21cm intensity mapping:

using cosmic neutral hydrogen as tracer of large scale structure of the universe

Isabella Paola Carucci

CosmoStat group since April 2019

Room: 274

Post Doc seminar

1 October 2019


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Ionian Sea
Archaia
Olympia
Αρχαία
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Algiers
مدينة الجزائر
Tunis

PhD, October 2017

Post Doc at University College Londo

Now in Cosmostat

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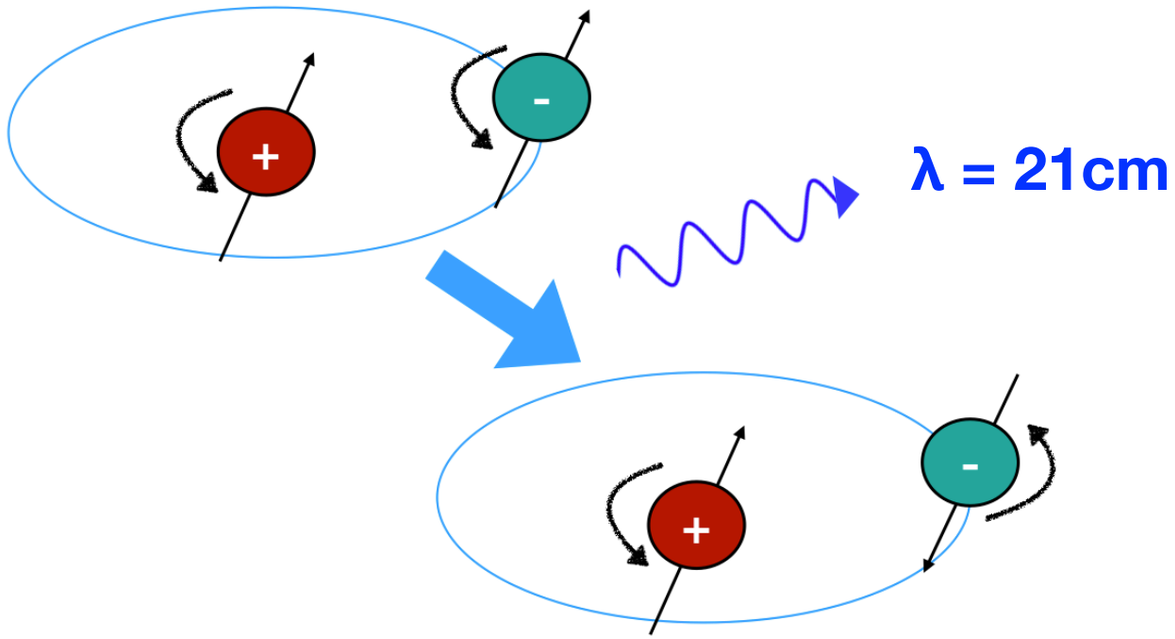
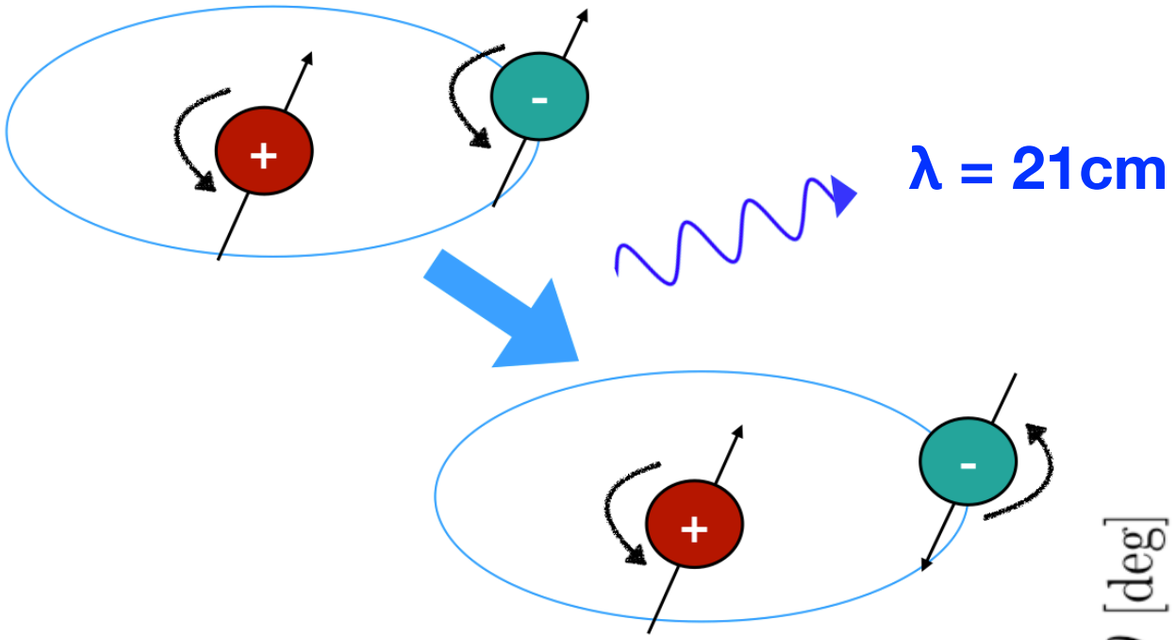
21cm radiation

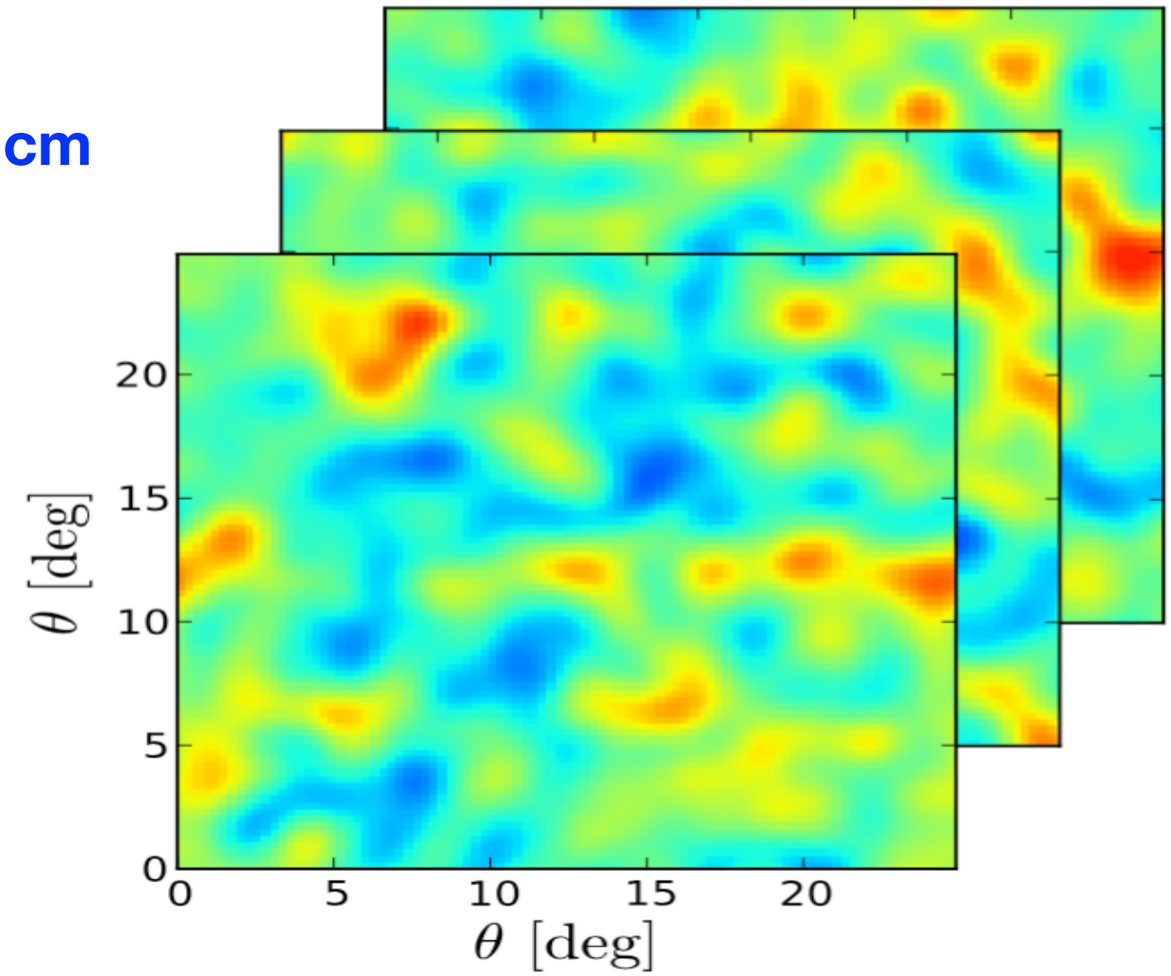


- spectrally isolated
- strongly forbidden: $t_{1/2} \sim 10^7$ years
- small obscuration

e.g. detecting a single **z** ~ **2.5** galaxy with an optimistic HI mass $M_{HI} \sim 6.5 \times 10^9\, M_\odot$ would require ~ **360 hours** with the SKA telescope [Kanekar+ 2010]

21cm intensity mapping



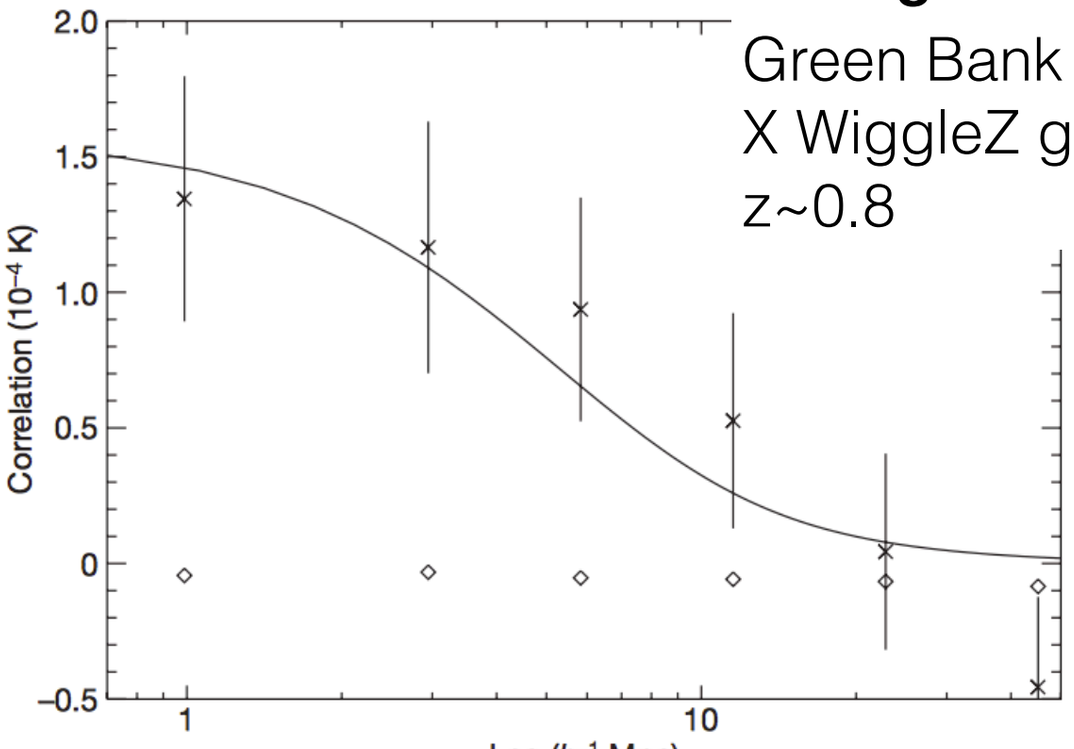


- spectroscopic nature
- large volumes (for cheap)
- Cosmology using HI as tracer!

measurements

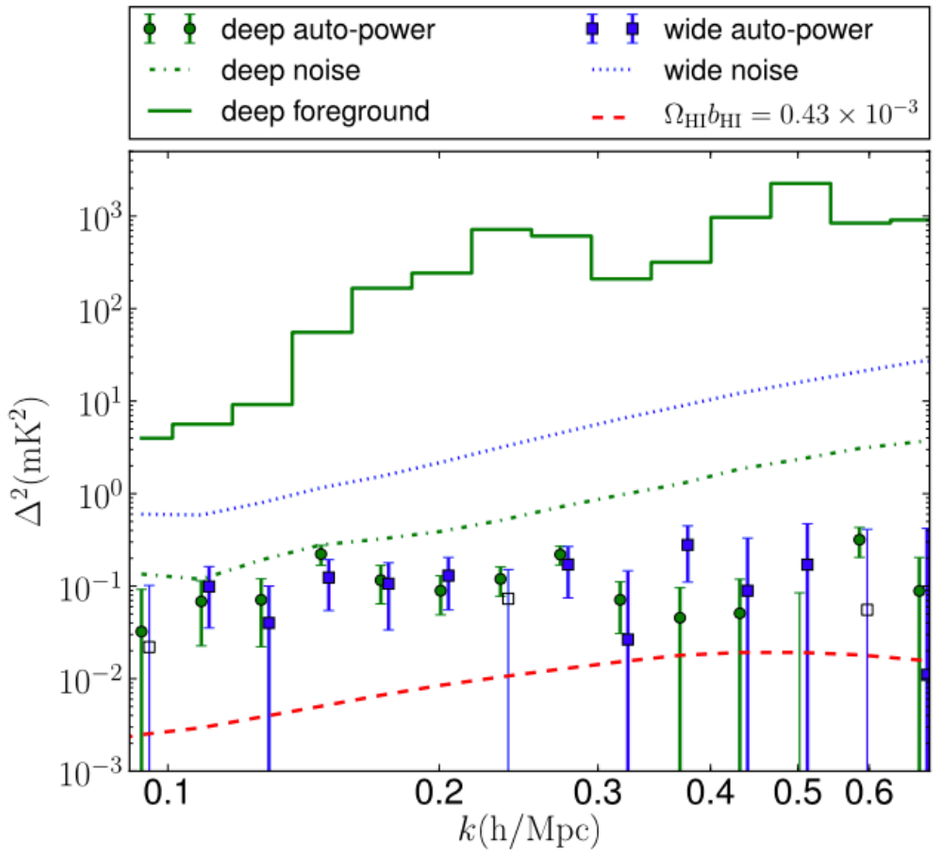
Chang+ 2010

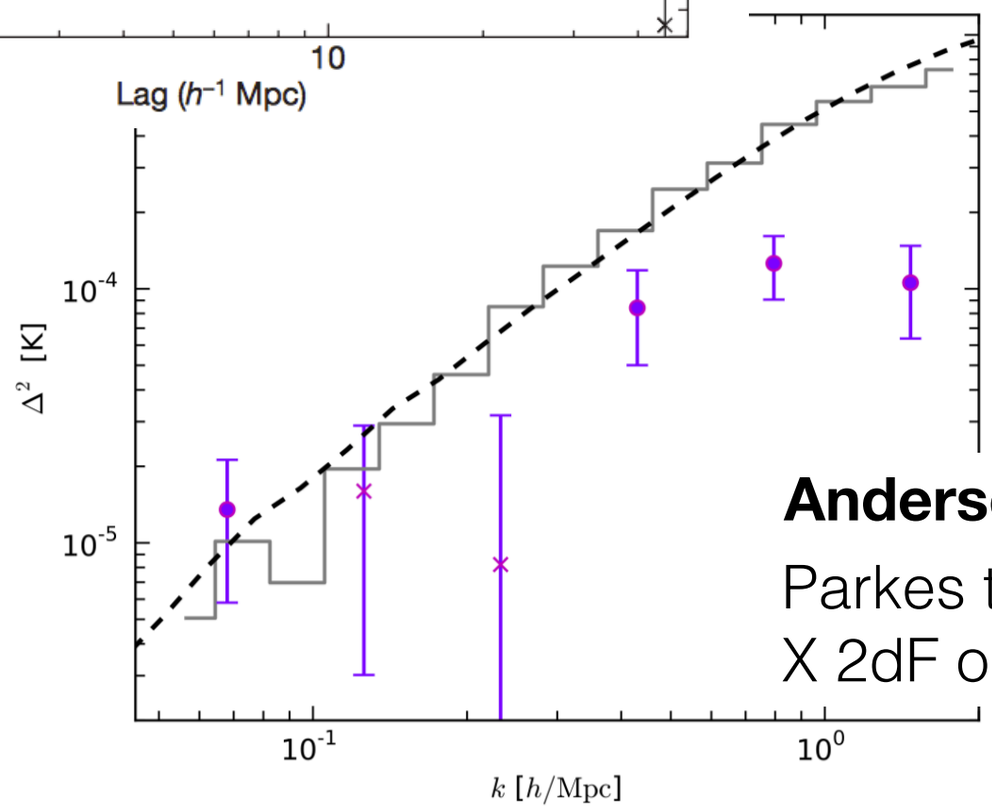
Green Bank Telescope
X WiggleZ galaxies
z~0.8



Switzer+ 2013

21cm IM auto-P(k)



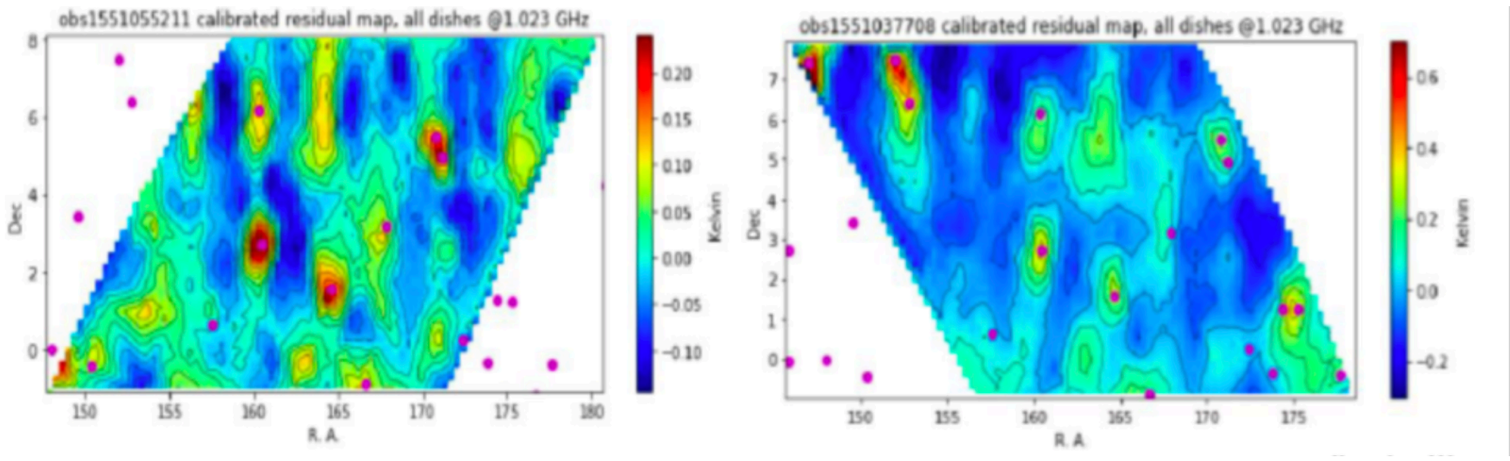


Anderson+ 2018

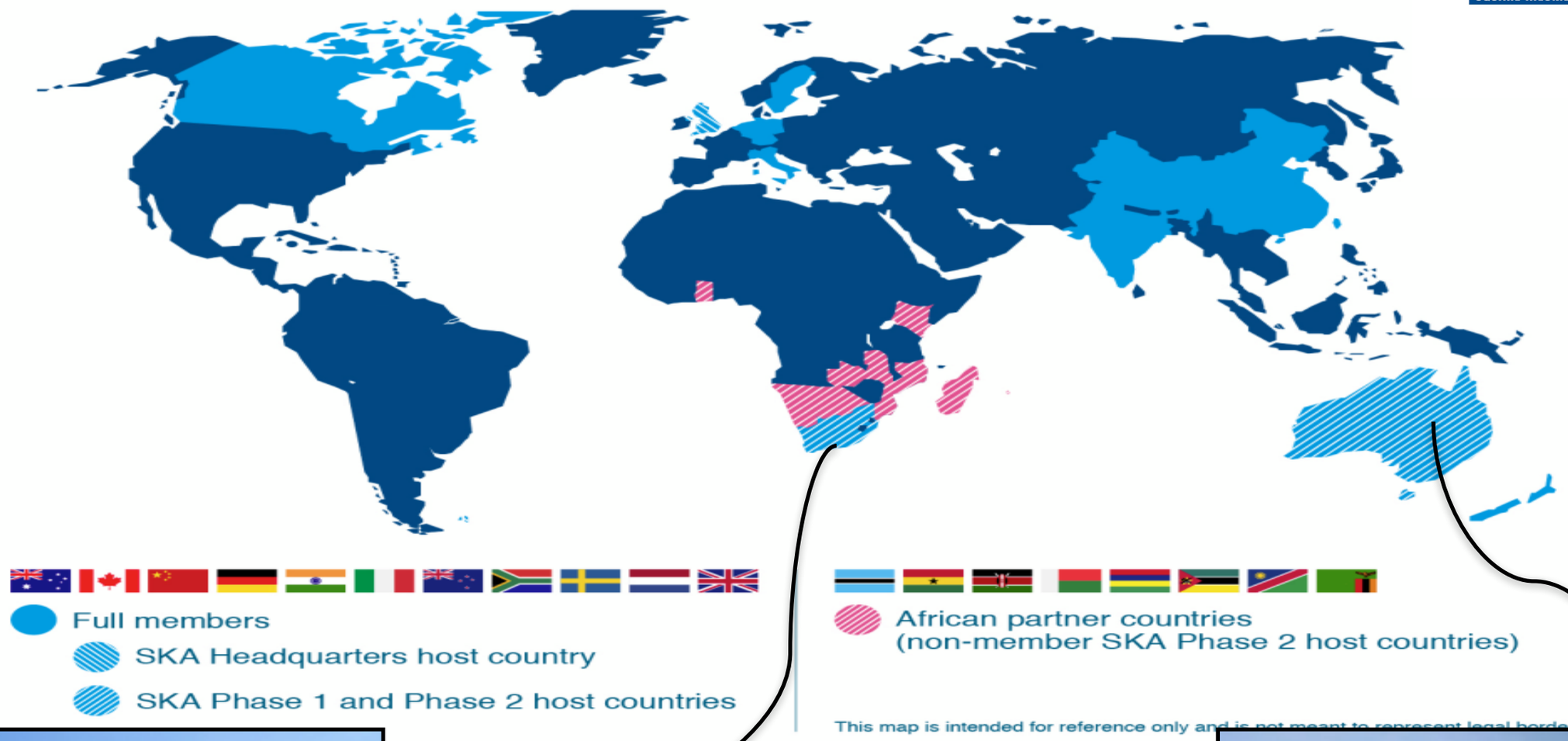
Parkes telescope
X 2dF optical galaxies

the future is bright

- SKA (**MeerKAT** already, single dishes, up to z~1.45)
- **Chime** (analysing data, interferometer, to z~2.5)
- **Tianlai** (analysing data, interferometer, to z~2.5)
- Bingo (being built, single dish, up to z~0.48)
- FAST (testing, single dish)
- HIRAX (dishes)
- ORT
- …



MeerKAT 21cm IM tests (courtesy of Mario Santos)



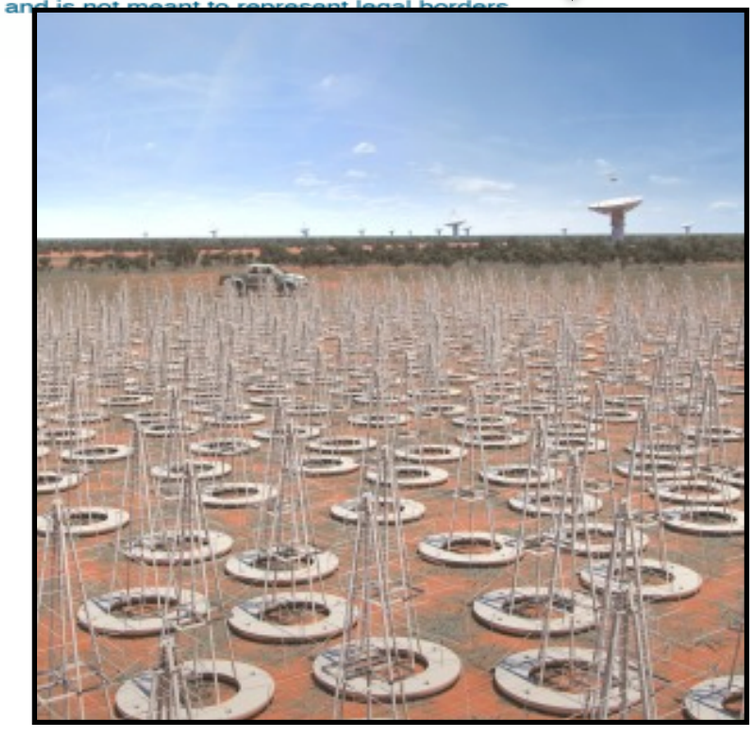
Phase I

SKA1-MID

- 0 < z < 3
- 200 dishes; 15m

SKA1-LOW

- 3 < z < 27
- 911 antennae

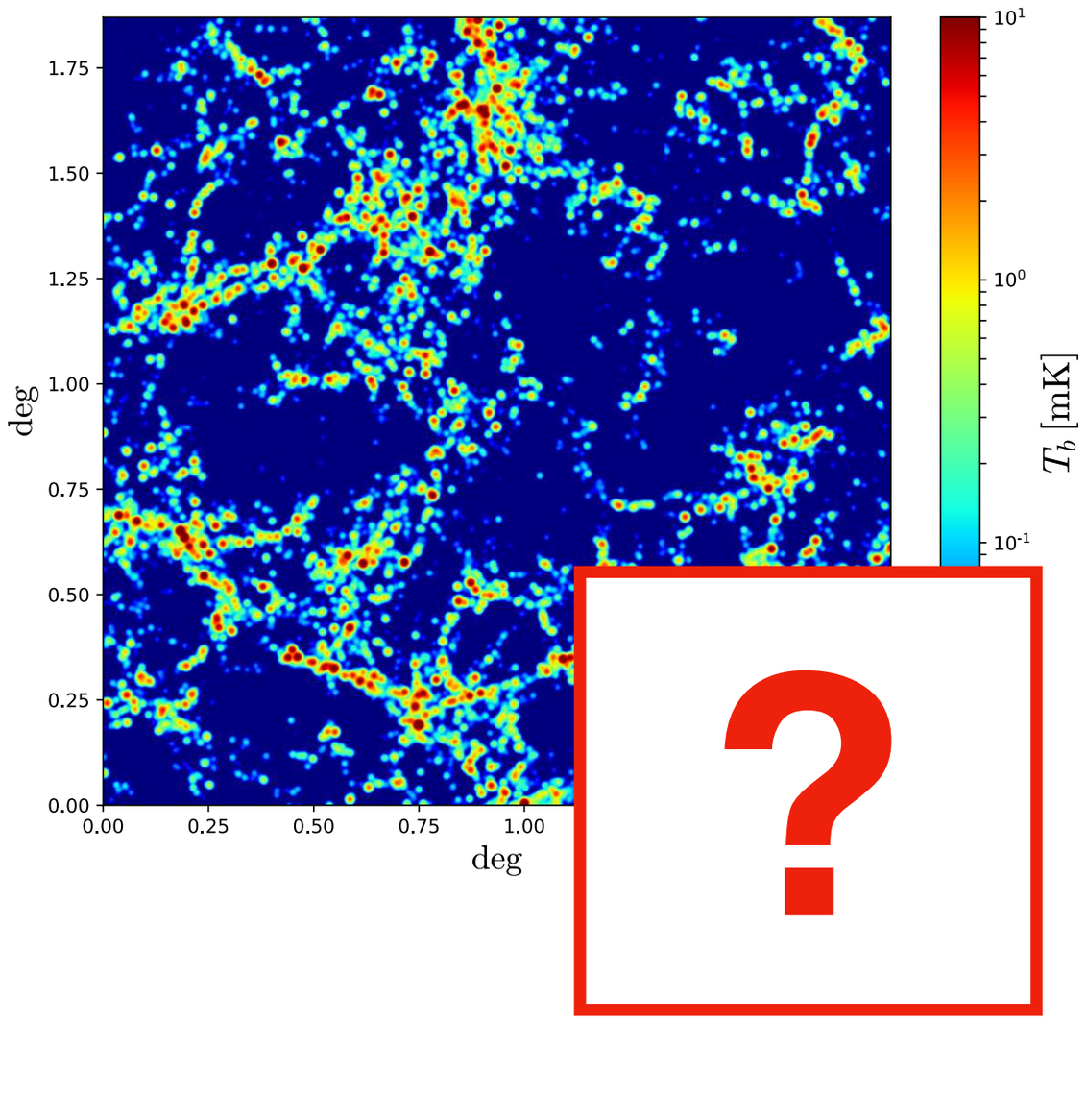


21cm intensity mapping:

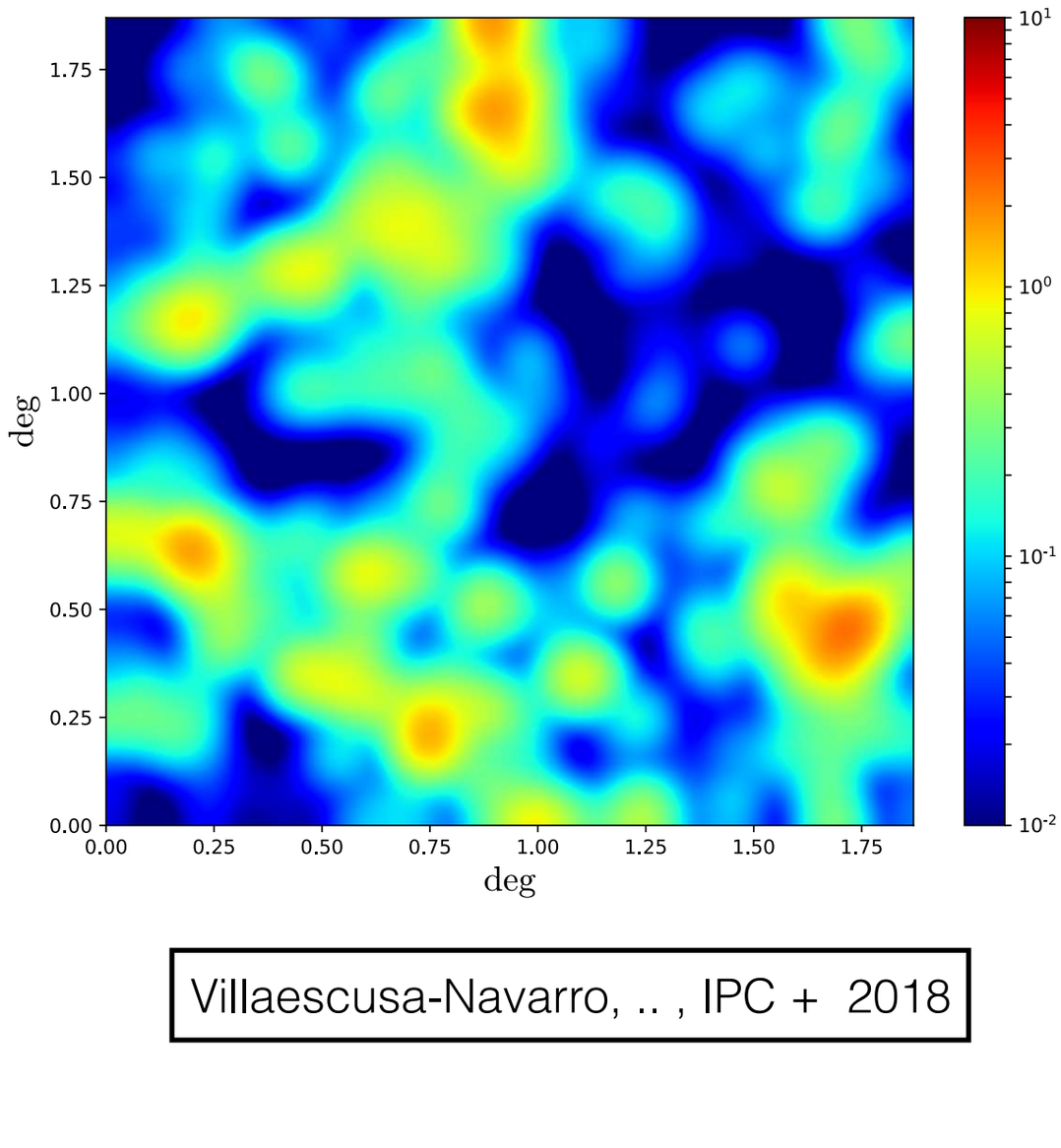
- modelling
- dependence on cosmology
- foreground cleaning and instrumental effects

Distribution of HI in the universe

modelling ⇨ forecasts



?



Villaescusa-Navarro, .. , IPC + 2018

Distribution of HI in the universe

How is it clustered?

$b_{HI} \simeq 0.8$ at z~0

- the clustering of **HI selected galaxies at z ~ 0** from the ALFALFA survey (Martin+ 2012, Guo+ 2017)

$b_{DLAs} = 1.99 \pm 0.11$ at z~2.3

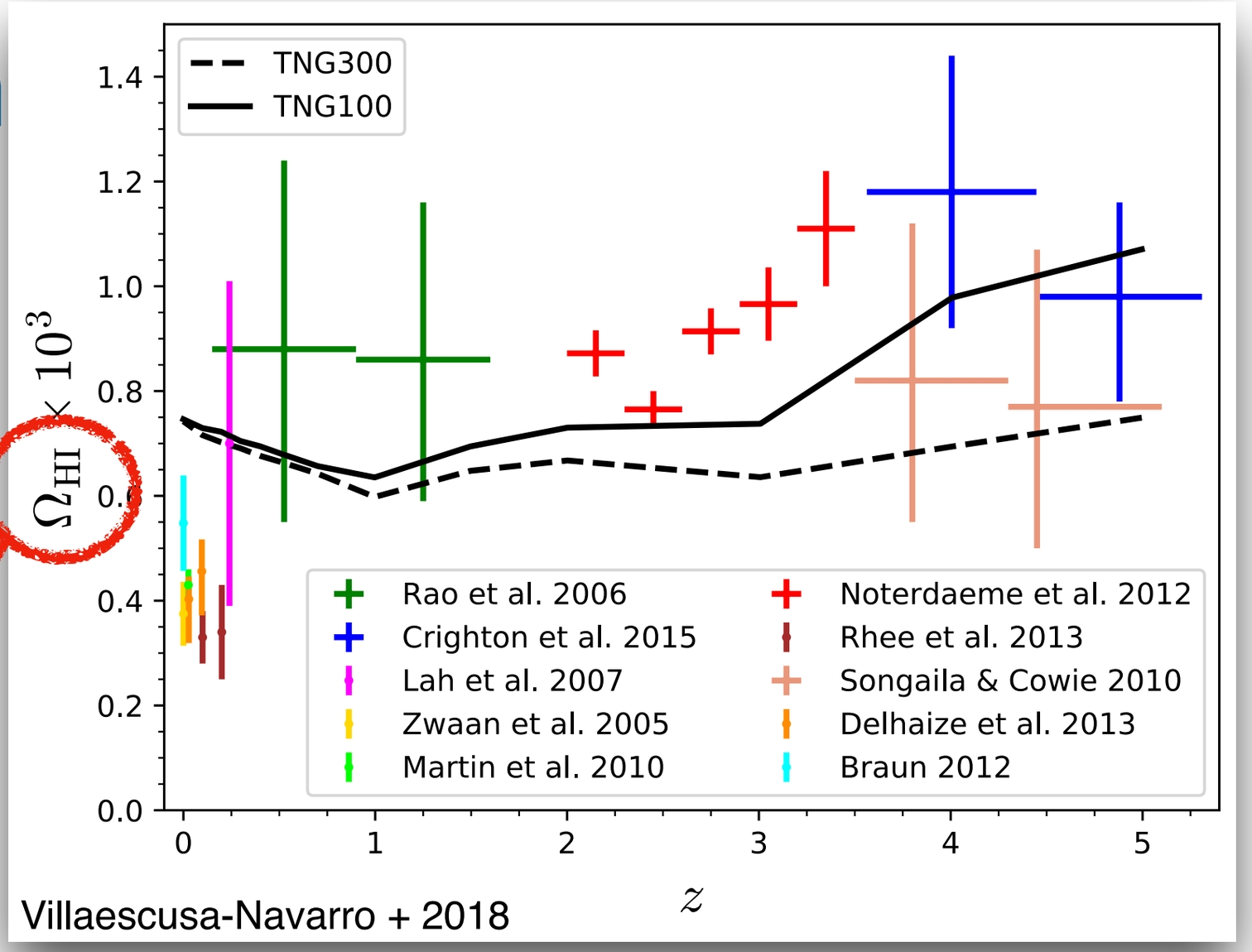
- the bias of the Damped Lyman-α systems **(DLAs) at z ~ 2.3** by BOSS collaboration (Perez-Rafols+ 2017)

$\Omega_{HI} \times b_{HI} = 0.62 \times 10^{-3}$ at z~0.8

- HI cosmic abundance times its linear bias, from **21cm IM observations at z ≃ 0.8** performed with the GBT by (Switzer+ 2013)

How much HI around?

Distribution

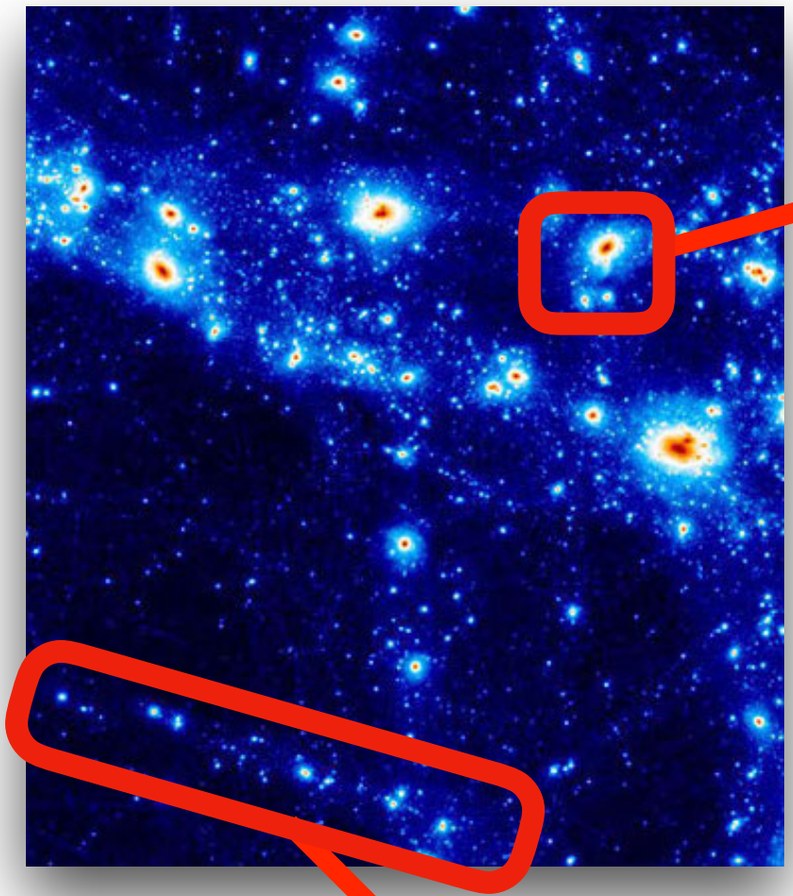


Villaescusa-Navarro + 2018

$\Omega_{HI} \times b_{HI} = 0.62 \times 10^{-3}$ at z~0.8

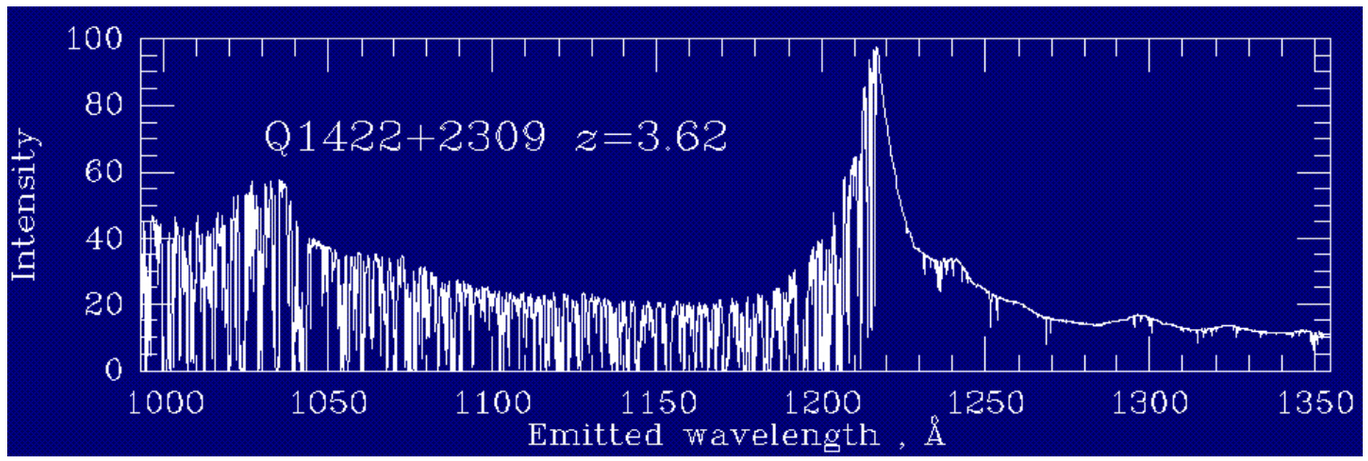
$$P_{21} \propto (\delta\overline{T}_b\, b_{HI})^2\, P_m$$
$$\propto (\Omega_{HI}\, b_{HI})^2\, P_m$$

Distribution of HI in the universe



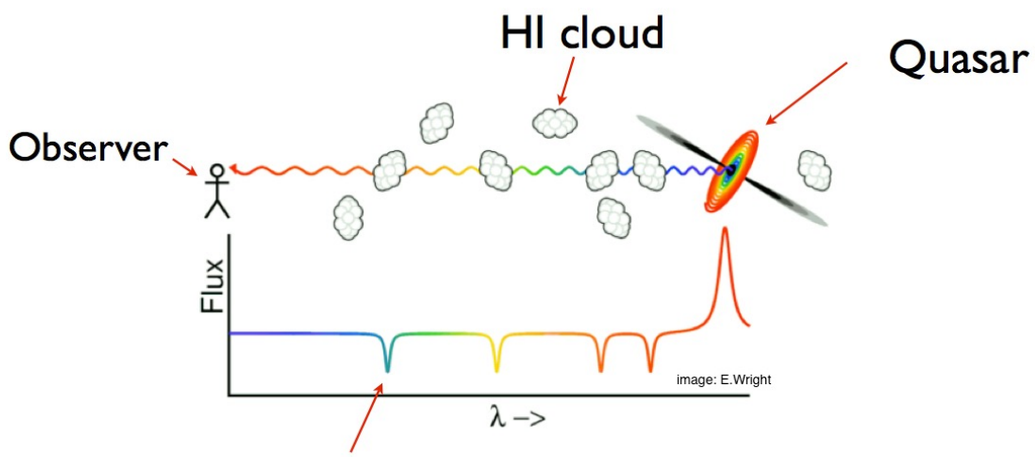
Halos (DLAs, i.e. galaxies)

Dense, self-shielding —> HI



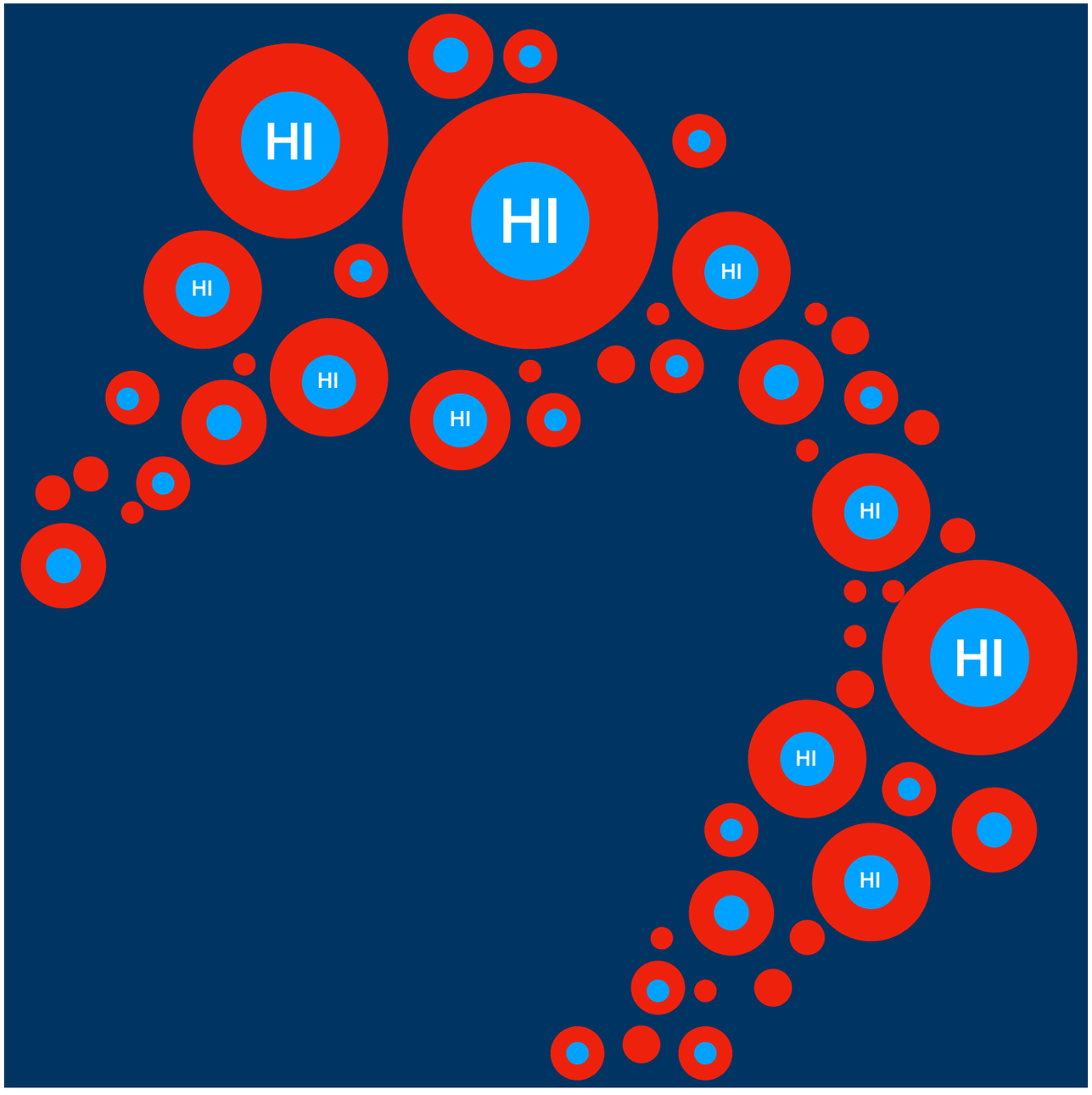
Filaments

mostly ionised H



Distribution of HI in the universe

Strategy 1:
HI resides in
DM halos



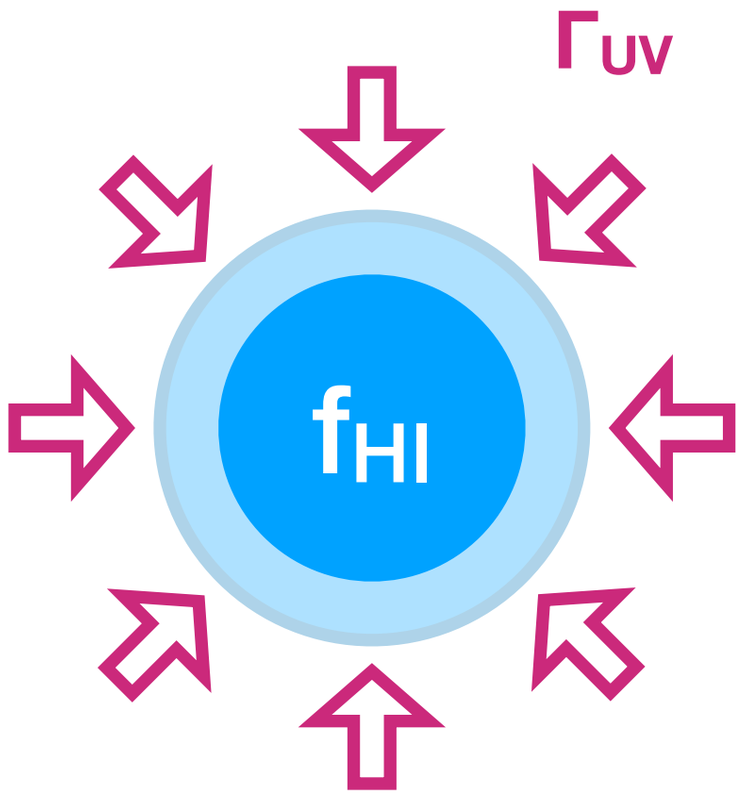
$M_{HI} = M_{HI}(M_{halo})$

if $M_{halo} > M_{min}$

Distribution of HI in the universe

Strategy 2:
Hydro sims

- assuming photo-ionization equilibrium, setting the HI/H fraction in order to reproduce the Lyman-α mean transmission flux



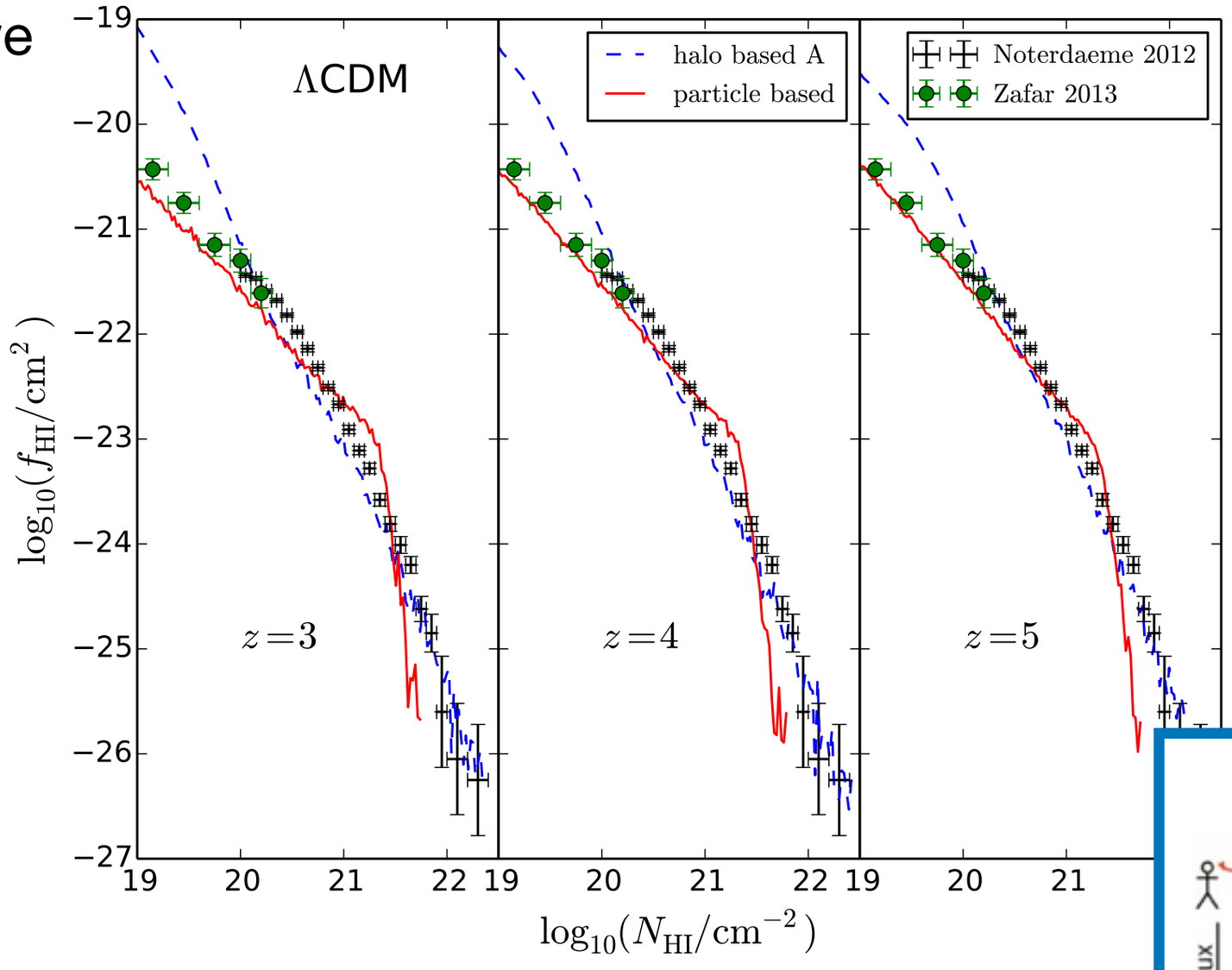
- mimicking HI self-shielding for high enough density regions

- letting H_2 forming for even denser regions

Davé+ 2013, Rahmati+ 2015, …

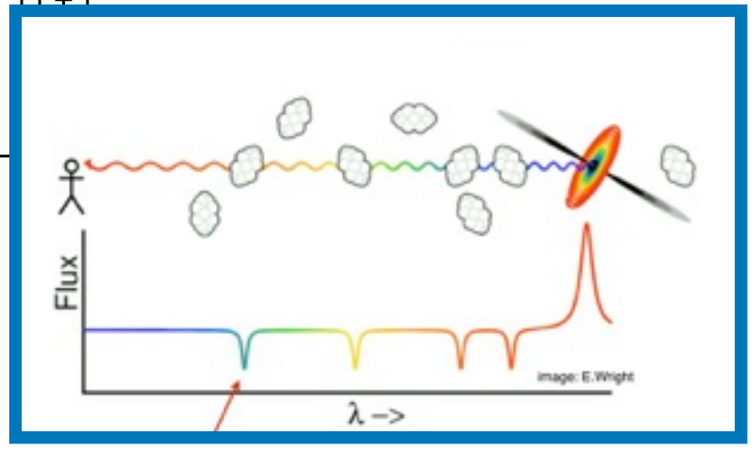
Distribution of HI in the universe

How can we test these methods?



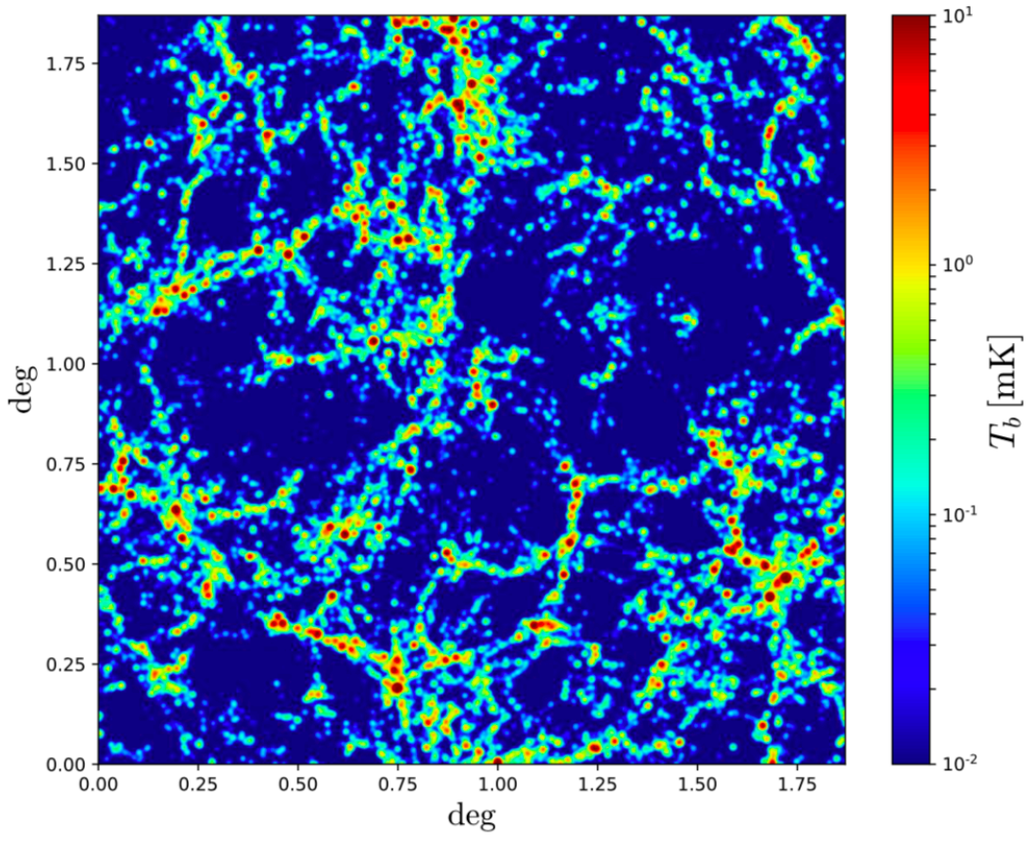
Carucci + 2015

HI column density distribution function

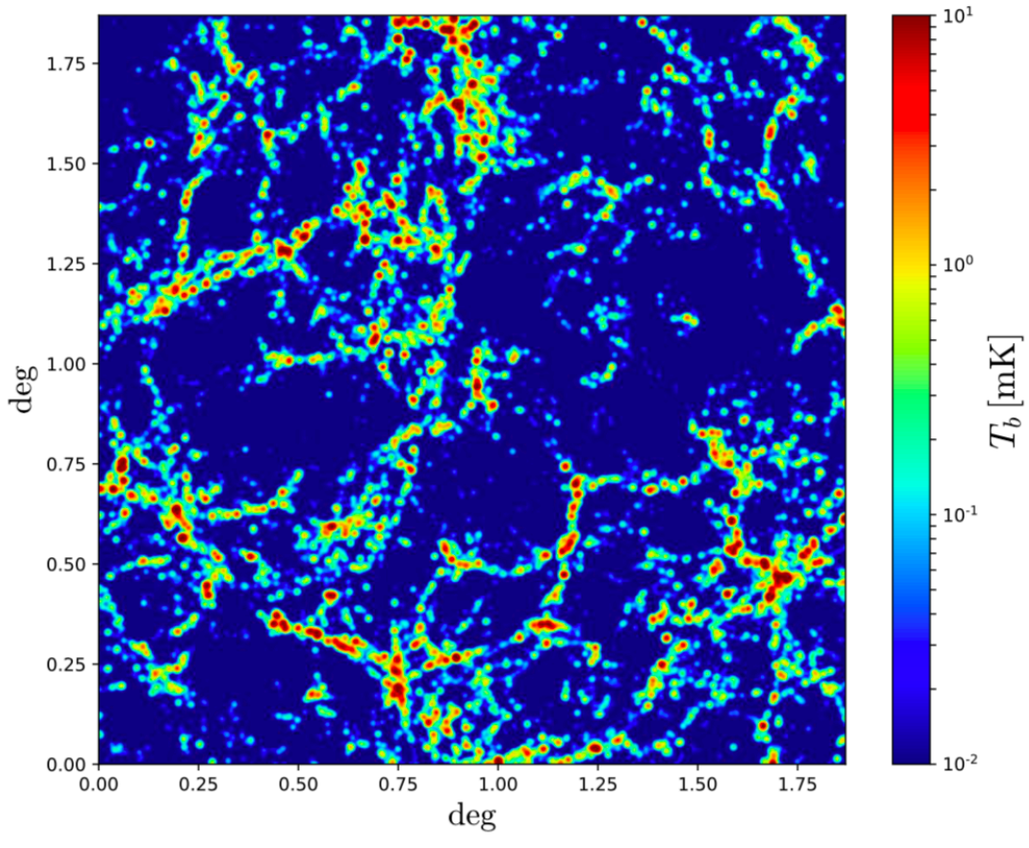


Distribution of HI in the universe

cheap Nbody



IllustrisTNG

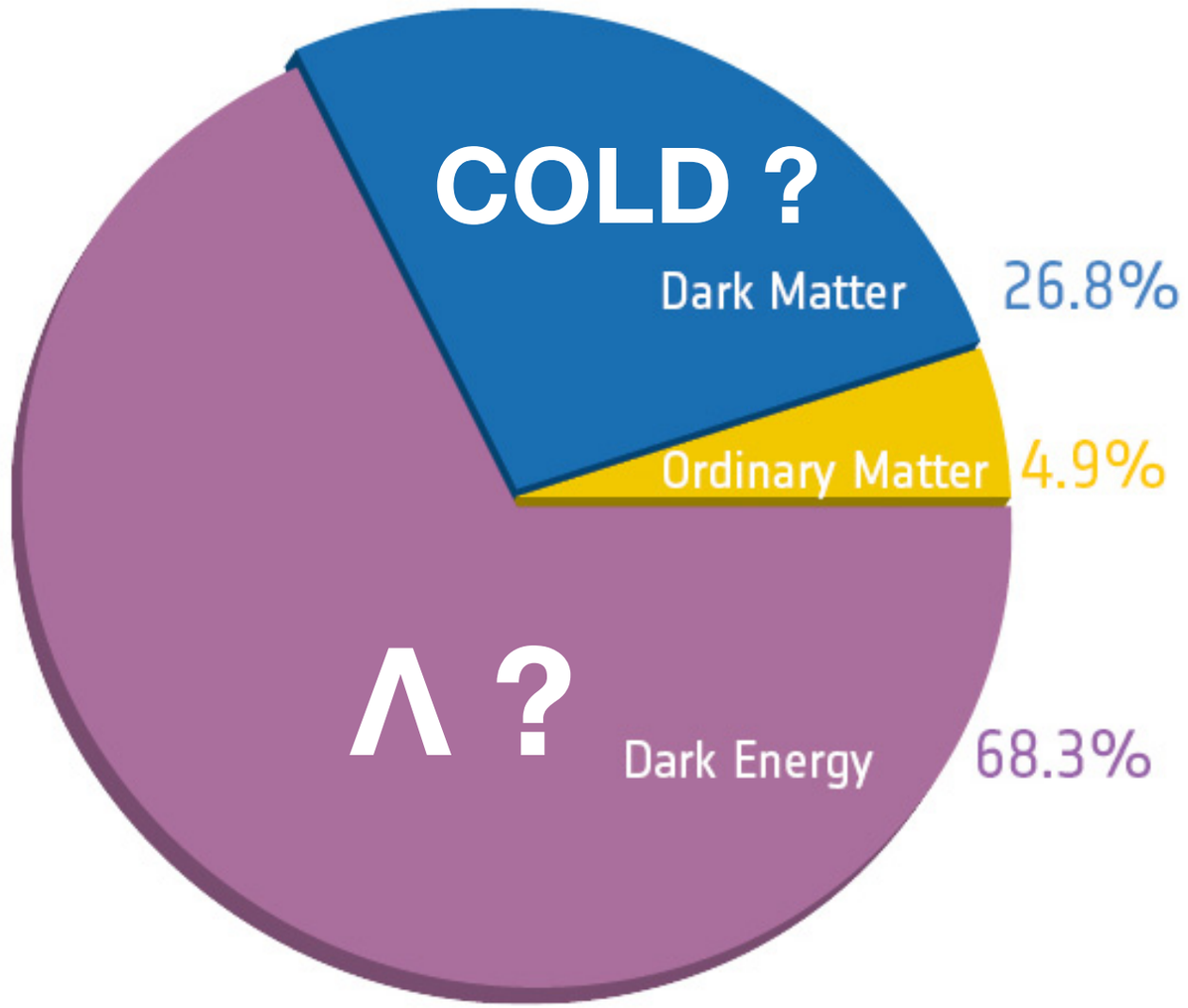


Villaescusa-Navarro, .. , IPC + 2018

21cm intensity mapping:

- modelling
- dependence on cosmology
- foreground cleaning and instrumental effects

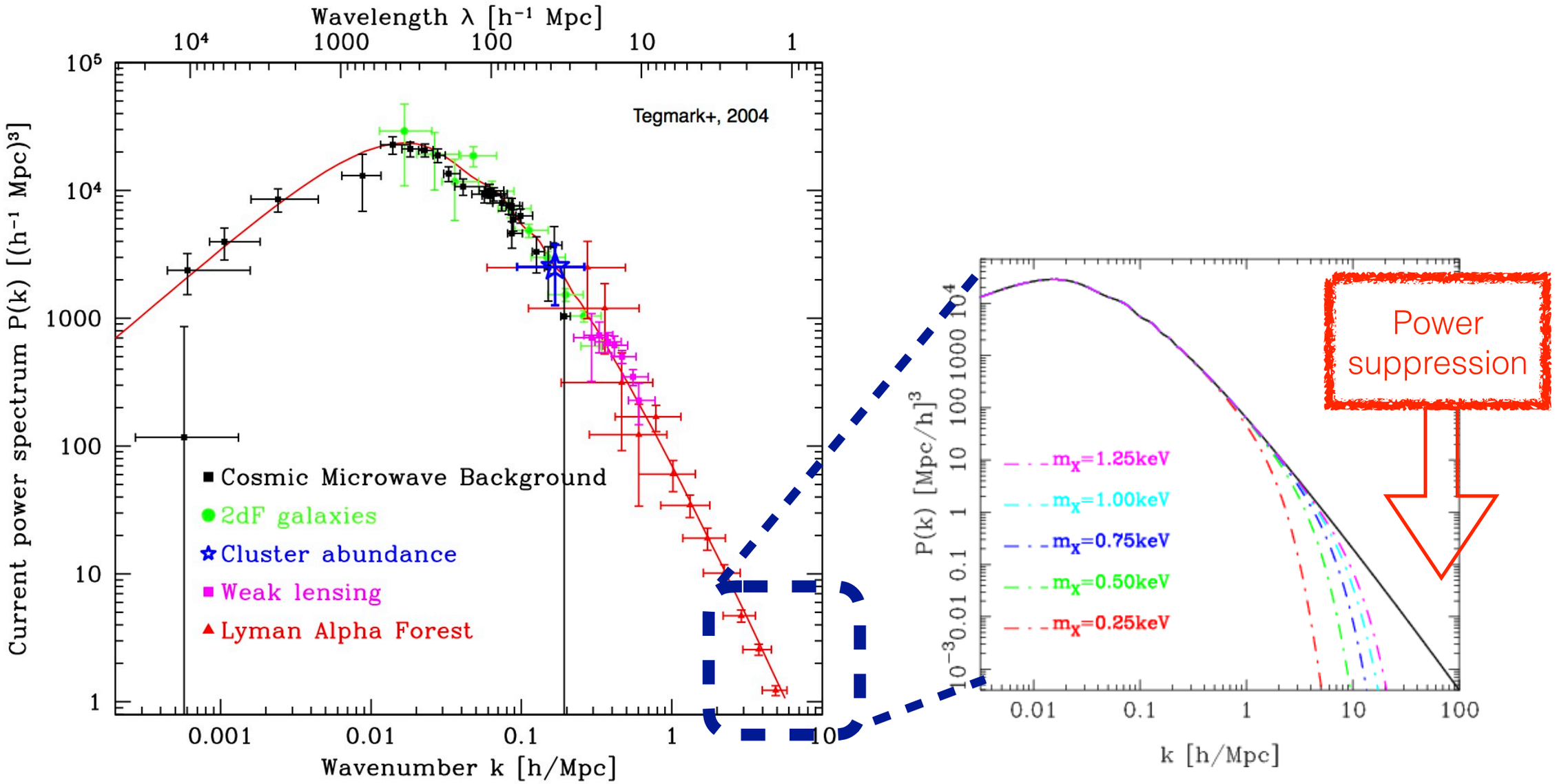
standard
ΛCDM model



Dark matter

$$\delta = \frac{\Delta\rho}{\rho}$$

$$<\delta(\mathbf{k})\ \delta(\mathbf{k'})> = \delta_D(\mathbf{k}+\mathbf{k'})\ P(\mathbf{k})$$



Dark matter

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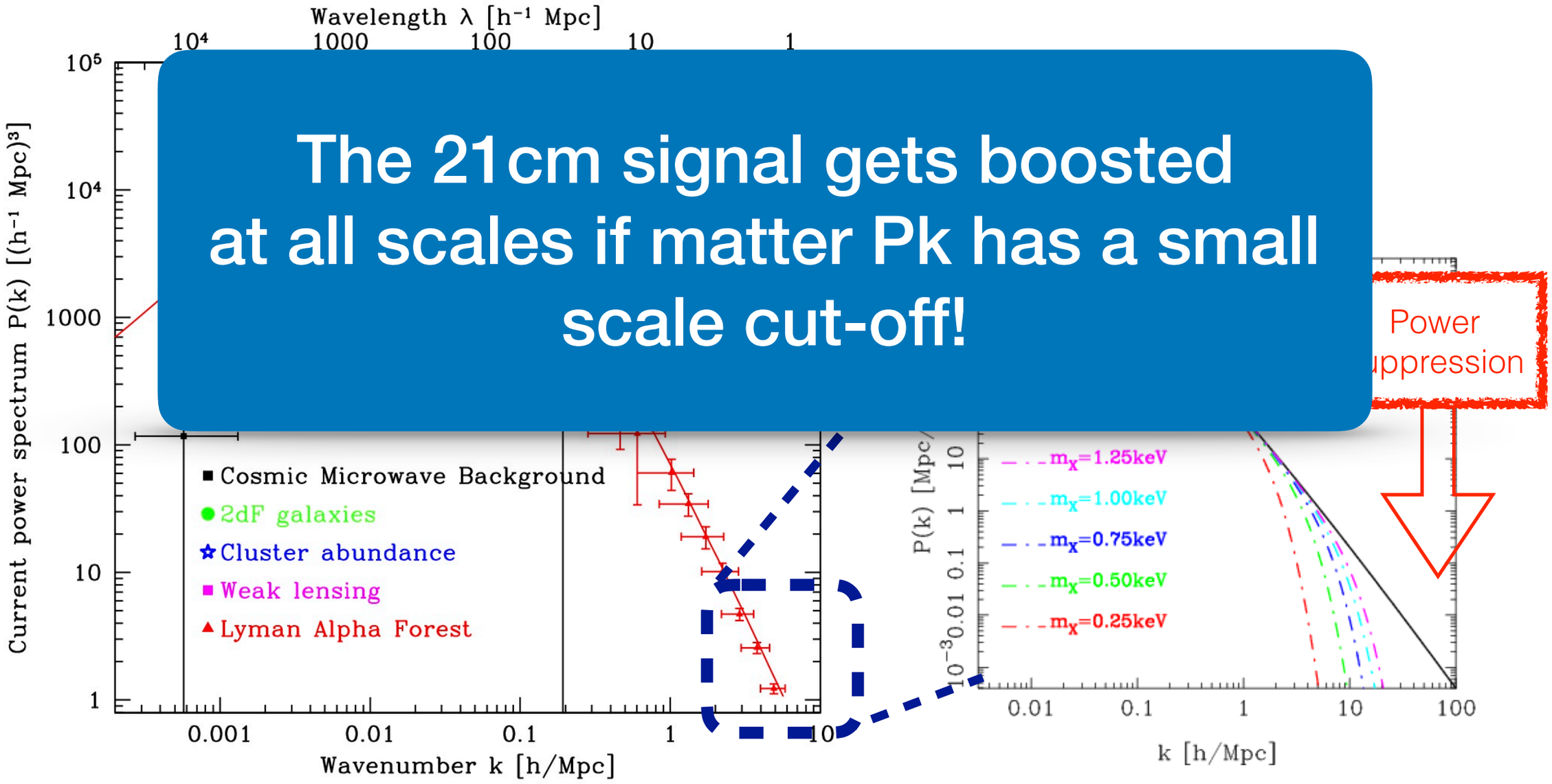
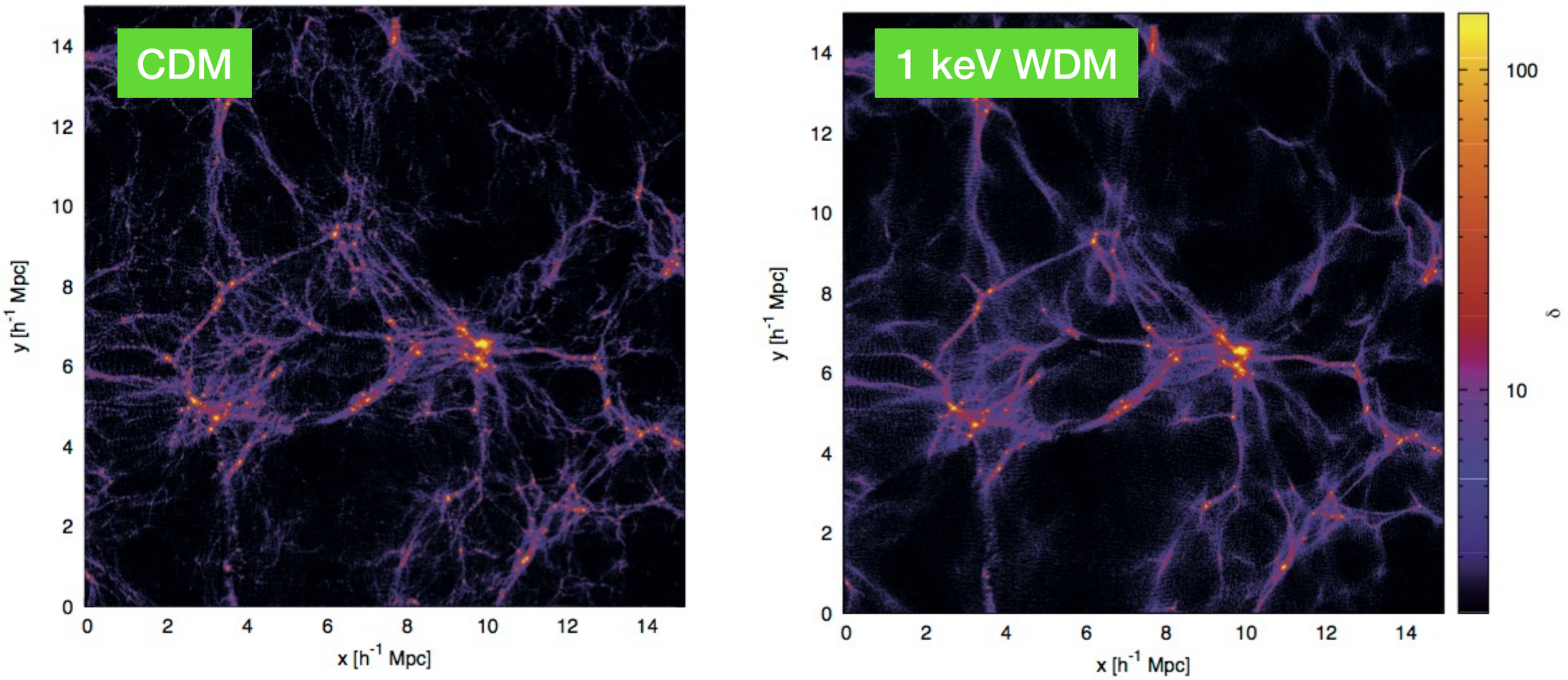


The 21cm signal gets boosted at all scales if matter Pk has a small scale cut-off!

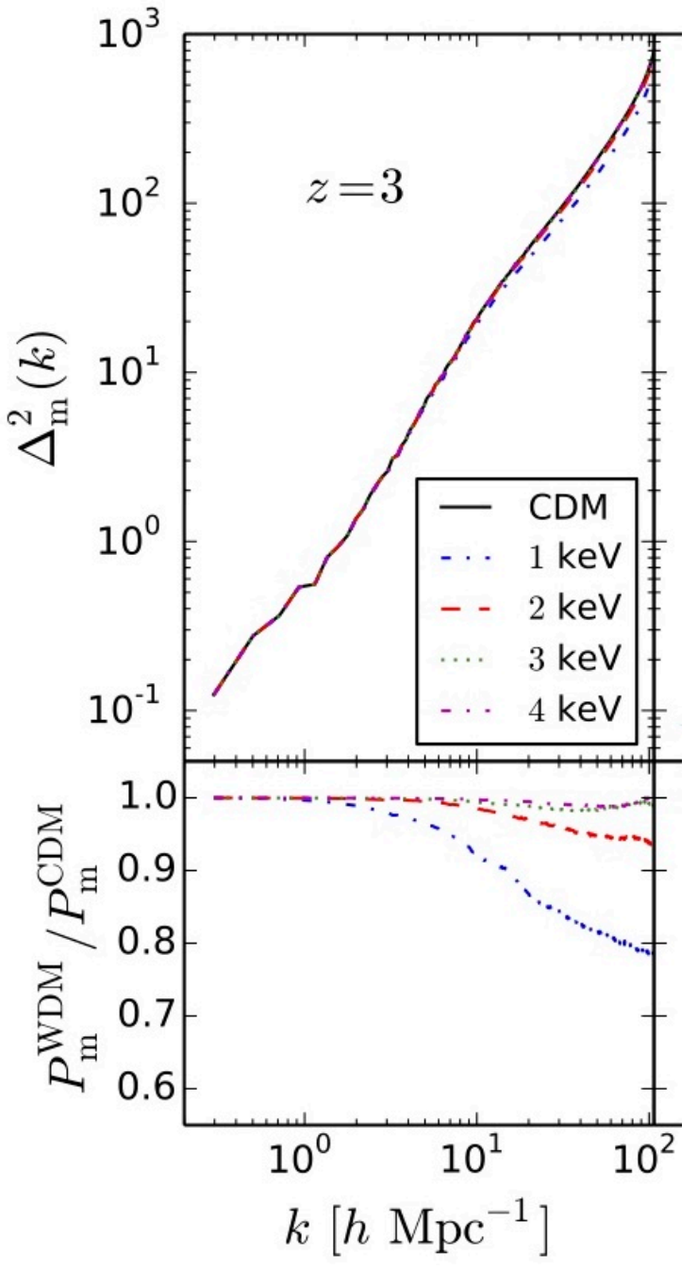
Dark matter models (hydro) simulations



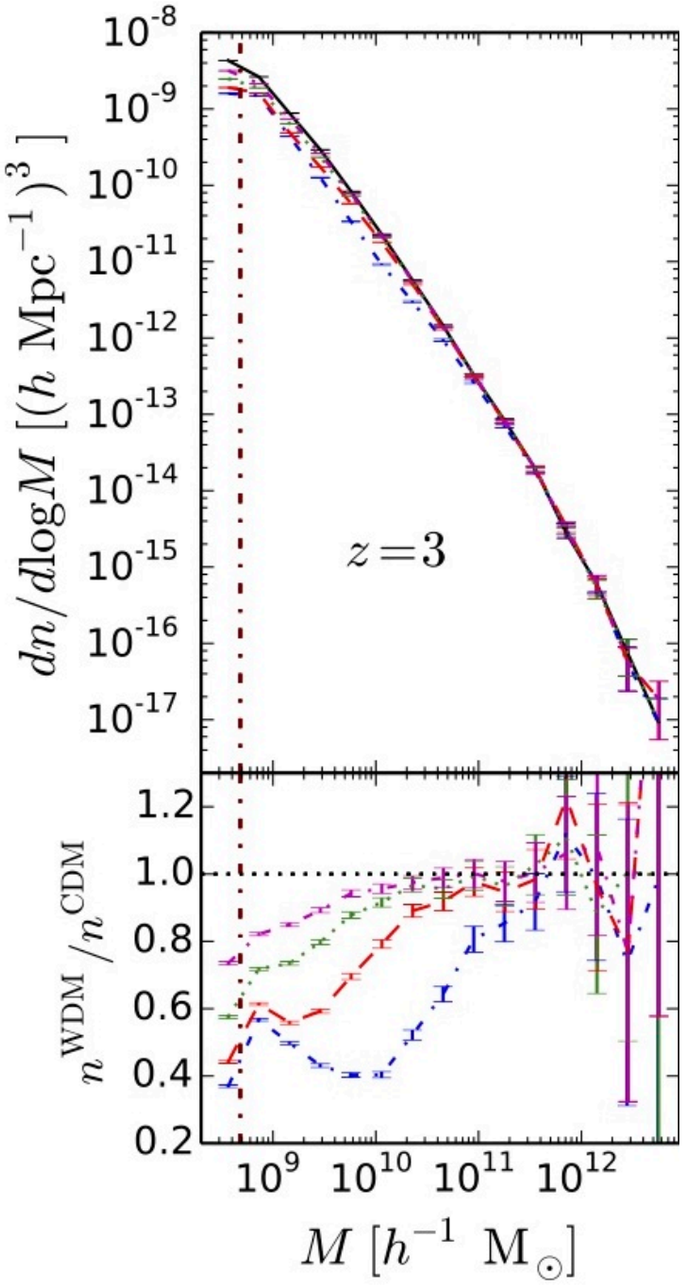
Carucci + 2015

Dark matter models (hydro) simulations

Total matter Pk

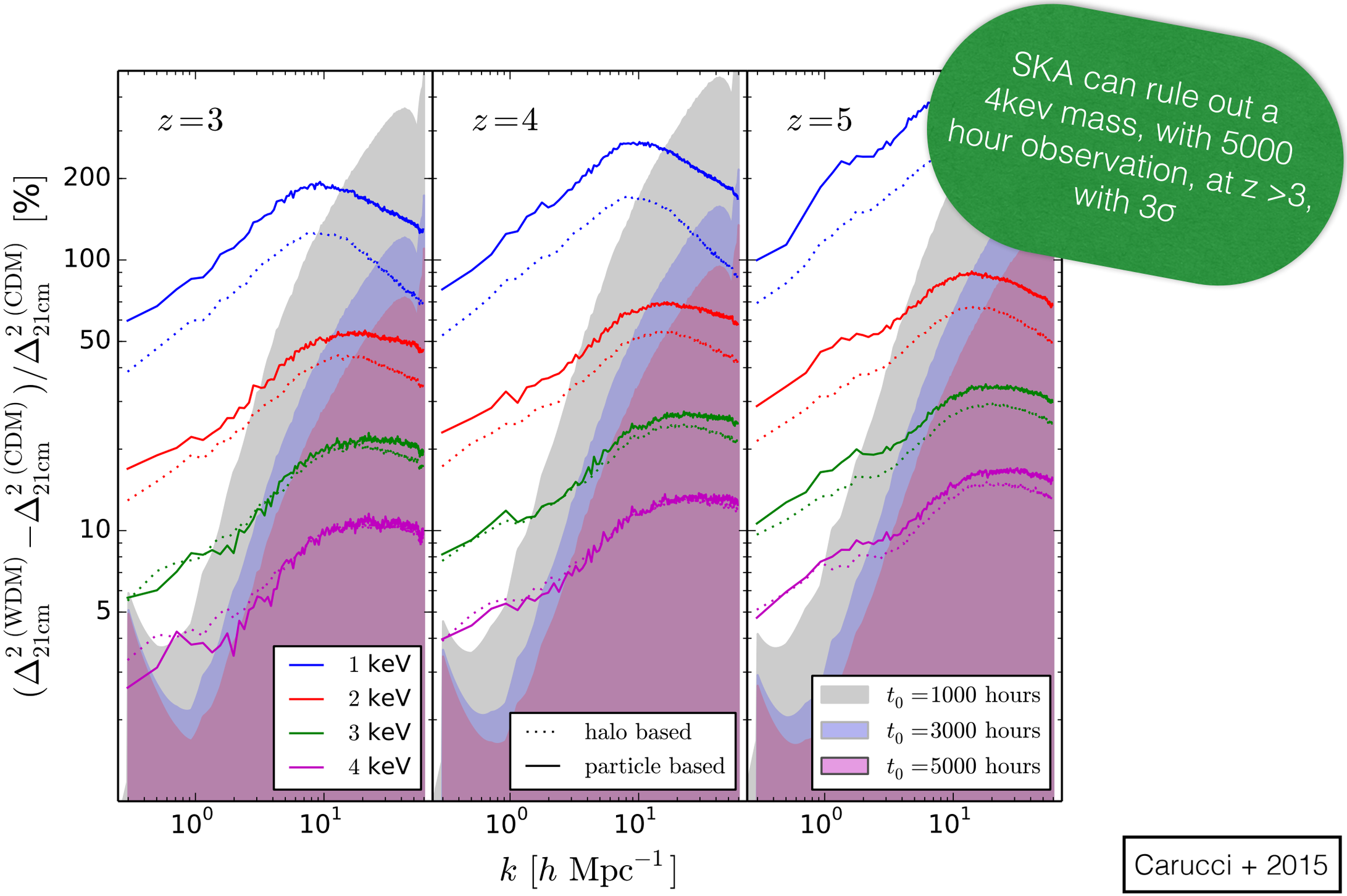


Halo mass function



Carucci + 2015

Dark matter models: 21cm signal



SKA can rule out a 4kev mass, with 5000 hour observation, at z >3, with 3σ

Carucci + 2015

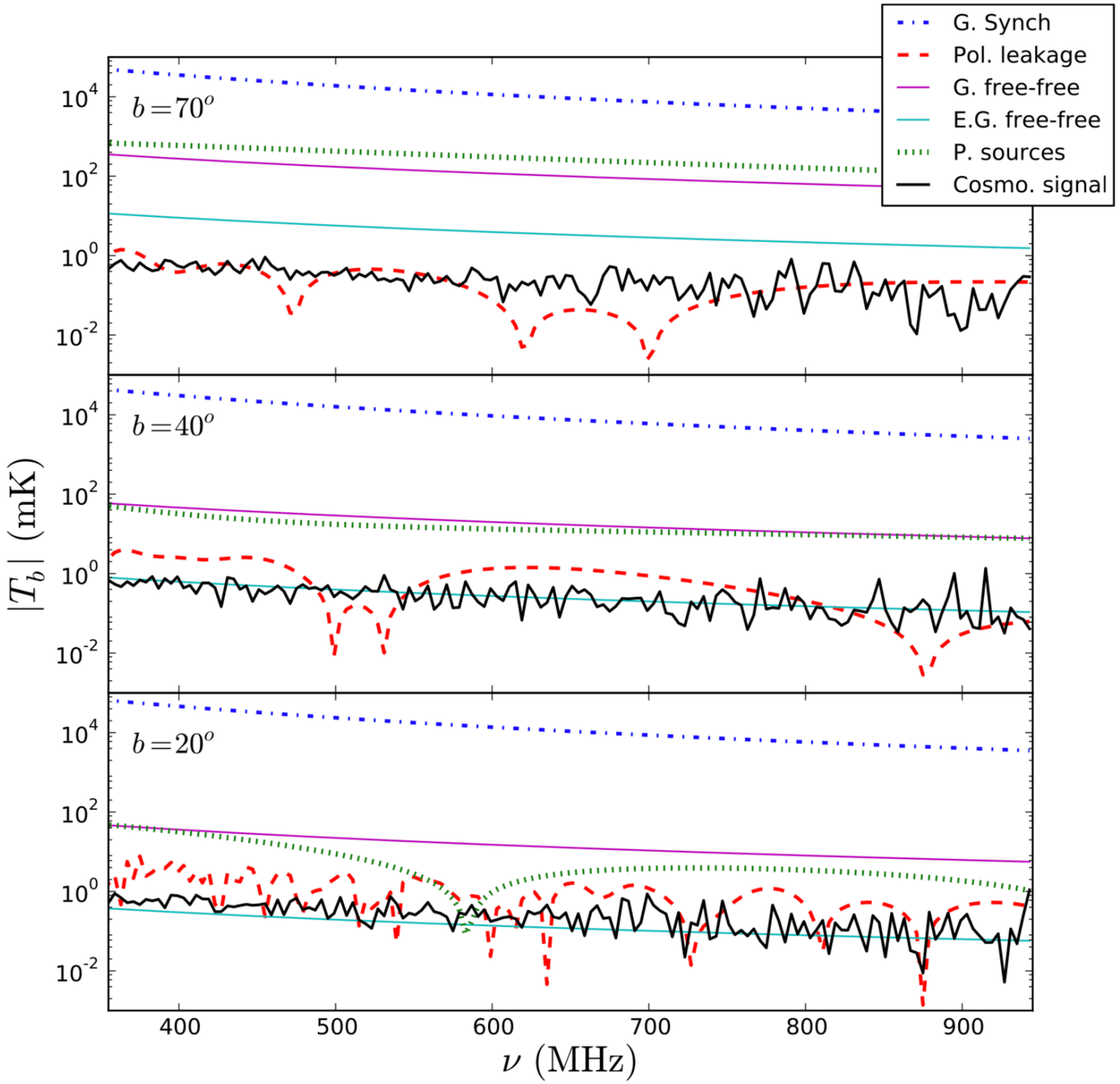
21cm intensity mapping:

- modelling
- dependence on cosmology
- **foreground cleaning and instrumental effects**

i.e. what am I doing here?

21cm intensity mapping:

buried under the foregrounds



Alonso+ 2014

GMCA: Generalised Morphological Component Analysis

Bobin + 2007, 2008, 2012

mixing matrix

$$\mathbf{X} = \mathbf{A}\ \mathbf{S}$$

signal

sources (foregrounds)

wavelet basis

$$\min_{\mathbf{A},\mathbf{S}} \underbrace{\|\Lambda \odot \mathbf{SW}\|_p}_{\text{Sparse regularisation}} + \frac{1}{2} \underbrace{\|\mathbf{X} - \mathbf{AS}\|_F^2}_{\text{Data fidelity}}$$

- BSS with **sparse** representation
- Iterative thresholding algorithm
- **No parameters to tune**

Tested on **CMB** (data, e.g.Bobin+ 2016)

And for **EoR** signal (sims, Chapman+ 2013)

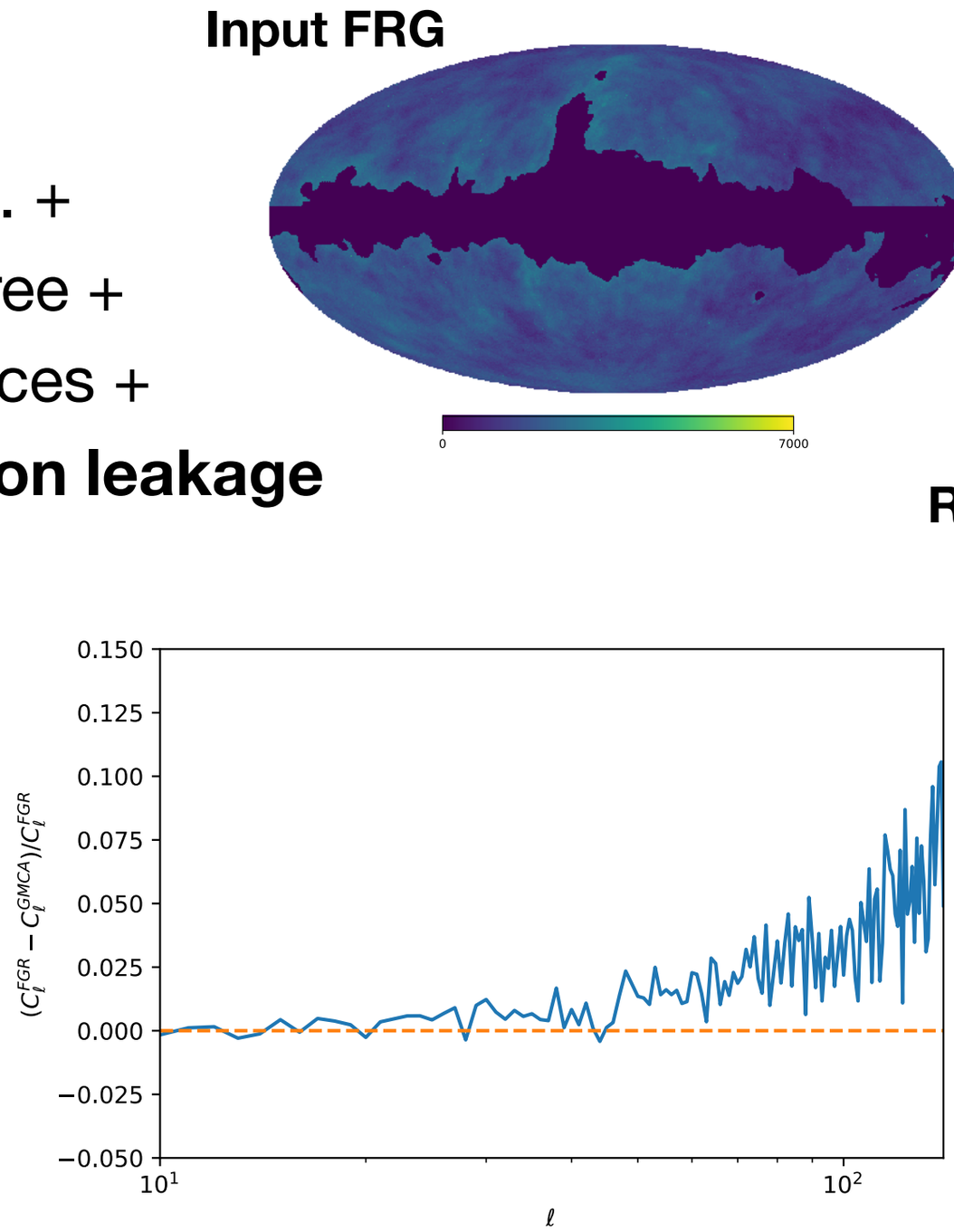
Jérôme Bobin

Melis Irfan

testing **GMCA on 21cm intensity mapping**

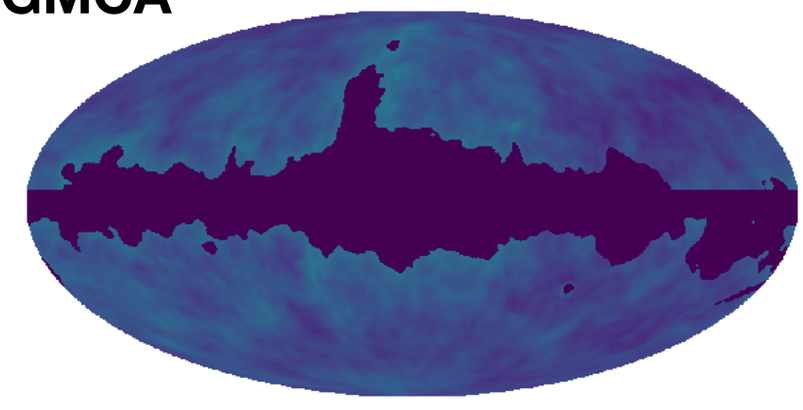
gal. synch. +
gal. free-free +
point sources +
polarisation leakage

Beam and noise as MeerKAT

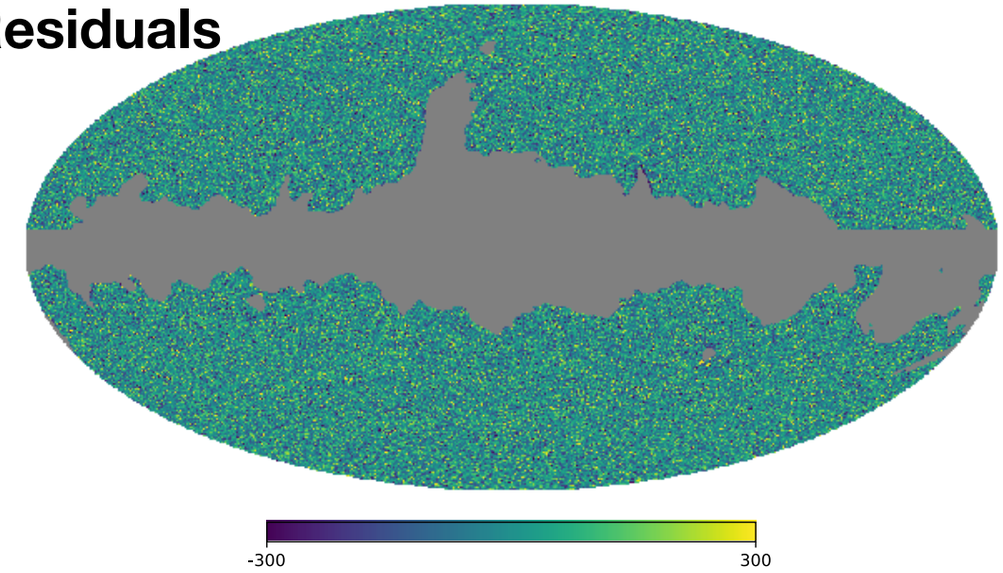


Input FRG

GMCA



Residuals

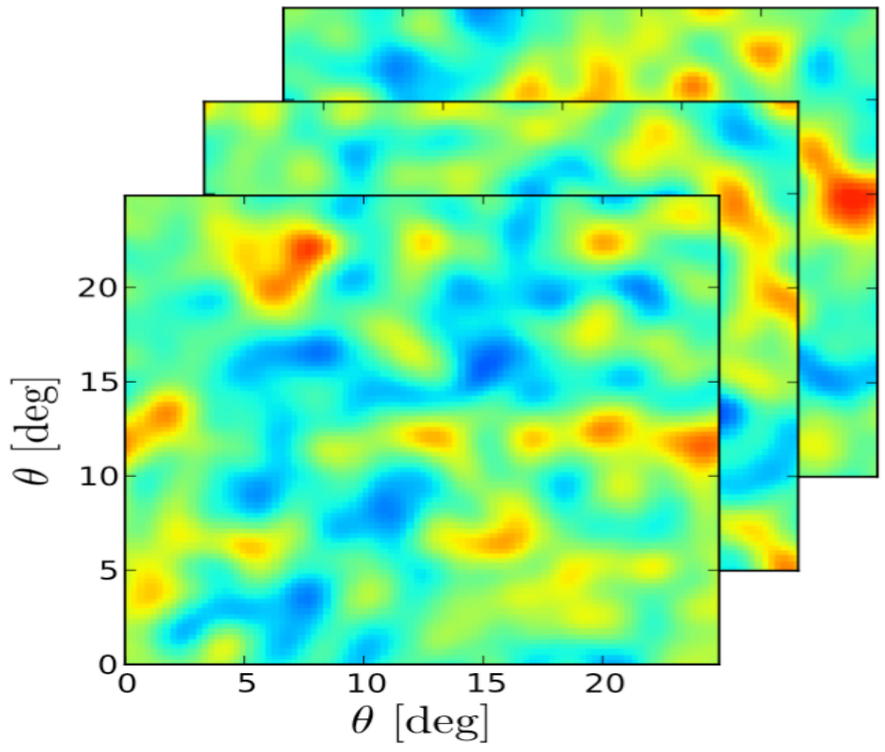


Summary

- We will soon start doing **cosmology** with **21cm IM**

- Unique test for the **nature of dark matter** and generally for theories that modify the **growth of structures**

- It is **observationally hard**, that's why we want to test/optimise **GMCA**: the sparsity based component separation is very well adapted to capture galactic foregrounds + effective framework to analyse multi-channel data.



Merci!