Sub-grid modeling of EoR physics

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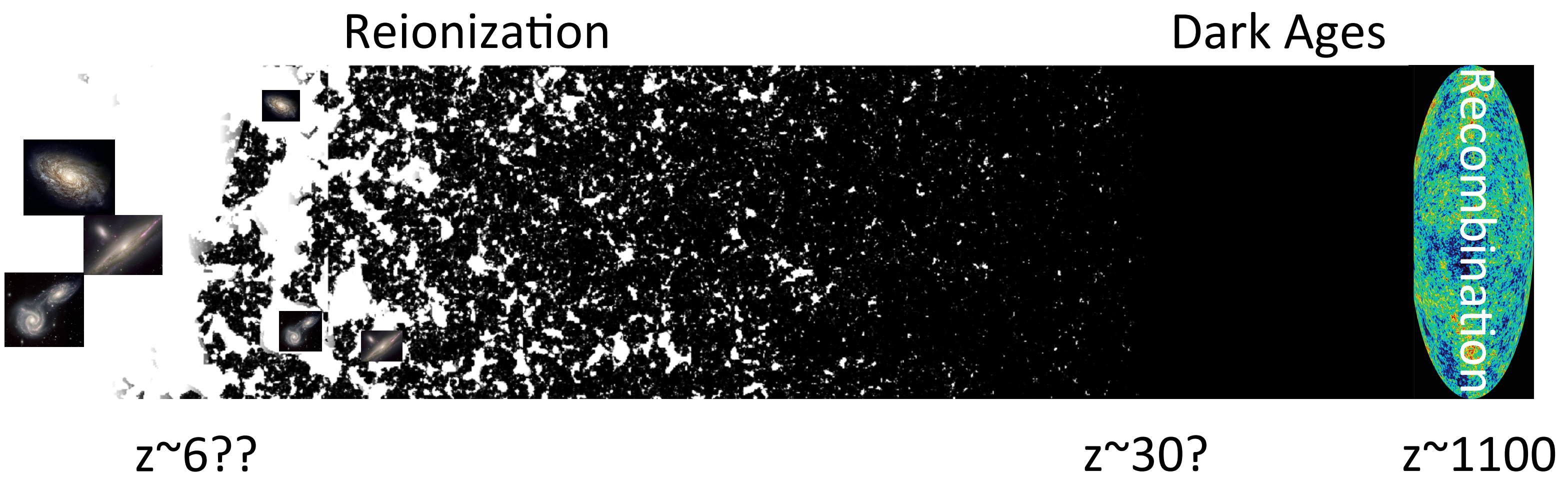
Scuola Normale Superiore, Pisa

(Sobacchi & Mesinger 2013ab; Sobacchi & Mesinger 2014)

Cosmic History and EoR



- Bulk of our light cone. Undiscovered frontier!
- One of the two important phase transitions: affected the vast majority of baryons.
- Only practical way of studying the high-z galaxy population, since most are too faint for direct observations
- Testbed for exciting early Universe physics
- Practical: many billions of € and $ devoted to observations of these epochs: 1 of 3 science goals stressed by the Decadal Survey of the US National Academies
- Theoretical progress is needed to confront upcoming observations!

Story of Sources and Sinks

Sources

UVB photo-heating feedback

- UVB heats the gas suppressing accretion on small halos
- Emissivity decreases

Sinks

Photon sinks

- High-density regions self-shield
- Photons lost to balance recombinations

↓

Reionization is delayed

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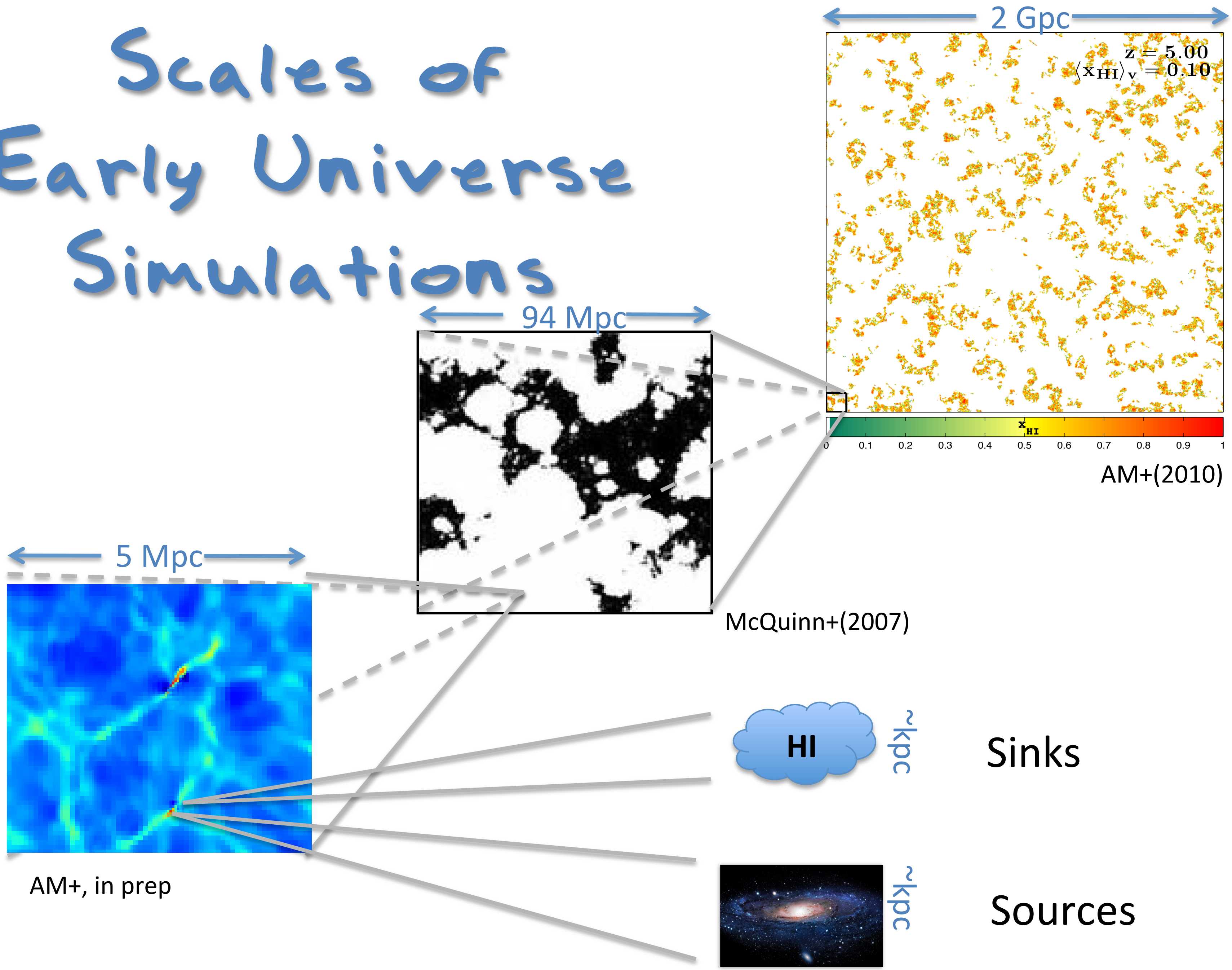
Inhomogeneous process: morphology changes

Scales of Early Universe Simulations



Sub-grid approach

Range of scales

- Box size $>$ 100s Mpc to model reionization
- Resolution $<$ kpc to model UVB feedback on sources and sinks

Not achievable with current RT simulations
(resolution $0.1 - 1$ Mpc)

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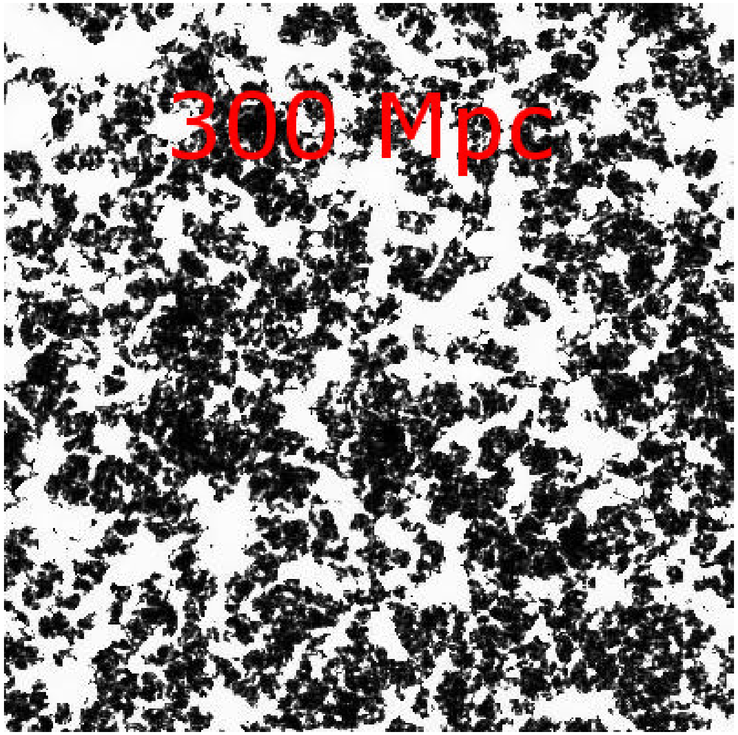
Sub-grid modelling

Large-scale reionization sims



21cmFAST (Mesinger + 2011)

A region is ionized if (e.g. Furlanetto + 2004)

integrated emissivity > recombinations per baryon

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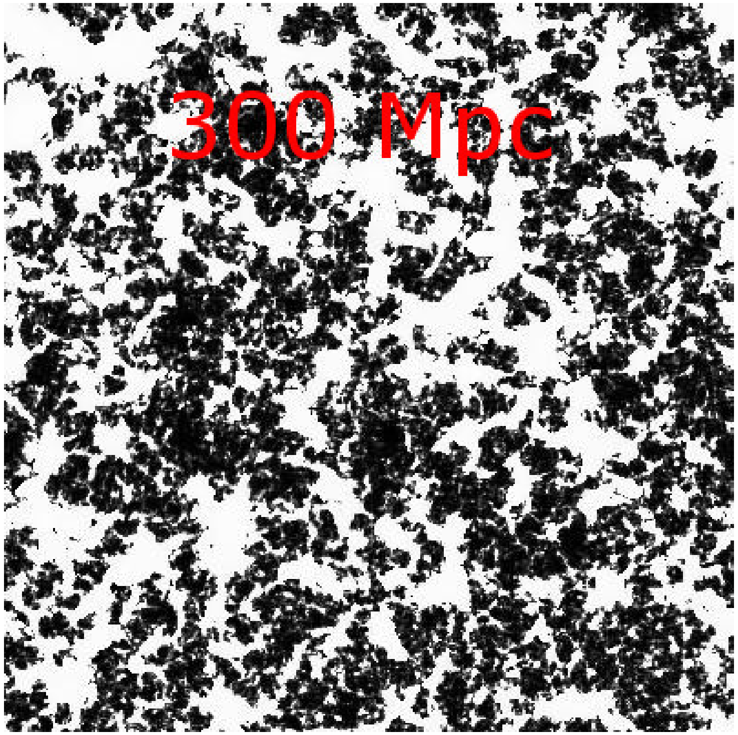

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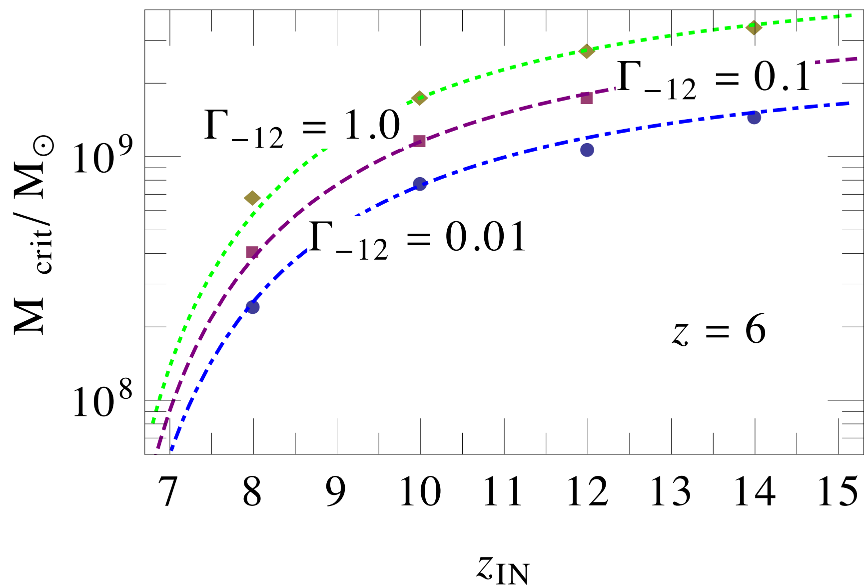
- emissivity: UVB feedback
- recombinations: sinks

Parameterized, local UVB feedback

UVB feedback (Sobacchi & Mesinger 2013)

- $M_{\rm crit}$: minimum mass of star-forming halos
- 1D simulations (confirmed by 3D; Noh & McQuinn 2014)
- Follow the **history of each cell**: $M_{\rm crit} = M_{\rm crit}\,(\Gamma_{\rm UVB}, z, z_{\rm IN})$



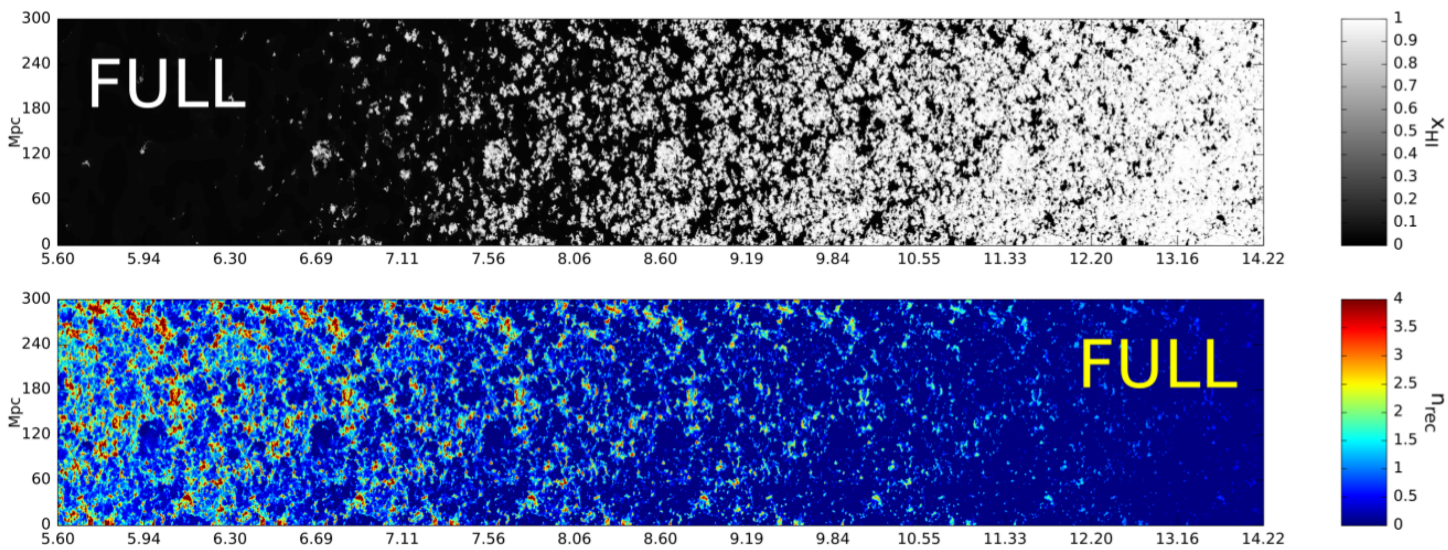
Parameterized, local sinks evolution

Sinks (Miralda-Escudé + 2000; Rahmati + 2013)

Recombination rate at Δ depends on **self-shielding**:

$\dot{n}_{\rm rec} = \int P(\Delta)\, \dot{n}_{\rm rec}(\Gamma_{\rm UVB}, z, \Delta)$

Follow the **history of each cell**: $n_{\rm rec} = \int_{z_{\rm IN}}^{z} \dot{n}_{\rm rec}$



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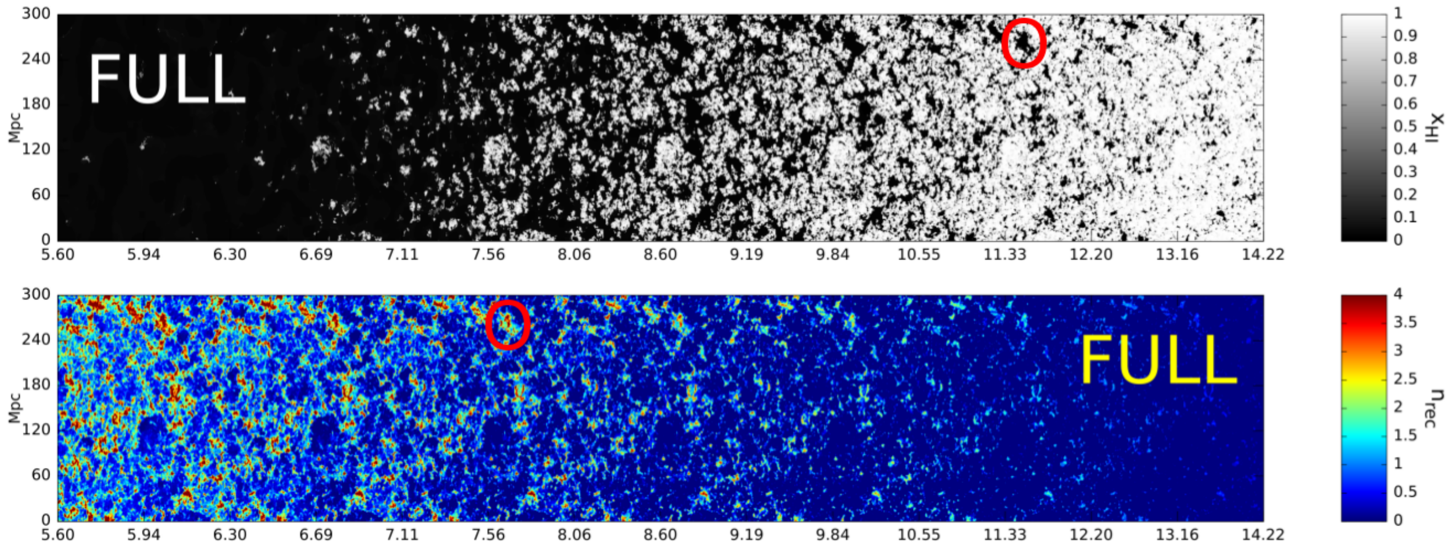

Simple picture

As time passes and an HII region grows

- only very massive halos host stars (high M_{crit}).
- many photons are lost to balance recombinations (high n_{rec}).

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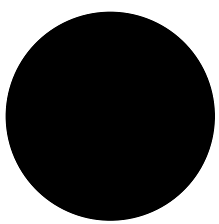

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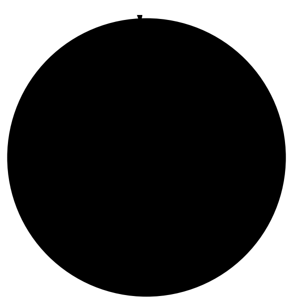

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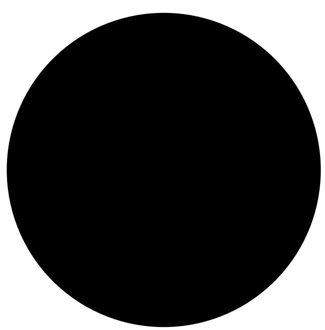

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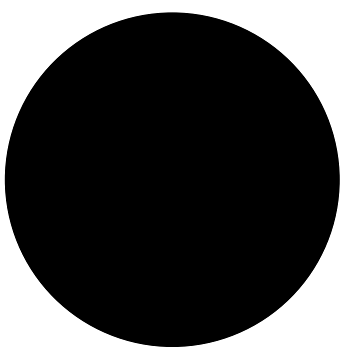

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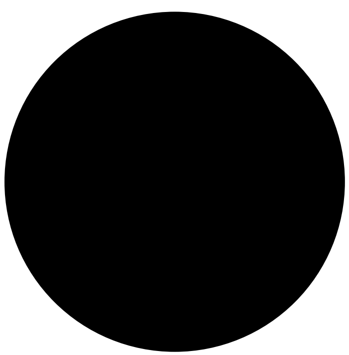

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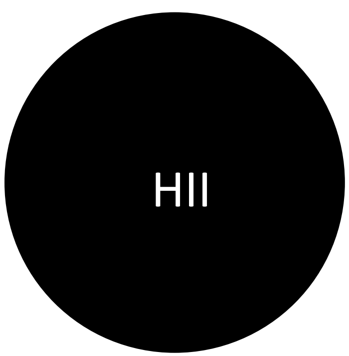

approaches recombination limited growth (e.g. Furlanetto & Oh 2005)

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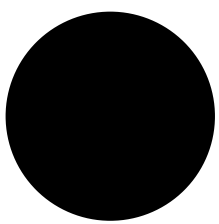

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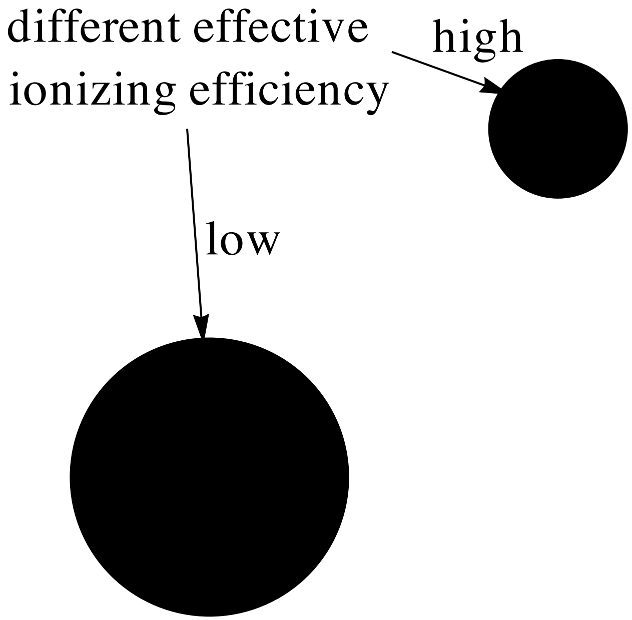

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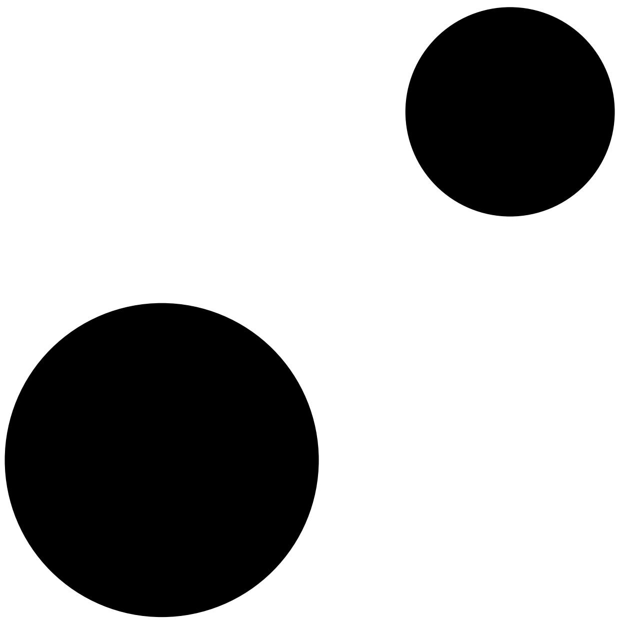

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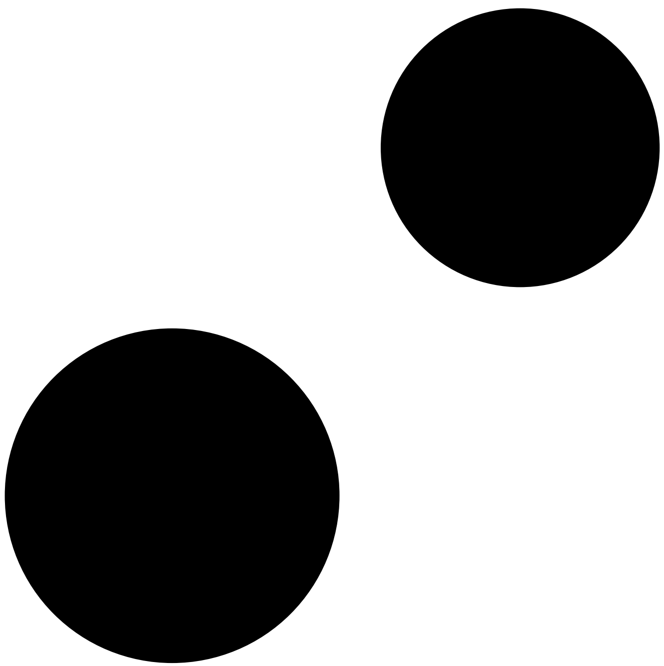

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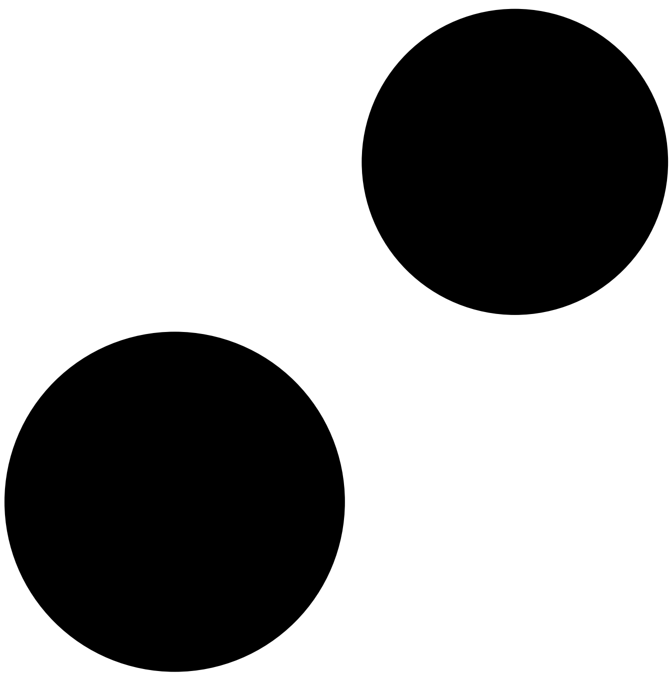

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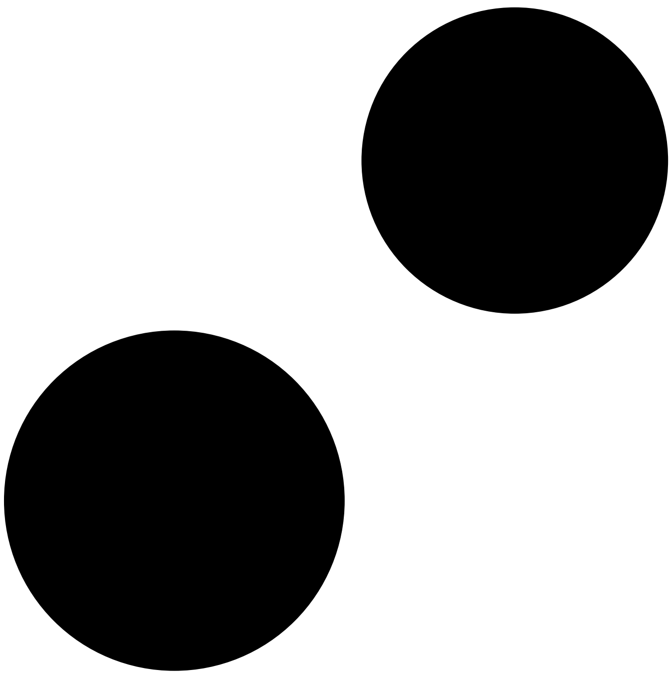

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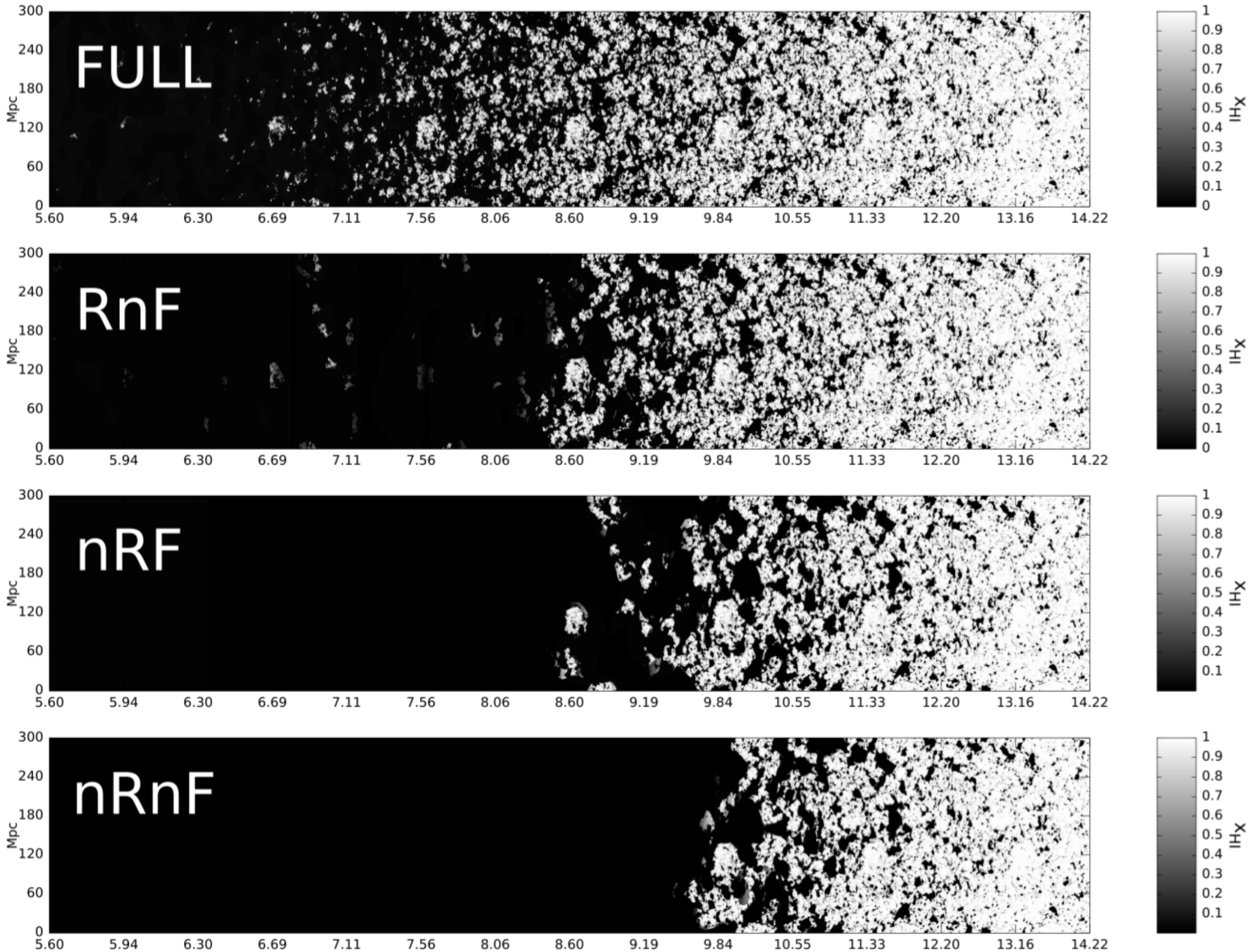
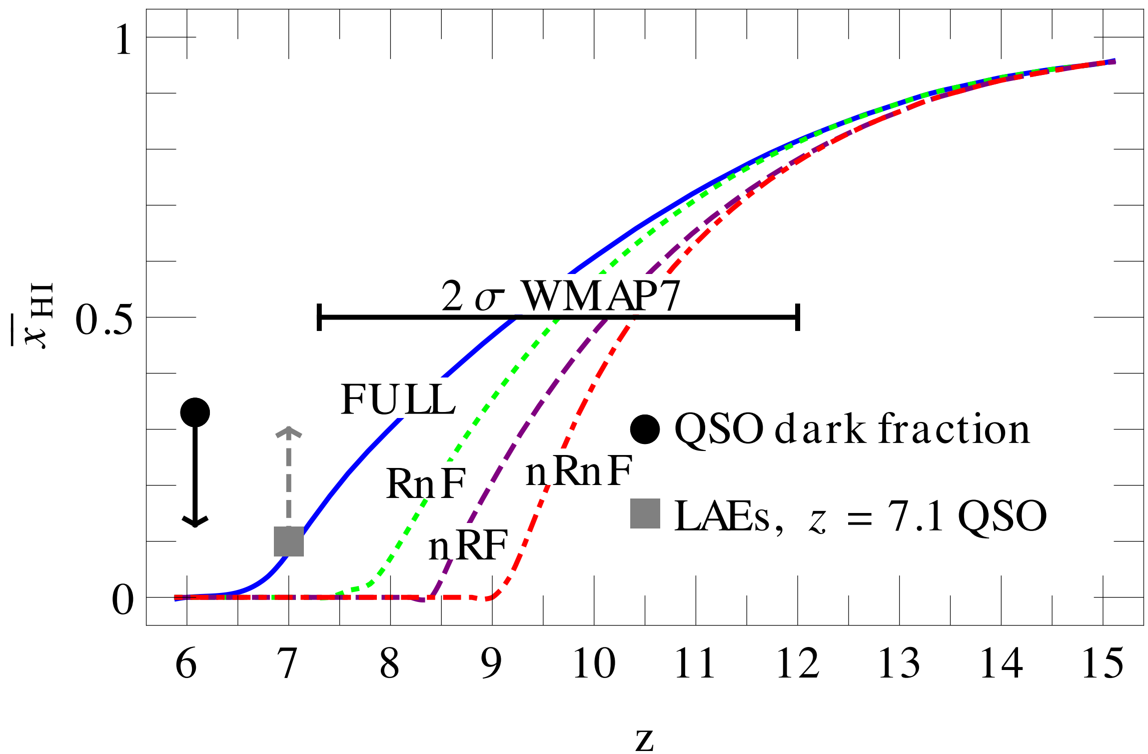
- **Delay** end stages
- **Suppress HII regions**

Morphologies



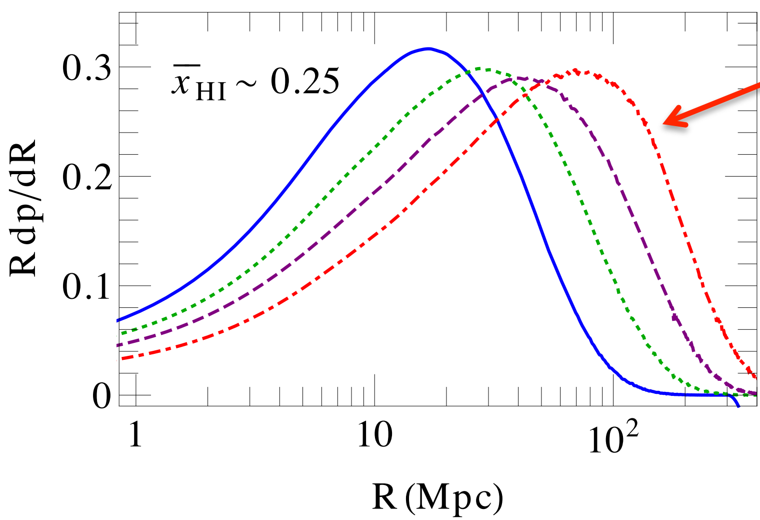
Reionization History

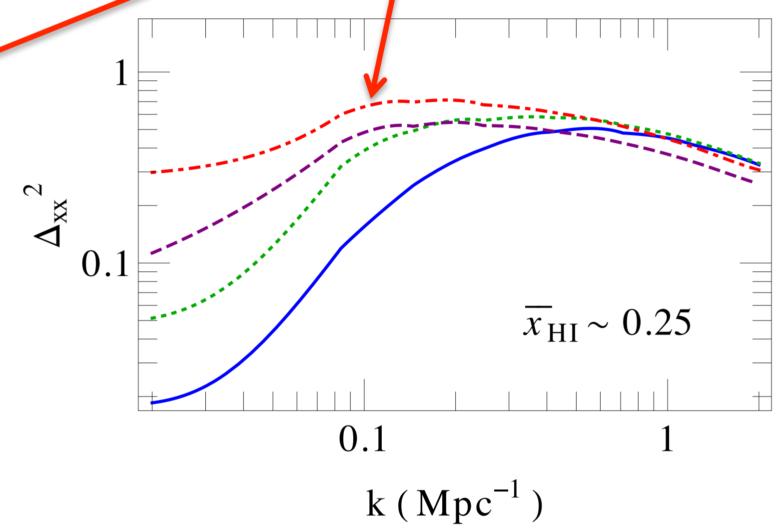
- Large delay of end stages: $\Delta z \sim 2.5$.
- τ_e less affected: FULL consistent within 1σ WMAP.



More uniform reionization morphology

Ignoring sub-grid feedback
(~ most reionization sims)





More uniform reionization morphology

With sub-grid models of sources and sink evolution

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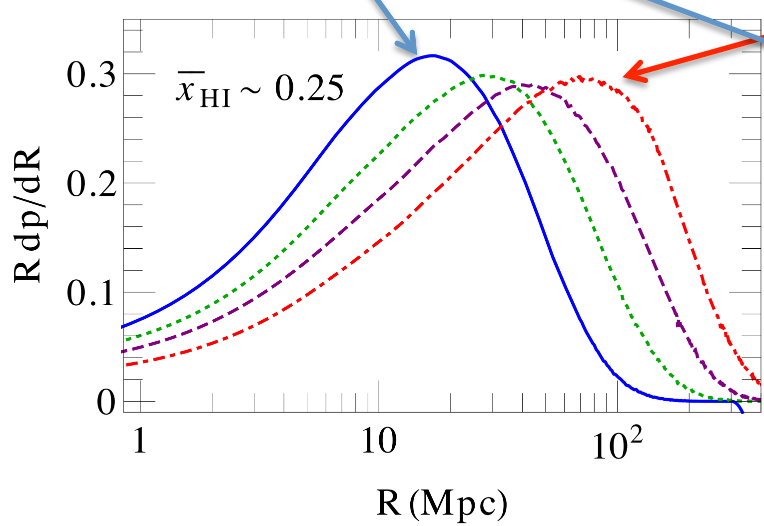

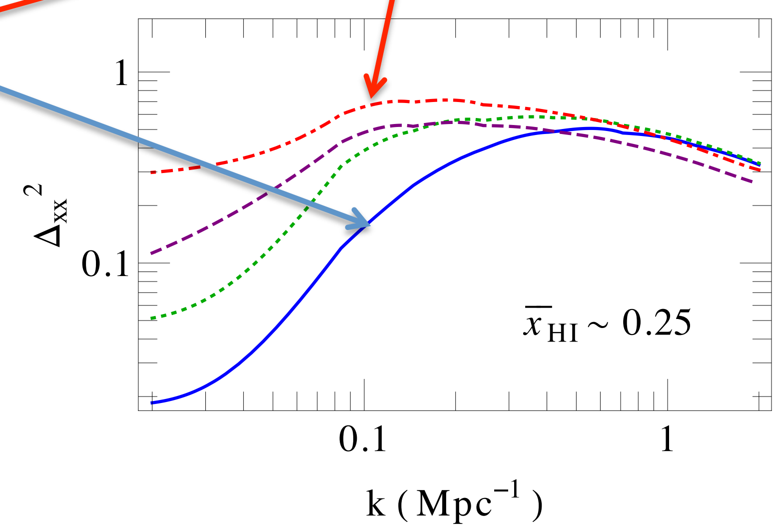

More uniform reionization morphology

Factors of > 2-3 smaller typical HII regions , and more uniform structure

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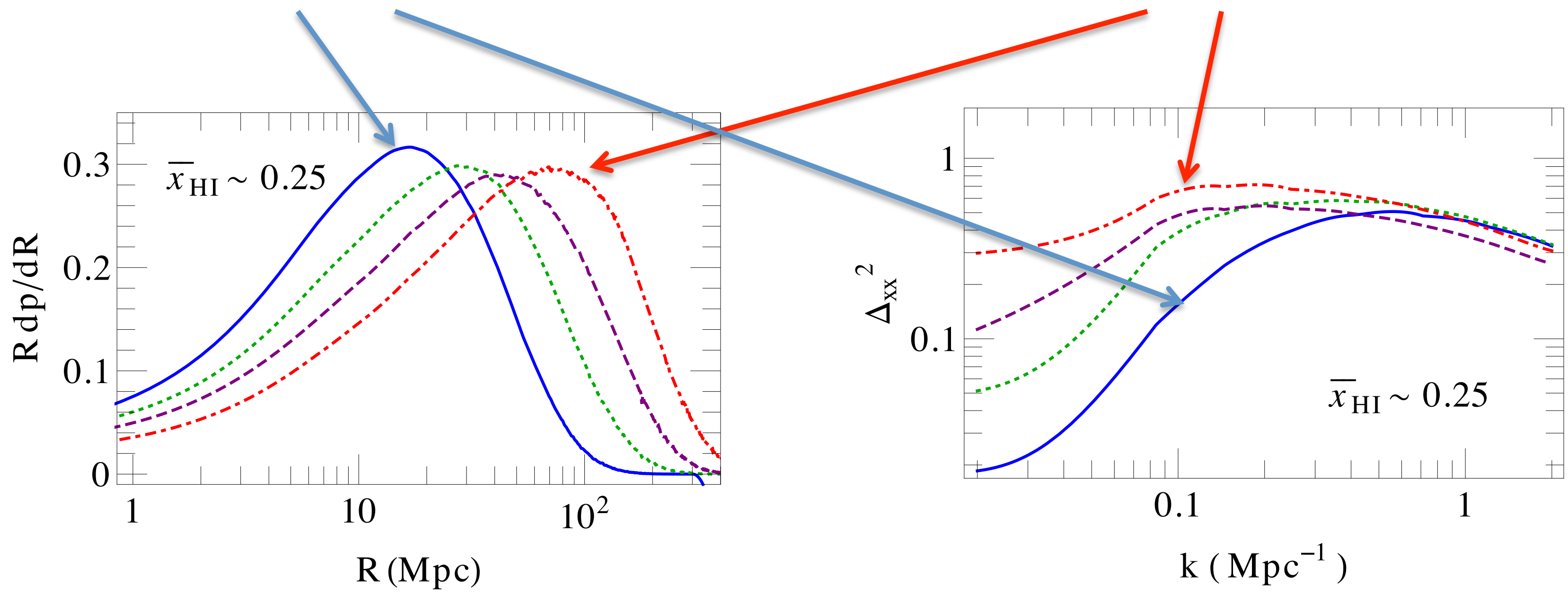
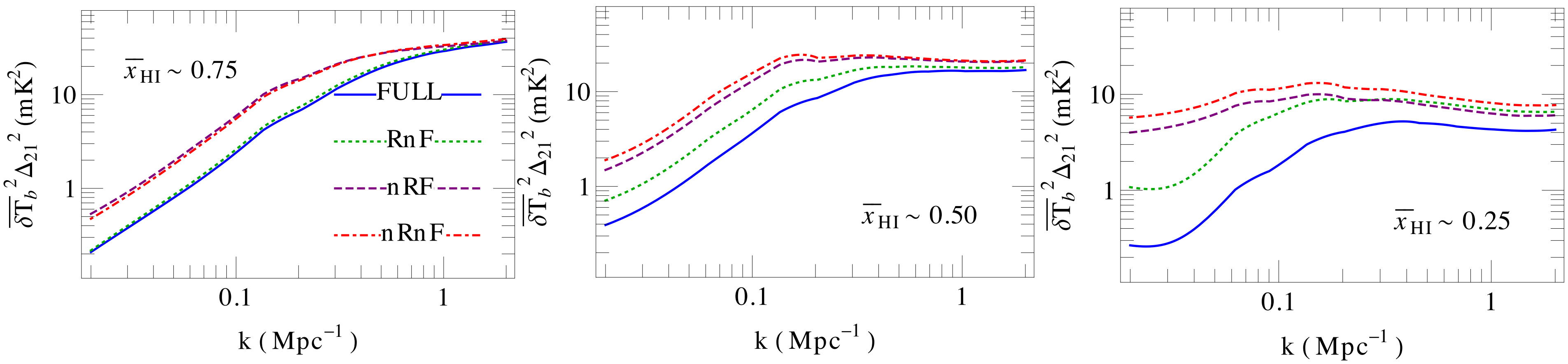


This means the 21cm signal is smaller than expected!



suppression of large-scale 21cm power by factors of >3-5 throughout reionization, and a steeper spectrum(mostly due to inhomogeneous recombinations).

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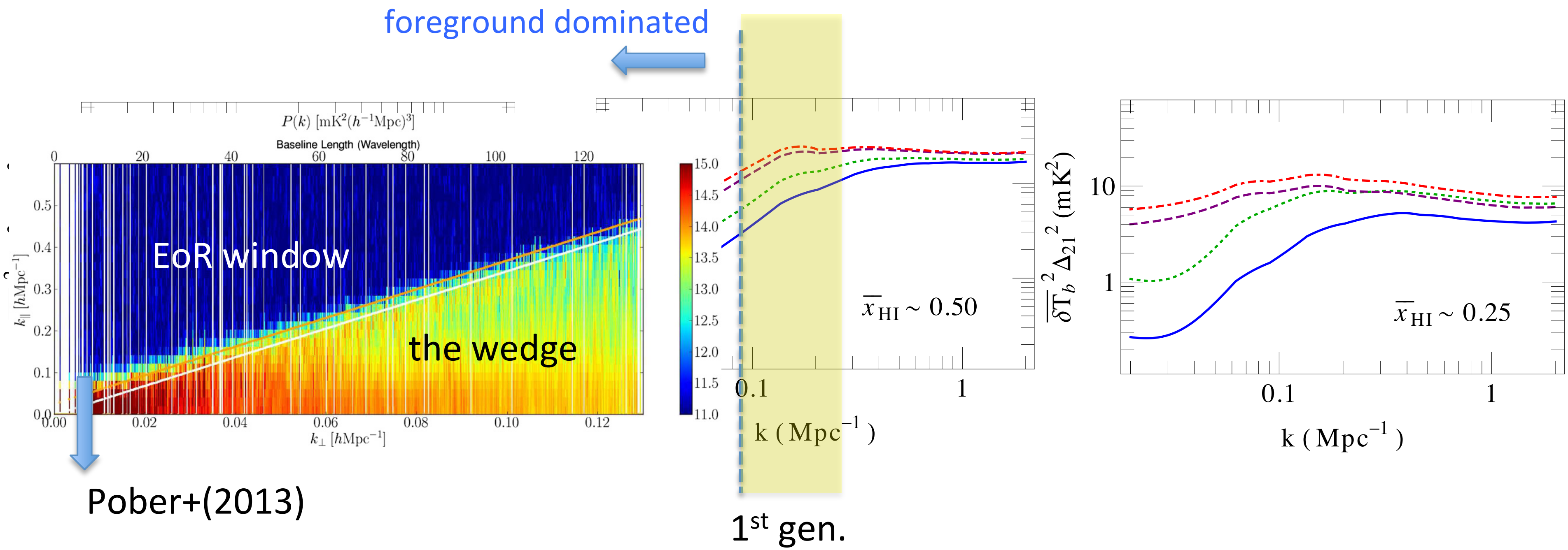

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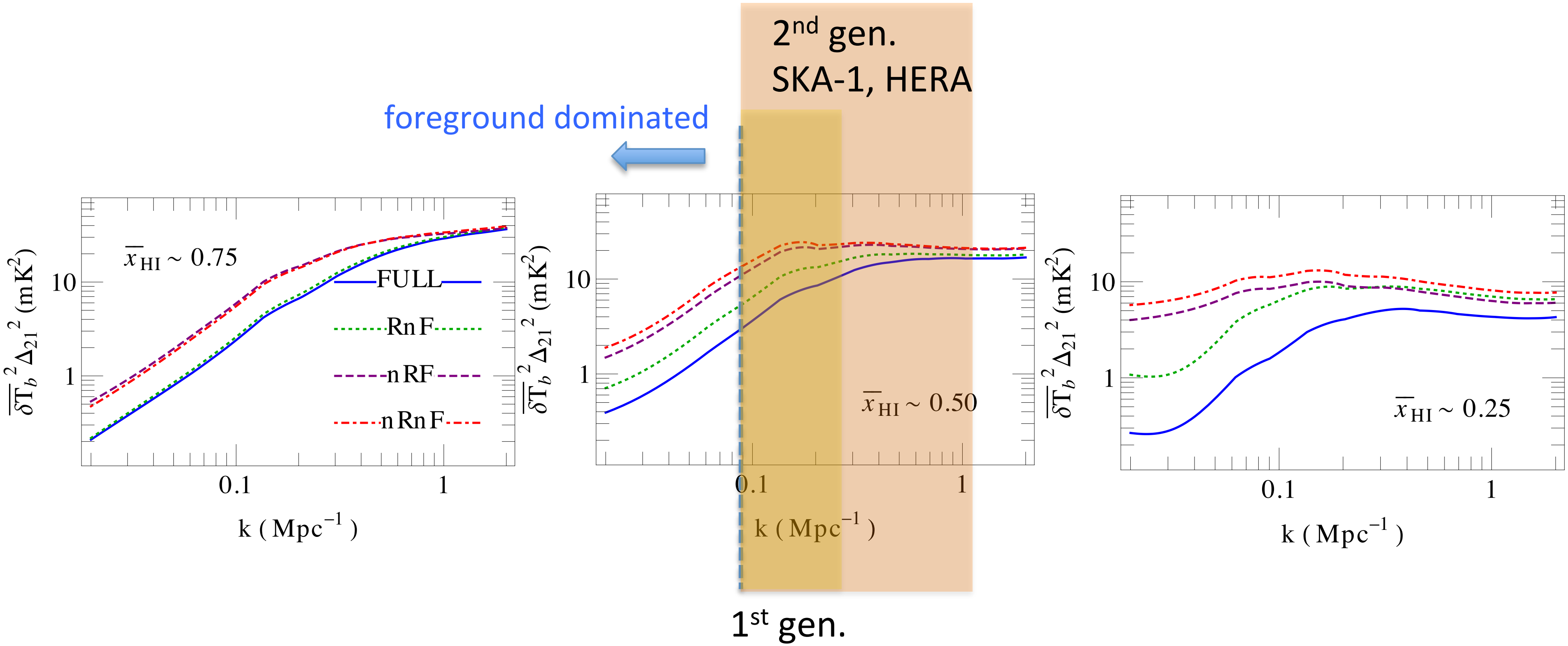

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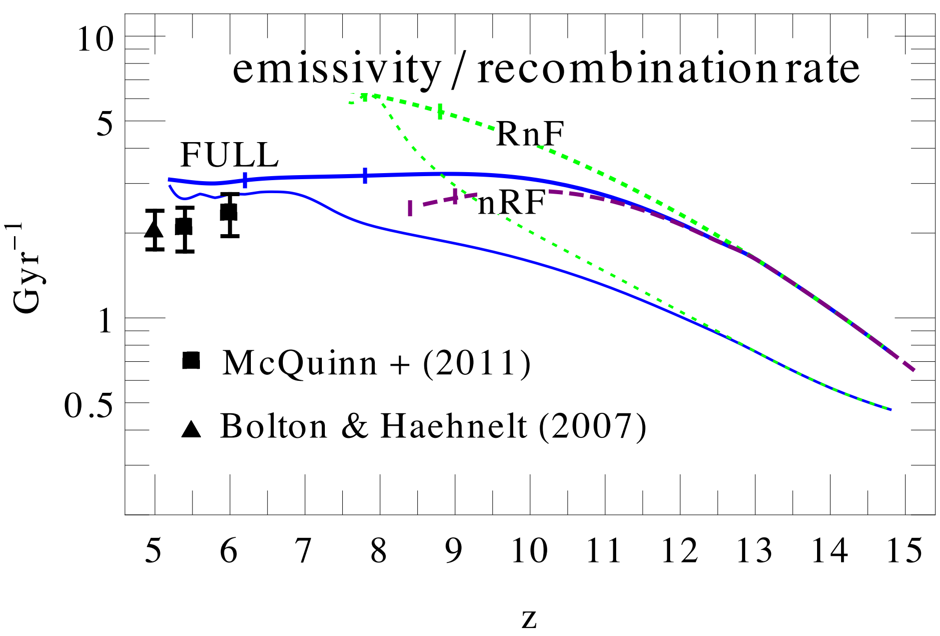
IGM evolution

UVB feedback + recombinations

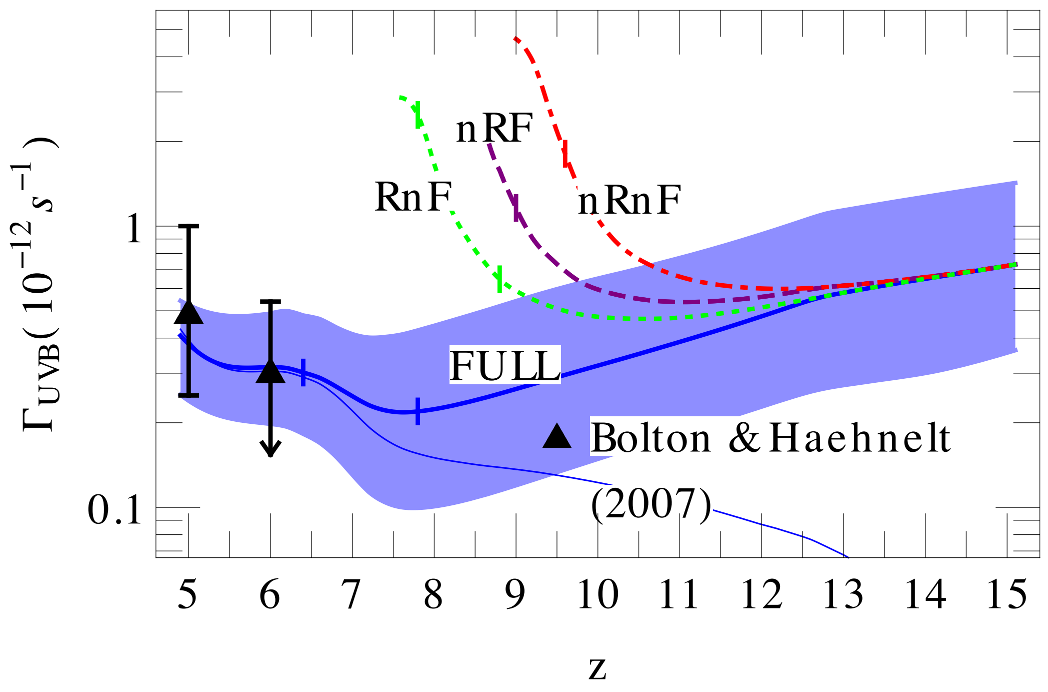
Early start of reionization + photon-starved reionization end



Conclusions

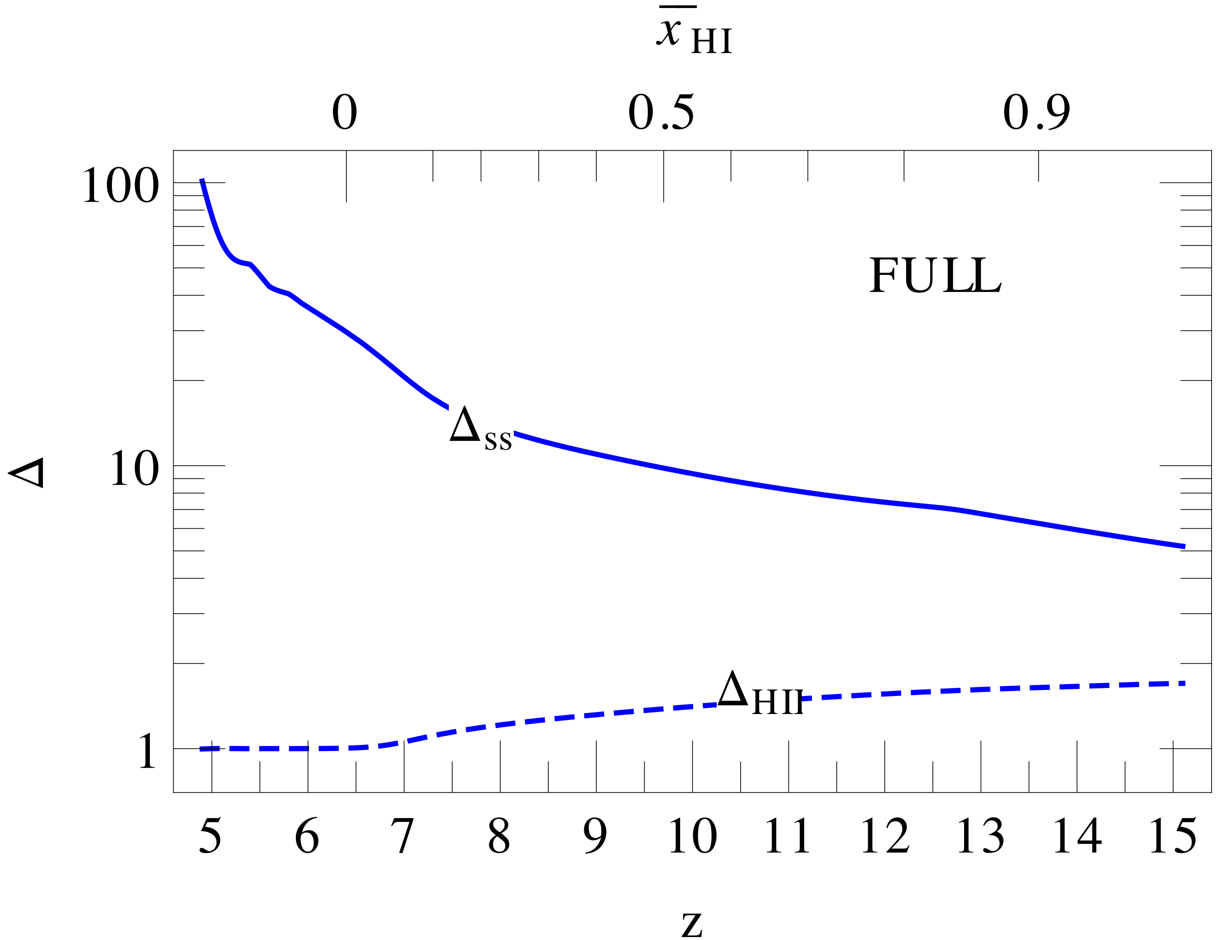
- Sub-grid modelling necessary to model UVB feedback and recombinations
- Recombinations more important than UVB feedback to determine reionization evolution and morphology
- Early start and late, photon-starved end of reionization
- Sizes of HII regions suppressed by factors of $> 2 - 3$
- **Combined effect of recombinations and UVB feedback necessary to interpret (upcoming) observations**

Gammas



nRF
RnF
nRnF
FULL
Bolton & Haehnelt (2007)
$\Gamma_{UVB}(10^{-12} s^{-1})$
1
0.1
5
6
7
8
9
10
11
12
13
14
15
z

Deltas



$\bar{x}_{HI}$
0
0.5
0.9
100
10
1
FULL
Δ_{ss}
Δ_{HII}
Δ
5
6
7
8
9
10
11
12
13
14
15
z