Constraining reionization with Lyman-alpha emitters and the CMB

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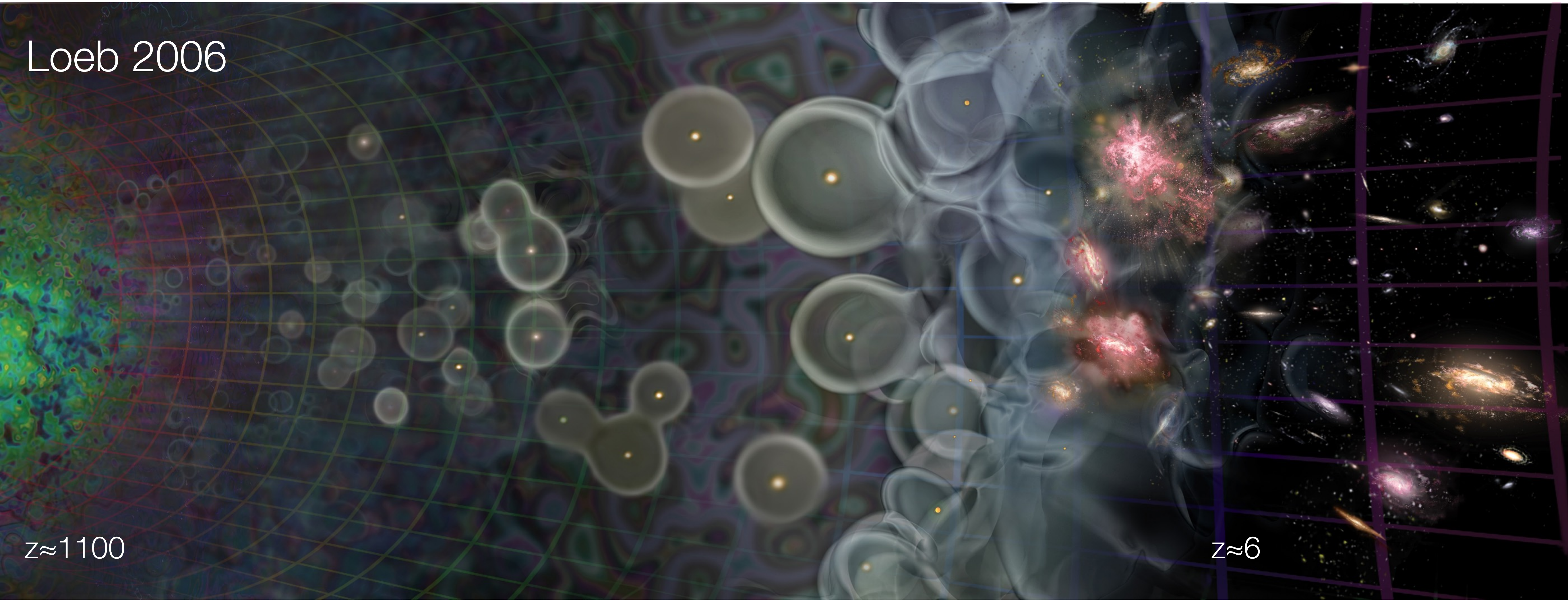
collaborators: Tirthankar Choudhury, Martin Haehnelt, James Bolton

Illuminating the Dark Ages 2016, MPIA

CMB and the epoch of reionization

time



CMB

cosmic
dark ages

first stars
and galaxies

reionization

today

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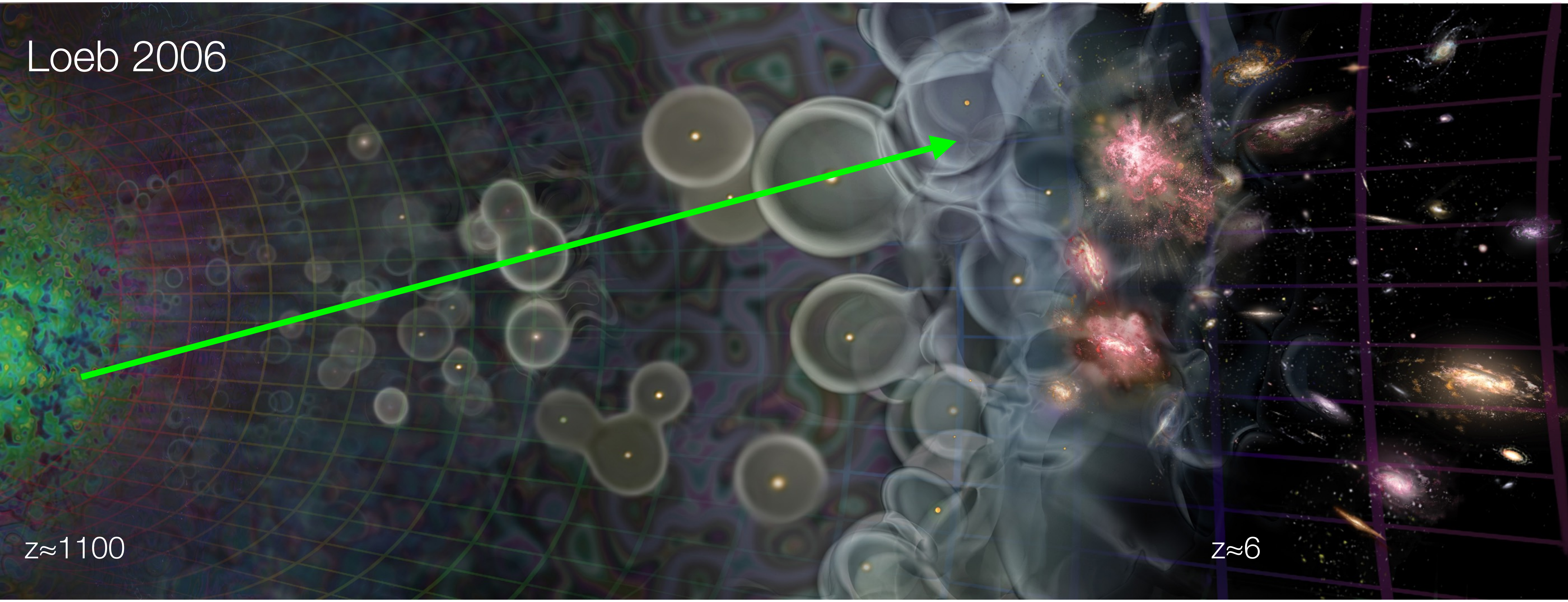

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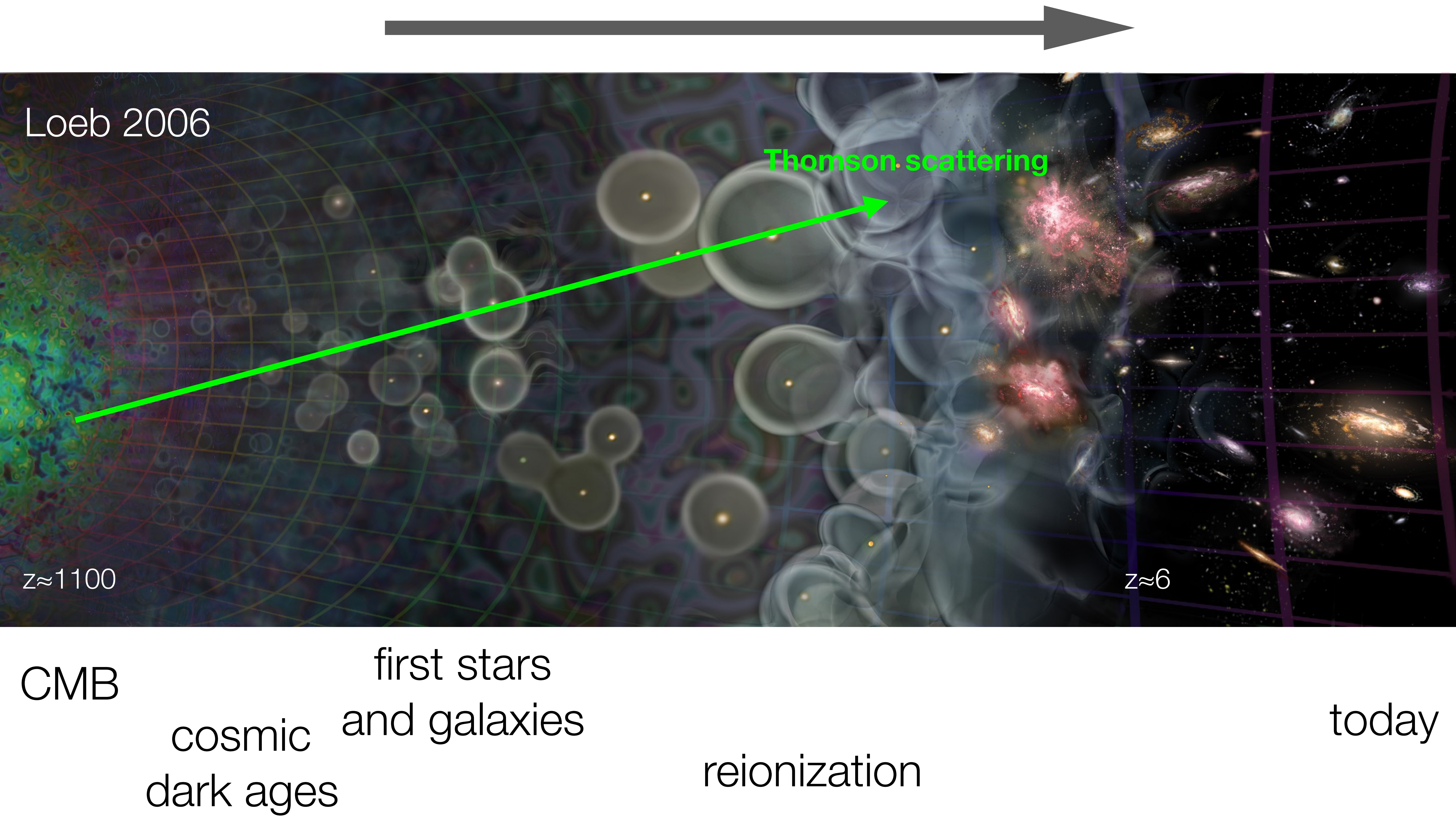

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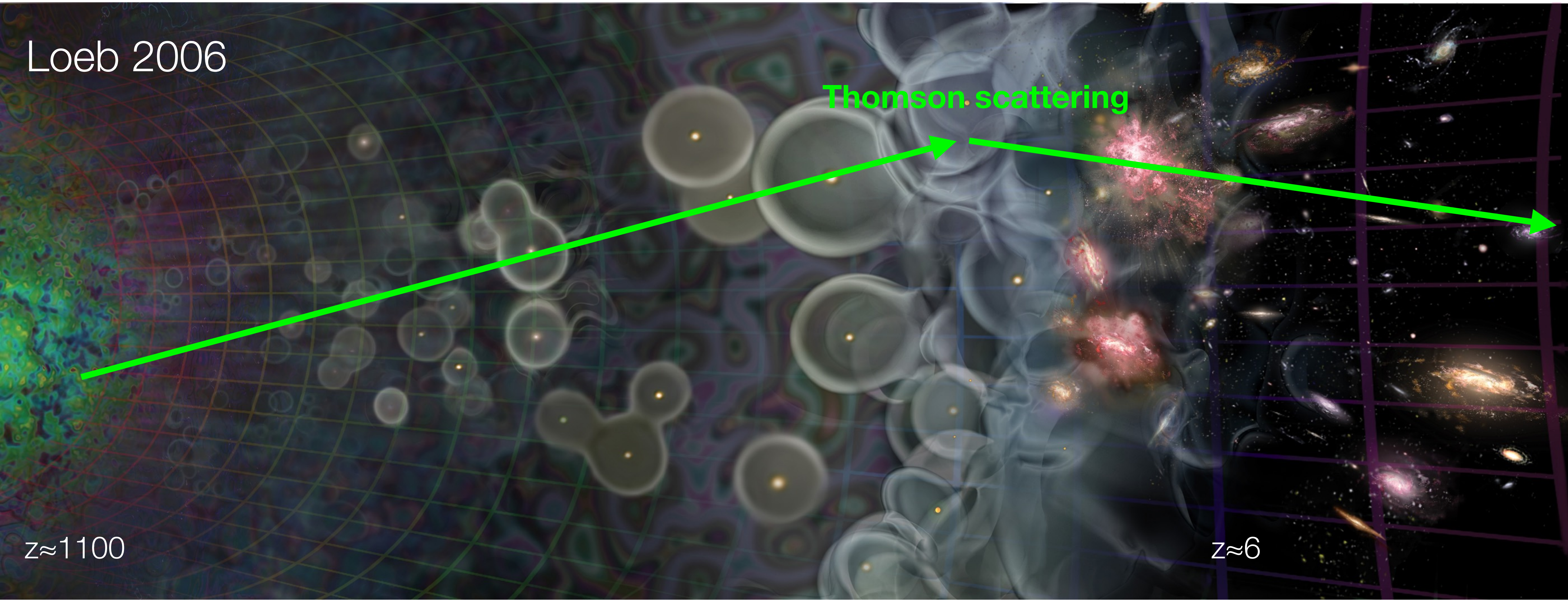

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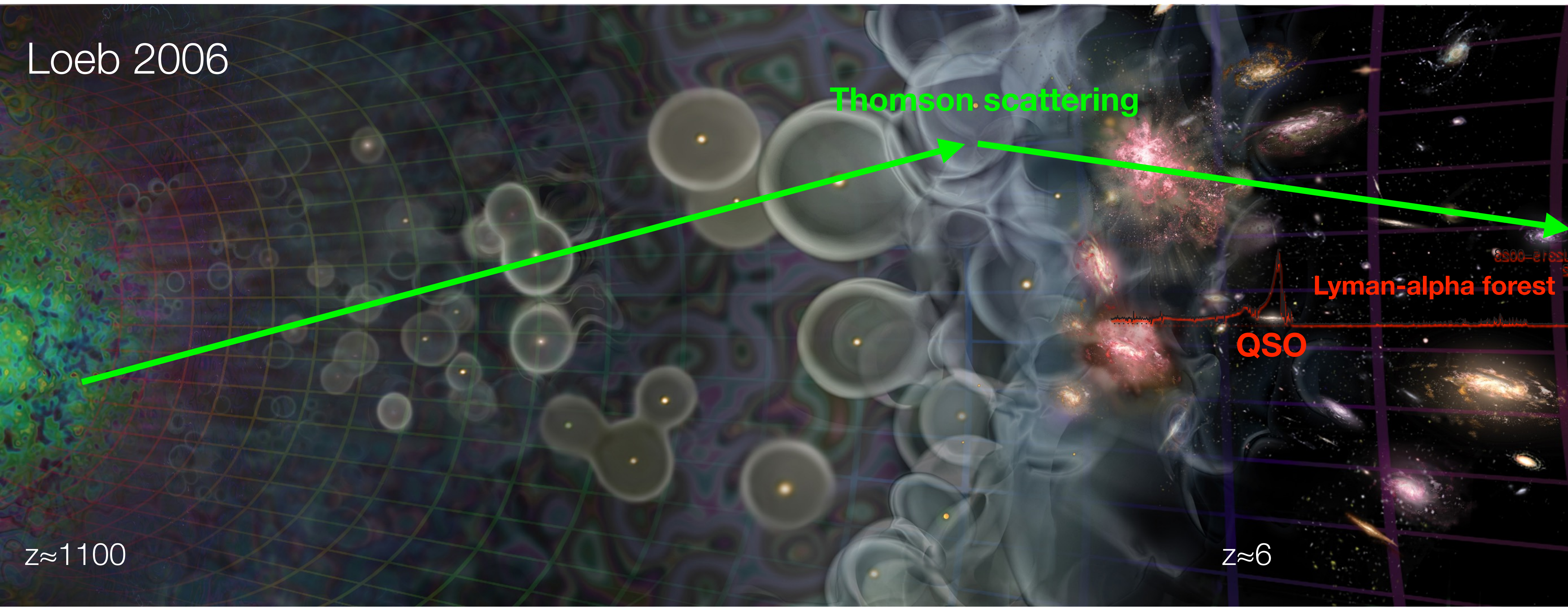

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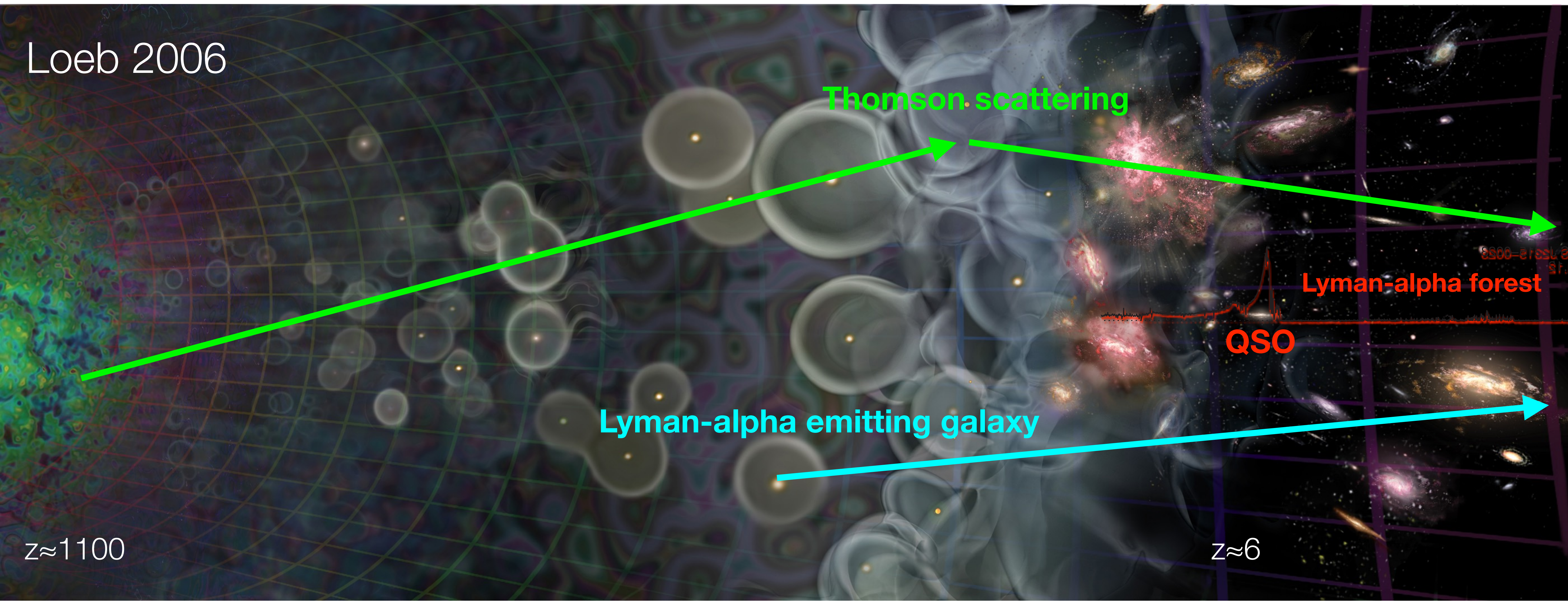

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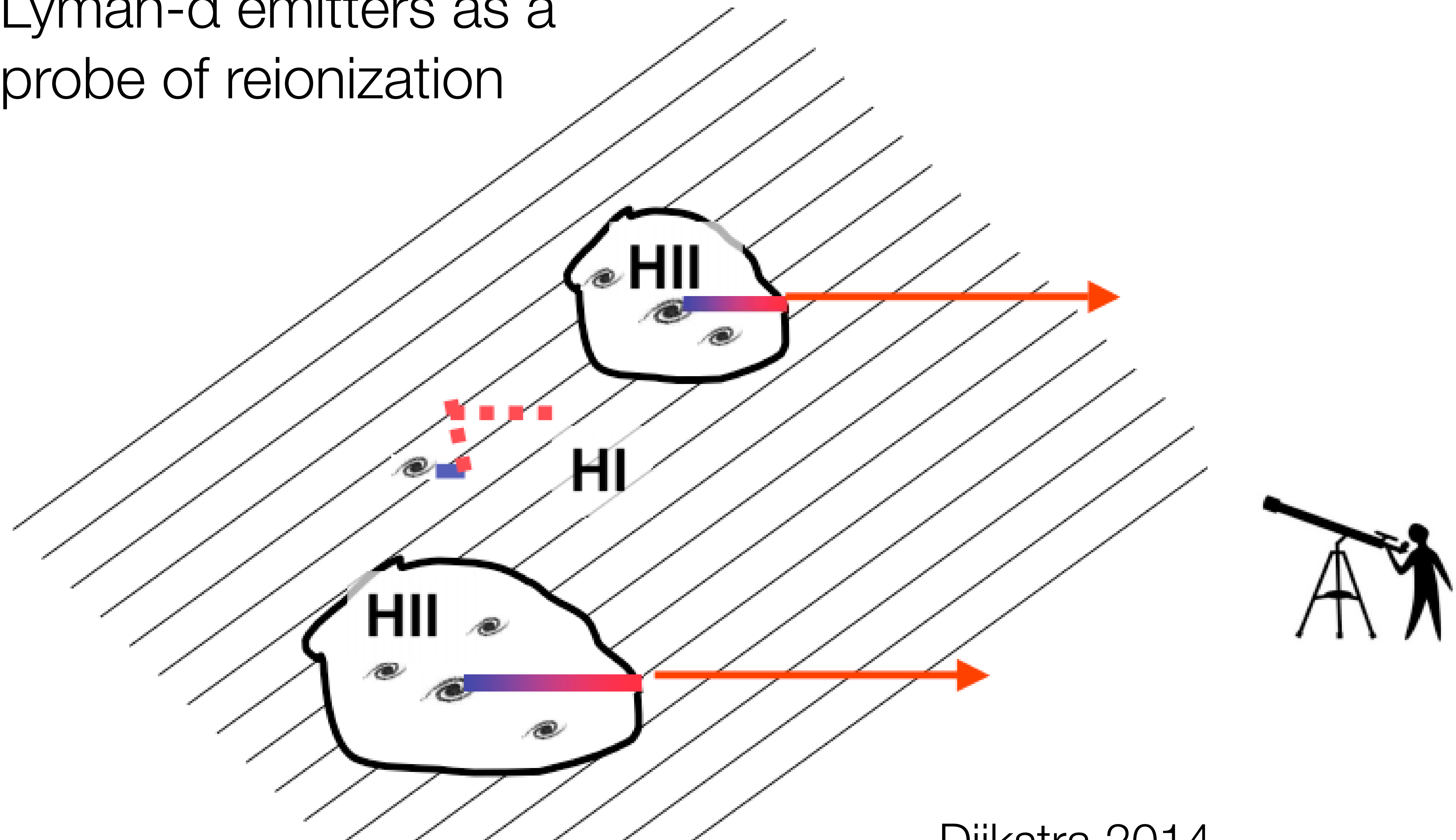
Probing the ionization & thermal state of the IGM

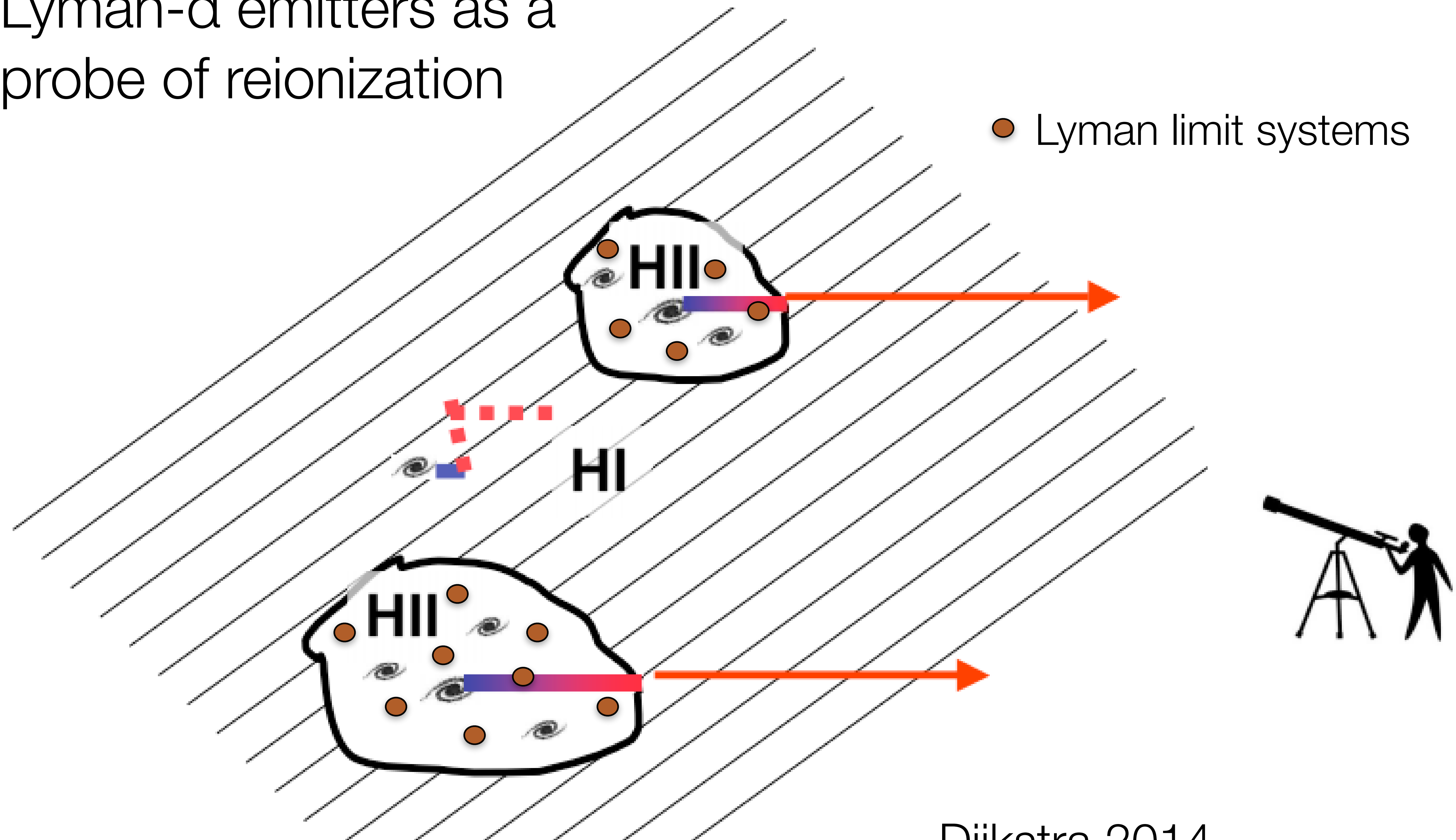
- Lyman-α emitters as a probe of reionization



Dijkstra 2014

Probing the ionization & thermal state of the IGM

- Lyman-α emitters as a probe of reionization

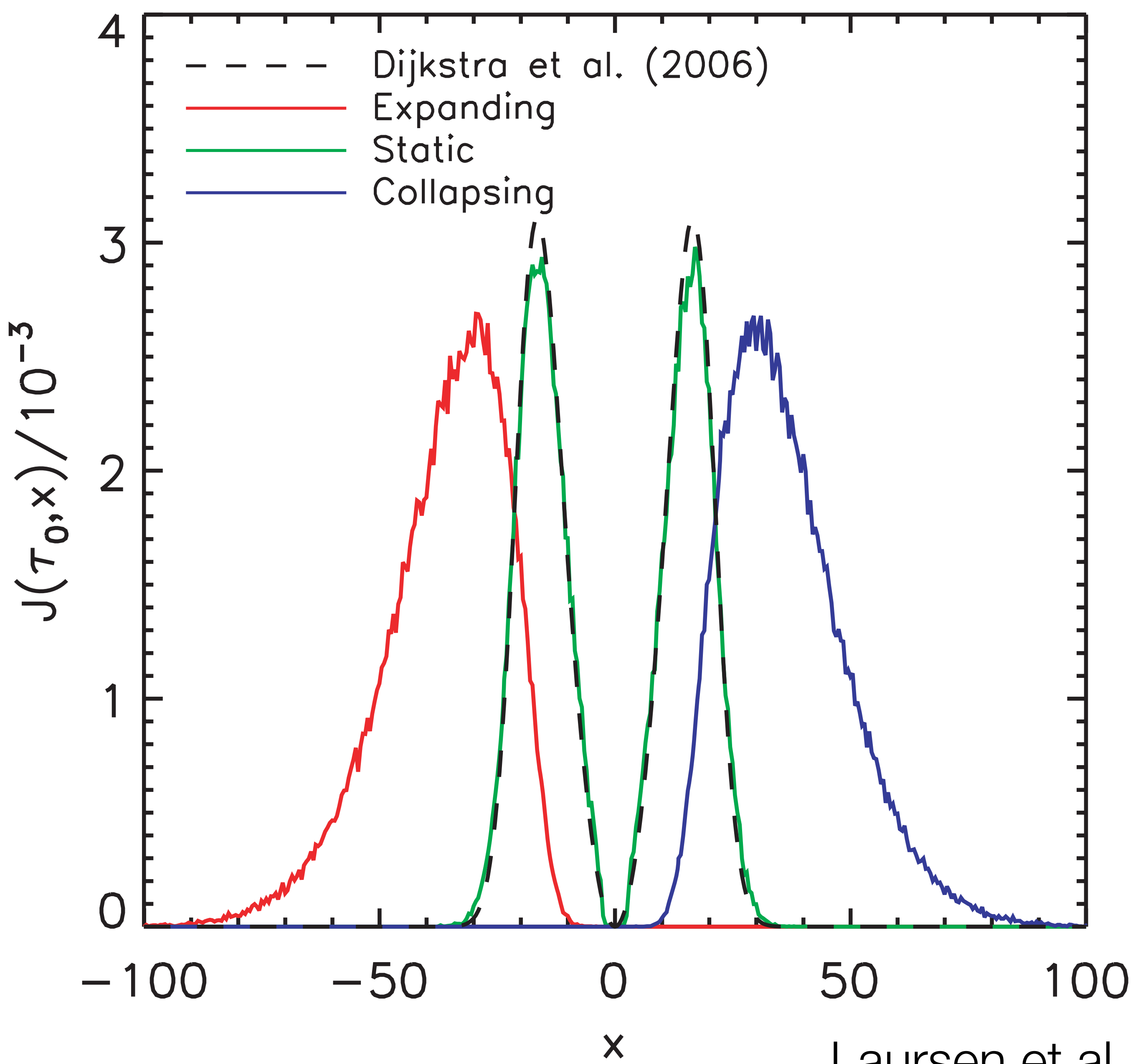


Dijkstra 2014

Probing the ionization & thermal state of the IGM

frequency diffusion of Lyman-α photons

- Lyman-α emitters:
  - line usually redshifted with respect to systemic velocity



Laursen et al. 2009

Probing the ionization & thermal state of the IGM

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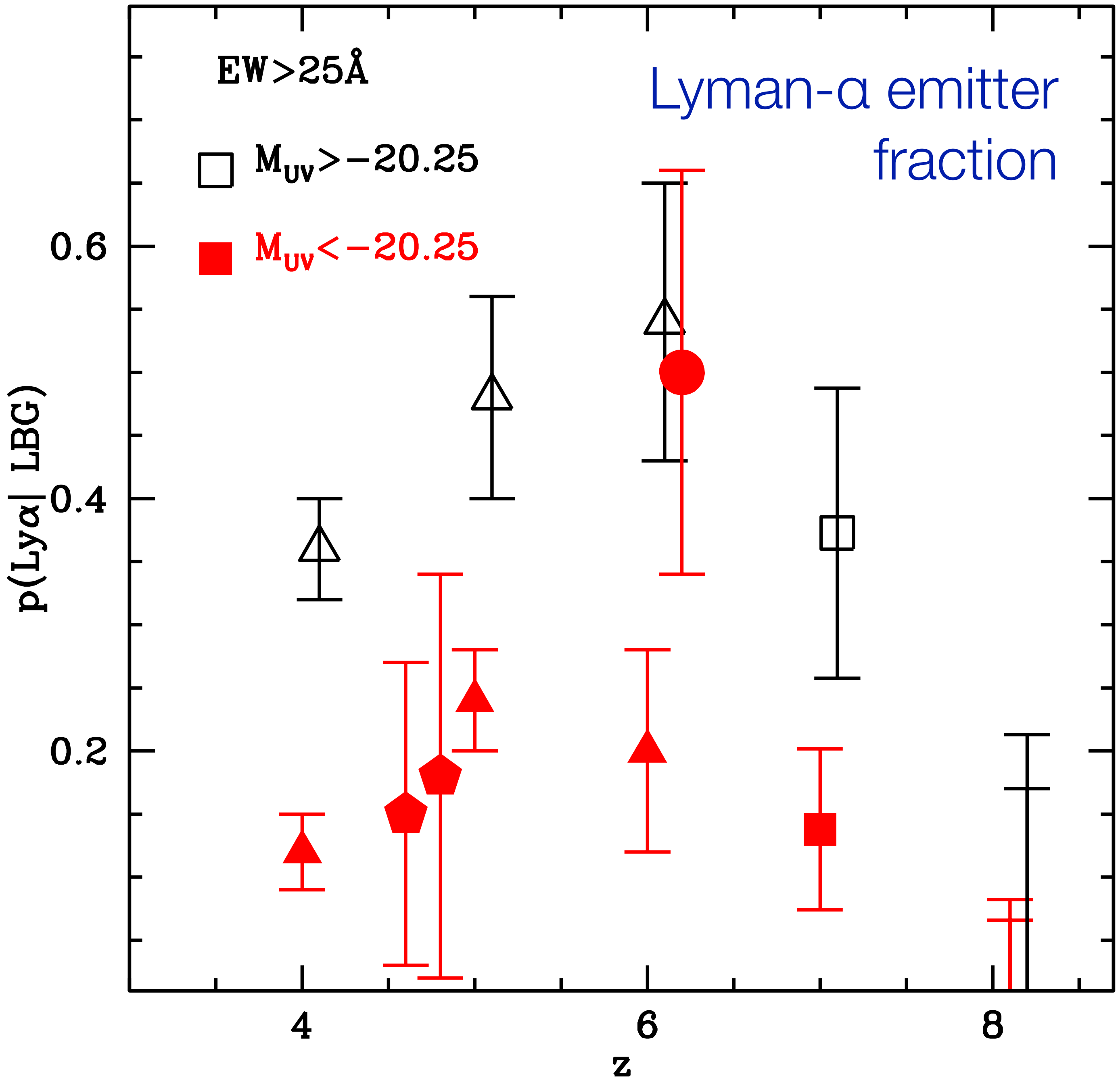


Treu et al. 2013

Semi-numerical models of reionization

- semi-numerical models based on the ionizing photon budget, ionized if:

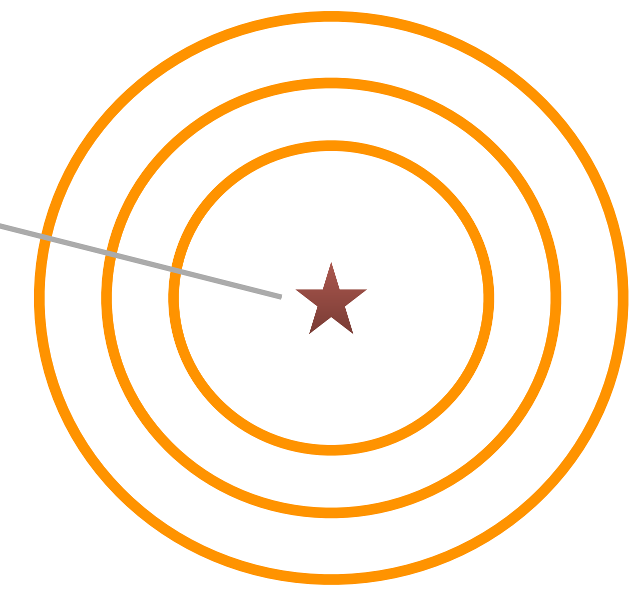
ionizing photons - recombinations > number of hydrogen atoms

- excursion set approach:

check for each point if there is any radius inside which the ionization condition is satisfied

↓ no ↓ not ionized

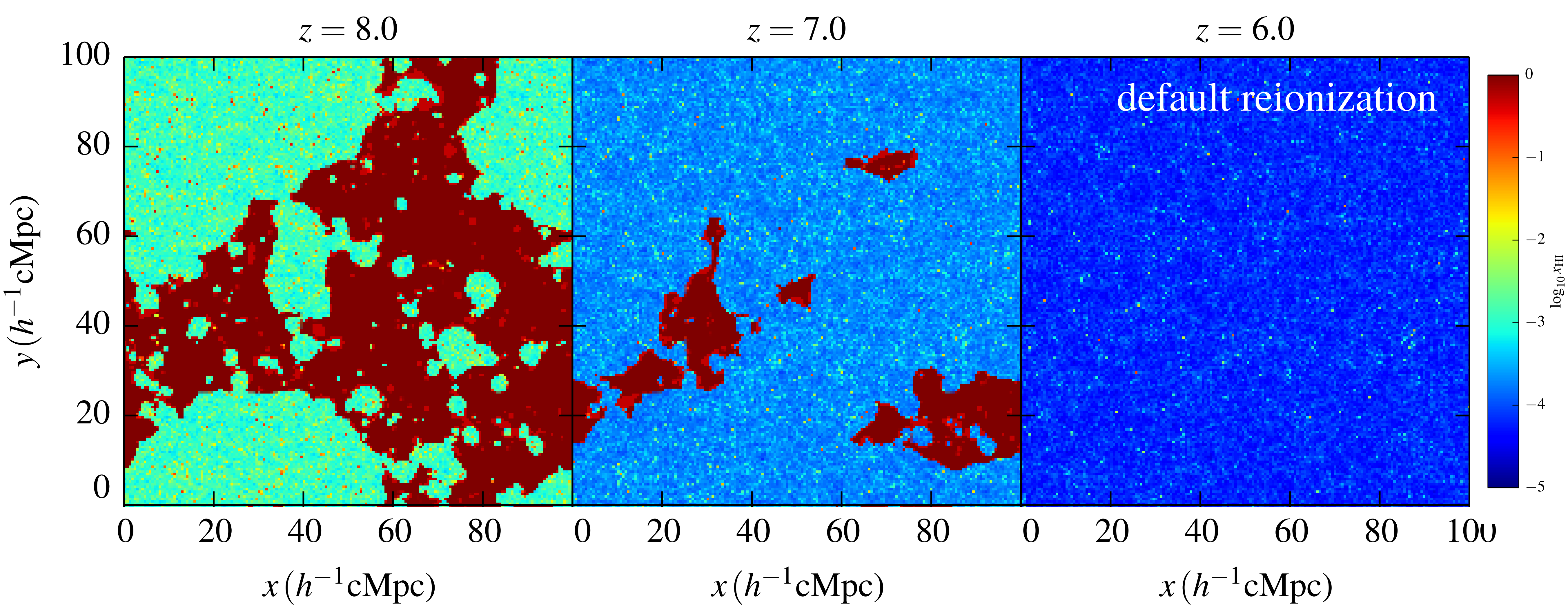
↓ yes ↓ ionized



Semi-numerical reionization in post-processing

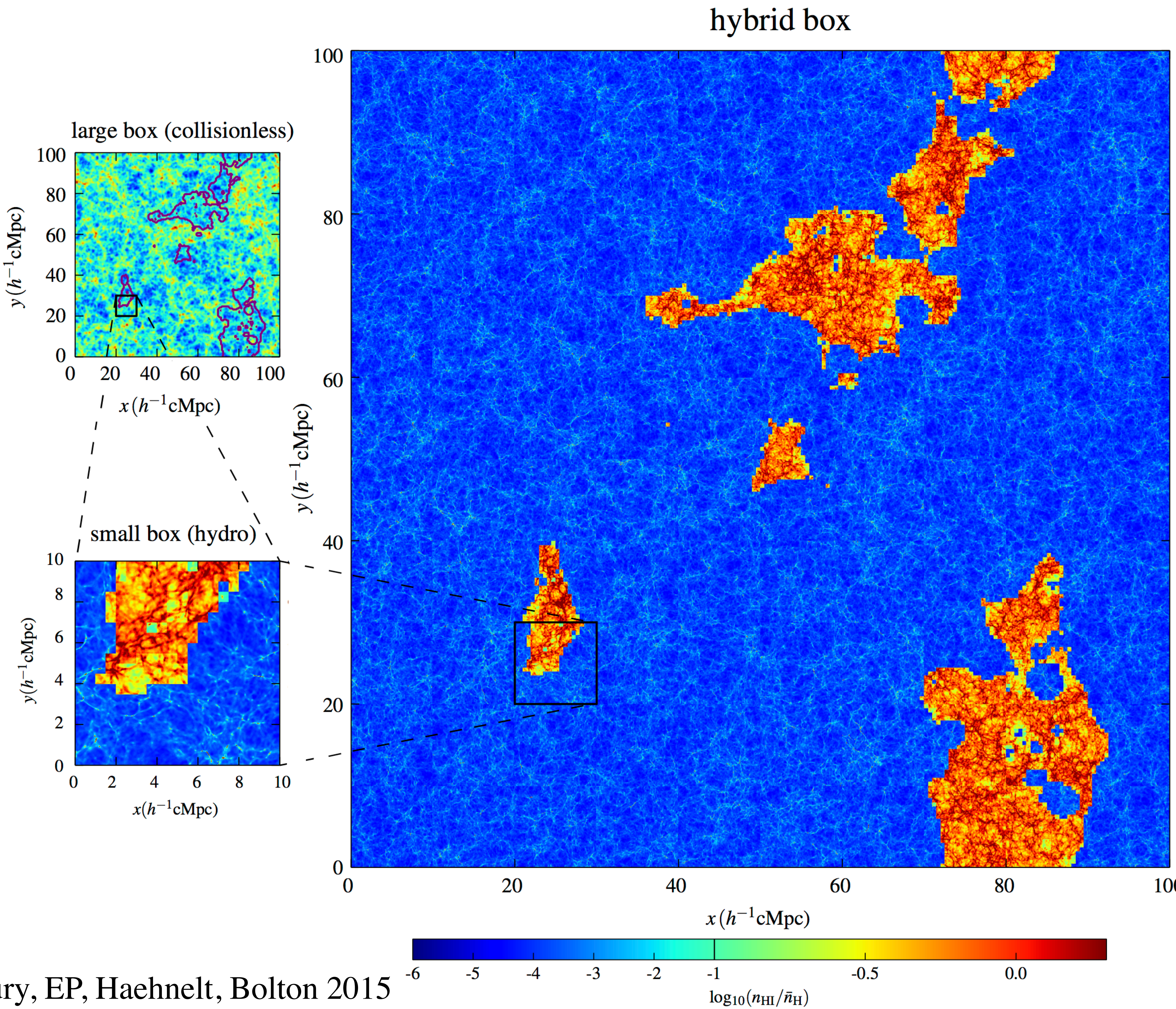
- empirical assignment of ionizing luminosity to halos

  -> get ionized regions in post-processing from simulations



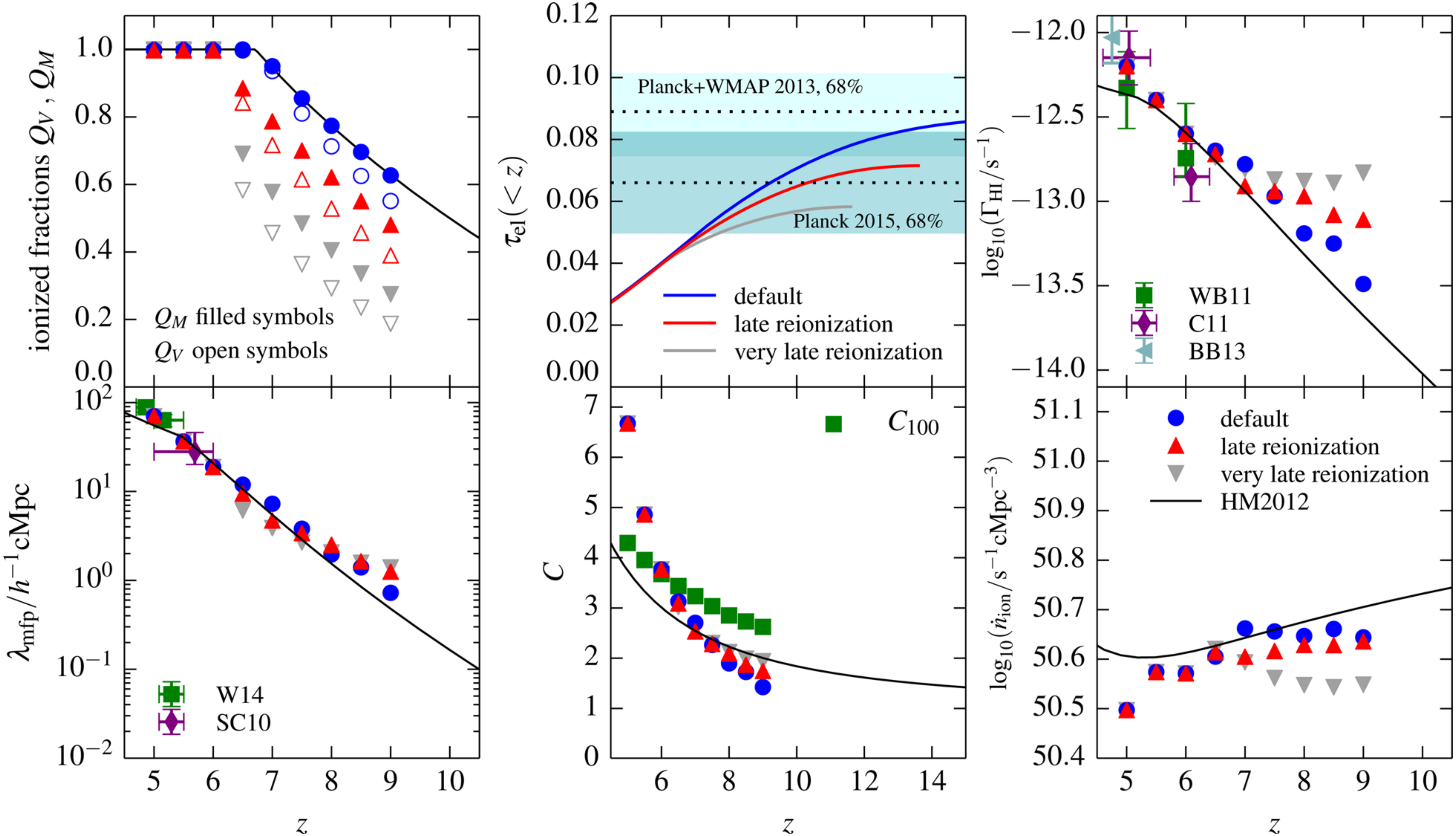
Choudhury, EP, Haehnelt, Bolton 2015

hybrid technique combining large and small box



Choudhury, EP, Haehnelt, Bolton 2015

Iterative calibration of the photoionization rate



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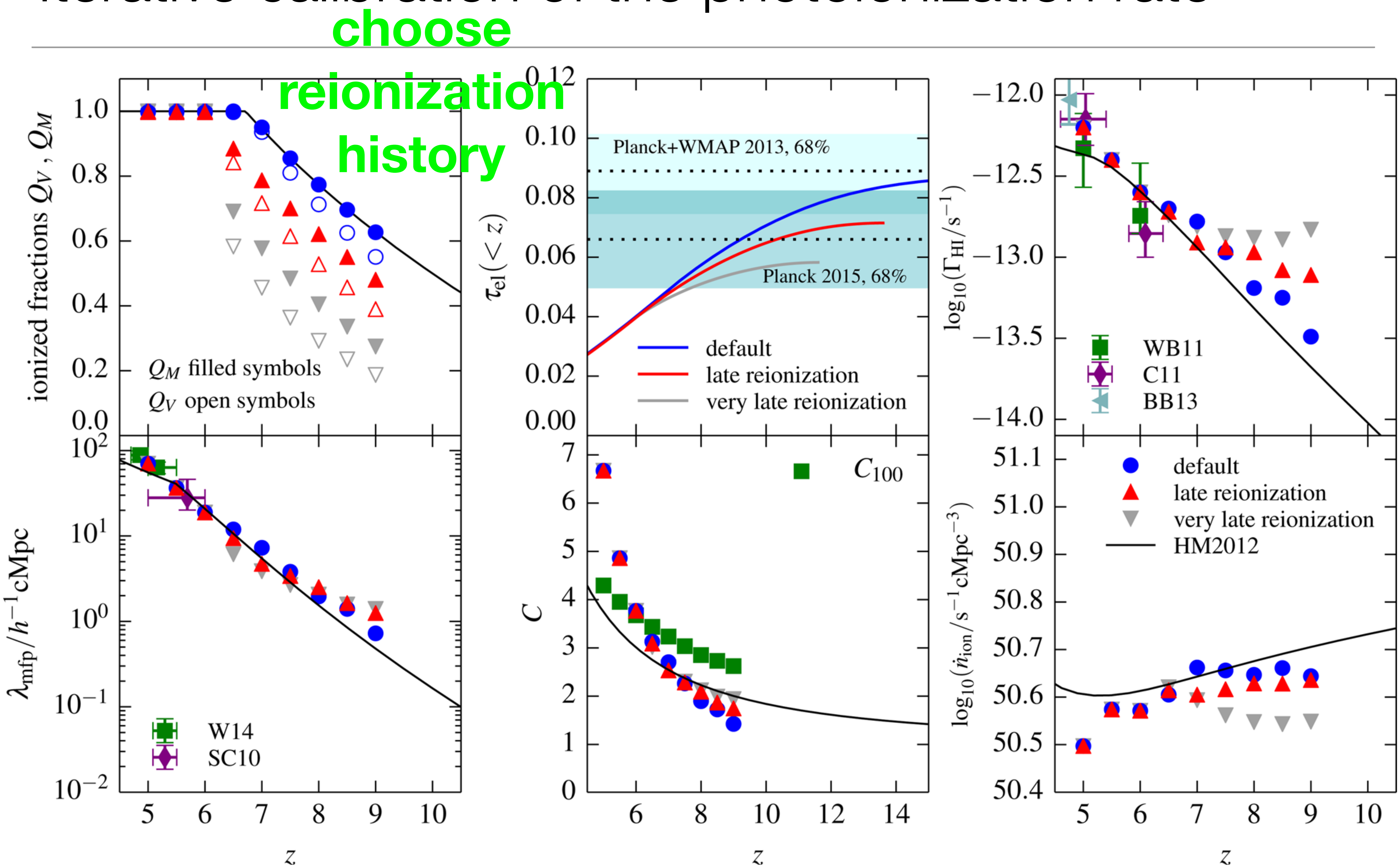

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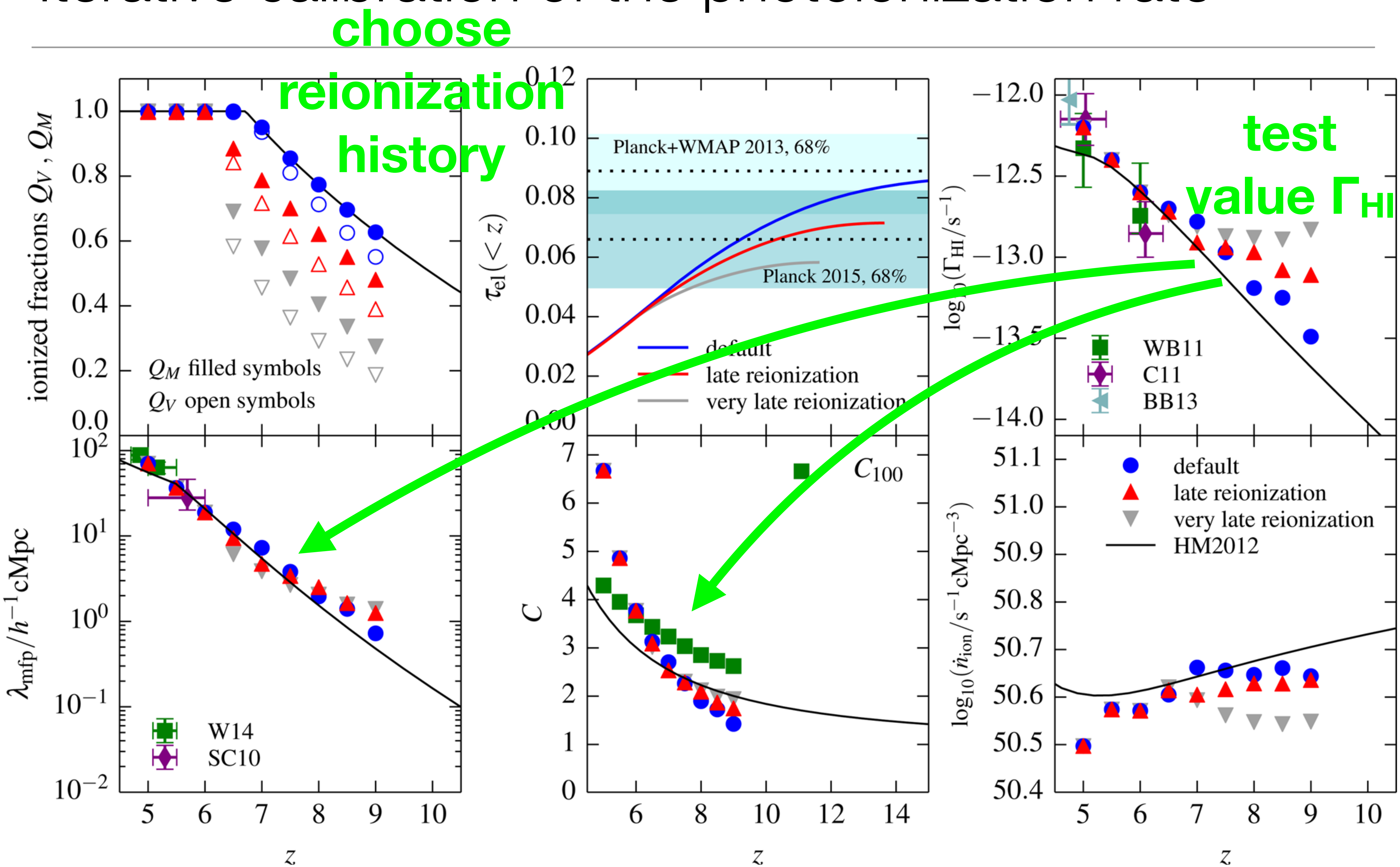

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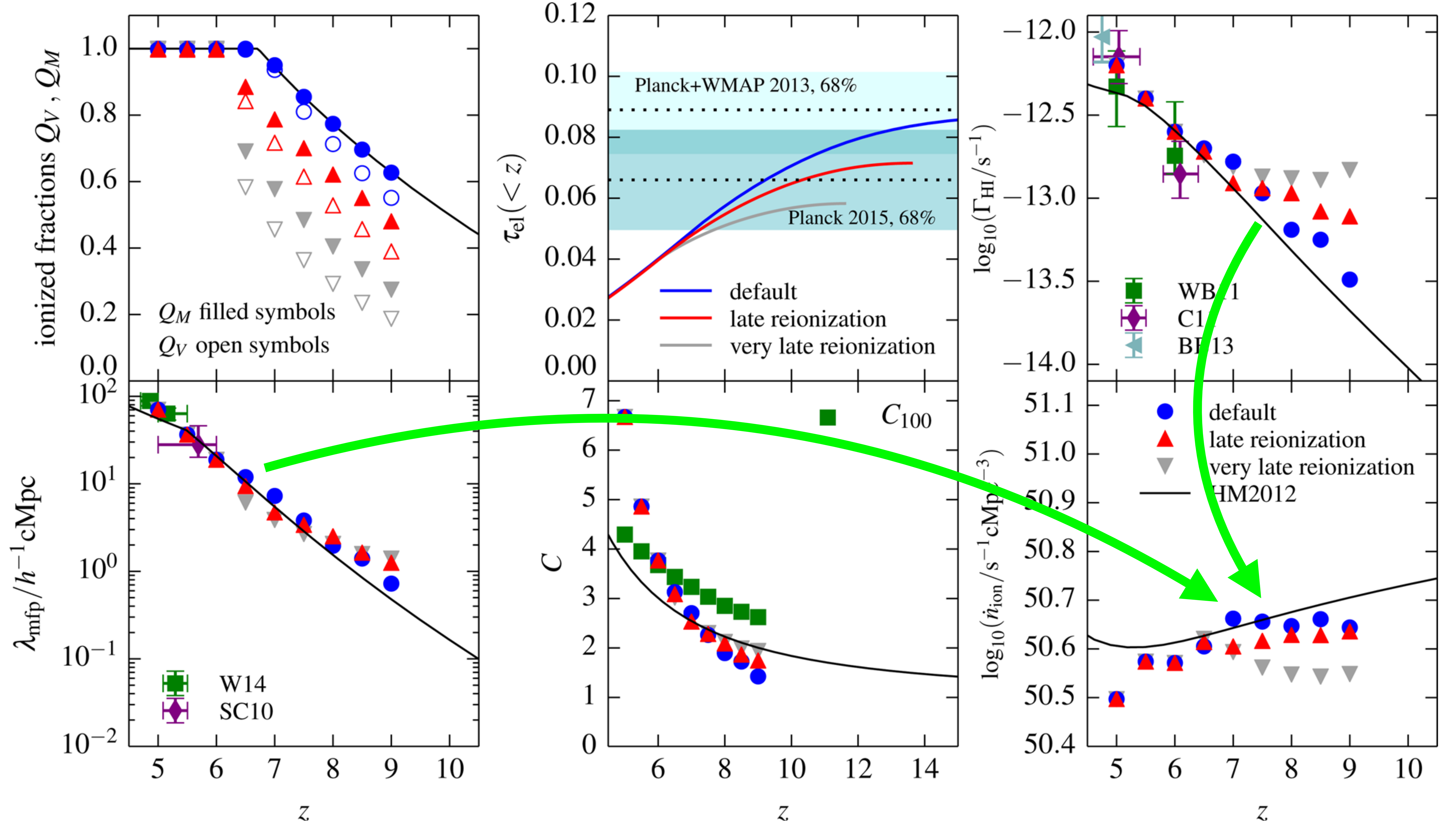

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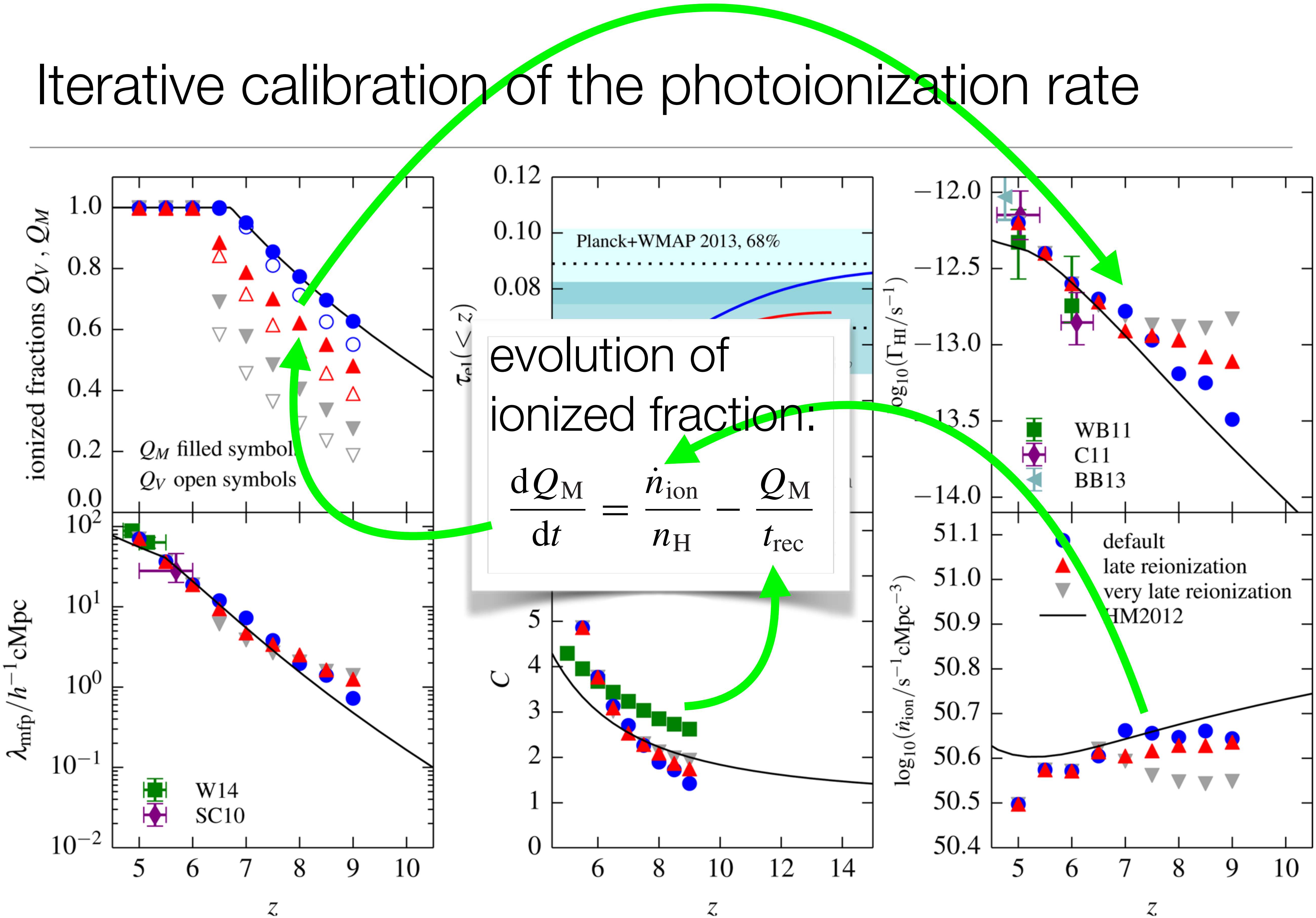

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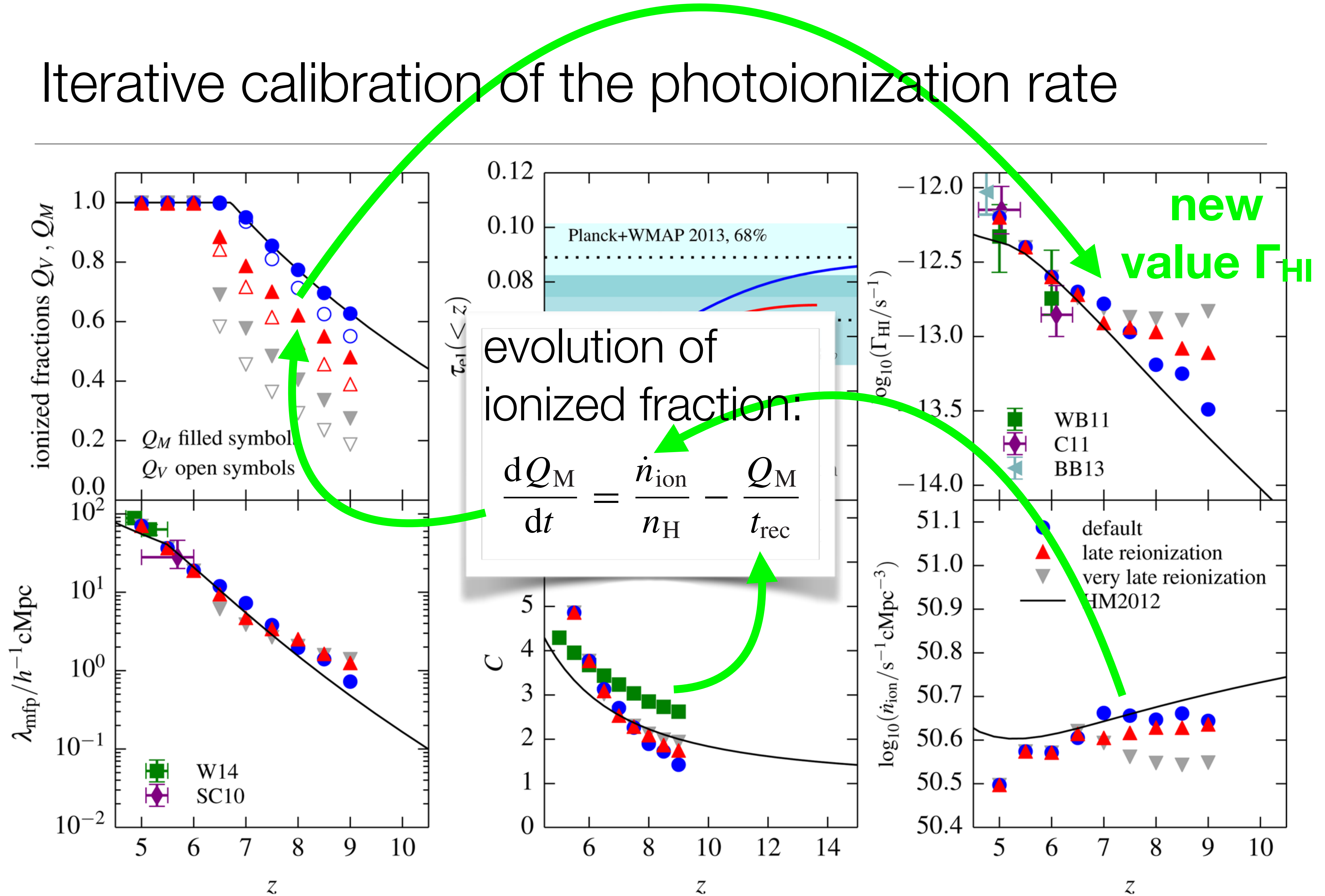
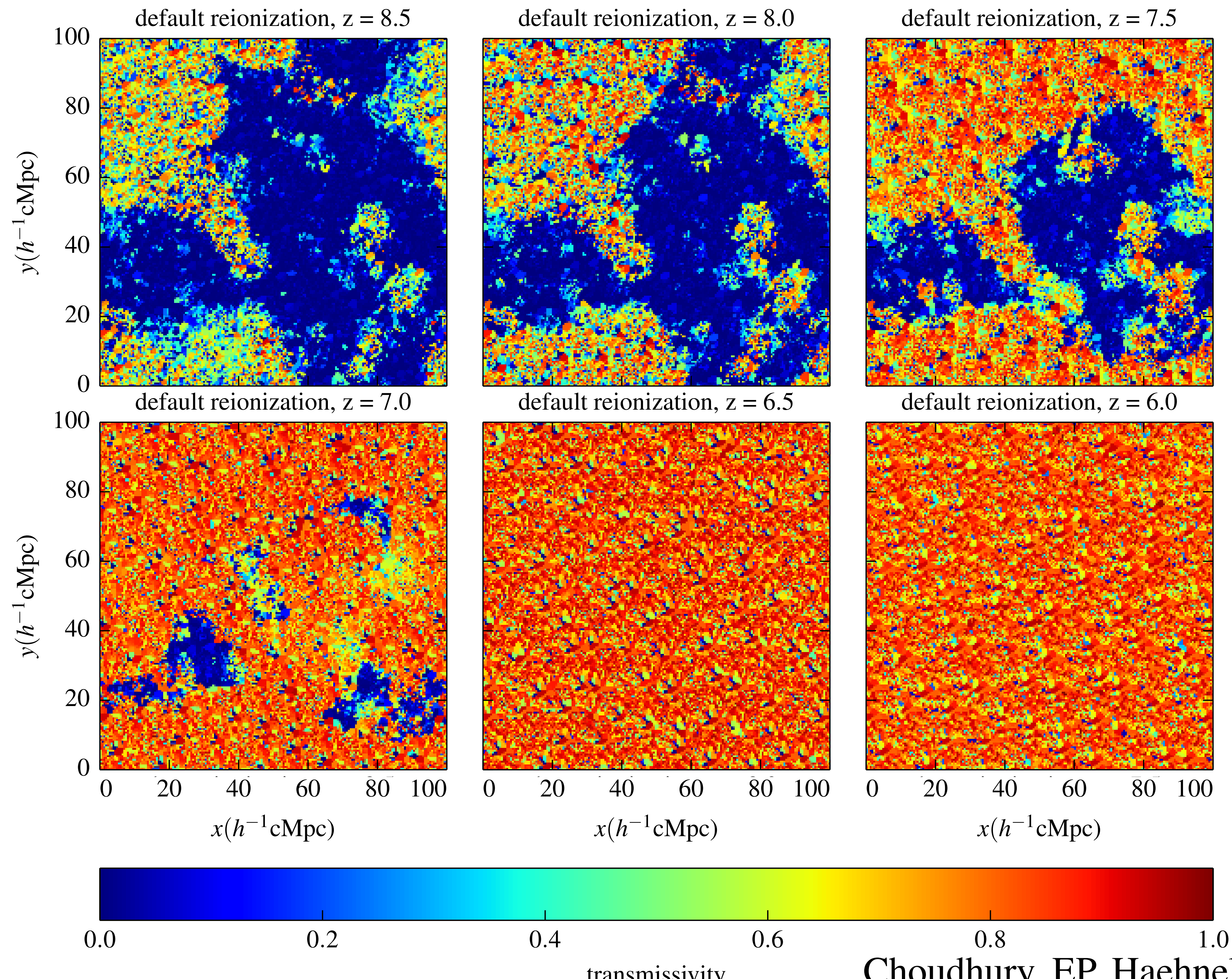


Choudhury, EP, Haehnelt, Bolton 2015

Transmissivity for Lyman-α emission lines



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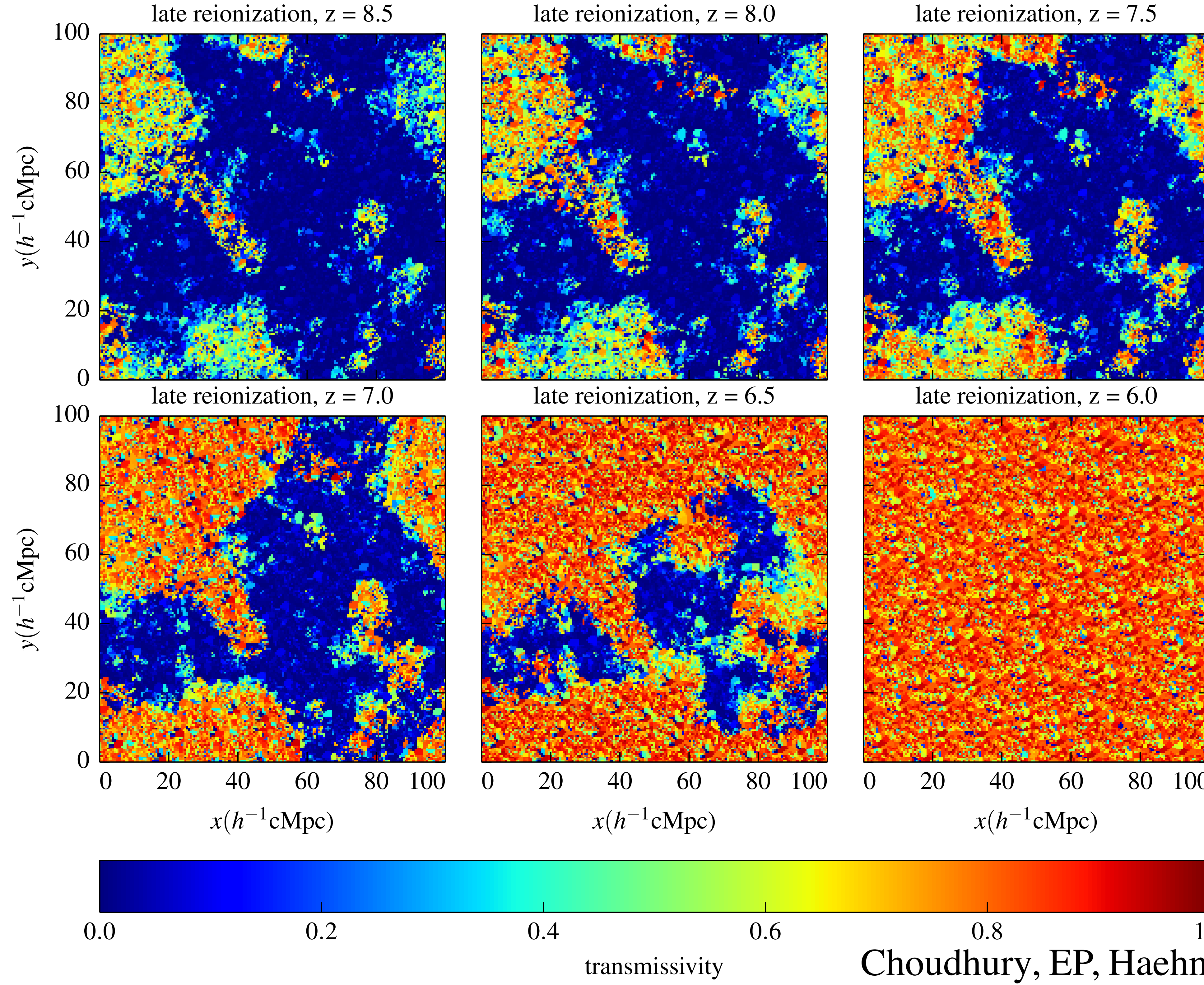
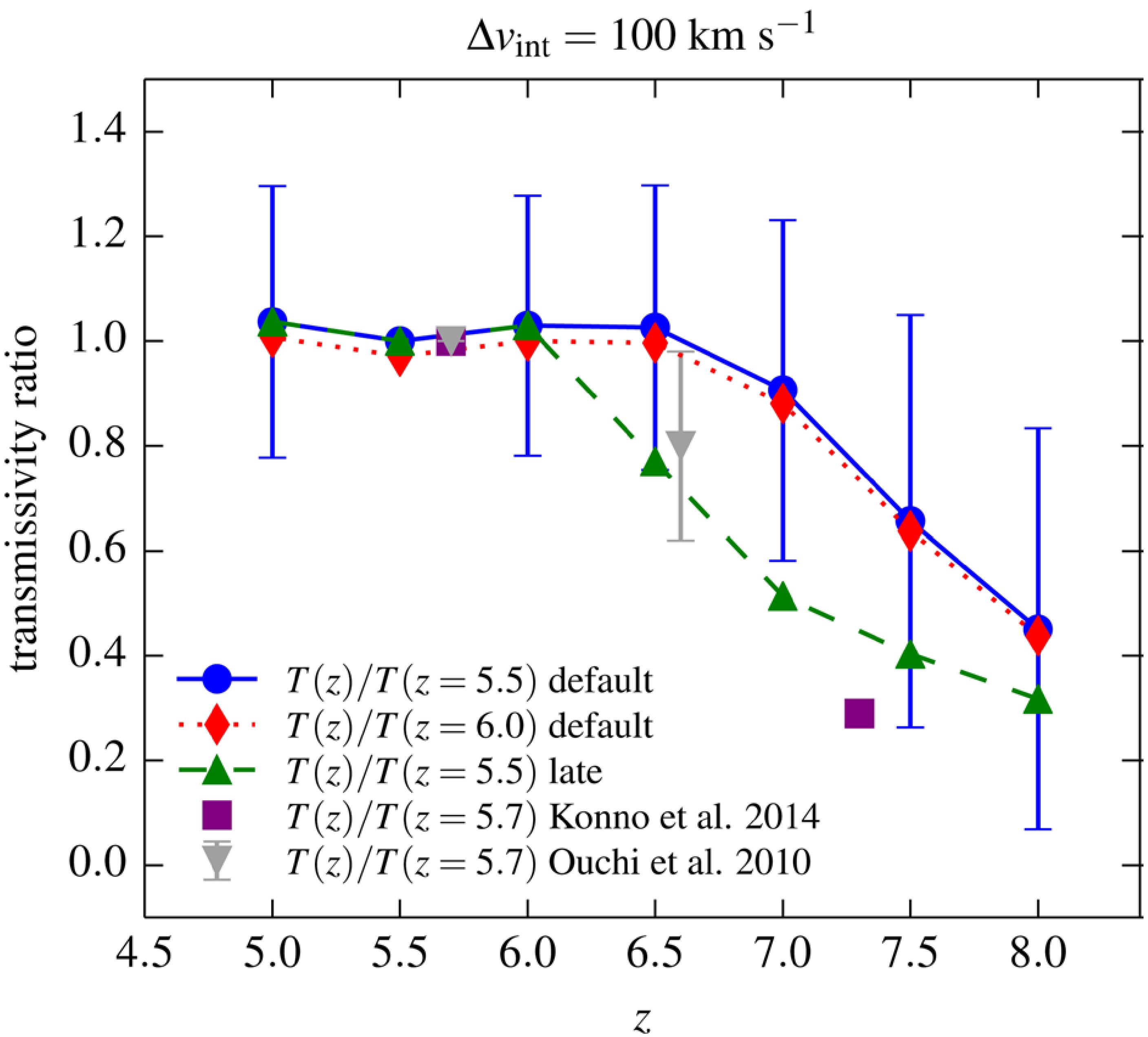


Choudhury, EP, Haehnelt, Bolton 2015

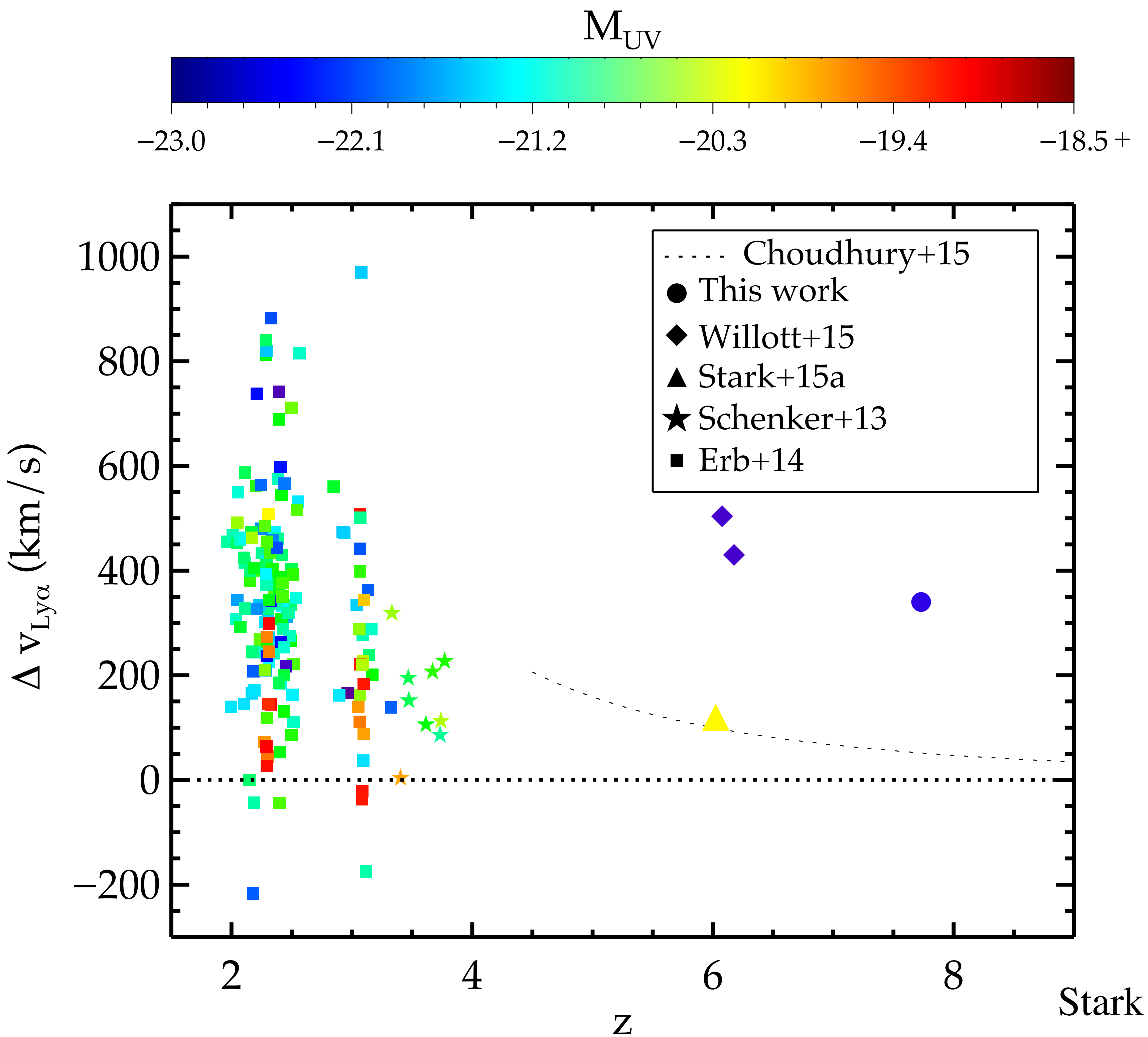
Redshift evolution of the transmissivity

constant velocity
shift



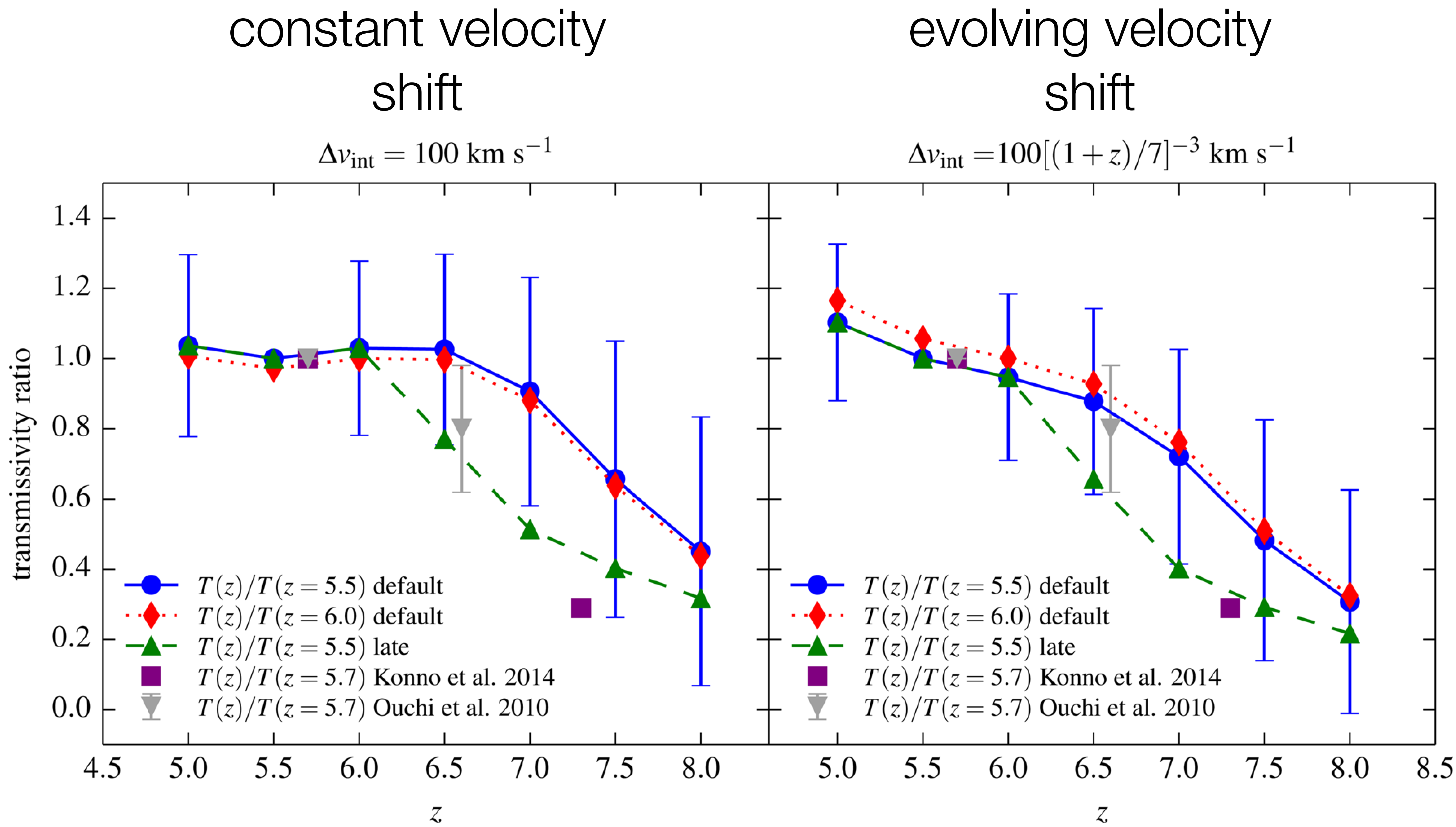
Choudhury, EP, Haehnelt, Bolton 2015

Intrinsic velocity shift vs redshift and luminosity



Stark et al. 2016

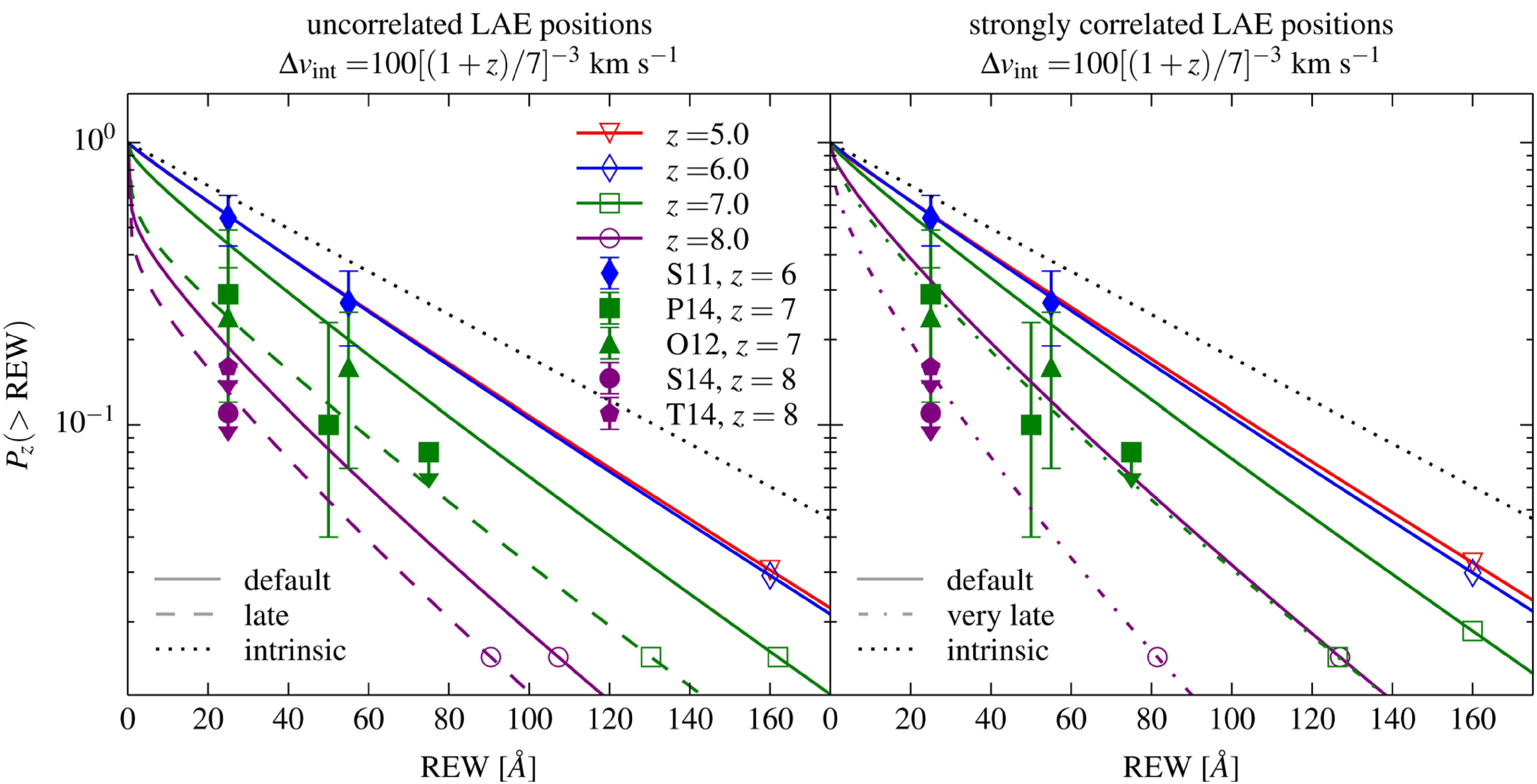
Redshift evolution of the transmissivity



Choudhury, EP, Haehnelt, Bolton 2015

Cumulative Lyman-α equivalent width distribution

evolving velocity shift



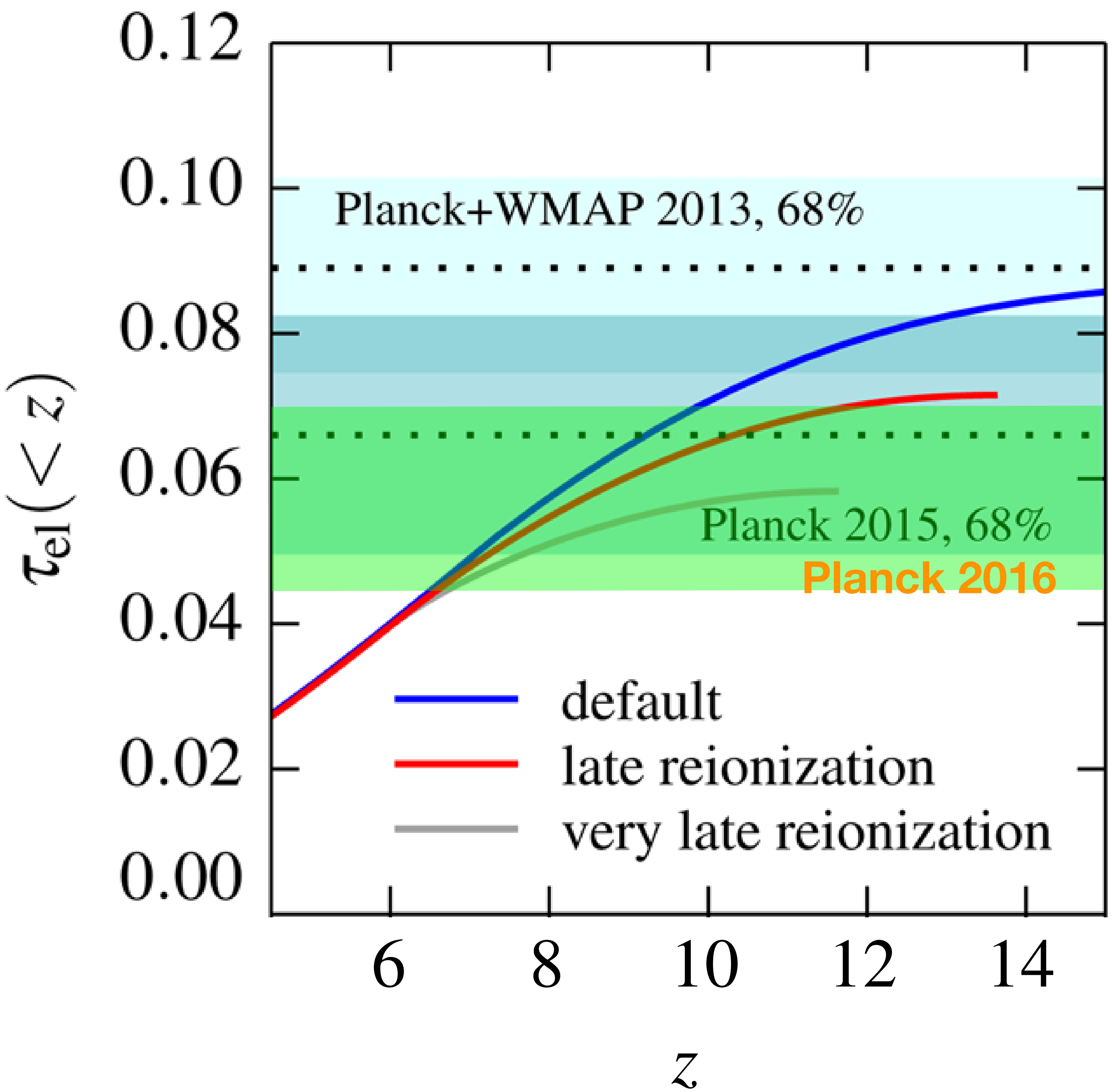
Choudhury, EP, Haehnelt, Bolton 2015

Consistency with latest Planck constraints

- optical depth in Planck 2015/16 came down
- consistent with what we need for the Lyman-α emitters

  -> reionization ends around z~6 and is not too extended

Thomson scattering optical depth



Choudhury, EP, Haehnelt, Bolton 2015

Summary

- **Lyman-α emitters:**
    - favour a late and not too extended reionization history (finishing at z~6)
    - evolution of intrinsic velocity offsets may be important
- **CMB:**
    - Planck 2015/16 find lower optical depths -> late reionization in agreement with LAEs