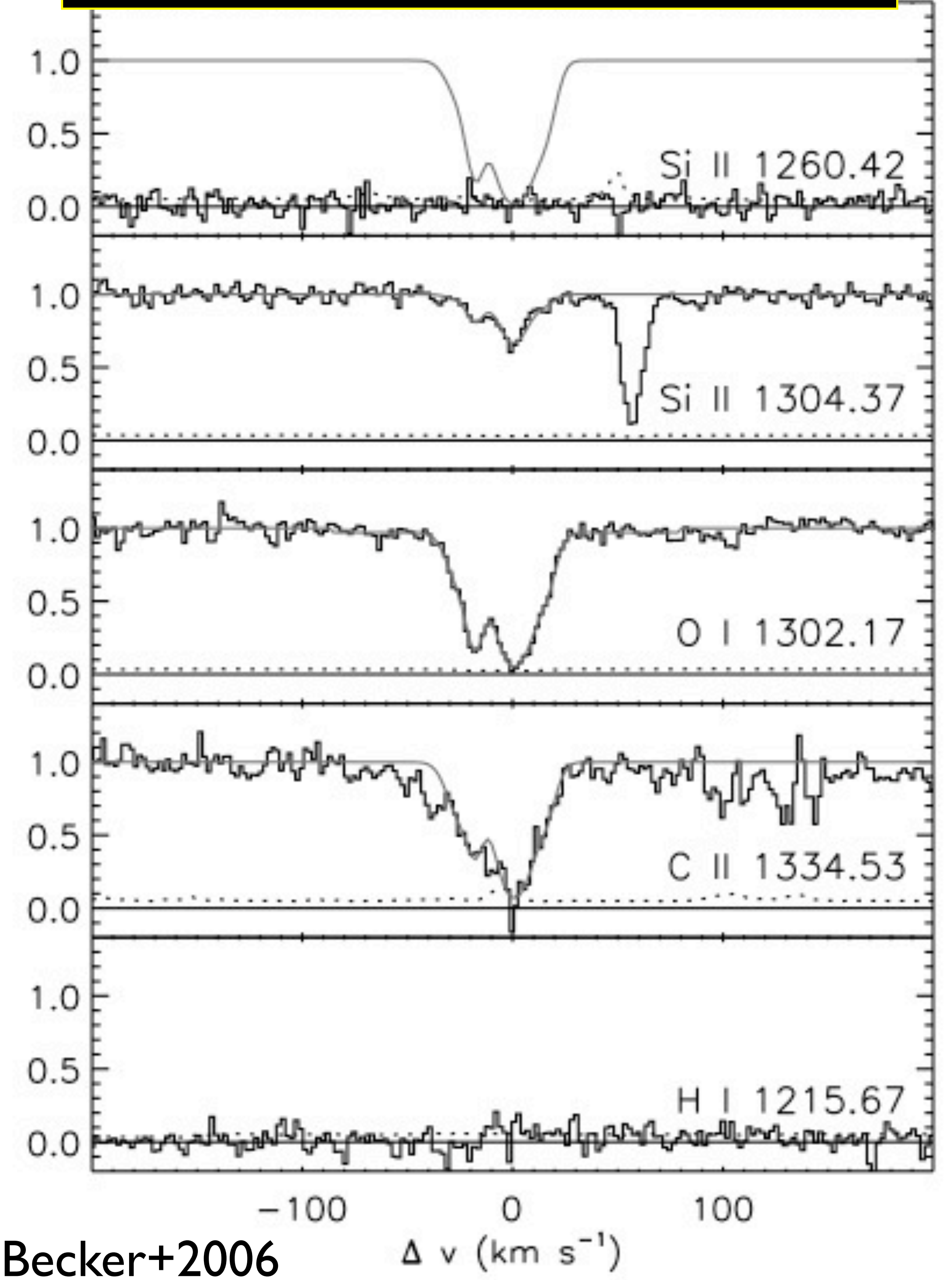
Takeaway: T_{IGM}

Models that reproduce τ_{CMB} can also reproduce T_{IGM} if the UVB reflects a Population II spectrum.
(see also Raskutti, Bolton, Wyithe, & Becker 2012)

Modeling OI Absorbers

Motivation: Searching for Low-Mass Galaxies

absorber at z = 6.0097



Becker+2006

Observations (Becker+06,11,13)

- selected as absorbers along sightlines to high-z quasars;
- HI is saturated;
- number density comparable to DLAs/sub-DLAs at z = 3;
- column density ratios same as DLAs at z~3

Motivation: Searching for Low-Mass Galaxies

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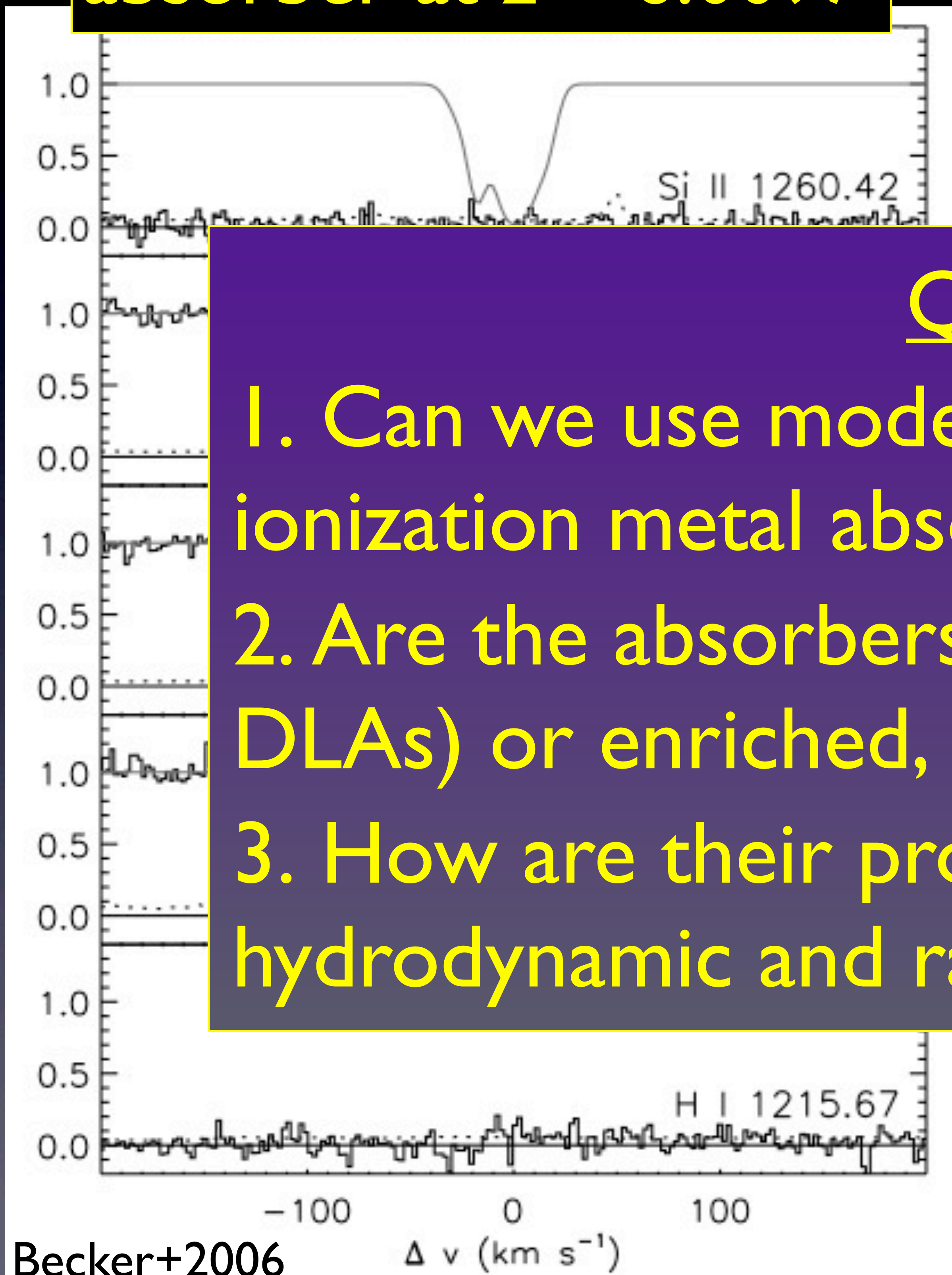

Becker+2006

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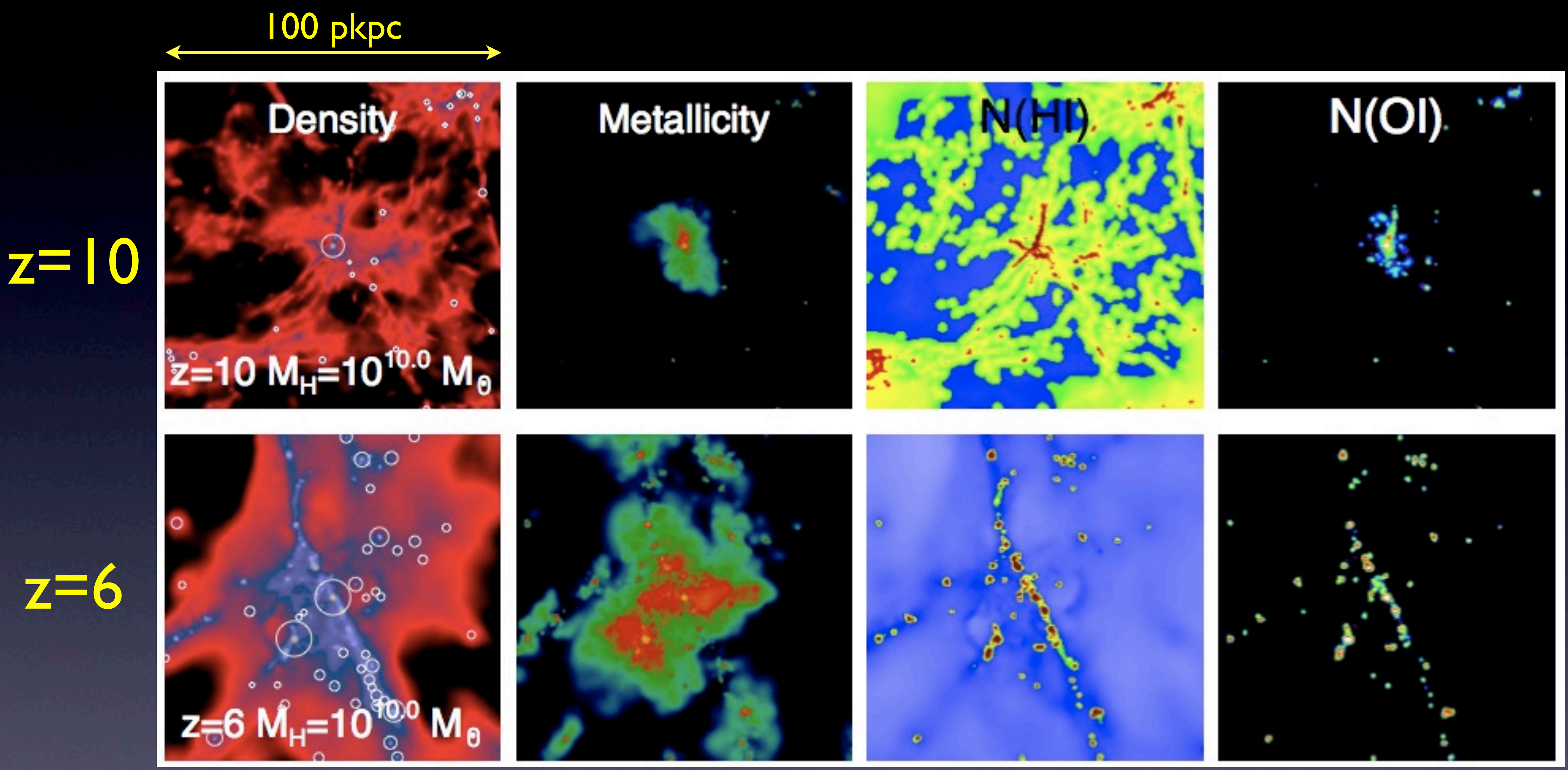
<u>Questions</u>

1. Can we use models to interpret low-ionization metal absorbers?
2. Are the absorbers galaxies (analogous to DLAs) or enriched, neutral bits of IGM?
3. How are their properties shaped by hydrodynamic and radiative feedback?

How Does OI Relate to Neutral Gas?



KF+2013, submitted

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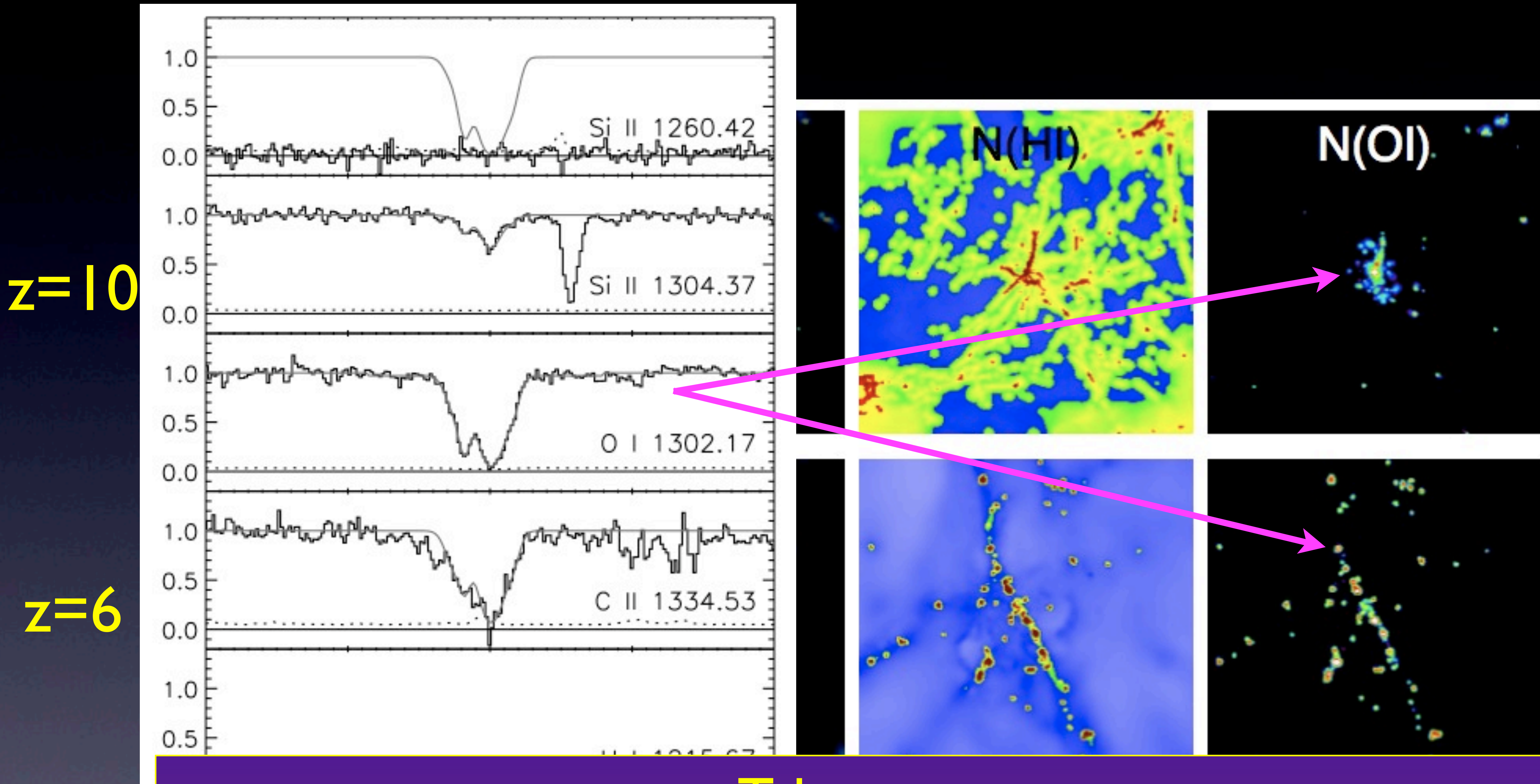
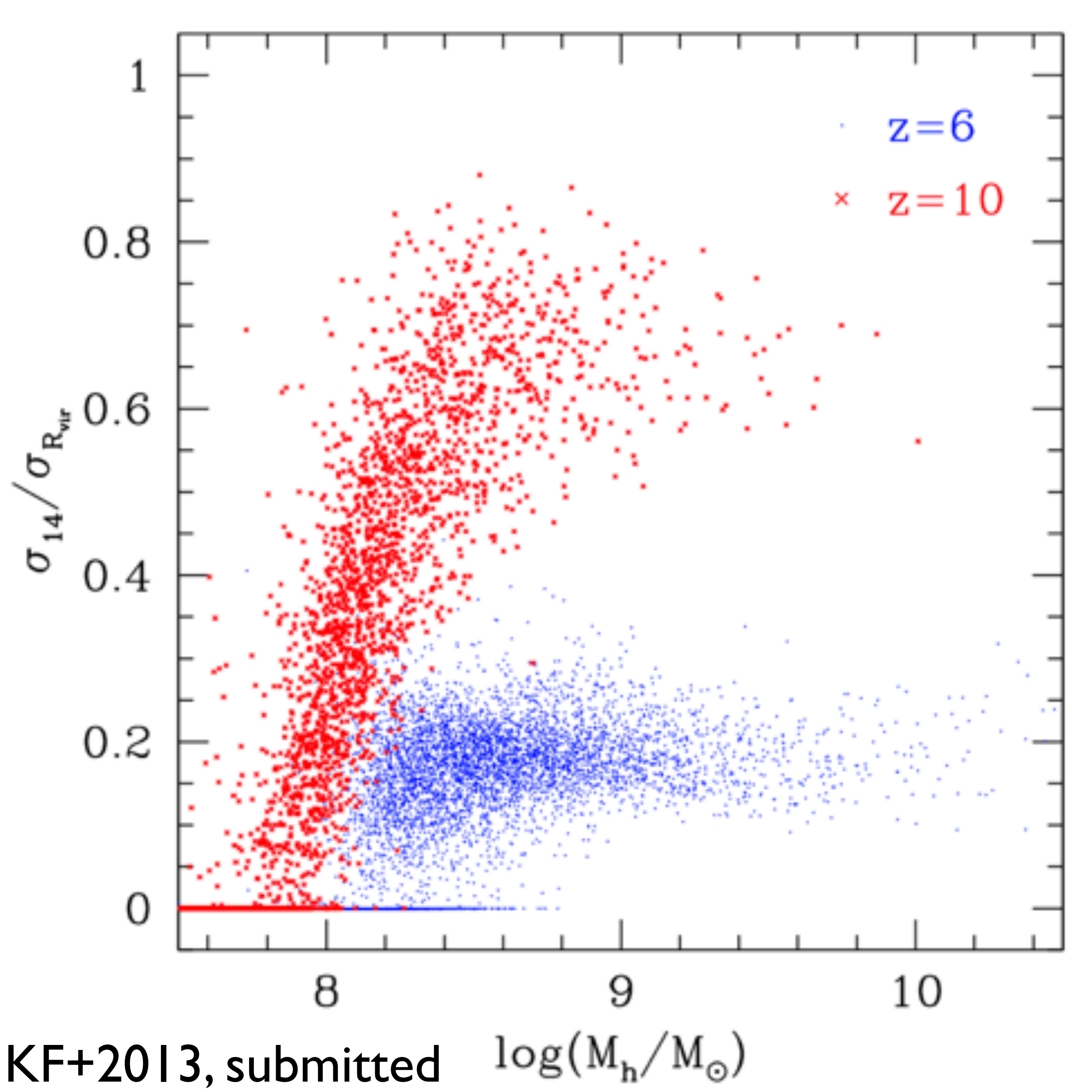


Takeaway

OI concentrates around halos, indicating a close association with star formation.

Reionization Suppresses the Cross-Section for Low-Ionization Metal Absorption



KF+2013, submitted

- The fraction of the virial cross section that is visible in absorption declines
- The minimum mass for appearing as an absorber grows (similar to the filtering mass)

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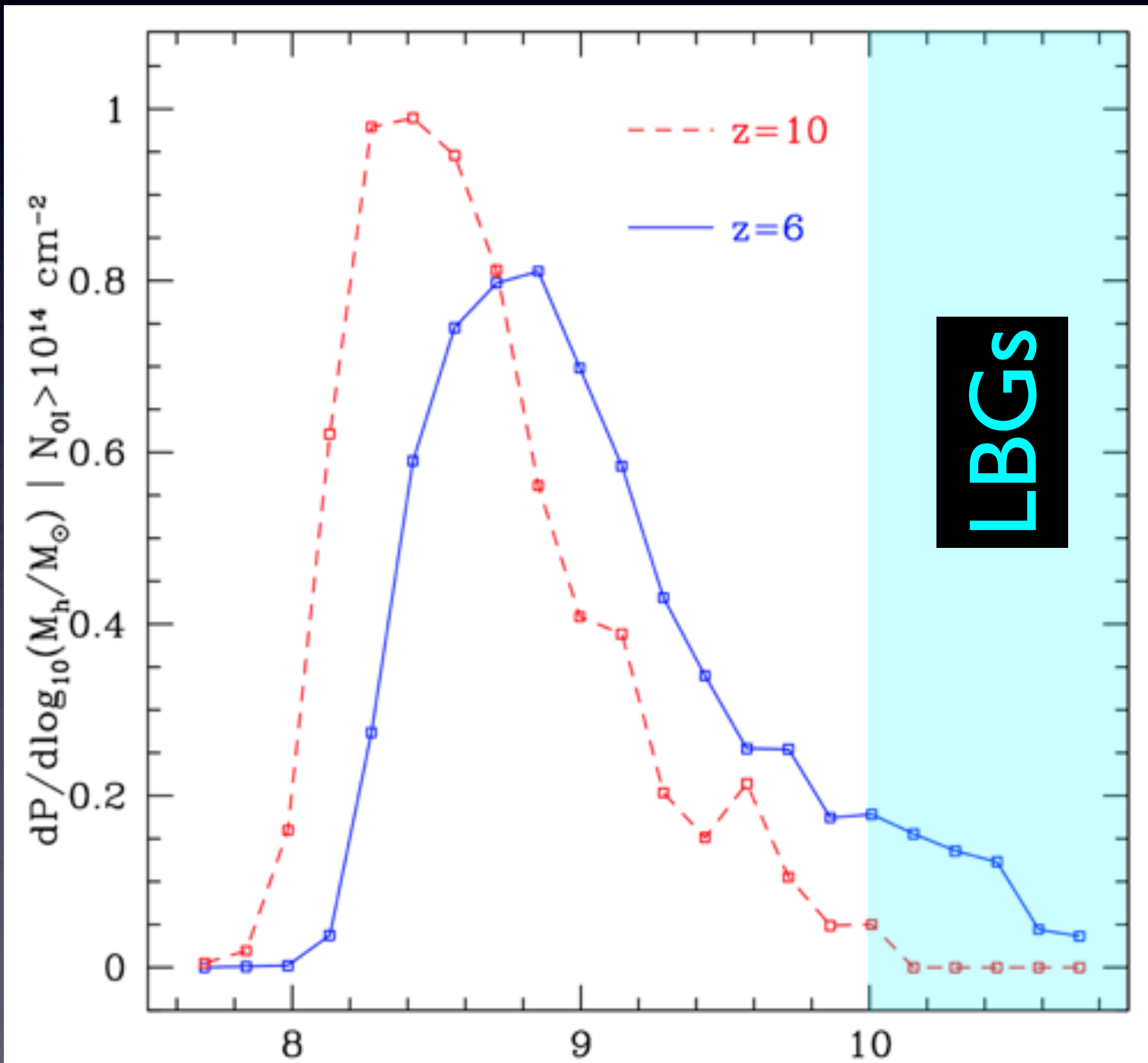


KF+2013, submitted

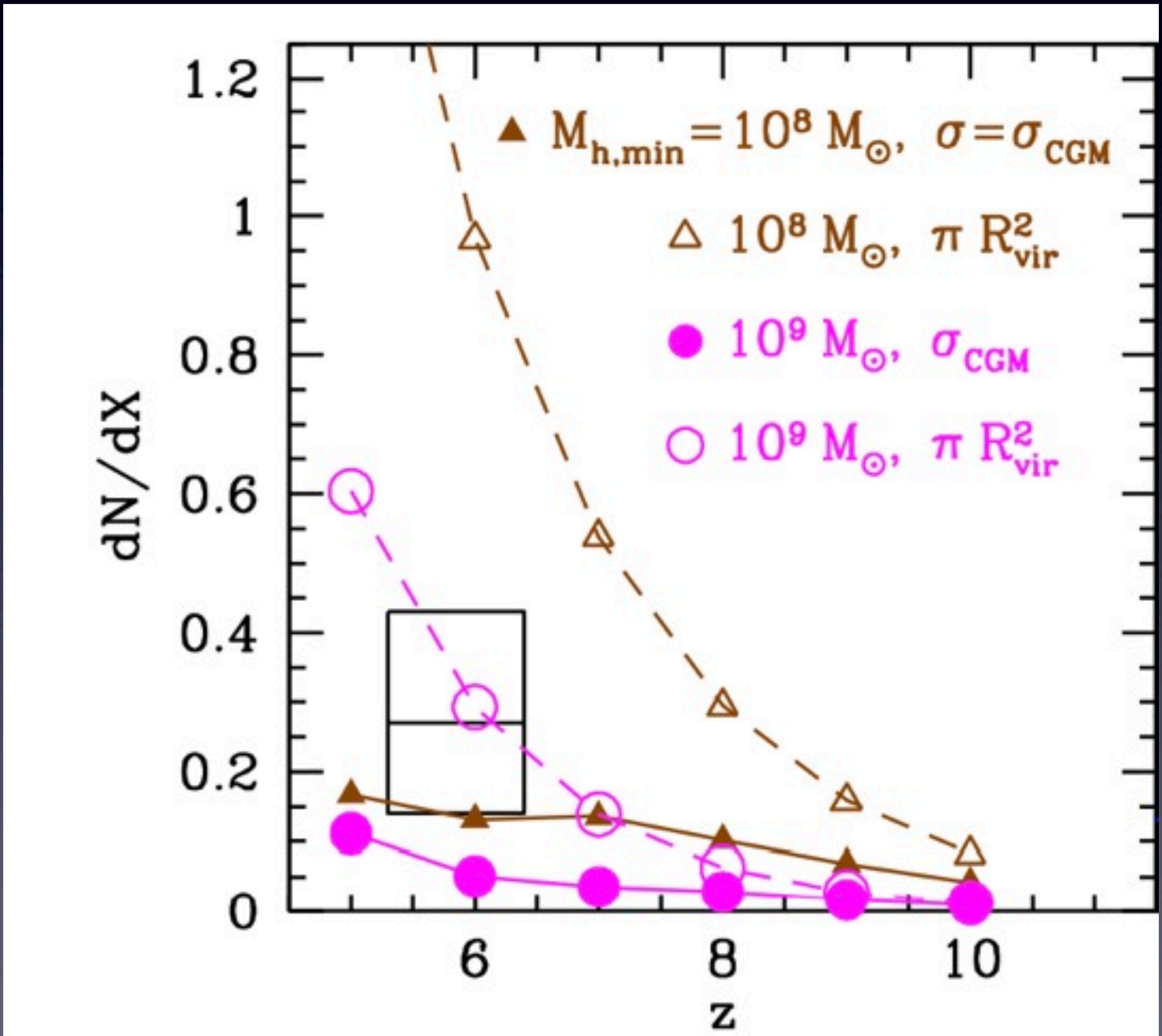
- Characteristic host halo mass grows
- $M_h < 10^{9.5}\ M_0$ for $z \geq 6$
- This is 10-100× less massive than host halos of LBGs/LAEs (e.g., Muñoz & Loeb 2011; Ouchi+2010)!

How does the OI absorber abundance evolve?

- The growth of new galaxies should drive the abundance of absorbers *up*. Meanwhile,
- The encroachment of ionization fronts as reionization proceeds (the background amplifies and the virial overdensity declines) should drive the abundance of absorbers *down*.

  ➡ How does the overall abundance evolve?

Reionization Leads to Slow Evolution in the Abundance of Low-Ionization Metal Absorbers



KF+2013, submitted; observations from Becker+2011

- Predicted abundance in marginal agreement with observations (given the uncertainties!)

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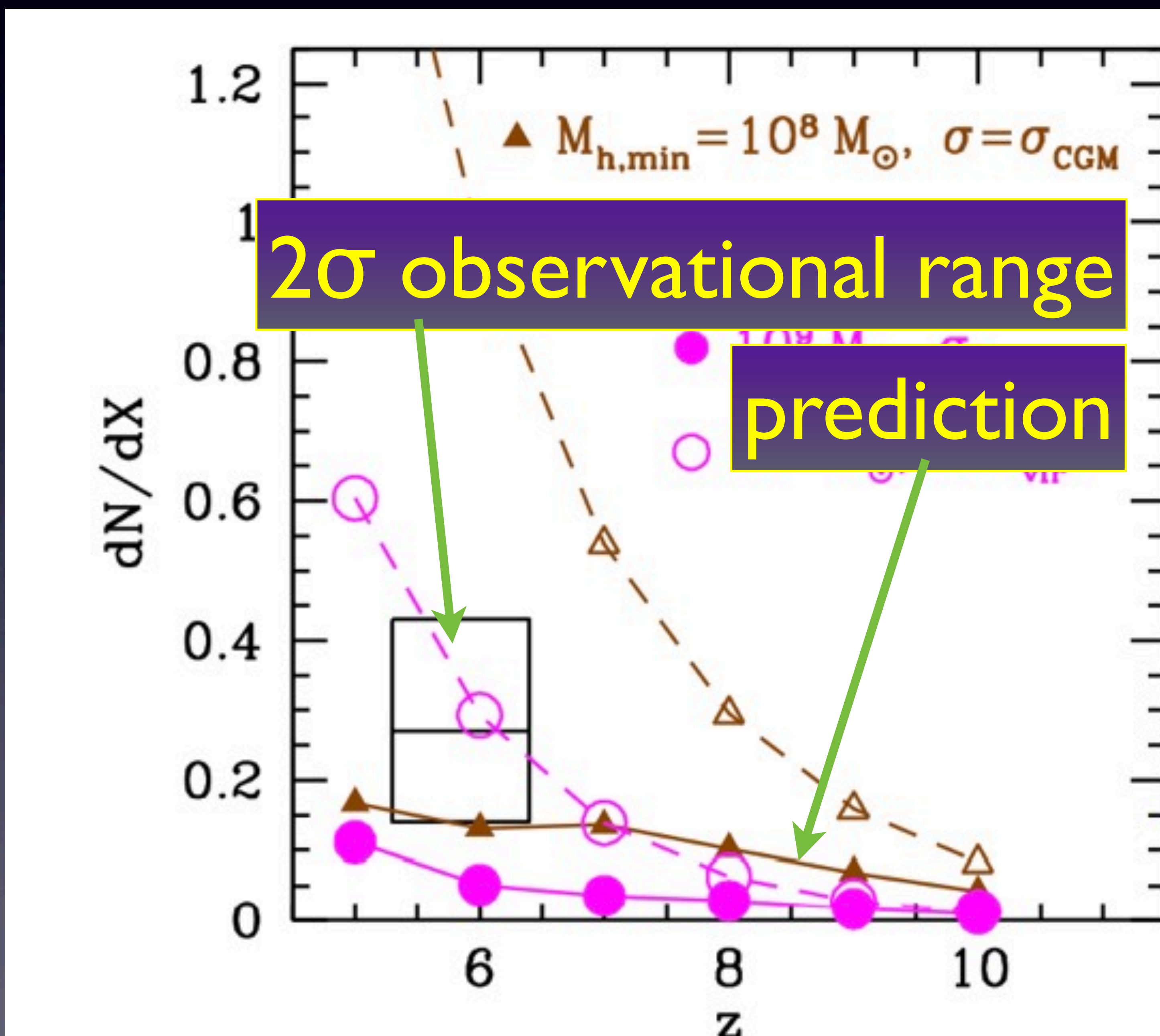

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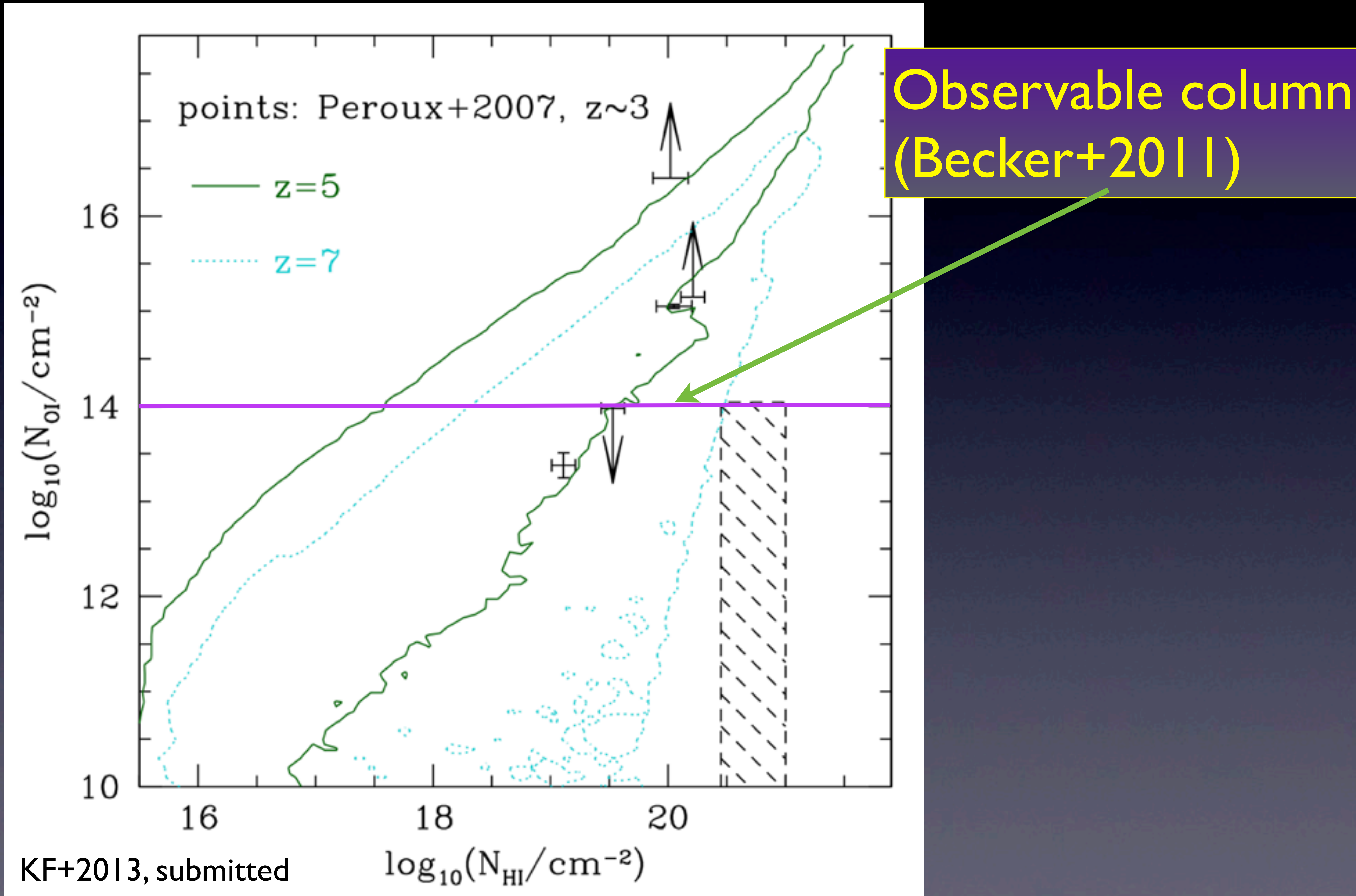
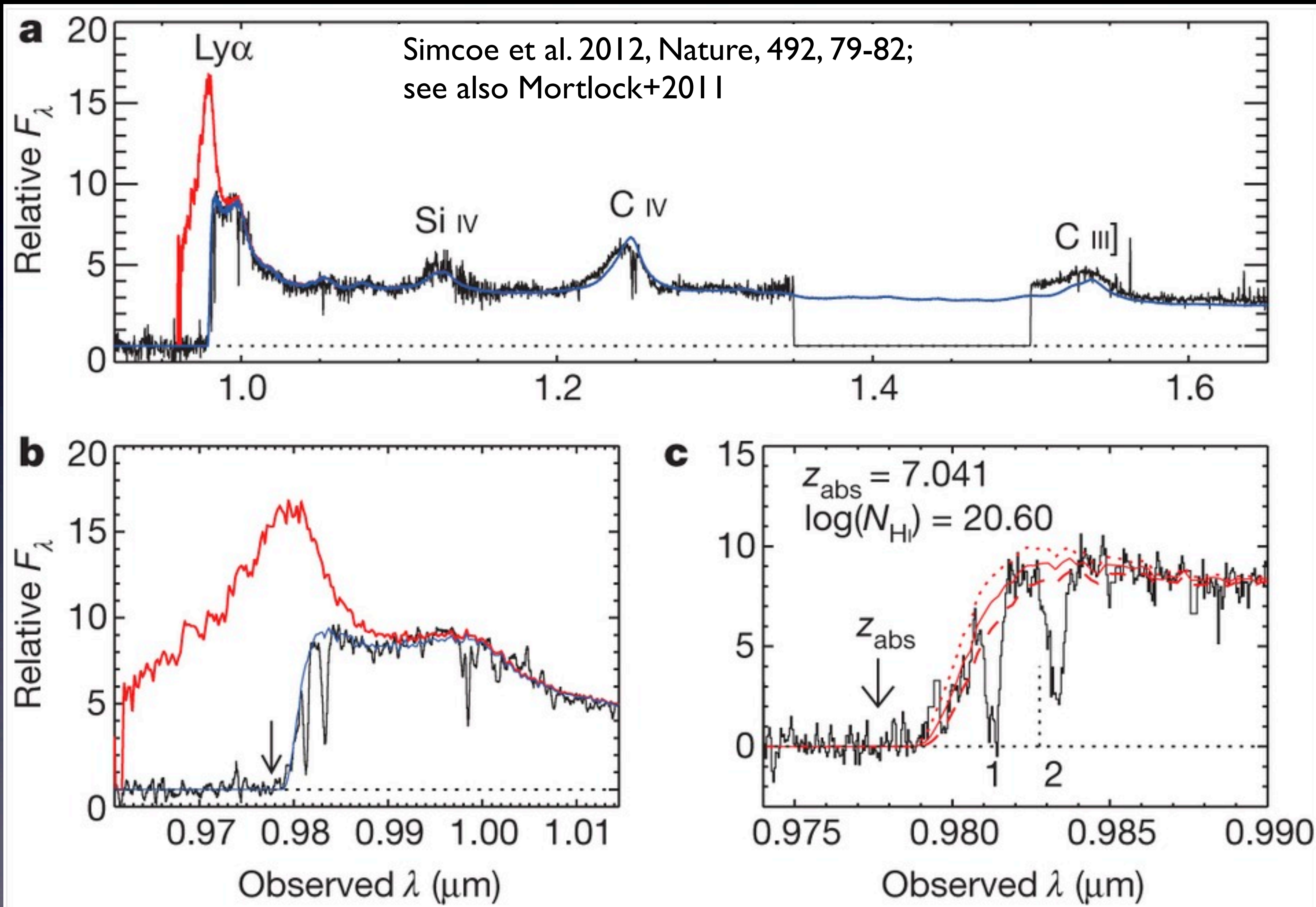
OI Absorbers are sub-DLAs & DLAs



Is the z=7 Universe Partially Neutral?



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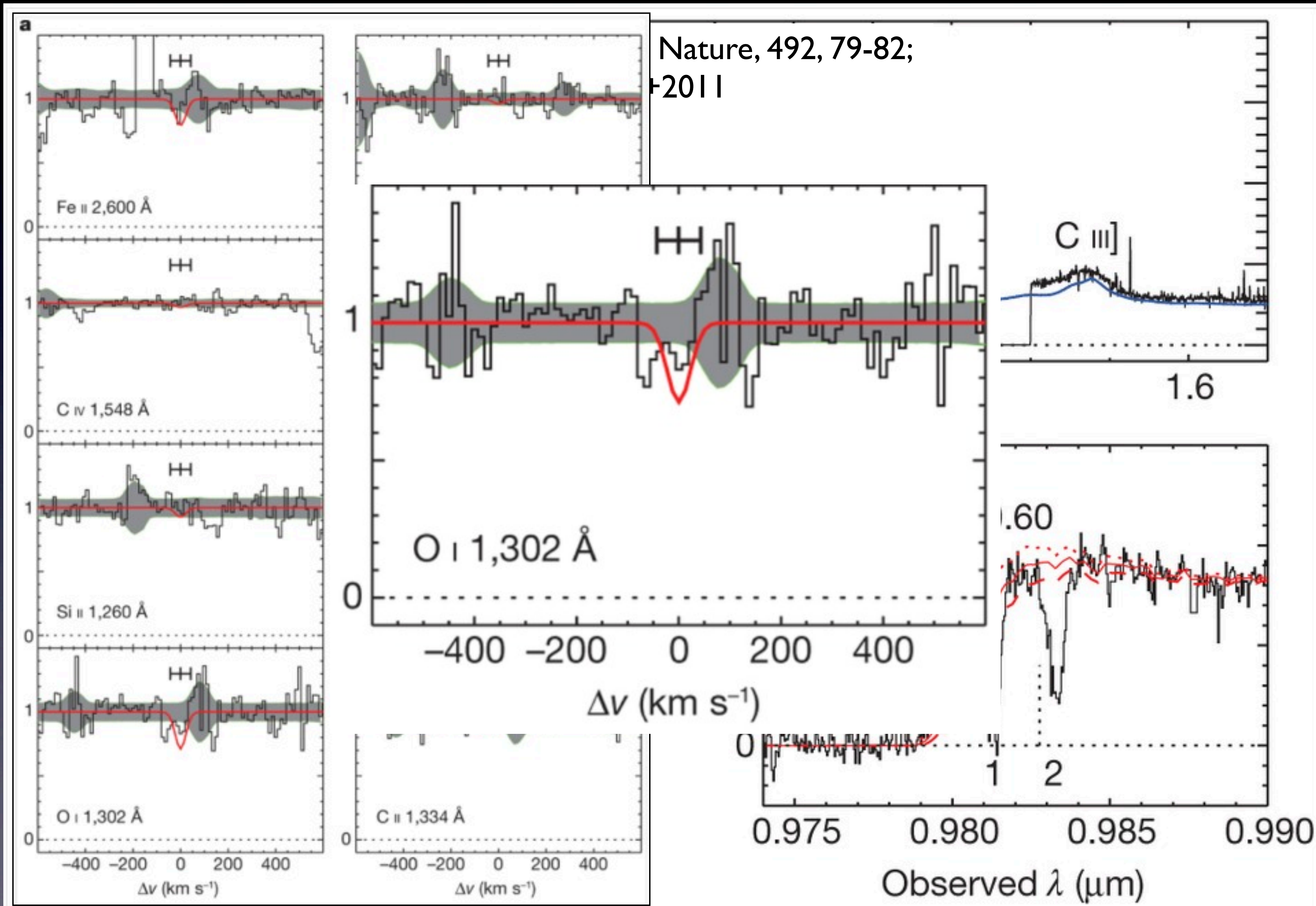

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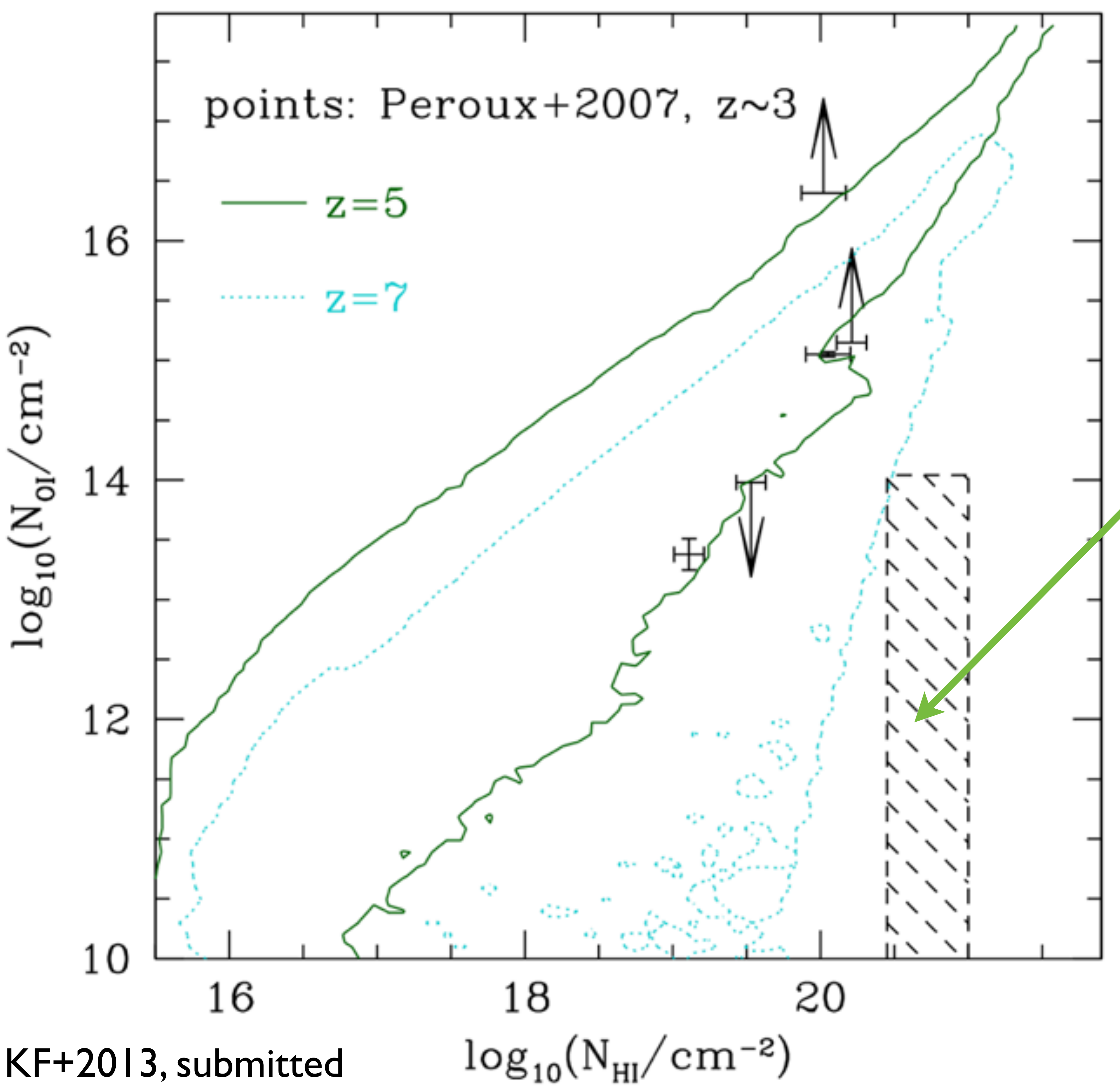

KF+2013, submitted

Constraints by Simcoe+2012. The absorber in the foreground of ULASJ1120+0641 is inconsistent with arising in halo gas.

Takeaways: OI Absorbers

- Simulations reproduce the observed absorber abundance;
- Host halos have a characteristic mass of $M_h < 10^9\ M_0$; central galaxies have $M_{UV} > -15$ at $z > 6$

  ➡ Absorbers are potentially a powerful test of models that suppress star formation at these scales (Bouché +2010; Krumholz & Dekel 2012; Kuhlen+2012, 2013)

- $N_{HI} = 10^{19}\text{-}10^{21}\ cm^{-2}$
- The Simcoe+2012 metal absorber constraints on ULASJ1120+0641 (Mortlock+2011) are inconsistent with arising in halo gas; imply $x_{HI} > 10\%$ (Bolton+ 2011; Schroeder, Mesinger, & Haiman 2012)

Observational Constraints on Hydrogen Reionization ...that have been invoked in models

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Observational Constraints on Hydrogen Reionization ...that have now tested models

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Questions for Discussion

- The UV LF requires outflows. Outflows rule out self-regulation. Models without self-regulation cannot simultaneously match $\tau_{Ly\alpha}$ at z = 5–6 and τ_{CMB}. Is there an astrophysical solution such as $f_{esc}(z)$ or should we just hope that Planck will bring down τ_{CMB}?

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- How can we invoke other observations to constrain galaxy formation at $z \geq 6$?
- Is there a connection between absorption-selected systems at $z \geq 6$ and the satellites of the Milky Way?

(end of presentation)