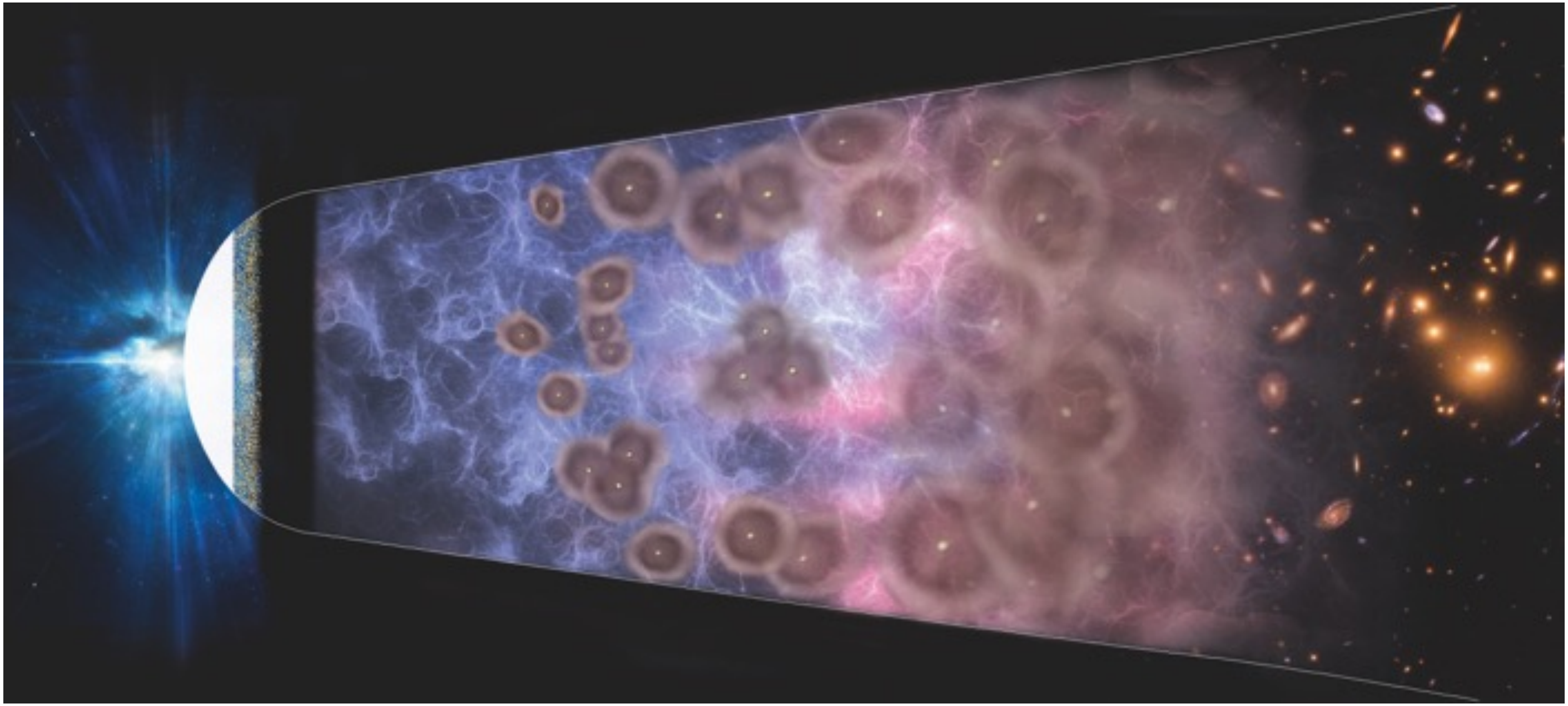
Exploiting galaxy-21cm synergies to shed light on the Epoch of Reionization

Pratika Dayal



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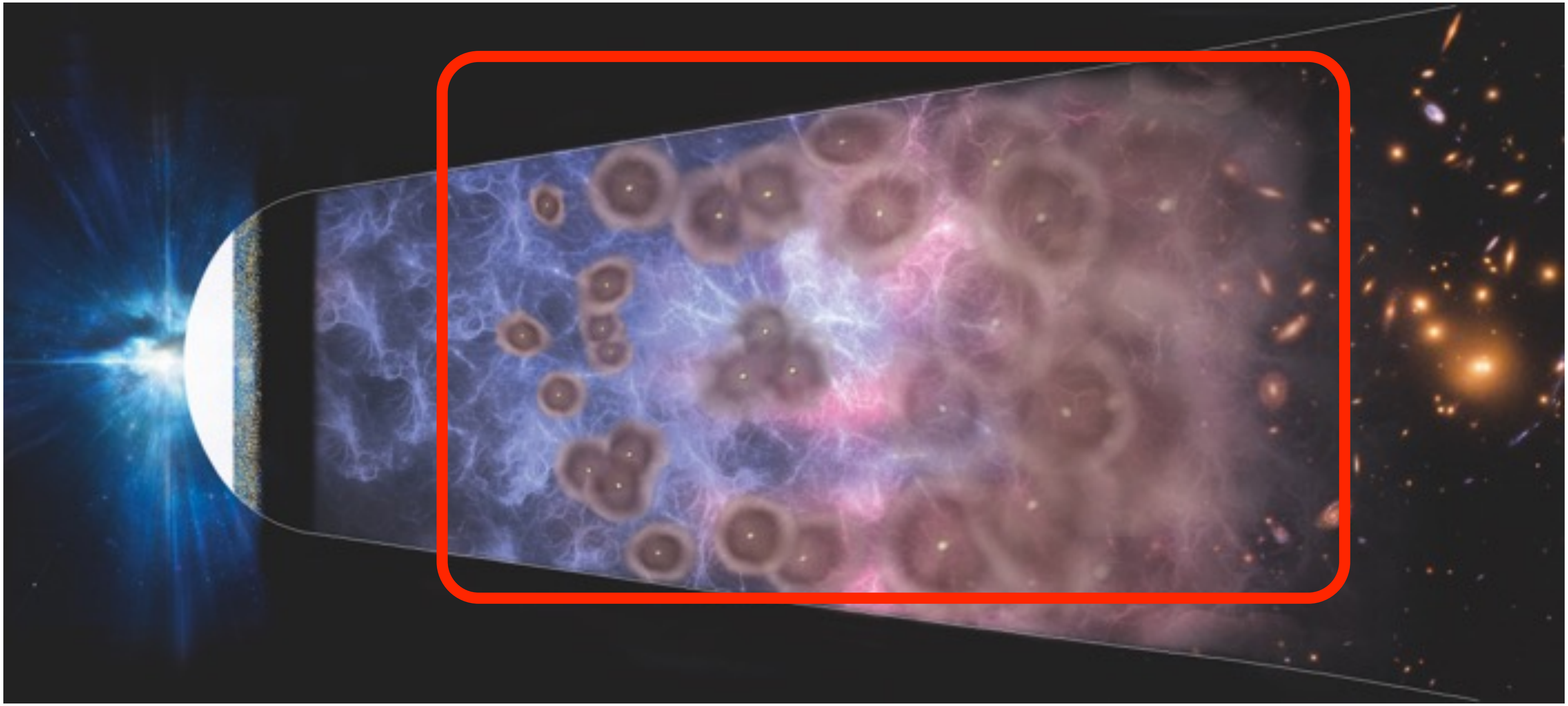

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Outstanding challenges

Linked to galaxy formation

- Minimum mass to which galaxies can form stars
- The star formation rates of early galaxies
- Escape of ionizing radiation
- Dust enrichment of early galaxies
- GW from the early Universe

Linked to reionization

- External (UV) feedback impact
- Key reionization sources (galaxies, BHs or..?)
- Using combination of galaxy and large scale data to constrain reionization topology and history in era of 21cm cosmology

Linked to cosmology

How can early galaxies be used to probe the cosmological model, specially in context of Dark Matter models

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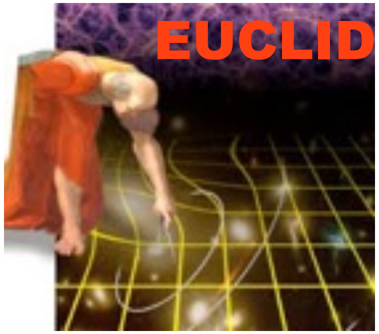
How can early galaxies be used to probe the cosmological model, specially in context of Dark Matter models

Key collaborators and collaborations

Volker Bromm: University of Texas at Austin, USA
Benedetta Ciardi: Max Planck Institute for Astrophysics, Germany
Tirthankar Choudhury: National Centre for Radio Astronomy, India
James Dunlop: Institute for Astronomy, U.K.
Andrea Ferrara: Scuola Normale Superiore, Italy
Stefan Gottloeber: Leibniz institute for Astrophysics, Germany
Anne Hutter: Swinburne Institute of Technology, Australia
Hiroyuki Hirashita: ASIAA, Taiwan
Umberto Maio: Leibniz institute for Astrophysics, Germany
Antonella Maselli: University of Barcelona, Spain
Andrei Mesinger: Scuola Normale Superiore, Italy
Volker Mueller: Leibniz institute for Astrophysics, Germany
Noam Libeskind: Leibniz institute for Astrophysics, Germany
Fabio Pacucci: Kapteyn Institute, The Netherlands
Catherine Trott: ICRAR, Perth, Australia
Livia Vallini: Nordita, Stockholm, Sweden
Gustavo Yepes: Universita Autonoma di Madid, Spain…

ALMA

SKA
SQUARE KILOMETRE ARRAY



Modelling reionization: evolution of volume filling fraction of ionized hydrogen

Fractional volume filled with ionized hydrogen

Growth of ionized regions due to ionizing photon output

Decrease in ionized region sizes due to recombination

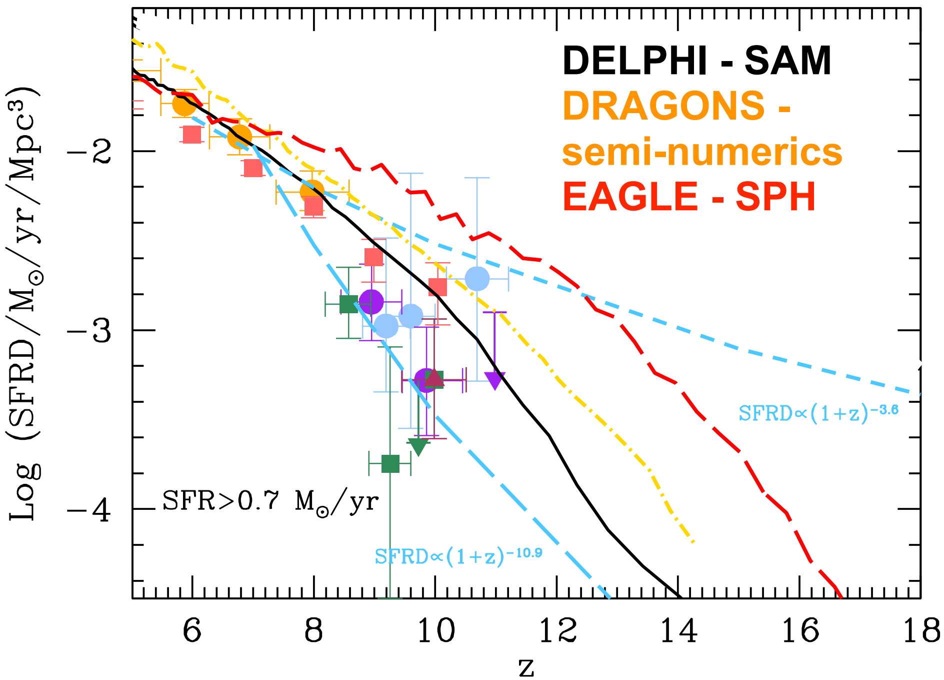
$$\frac{dQ_{II}}{dt} = \frac{\boxed{dn_{int}}\,\boxed{f_{esc}}}{dz}\frac{1}{n_H} - \frac{Q_{II}}{t_{rec}}\frac{dt}{dz}$$

$$t_{rec} = \frac{1}{\chi\, n_H\, (1+z)^3 \alpha_B\, \boxed{C}} \, .$$

Measure of over-density as fn(space,time)

Dayal & Ferrara, 2018, Physics Reports, Volume 780, pg. 1-64

The source term: (some) basic problems



SFR density (used to model reionization) extremely uncertain at z>8.

Dayal & Ferrara, 2018, Physics Reports, Volume 780, pg. 1-64

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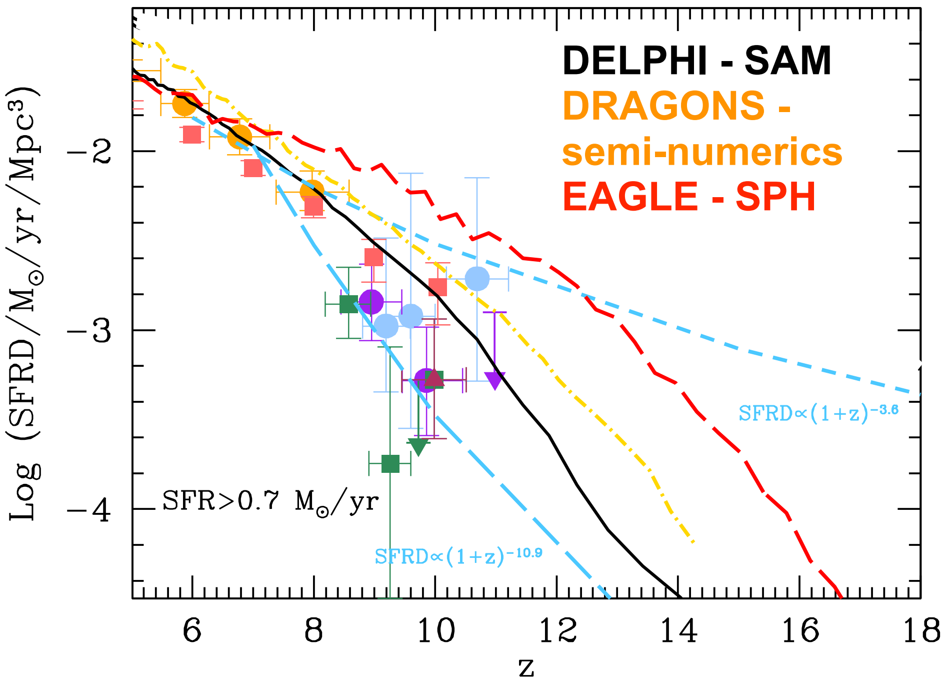

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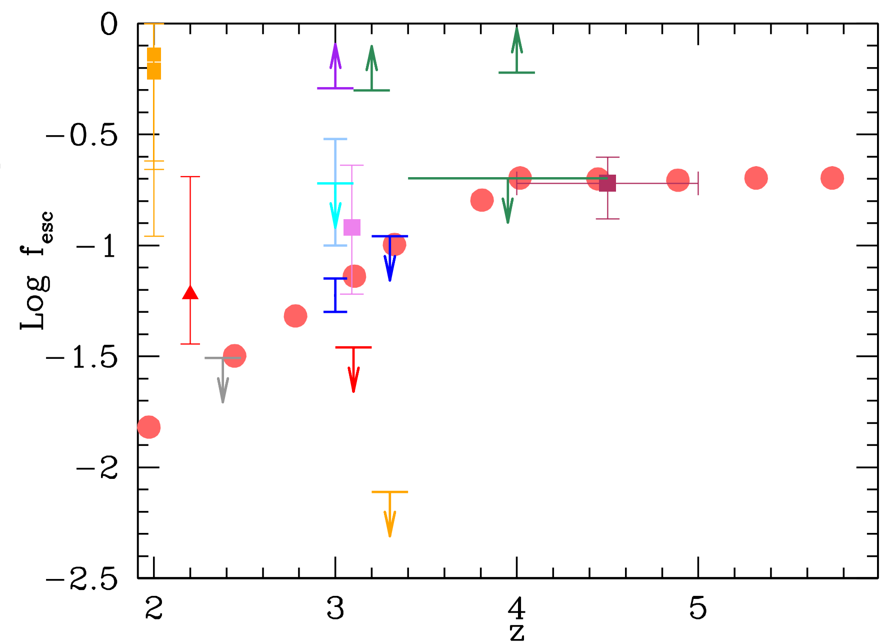
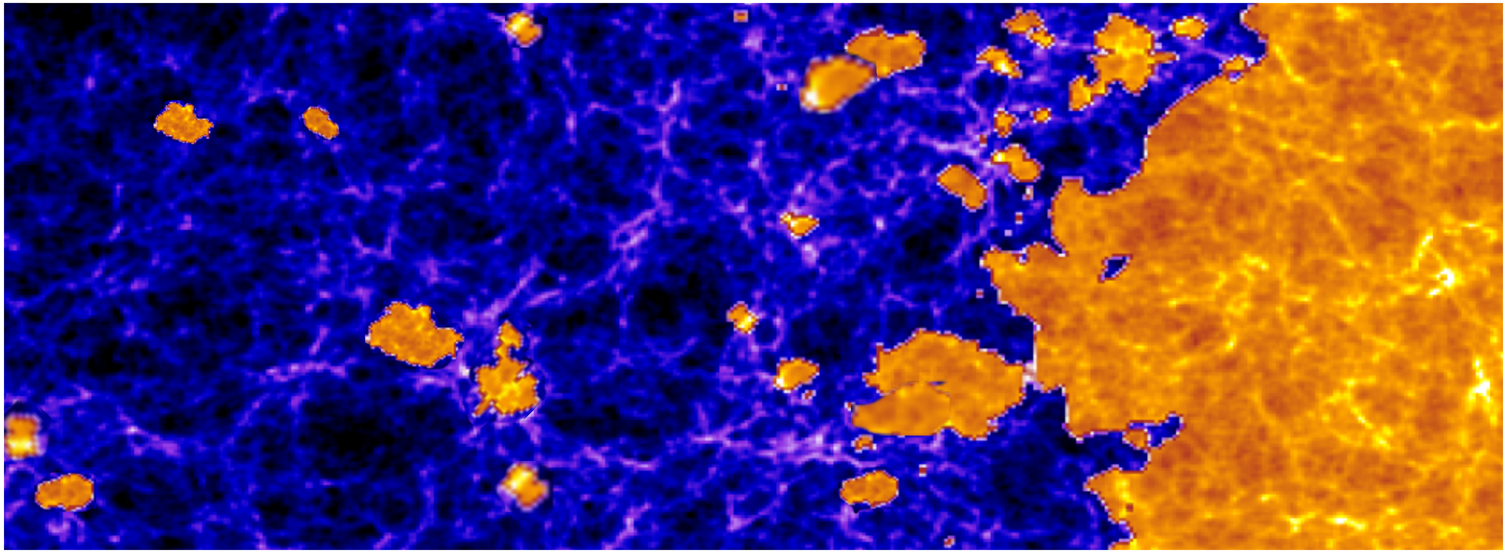


(Tentative) increase with z?

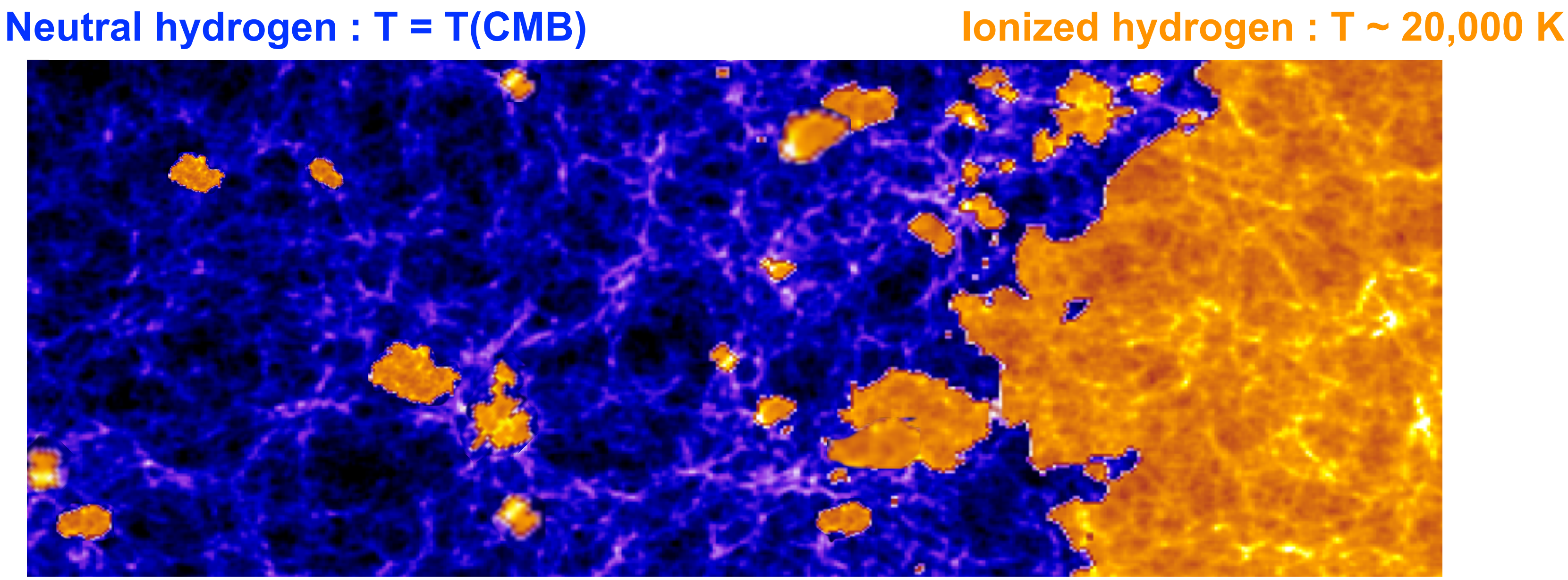
The impact of reionization feedback on galaxy formation

Neutral hydrogen : T = T(CMB)

Ionized hydrogen : T ~ 20,000 K

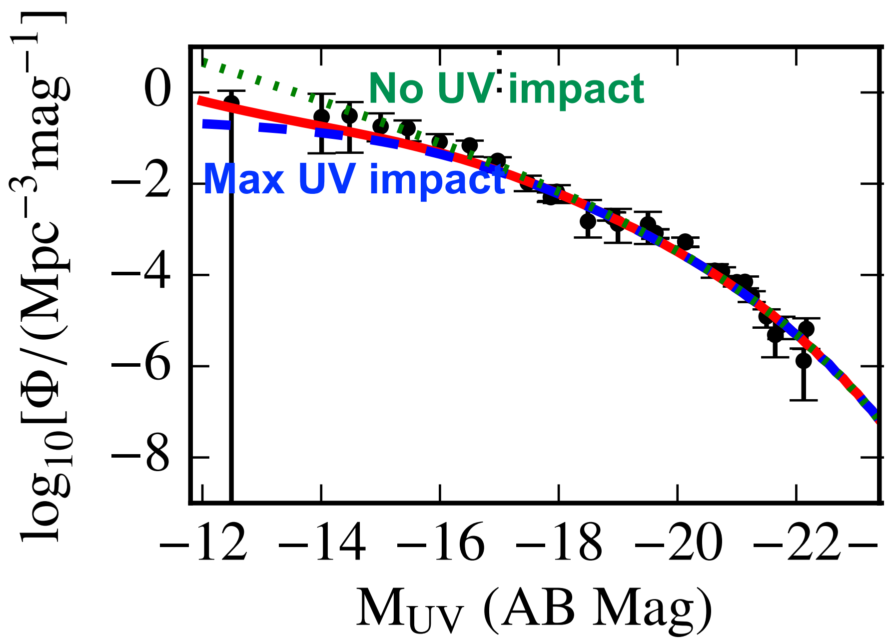


The impact of reionization feedback on galaxy formation

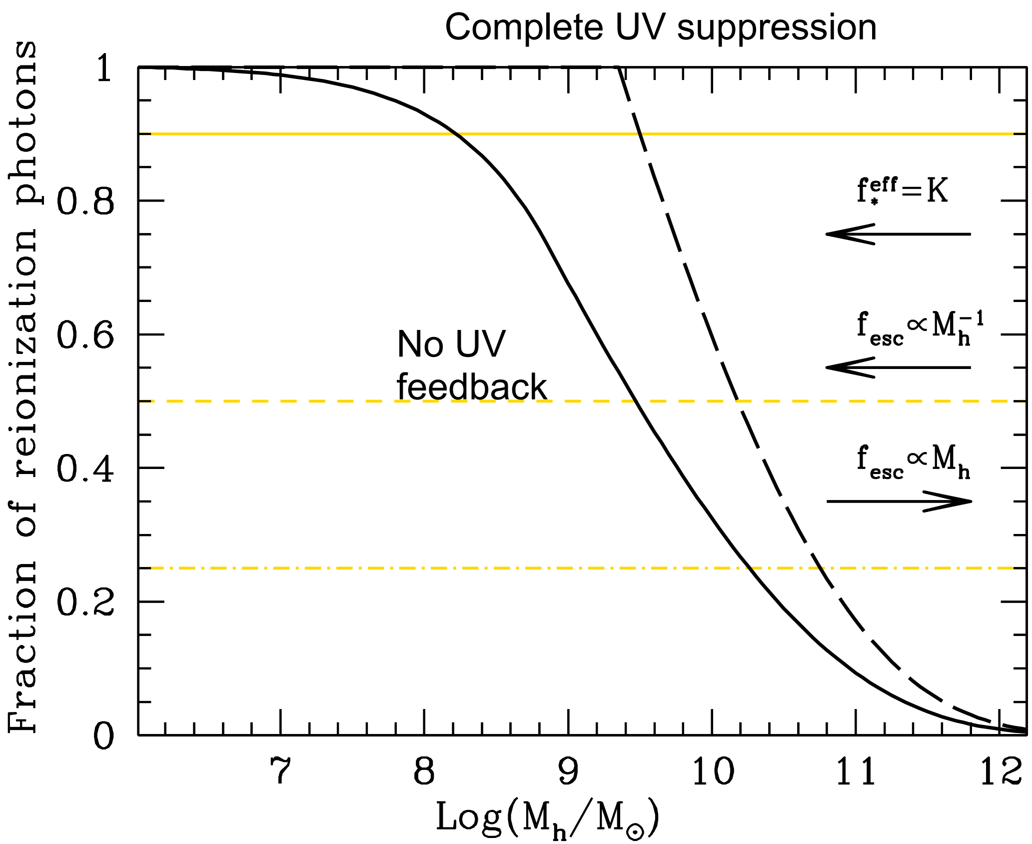


- The UVB created during reionization can suppress the gas mass of low-mass galaxies, flattening the faint-end slope.
- Variation of faint end slope of UV LF in multiple JWST fields can be used to explore fluctuating UVB (fixing critical mass value)

Choudhury & PD, 2019



Key sources of reionization remain hidden



Key reionization sources depend on SF efficiency (impacted by UV feedback) and the escape fraction

PD & Ferrara, 2018, Physics Reports,780, 1

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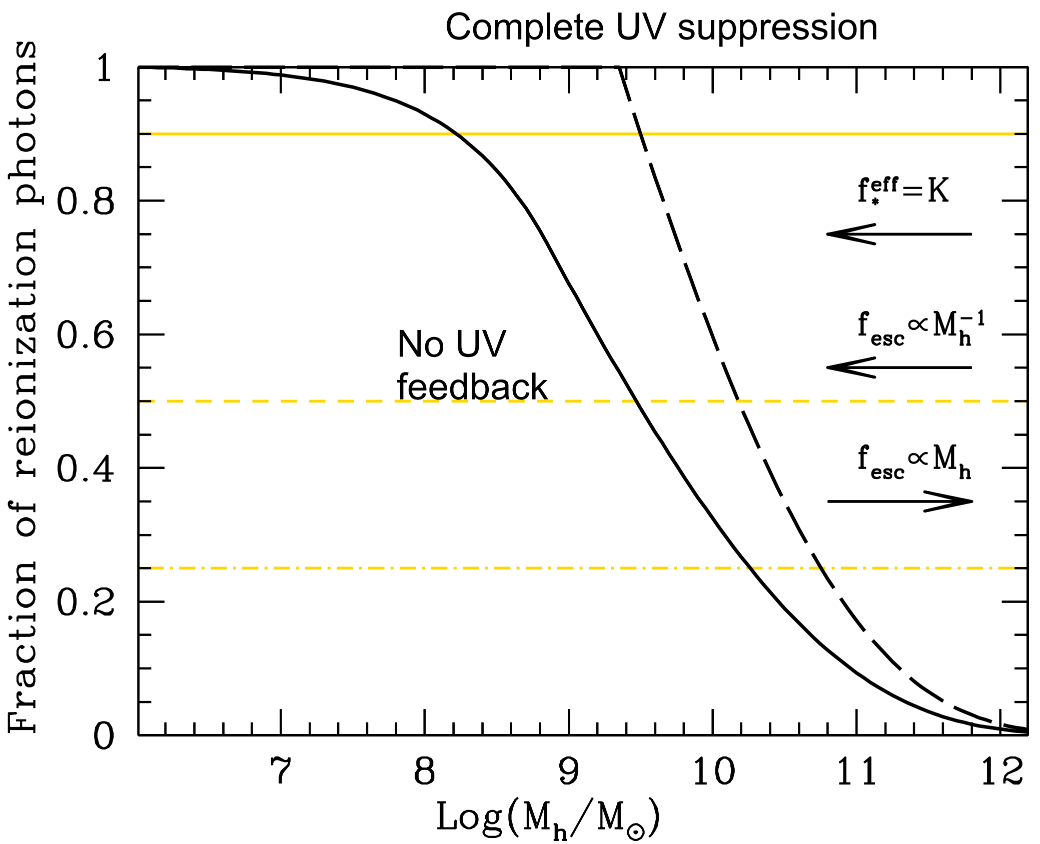

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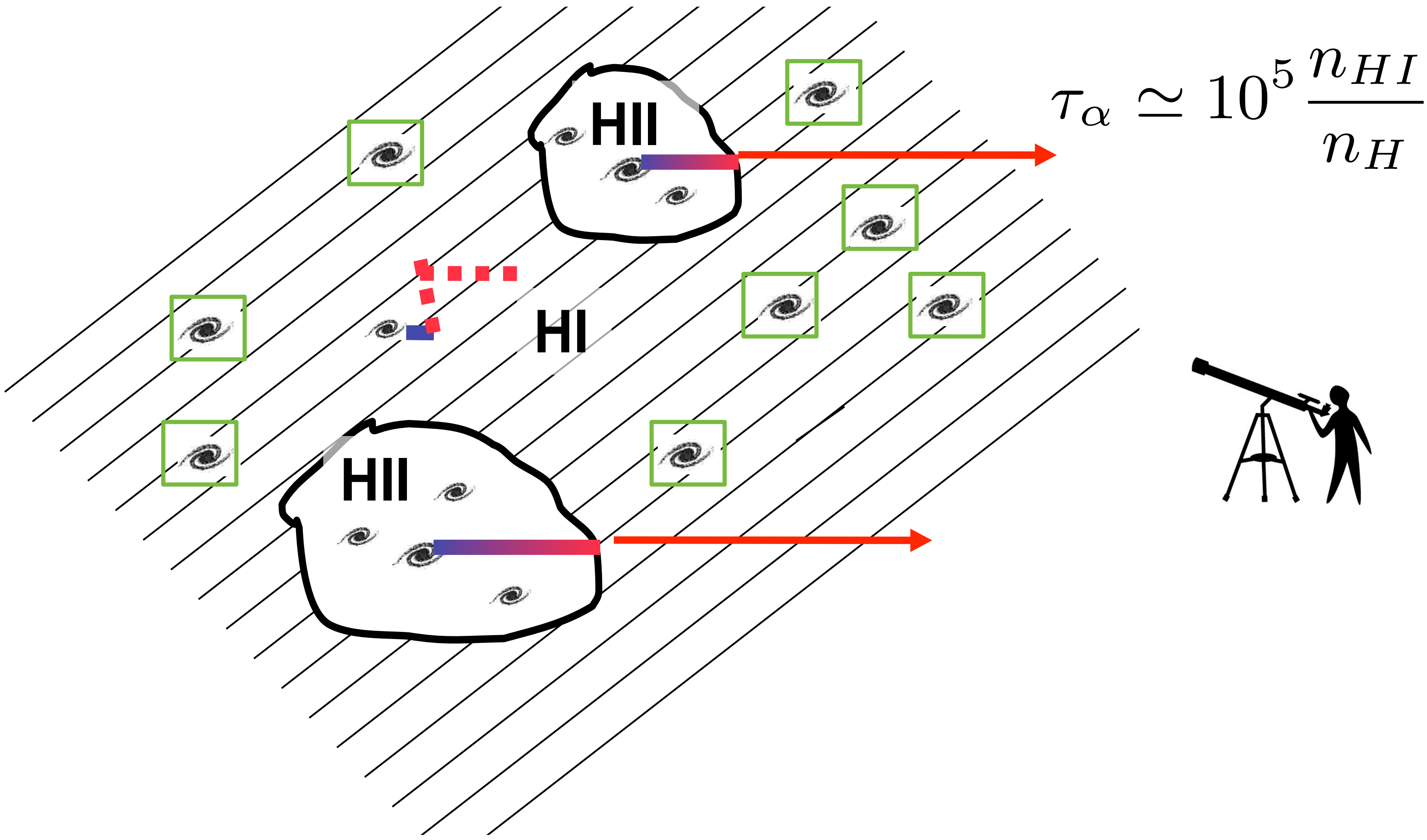
Key sources and topology (patchiness) of reionization fundamental open questions

Lyman Alpha emitters (LAEs) : a new probe of the patchiness and topology of reionization



This naturally implies a (huge?) sub-population of galaxies hidden in the Lyman Alpha, with more & more becoming visible as reionization proceeds

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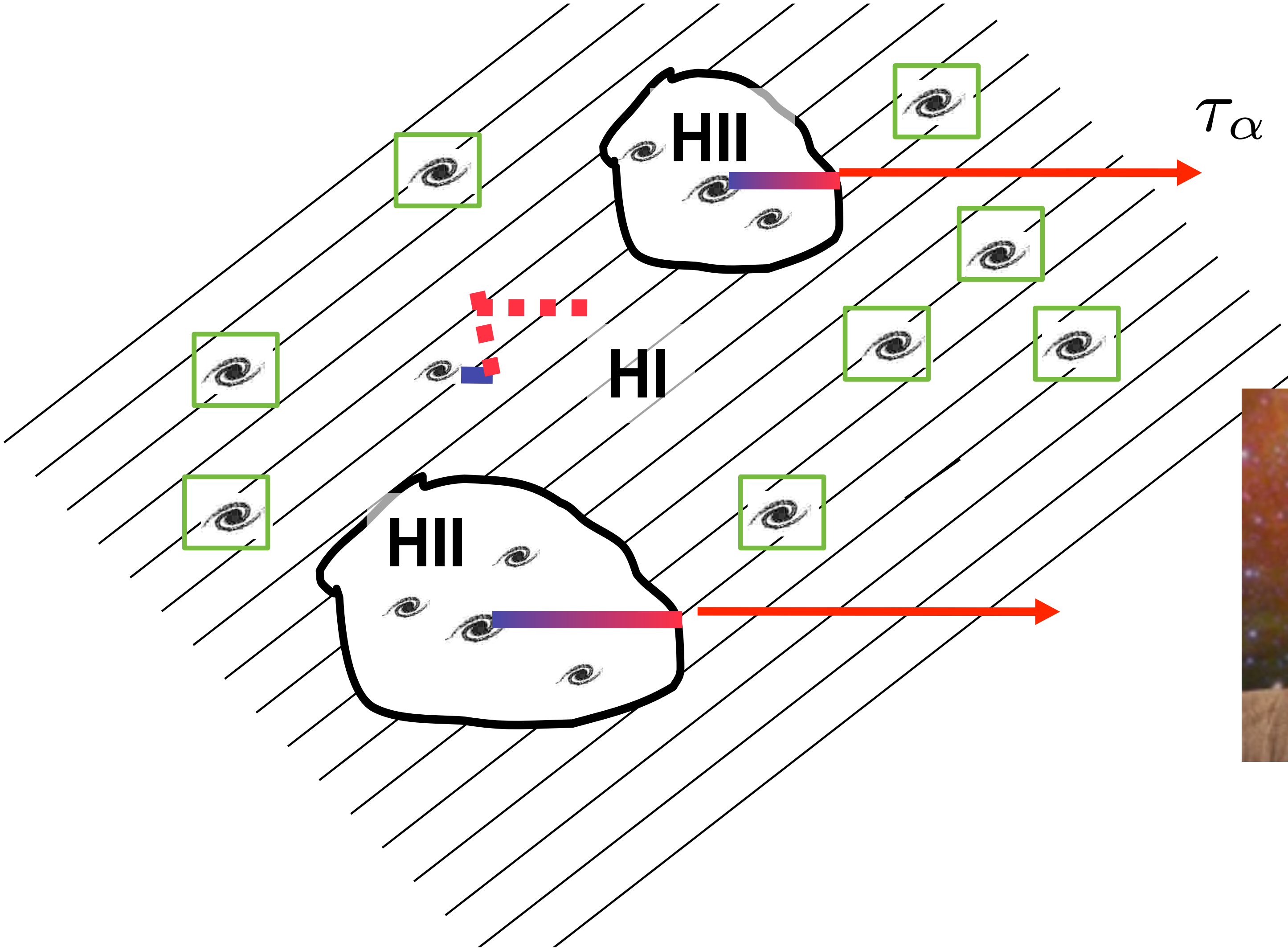
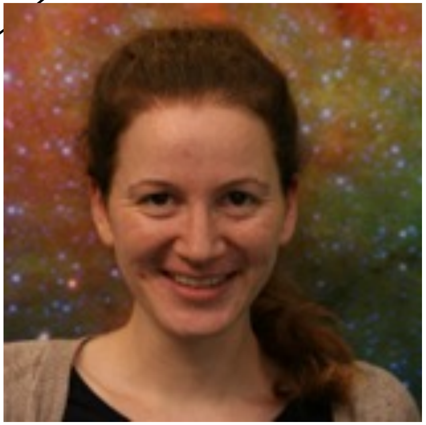


$$\tau_\alpha \simeq 10^5 \frac{n_{HI}}{n_H}$$



Anne Hutter

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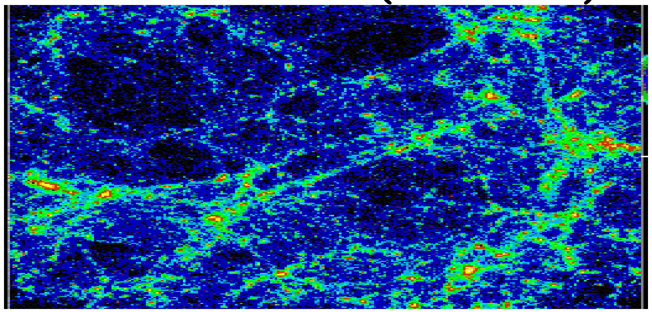
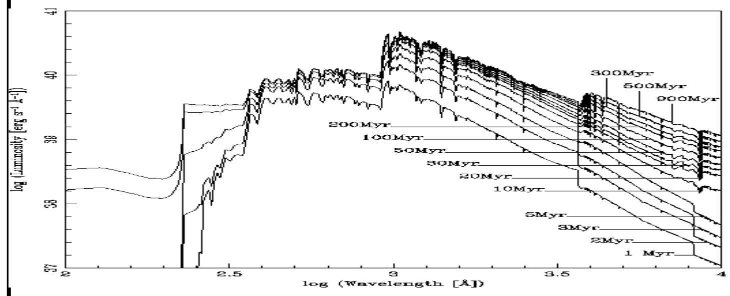
The full LAE model: SPH+radiative transfer

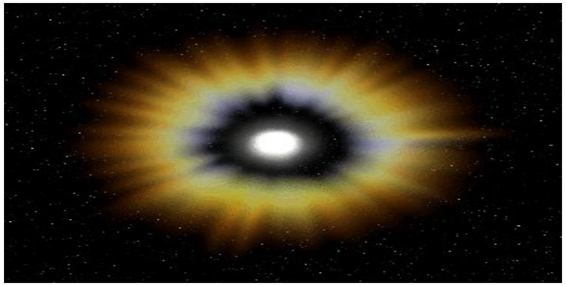
1. SPH simulations (GADGET3)



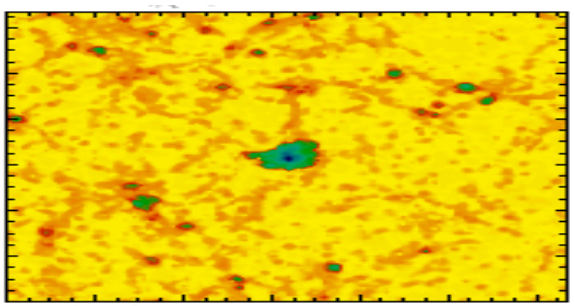
2. Intrinsic spectrum (SB99)



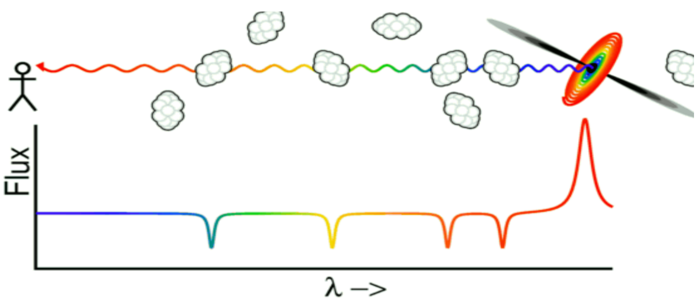
3. SNII dust enrichment



4. RT - pCRASH



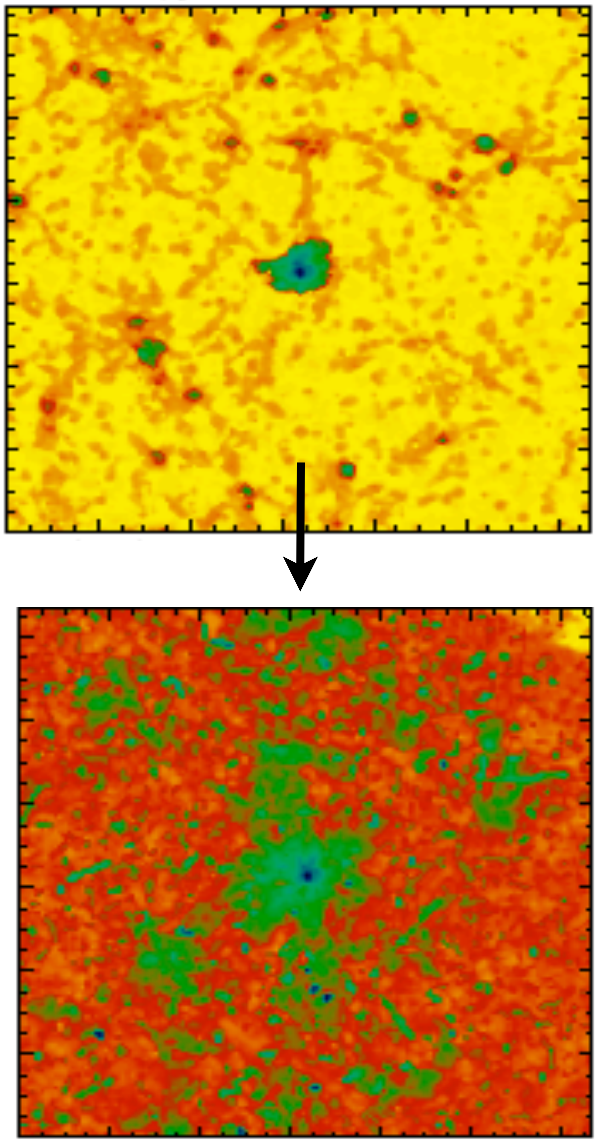
5. IGM Transmission

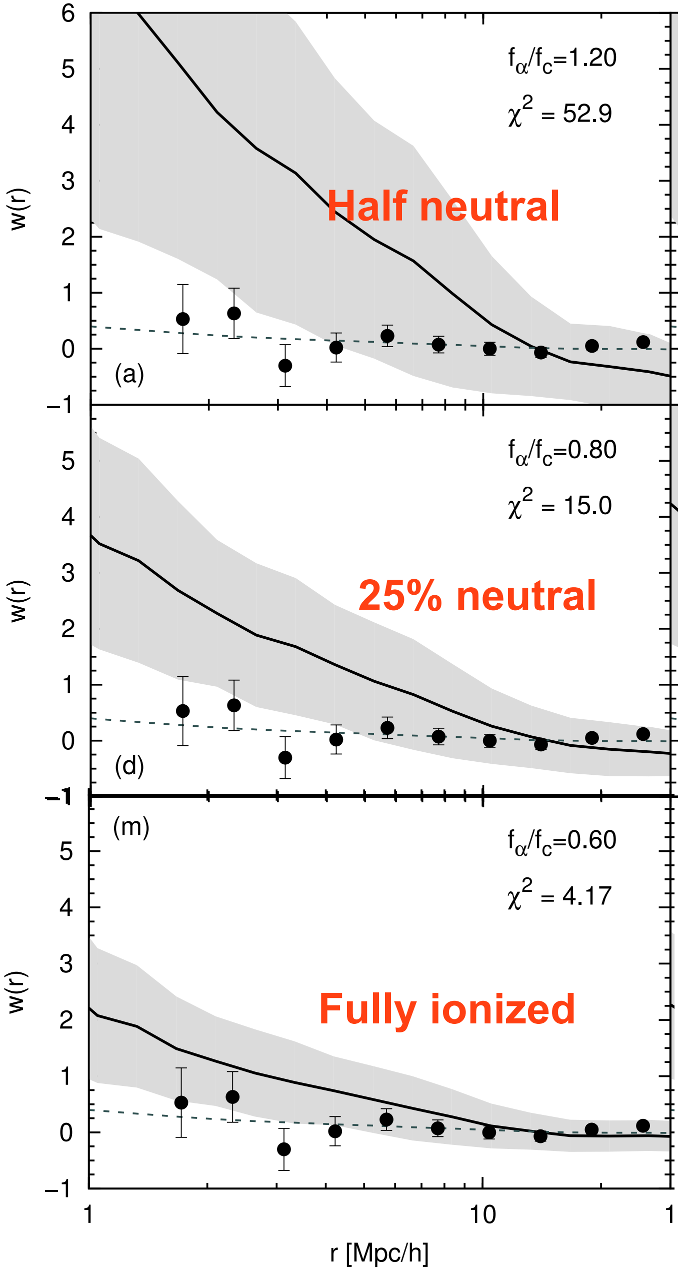


Dayal+10,12; Hutter+14,15,16

Reionization hints from clustering evolution of LAEs

Neutral; ionized

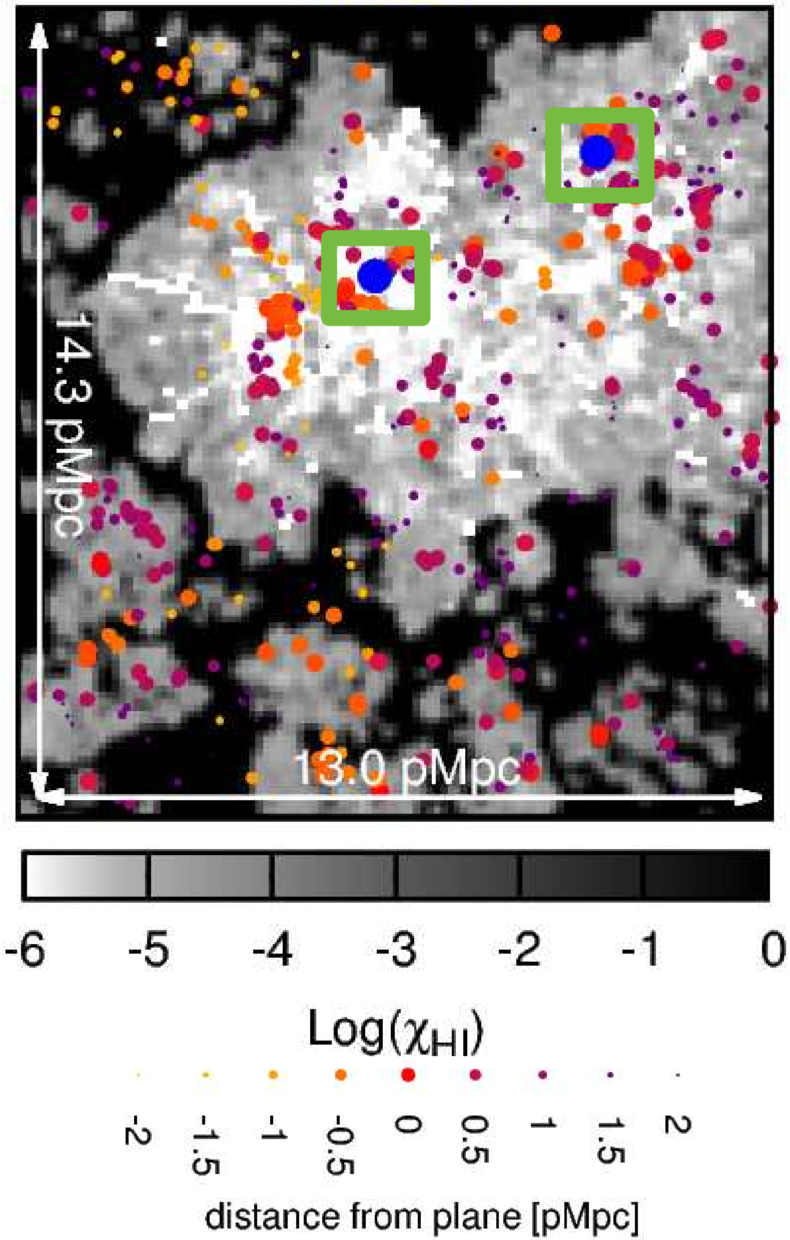


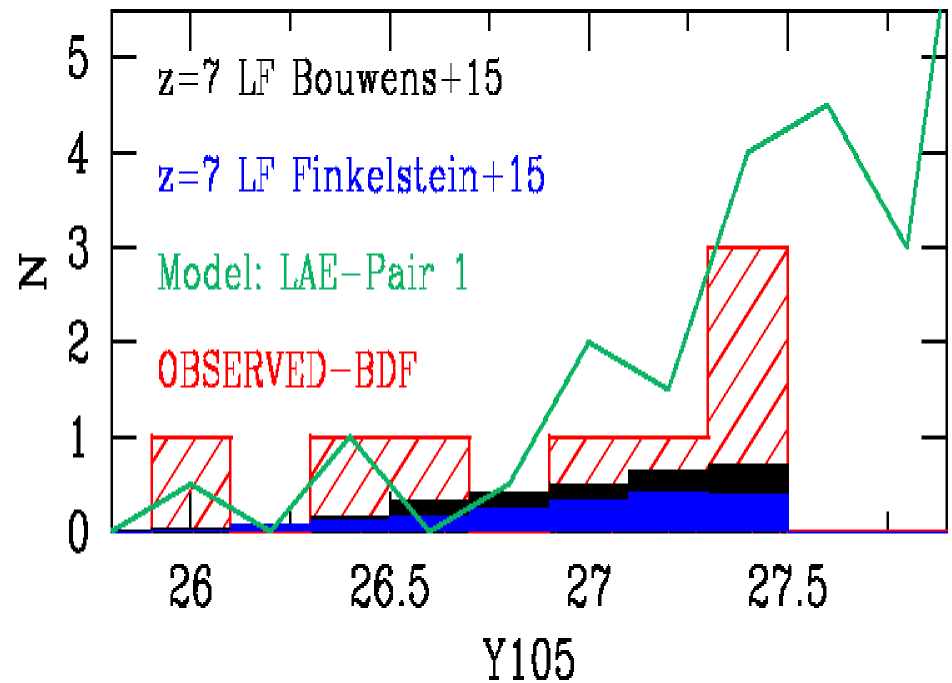


Reionization progress decreases measured clustering of LAEs

McQuinn+08; Hutter, PD+2016

First evidence for an over-dense reionized patch

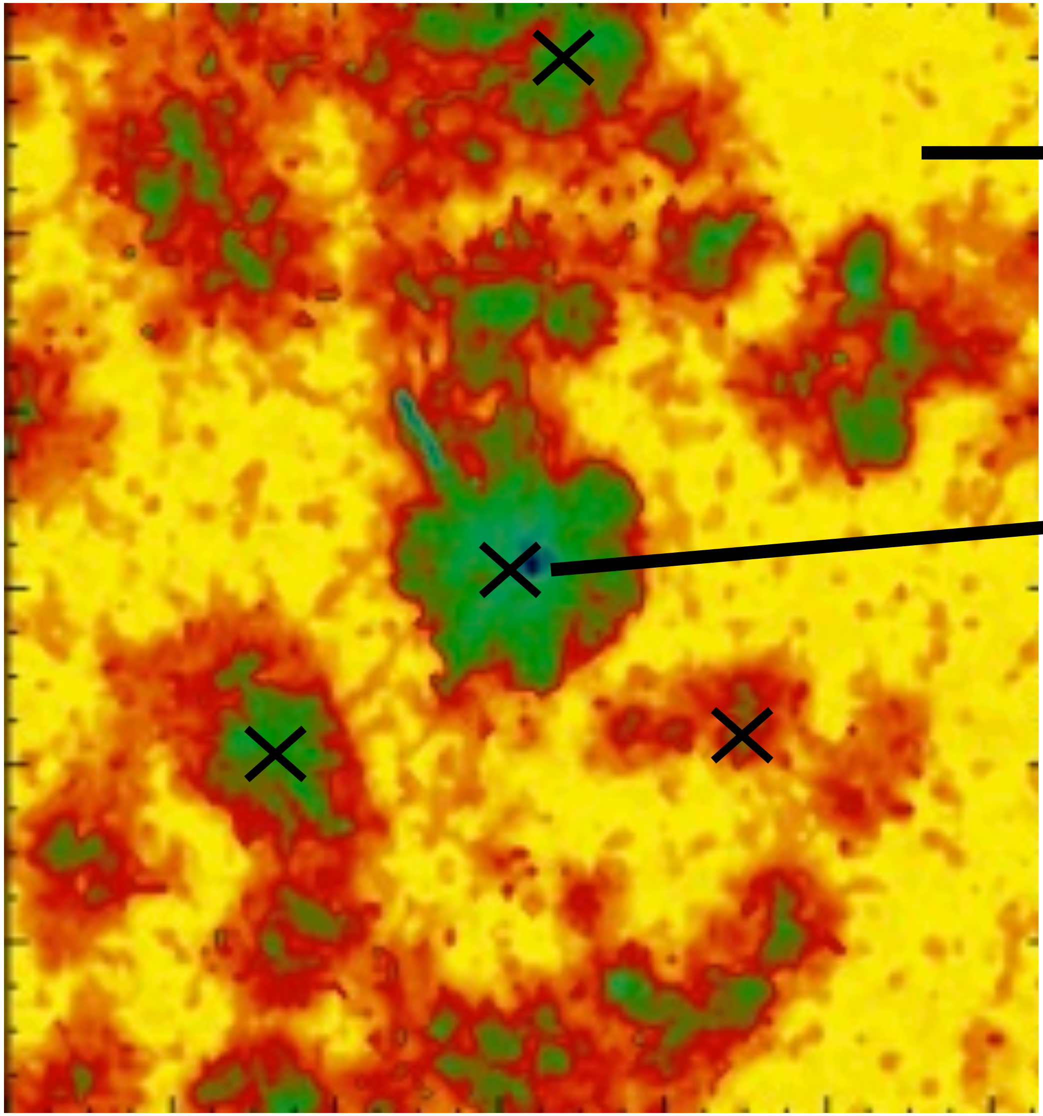




Clustered galaxies preferentially visible in Lyman Alpha

Castellano, PD+2016; Castellano+2017

Looking towards the future: 21cm with the SKA



21cm emission from neutral hydrogen

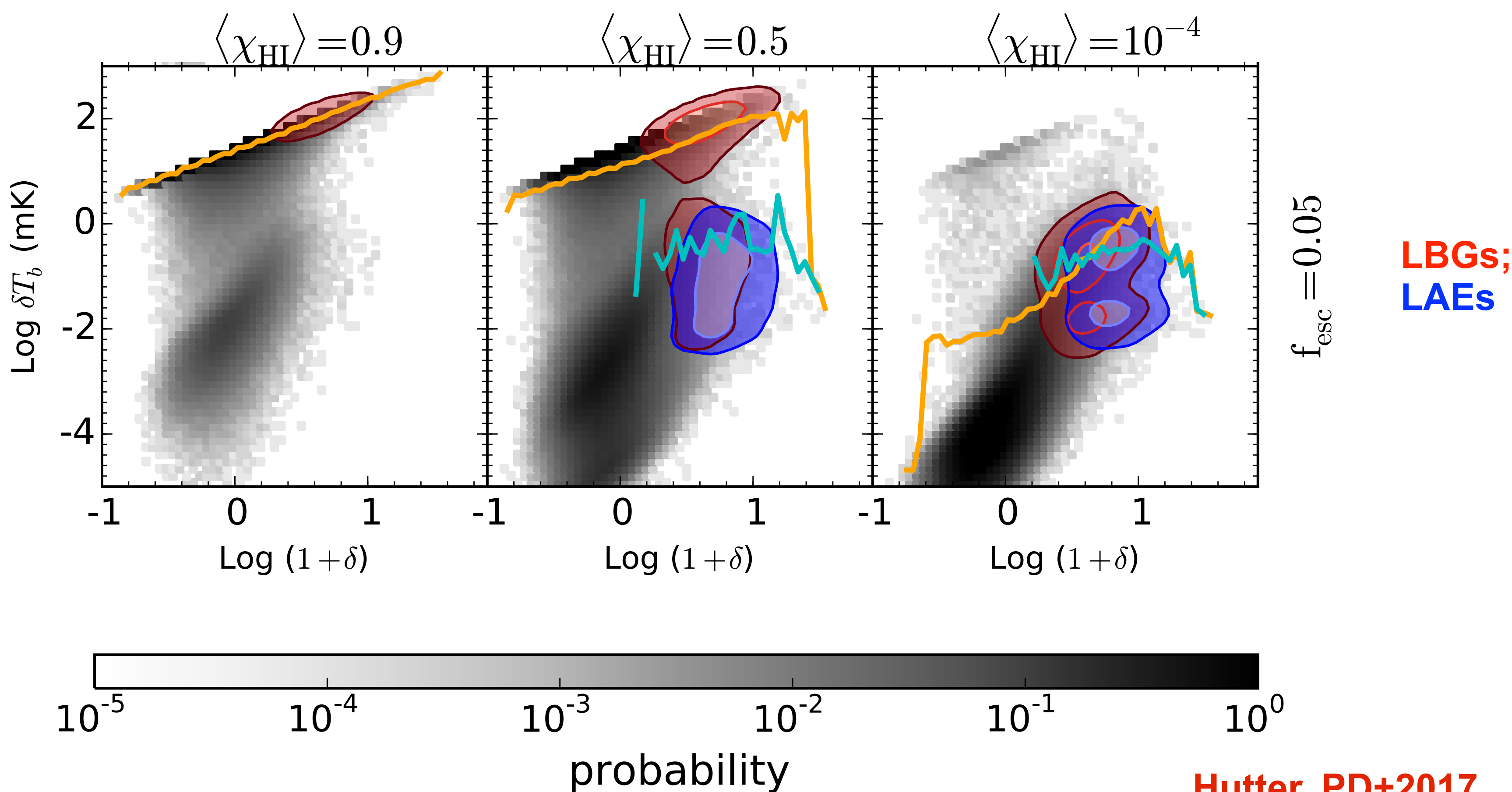
Galaxy populations
HST, VLT, Subaru,
JWST, E-ELT, EUCLID,
E-ELT

Cross-correlating 21cm data with (spectroscopically confirmed) galaxy data will be key to yield information on reionization sources & topology

The SKA EoR "synergy" group

- Enormous efforts in trying to link observed 21cm emission with underlying galaxy/QSO populations to shed light on reionization sources & topology.
- We require information on fields, survey volumes/depths to calculate and co-ordinate best possible survey strategies.
- Targeting collaborations with Subaru, WFIRST, Euclid and E-ELT.
- Co-ordinators: Pratika Dayal, Andrea Ferrara, Eric Zackrisson

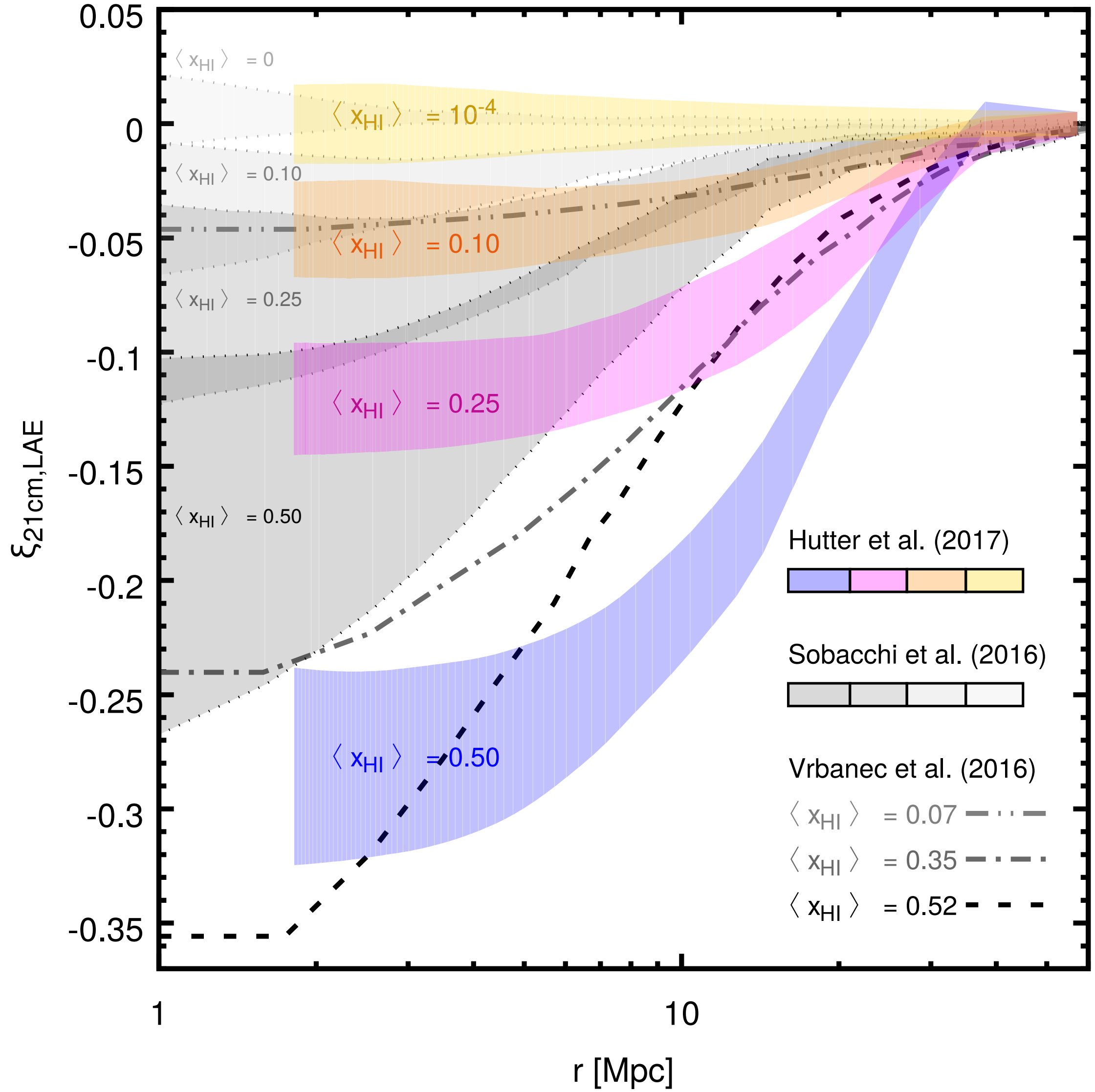
Relation between LAEs, reionization and 21cm brightness temperature



Hutter, PD+2017, ApJ, 836, 176

Lying in over-dense and highly ionized regions, LAEs show much lower 21cm brightness temperatures than average

The 21cm-LAE cross-correlation: hints on neutral fraction



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Combining 21cm and LAE data should allow us to differentiate between an IGM that is xx% ionized to one that is completely neutral

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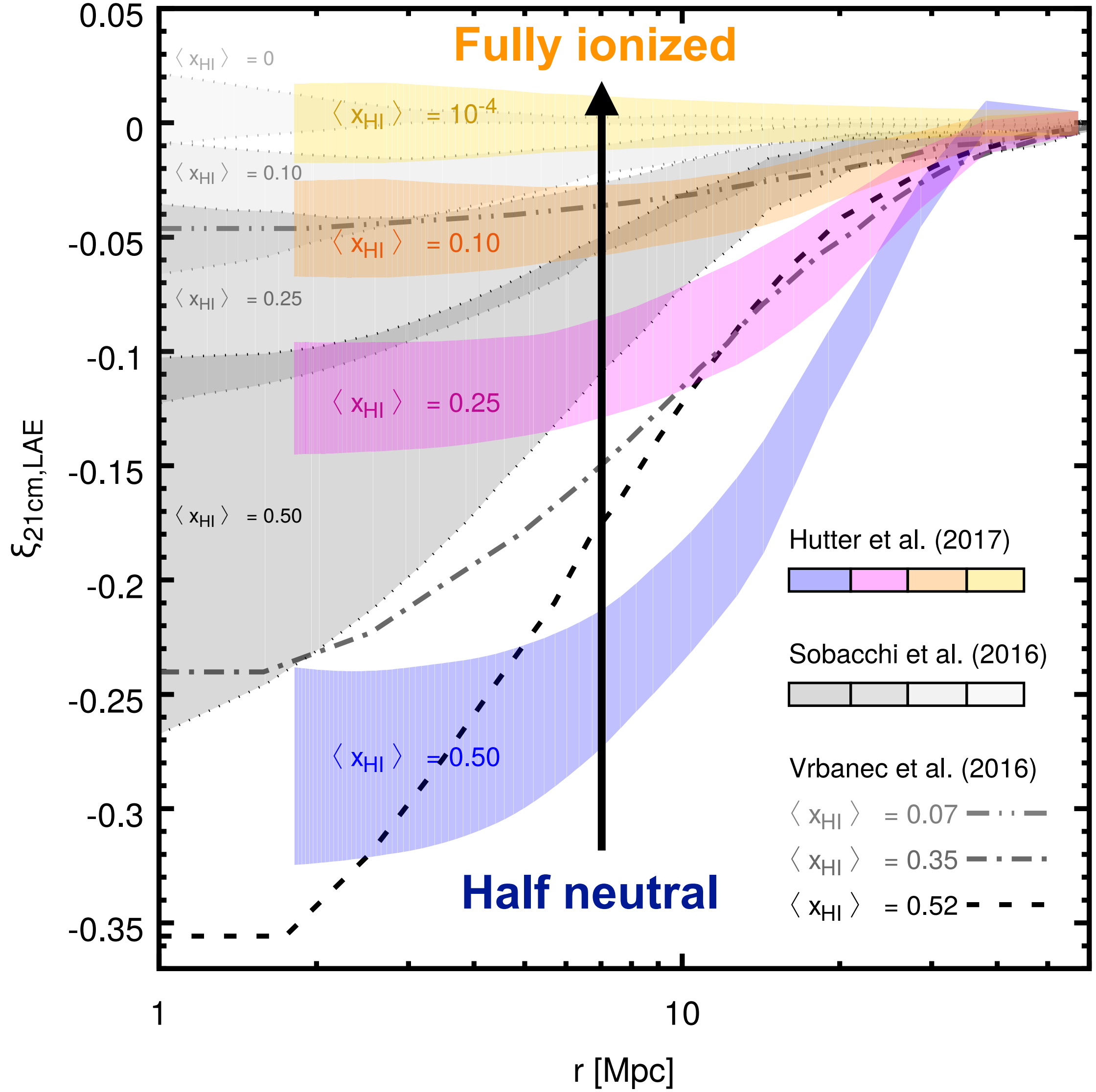

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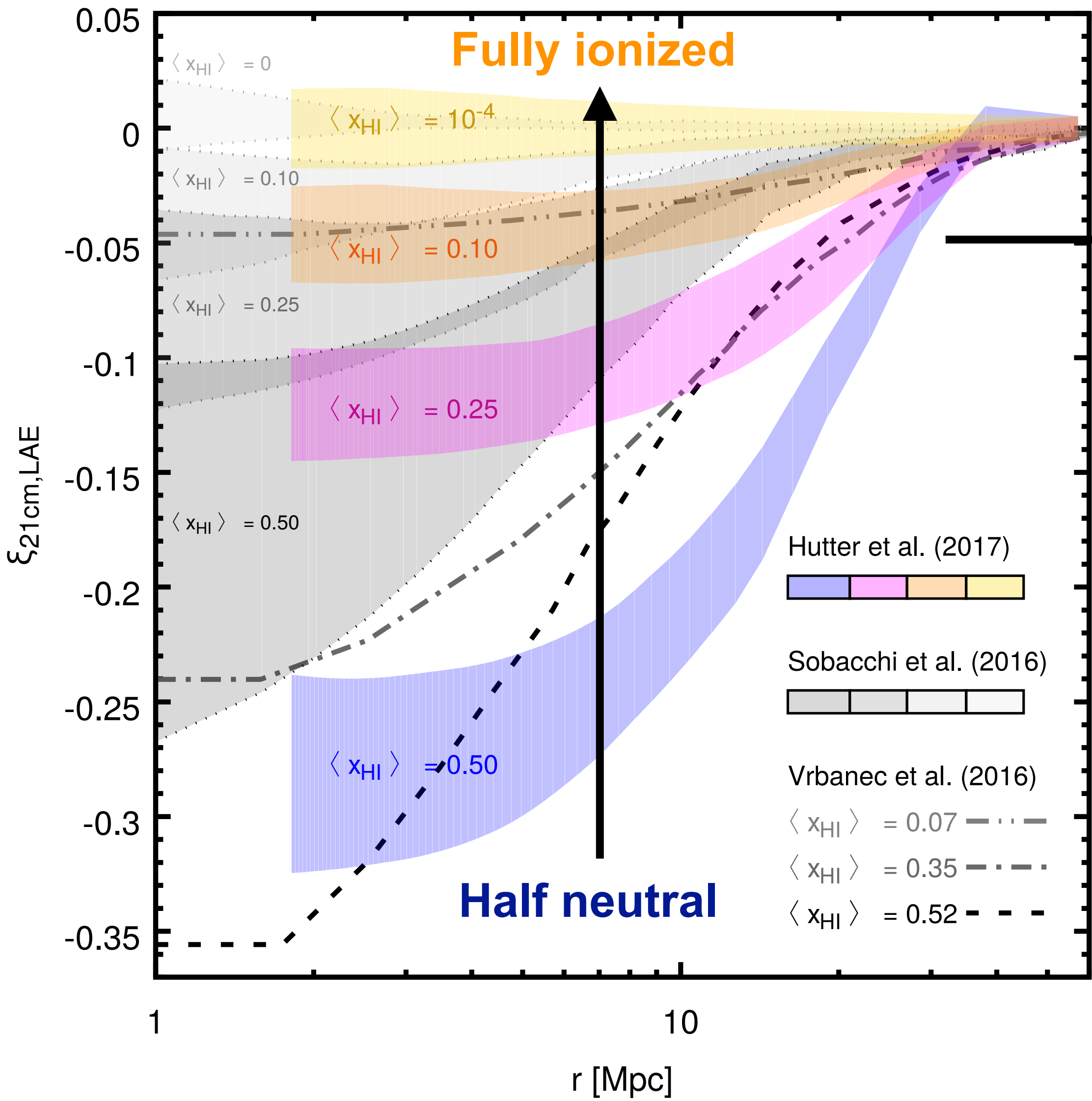

Scale of turn-over indicates typical ionized bubble sizes

Hutter, PD+2017, ApJ, 836, 176

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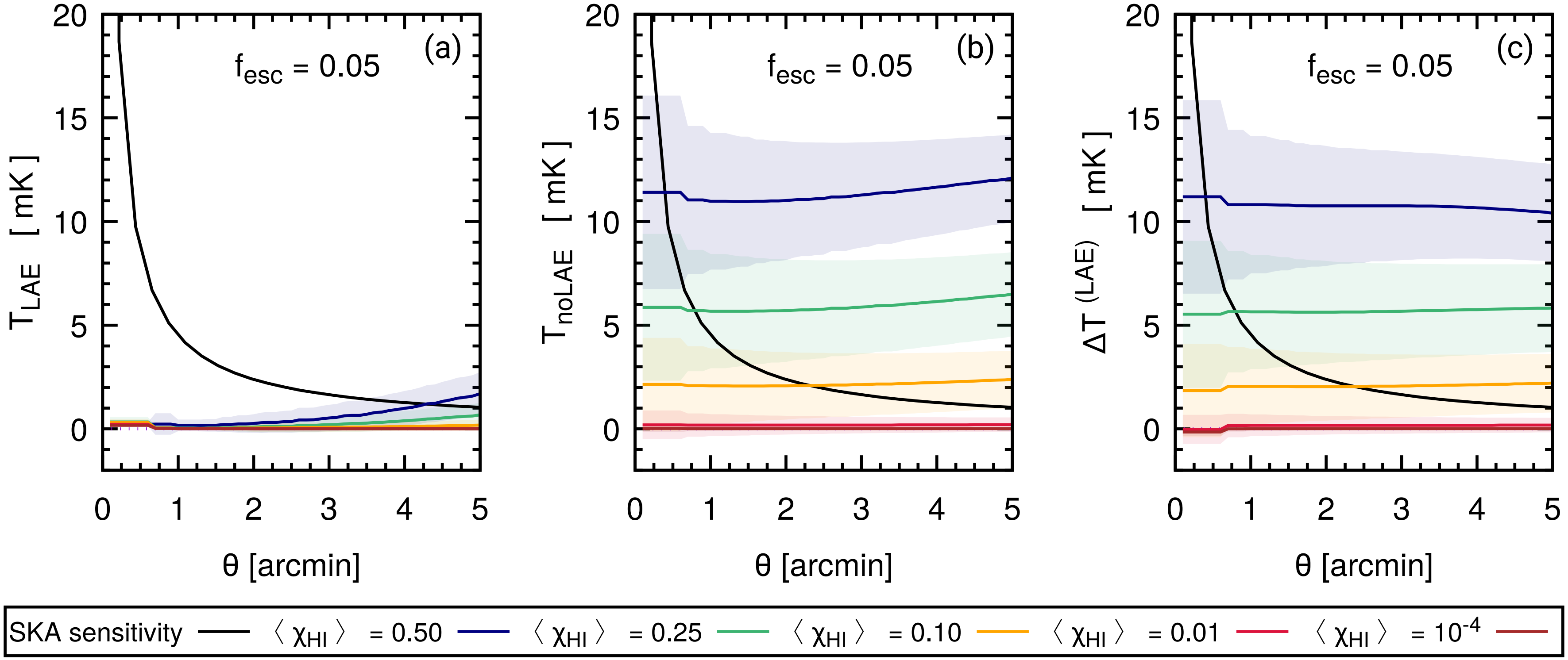
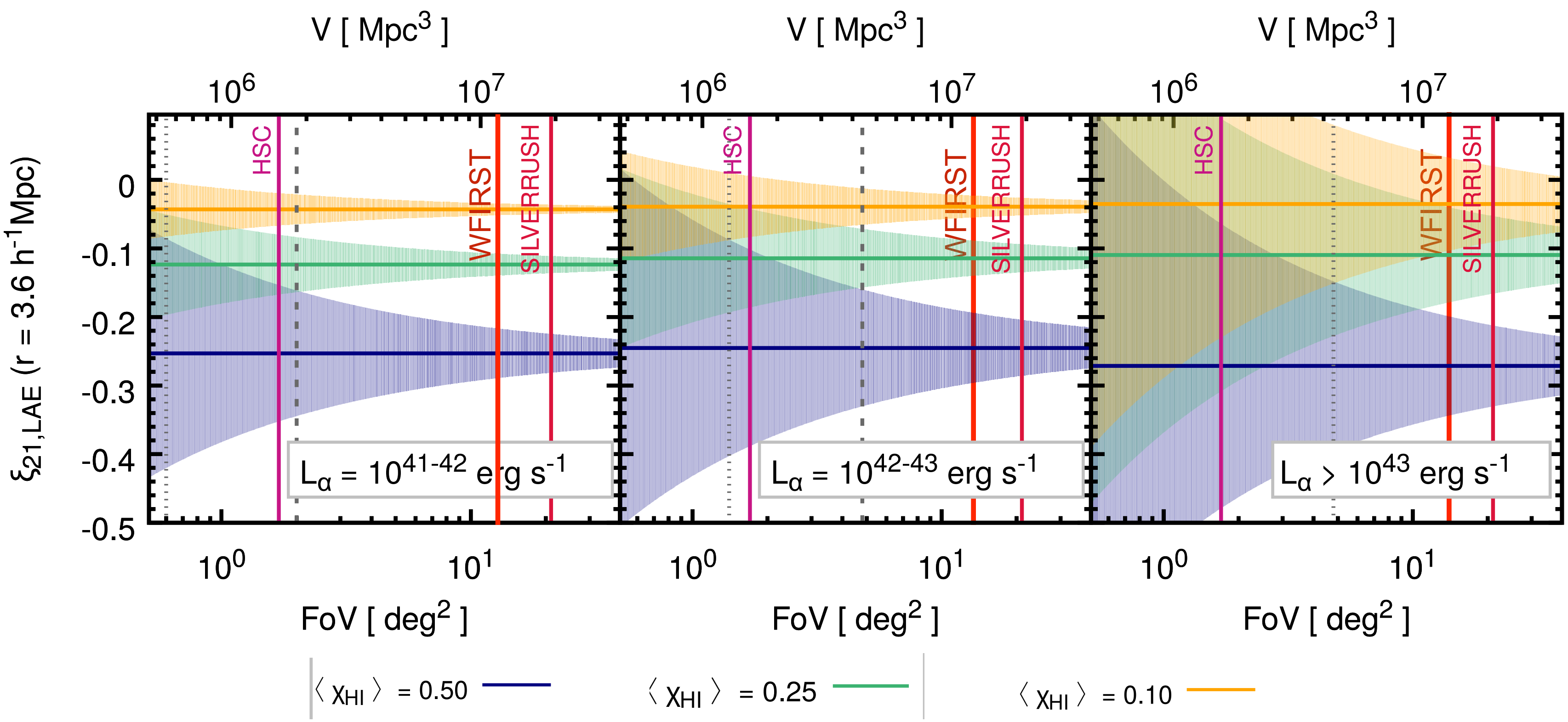
Topology of reionization: inside-out V/s outside in



Measuring 21cm brightness temperature in regions with/without LAEs can tell us if reionization proceeded inside out or outside-in..

Hutter, PD+2017, ApJ, 836, 176;
Hutter, PD et al., decadal paper, arXiv: 1903.03628

Survey parameters to optimise the 21cm-LAE correlation



Key issue: **As volume decreases, thermal noise increases. As number of LAEs decrease, shot noise increases.**

Solution: **25 deg2 surveys (Subaru/WFIRST) targeting intermediate luminosity LAEs most optimal - but smaller volumes can be compensated by probing to lower Lya luminosities**

Hutter, Trott & Dayal 2018;
Hutter, Dayal et al, 2019 (Astro 2020 white paper)

Summary

- Modelling reionization still open problem due to **key physical uncertainties for both galaxies and IGM** (z-evolution of cosmic SFRD, fesc, C).

- Due to these issues, **sources and topology of reionization** remain outstanding problems in astrophysics.

- **Galaxy (specially LAEs)-21cm correlations** will be invaluable in shedding light on the reionization state (fraction of neutral hydrogen) and topology.

- 25 deg2 surveys (Subaru/WFIRST) targeting intermediate luminosity LAEs most optimal - **trade-off between volume and Lya luminosity limit.**

- Contact Pratika Dayal, Andrea Ferrara or Erik Zackrisson for comments for/questions for/join the SKA EoR Synergy group.