Model and Exploratory Analysis of HI Content in the Halo Occupancy Method

for Cosmological & Astrophysics Inference with Density Estimatior Networks

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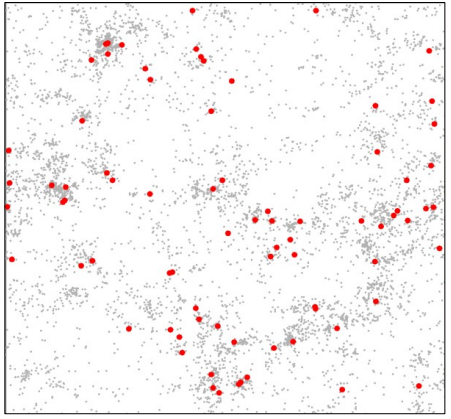
Presentation

- Model the HI content in galaxies for the intesity mapping:
  - Extend the Halo occupancy distribution (HOD) with Normalazing Flow networks.
  - Exploratory analysis of the M_{halo} – M_{HI} correlation
- Study the impact of the UV-background model in post-reionization simulations:
  - Time-evolution of the HI density profile in mock halo

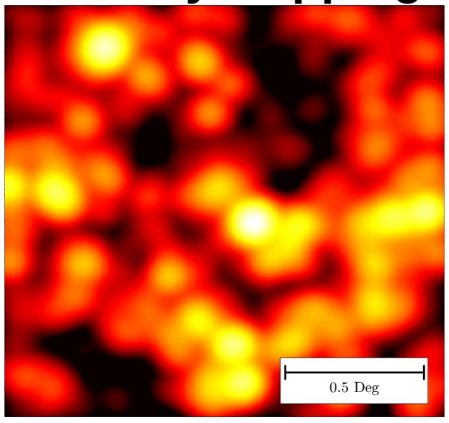
Post-Reionization with Intensity Mapping

Neutral hydrogen within massive galaxies is believed to be self-shielded against UV radiation from primordial sources at z < 5 (Villaescusa-Navarrao+ 2014).

Galaxy Observation



Intensity Mapping



Kovetz+ (2017)

$$T_b(z,\mathbf{n}) \approx \overline{T}_b(z)\left[1 + b_{\rm HI}(z)\delta_m(z,\mathbf{n}) - \frac{(1+z)}{H(z)}\, n^i \partial_i(\mathbf{n}\cdot\mathbf{v})\right]$$

- **Direct detection** of HI in galaxy via 21-cm emission line **is complex**.
- Observations of the **integrated 21-cm** line from **unresolved galaxies** over a wide sky area (Chang+ 2010).

Model Galaxy HI content with ML

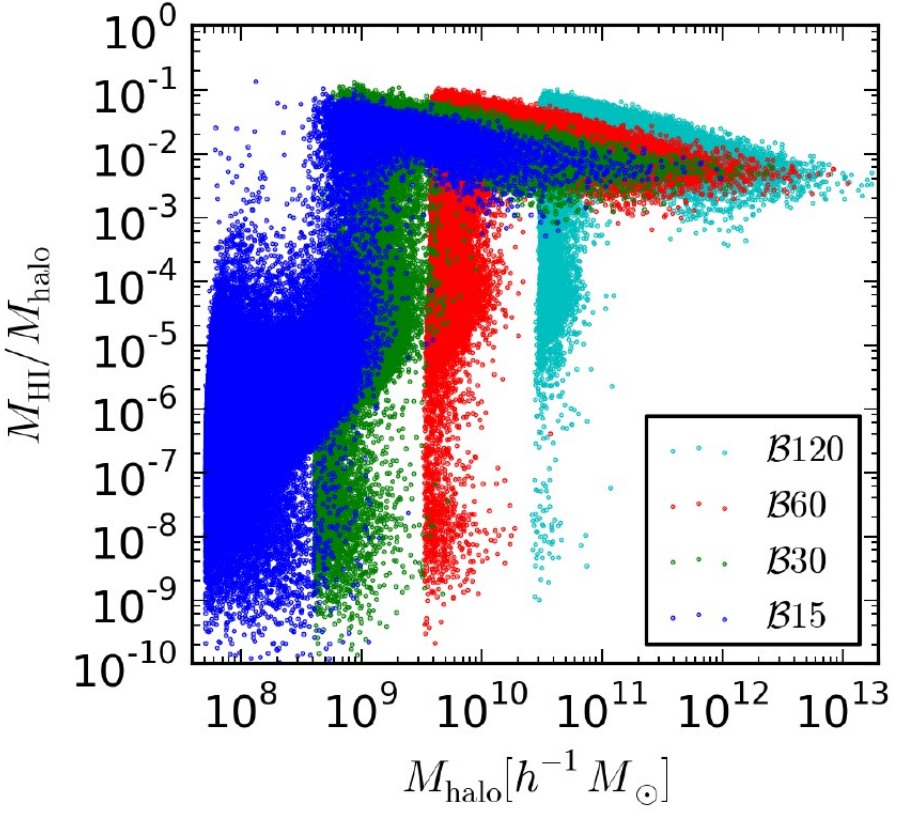
(Bianco+ in prep.)

Fast and computationally inexpensive model for the HI content in galaxies for post-EoR on large scales is to use:

- **<u>Halo Occupation Distribution (HOD)</u>**
  Follow power-law distribution
  Minimum halo mass
  Mass cut for radiative feedback

$$M_{HI}(M_h; z) = A(z)(M_h/M_{\rm cut})^{\alpha(z)} e^{-M_{\rm cut}(z)/M_h}$$

Villaescusa-Navarro+(2014)



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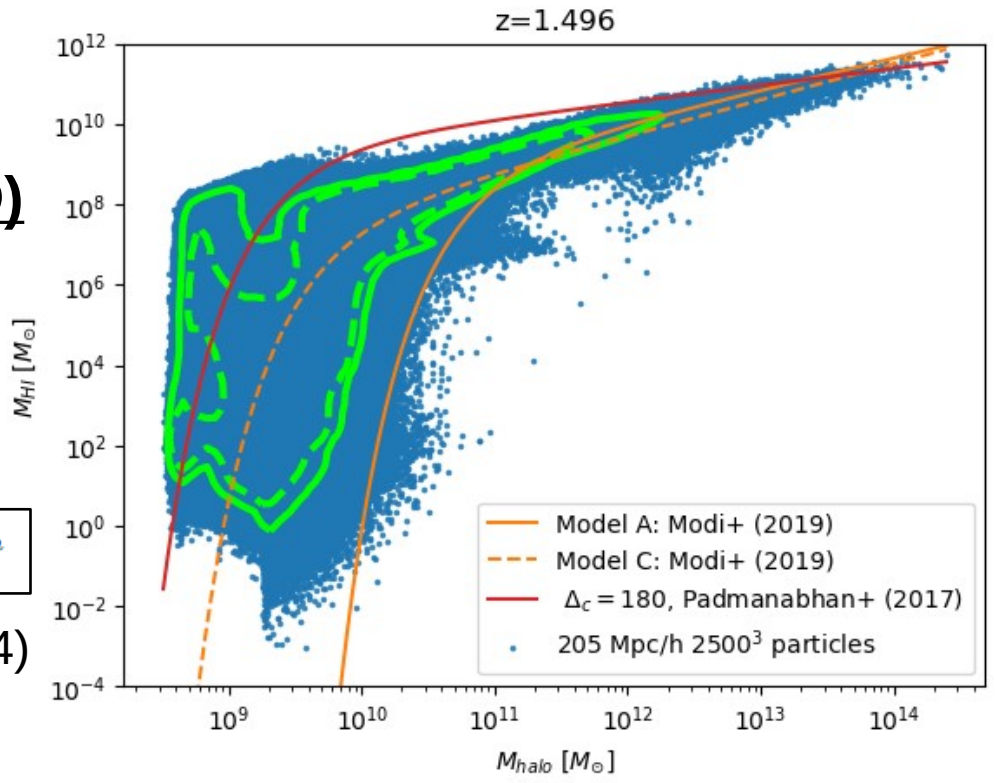
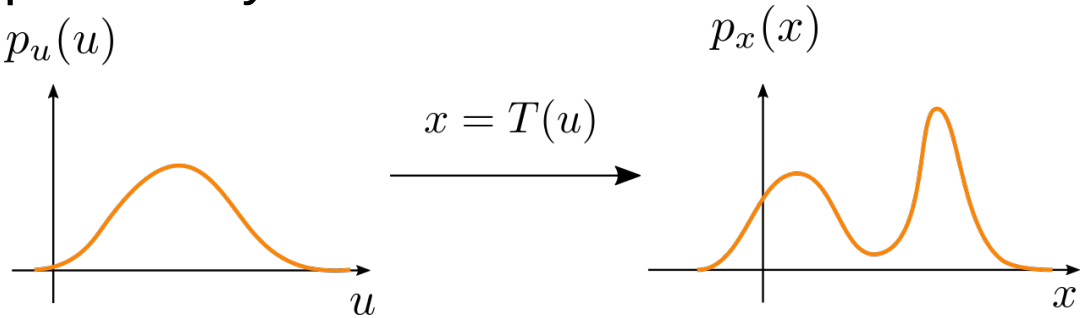


Normalizing Flow Network

(Bianco+ in prep.)

Normalizing flows are diffuse models that are based on the differentiable transformation of probability distributions:



$$p_x(\mathbf{x}) = p_u(\mathbf{u})|\det \mathbf{J}_T(\mathbf{u})|^{-1}$$

Employed **Masked Autoencoder for Density Estimation** (MADE)

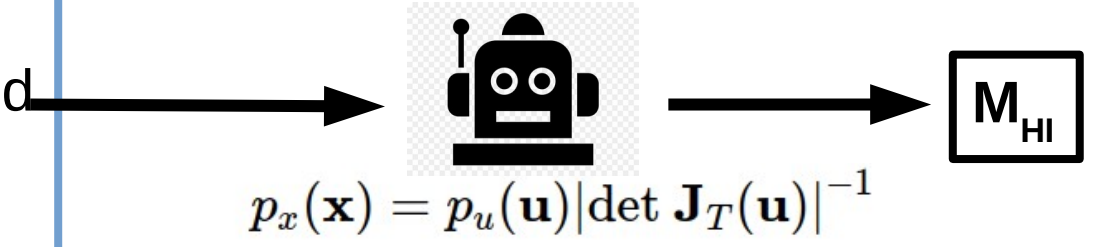
<u>Goal:</u> Employ high-resolution hydro-dynamical simulations to infer M_{halo} Vs M_{HI}

Normalizing Flow Network

(Bianco+ in prep.)

Inputs:

- M_{halo}
- σ_8 Ω_b, Ω_Λ, A_{SN}
- UV-background
- ρ_{gas}
- T_{gas}
- V_{Halo}
- N_{sat}
- M_{BH}
- BH accr. rate
- SFR



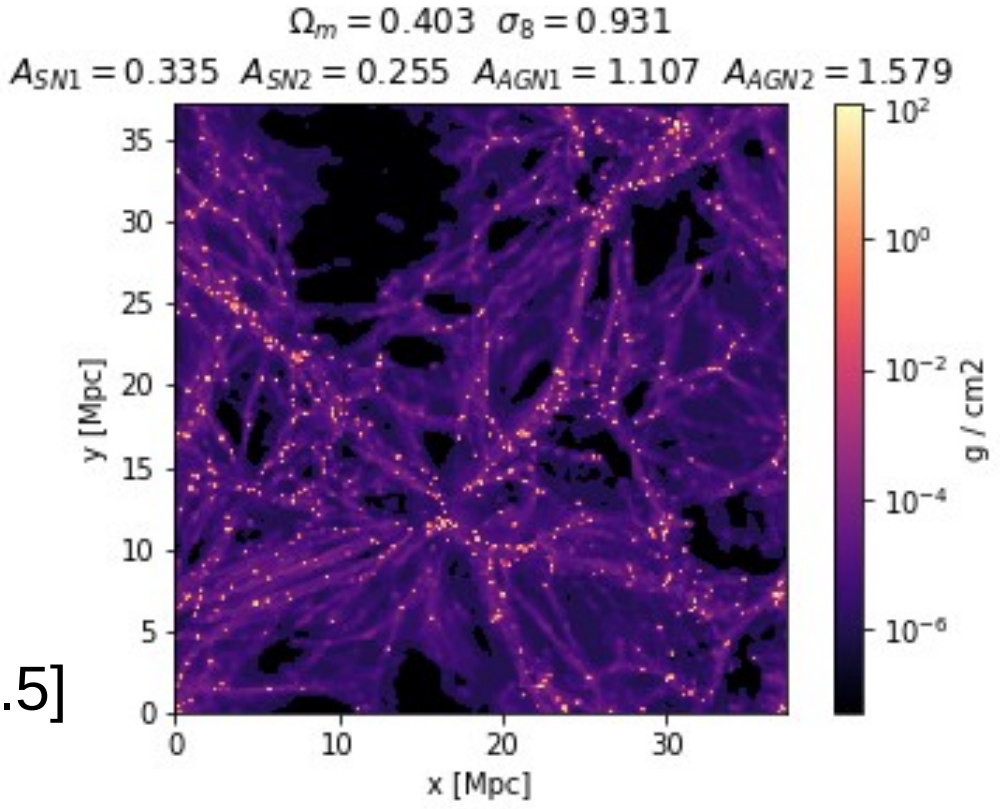
Two separated network with training strategies for:

- HOD model that account for the scatter and HI in low mass halos
- Exploratory analysis on the HI content in halos based on hydro-simulation outputs

CAMELS Dataset for ML in Cosmology

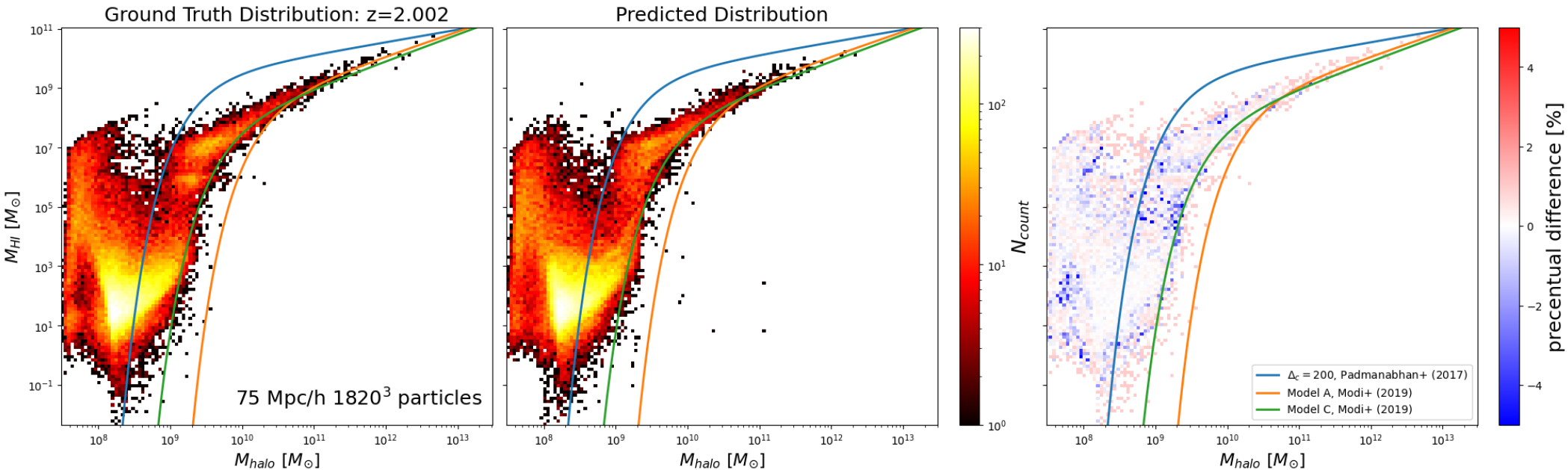
Use CAMEL dataset to model the HI mass in halos for ML inpaint

- 10’000 simulations
- 25 Mpc/h
- Varying astrophysical & cosmological parameters
- Different initial conditions
- Halo catalog and HI in halo
- several snapshot at z = [0.8, 2.5]



Model Galaxy HI content with ML

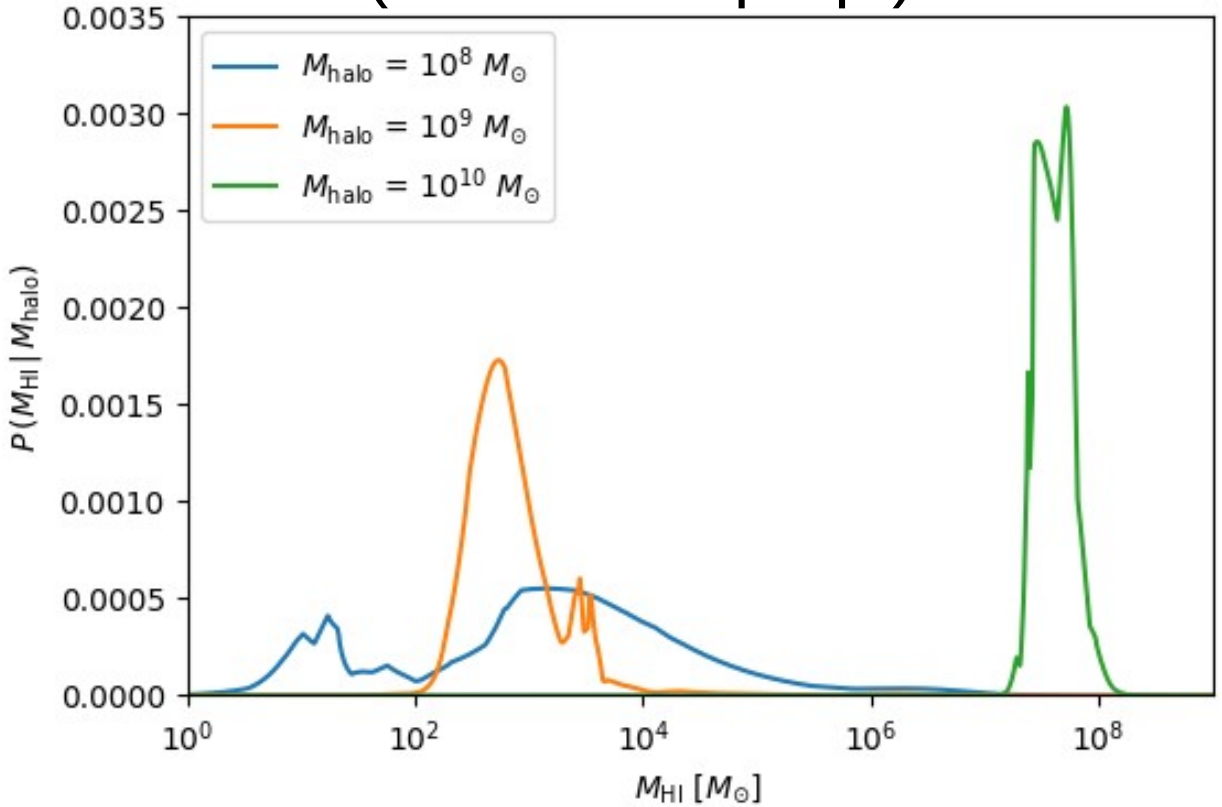
(Bianco+ in prep.)



Model the statistical distribution of the M_{halo} – M_{HI} correlation plot from high resolution hydrodinamic simulations (IllustrisTNG)

Model Galaxy HI content with ML

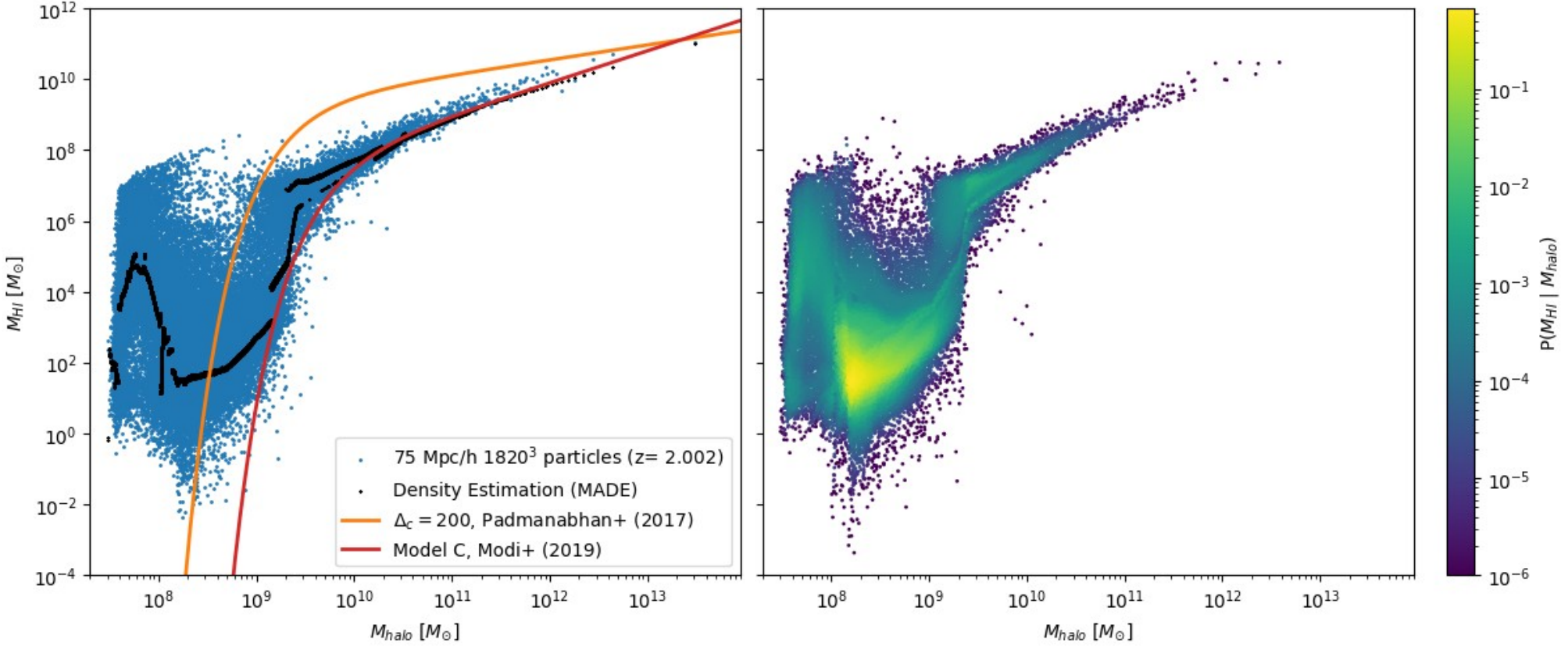
(Bianco+ in prep.)



Use Normalazing Flow network to describe the probability distribution for a given halo mass, M_{halo}

Model Galaxy HI content with ML

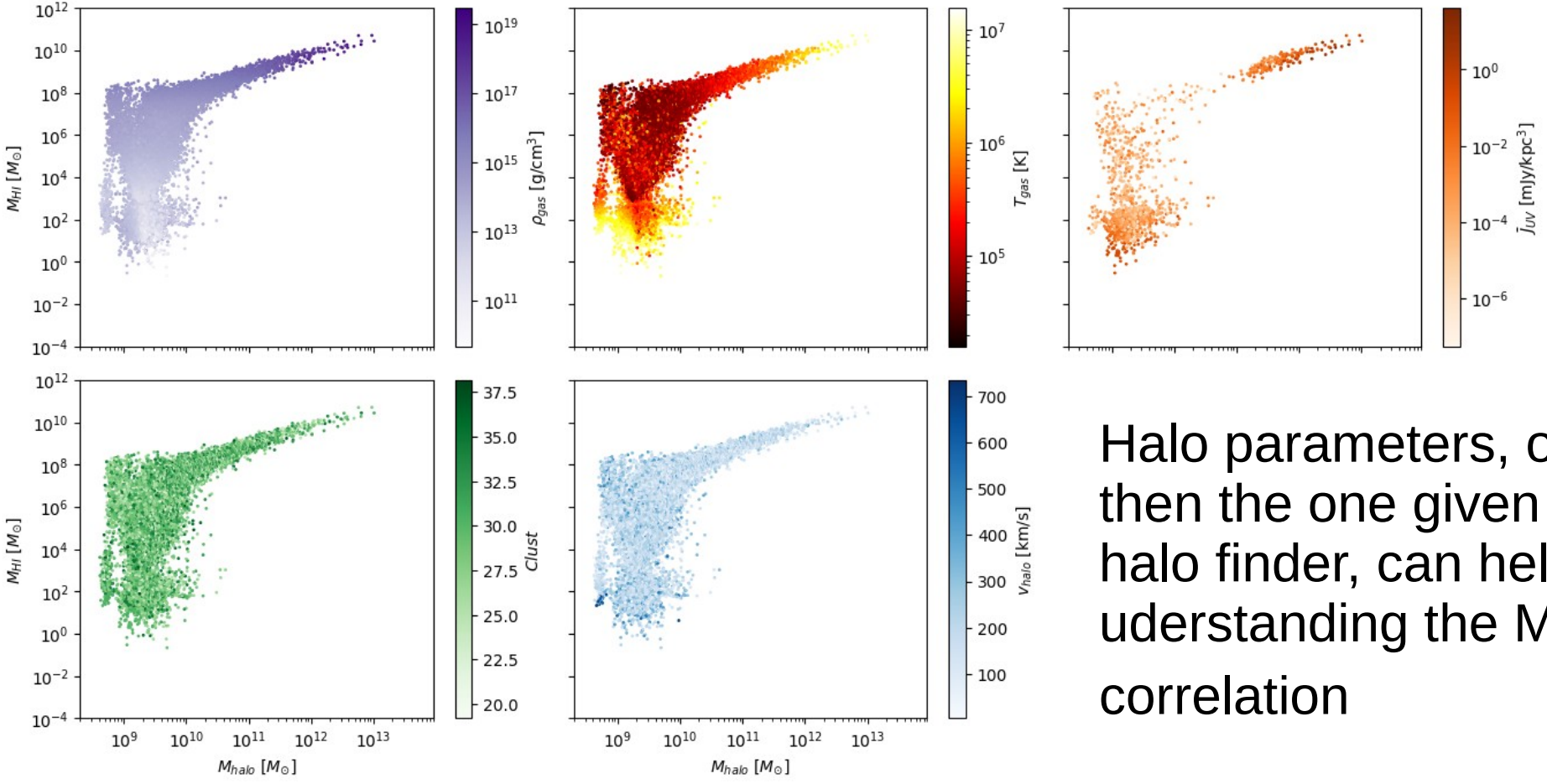
(Bianco+ in prep.)



Likelihood and fit to the maximum value of the probability distribution

Exploratory Analysis of HI in Halo

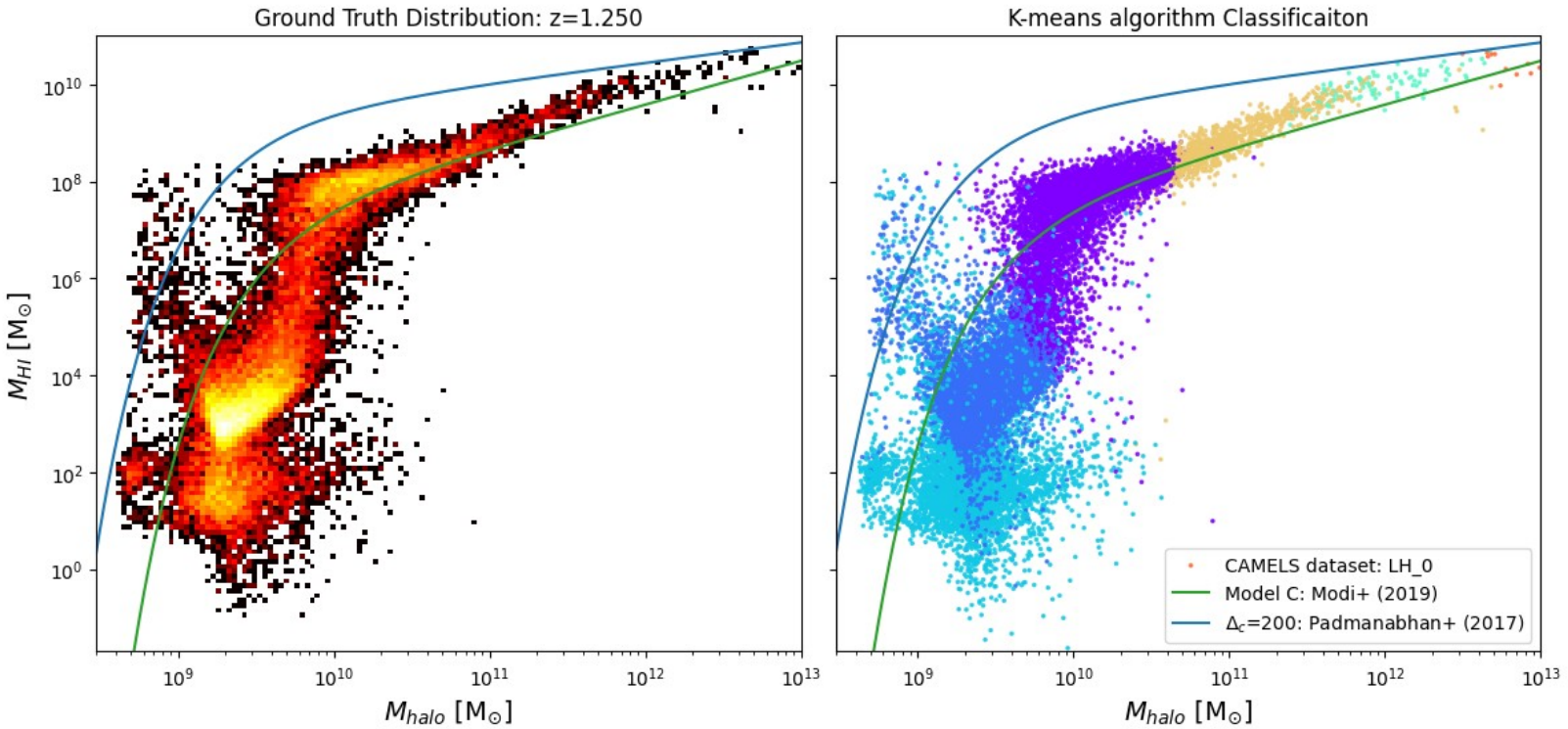
(Bianco+ in prep.)



Halo parameters, other then the one given by the halo finder, can help in uderstanding the M_{halo}-M_{HI} correlation

Exploratory Analysis of HI in Halo

(Bianco+ in prep.)



Halo can be devided in classes of based on their predominat feautres from hydro-dynamic simulations.

IM with large N-body

(Bianco+ in prep.)

- <u>Ushuu simulation:</u> V~2 Gpc^3, 14 snapshot between z=[0.8, 2.5], halo mass resolution: $M_{halo} \sim 10^8 M_{sun}$

cosmological parameters

Planck2015 (table 4, rightmost column)

Ω_m = 0.3089 Ω_L = 0.6911 h = 0.6774

σ_8 = 0.8159 Ω_b = 0.0486 ns = 0.9667

Linear Power Spectrum

z_init = 127 (2LPT)

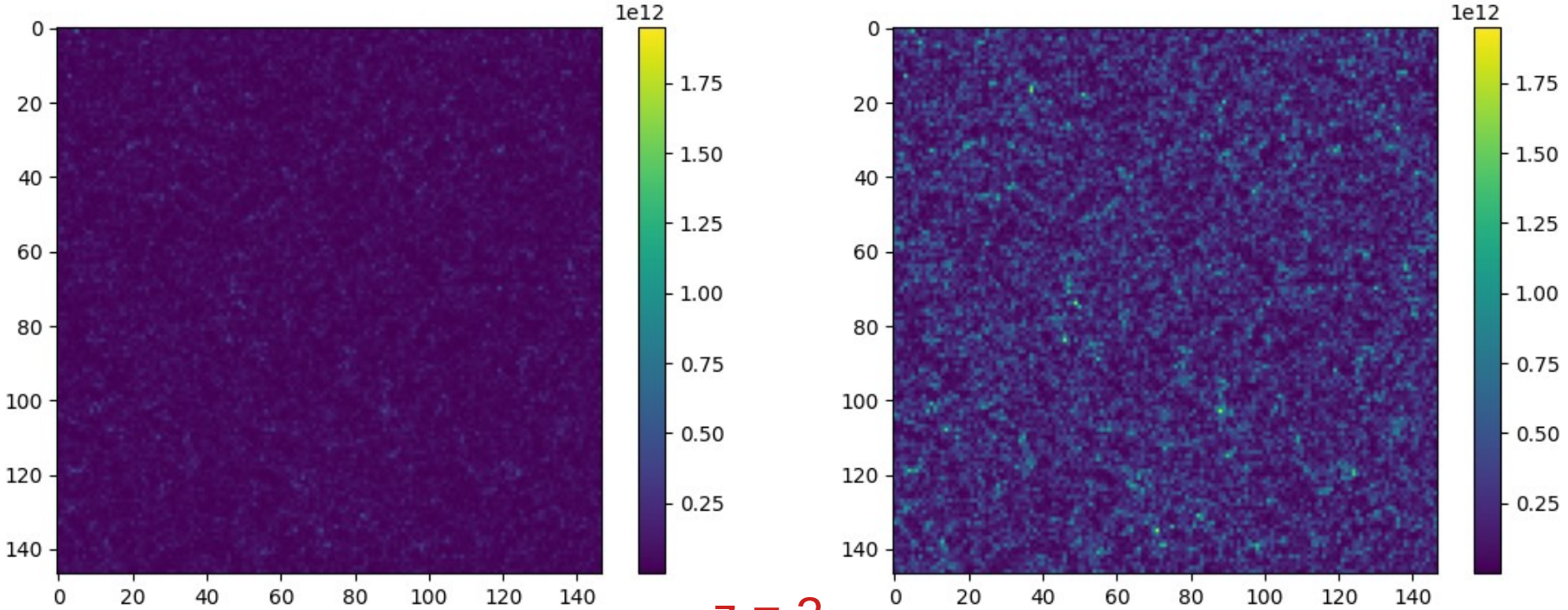
Simulation Name	Lbox Mpc/h	Npart	Mpart Msun/h	**Snap**	**Halo**	**Tree**	**DM**	**Lens**	**Gal**
Uchuu	2000	12800^3	3.27e8	List1	Yes	Yes	Yes	TBD	Soon
mini-Uchuu	400	2560^3	3.27e8	List2	Yes	Yes	Yes		Soon
micro-Uchuu	100	640^3	3.27e8	List3	Yes	Yes	Yes		Soon
Shin-Uchuu	140	6400^3	8.97e5	List4	Yes	Yes	Yes		Soon

Model Galaxy HI content with ML

(Bianco+ in prep.)

Create 21-cm image slice for intensity mapping observations for M_{HI}:

- FoV ~ 58 deg (z~0.7), frequency resolution = 390 kHz



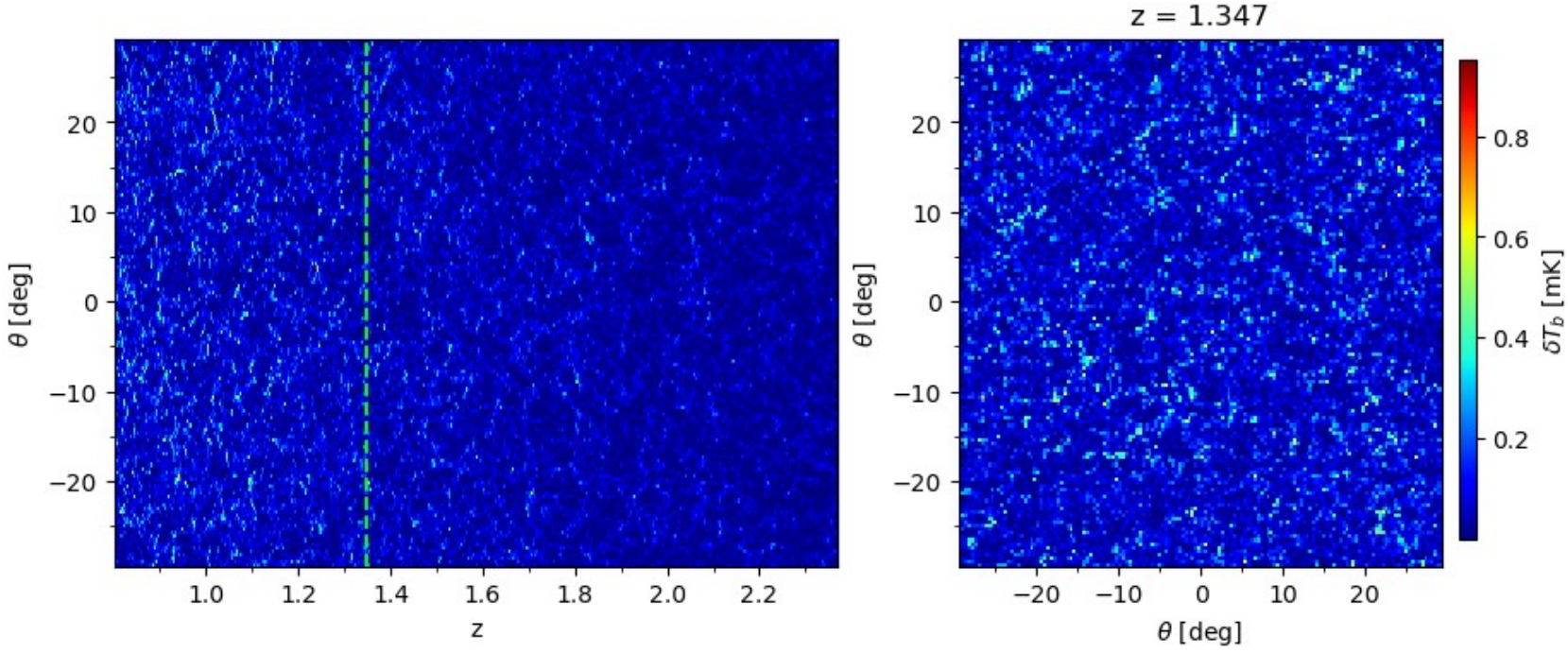
z = 2

Model Galaxy HI content with ML

(Bianco+ in prep.)

Create lightcone from the **Ushuu N-body halo catalog** for given HI model:

- With **redshift-space distortion** based on halos velocity
- FoV ~ 58 deg (z~0.7), frequency resolution = 390 kHz

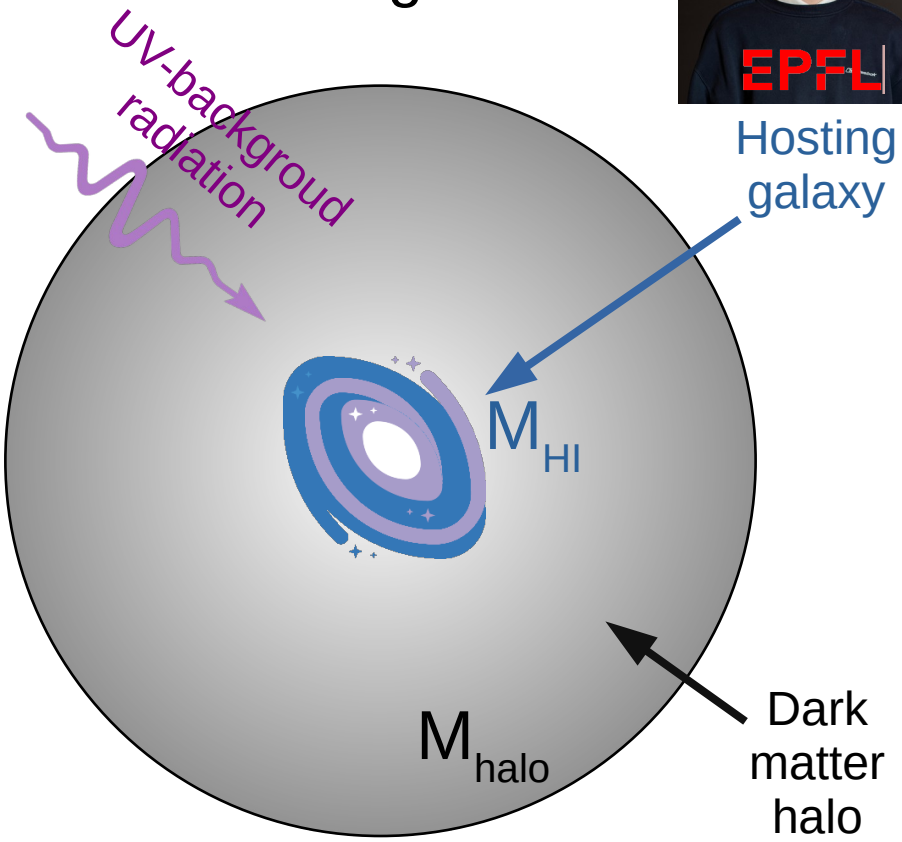


Study on the UV-Background Model

(Hirling, Bianco & Revaz in prep.)

Standard UV-background model assumes an homogeneous field of ionizing photons:

- How physically motivated is the current UV-background model ?
- Can we improve the model with proper RT simulations ?



Mock halo sssume HI density profile:

$$\rho_{\rm HI}(r) = \frac{\rho_0}{r^{\alpha_\star}} \exp(-r_0/r)$$

Study on the UV-Background Model

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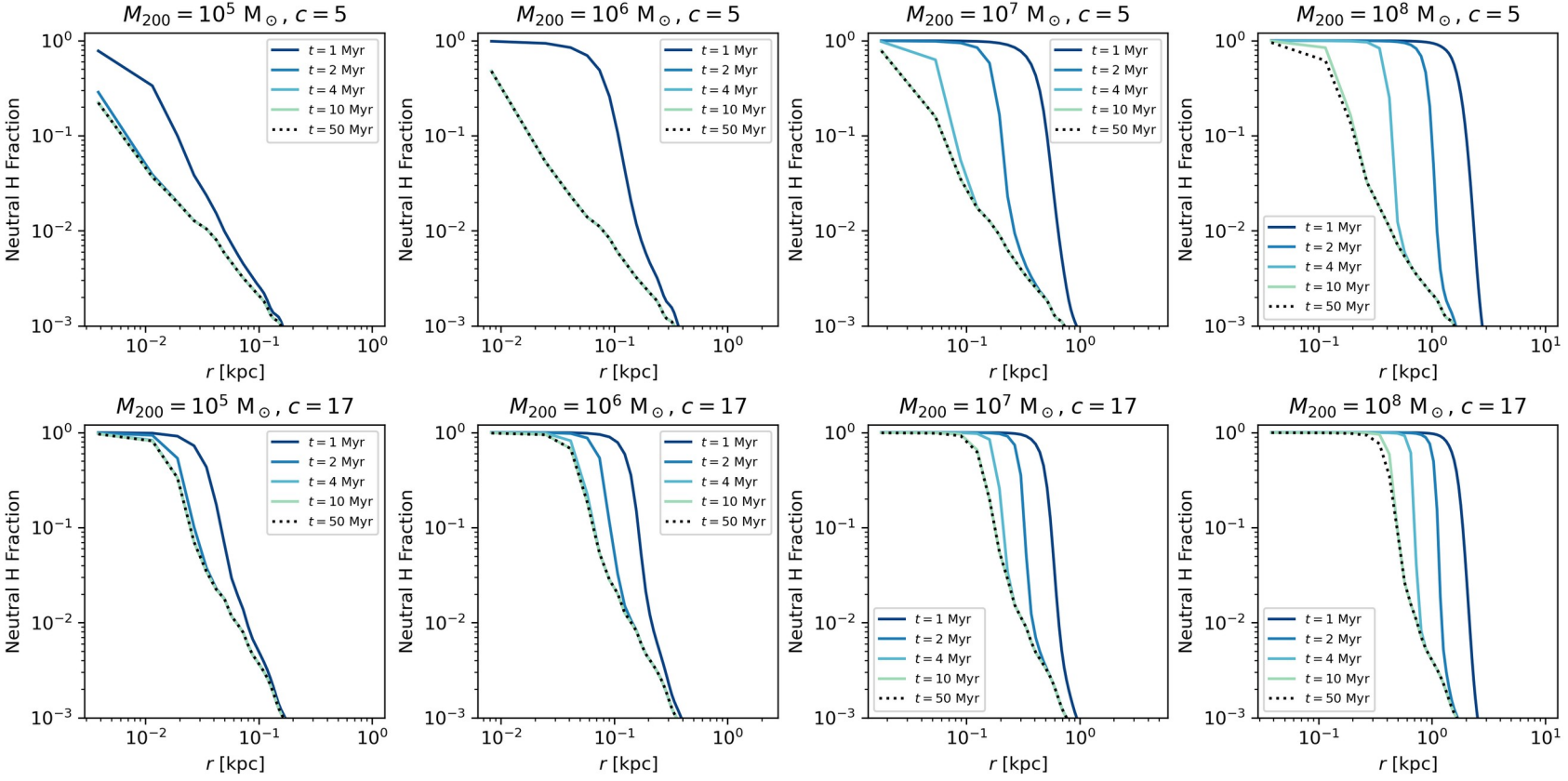
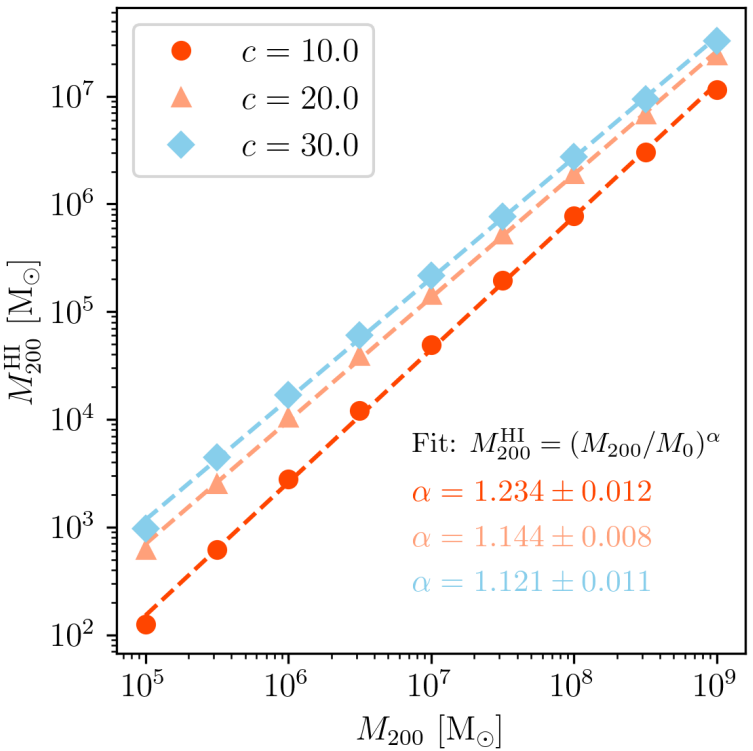


Evolution of the neutral hydrogen density profile, ρ_{HI}, on mock halo

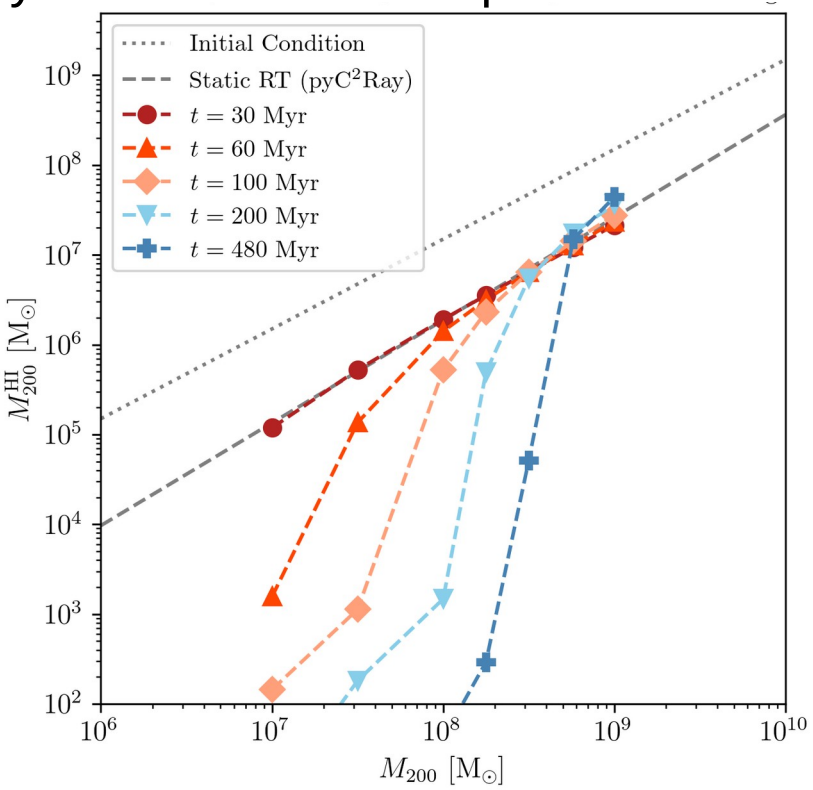
Study on the UV-Background Model

(Hirling, Bianco & Revaz in prep.)

Static case: (Swift+pyC2Ray)
no hydrodinamic only gas heating



Dynamic case: (Swift+Grakle+Rahmati)
hydrodinamic with empiricla RT



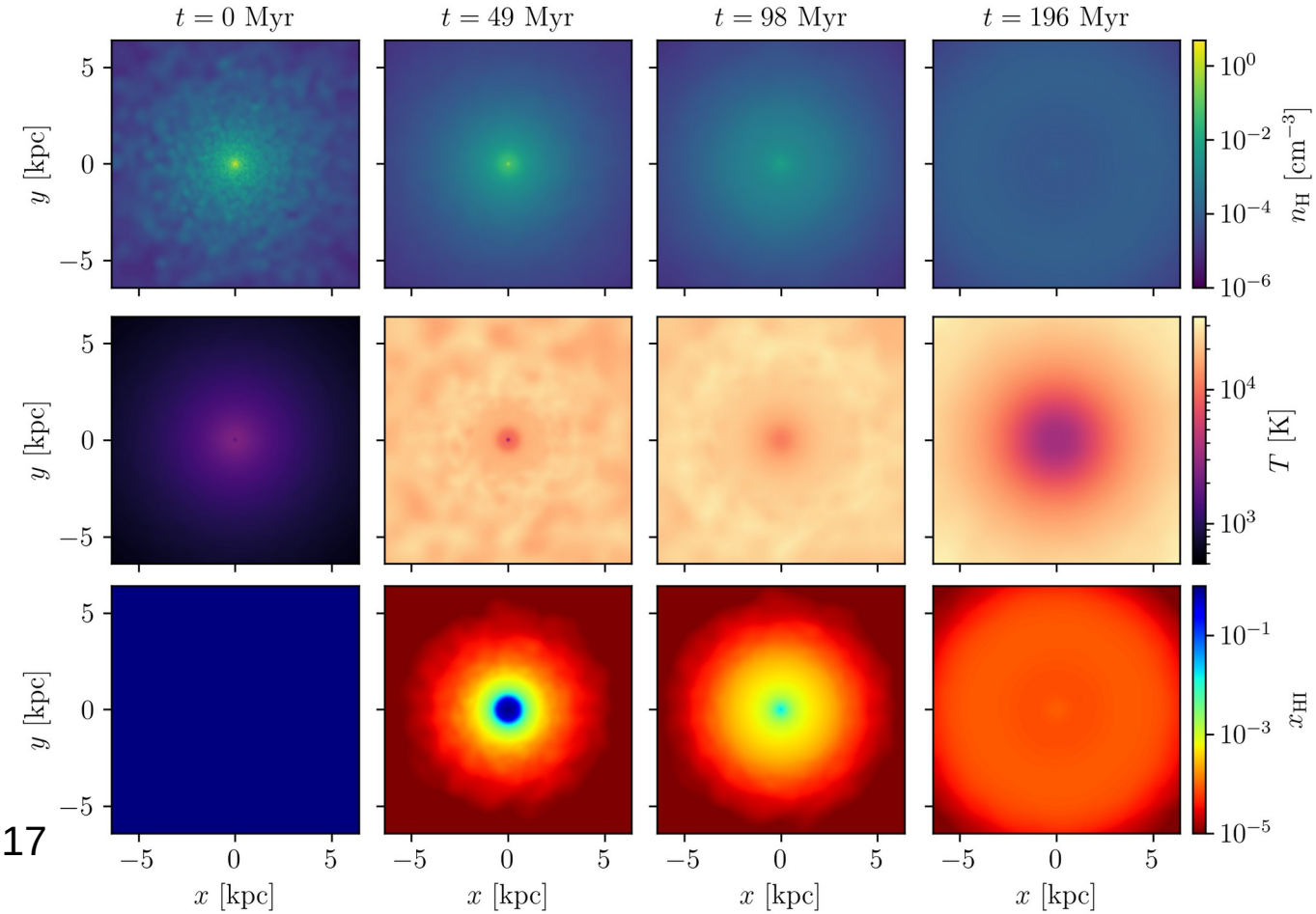
Study on the UV-Background Model

(Hirling, Bianco & Revaz in prep.)

Gas density distribution

Temperature evolution

HI fraction



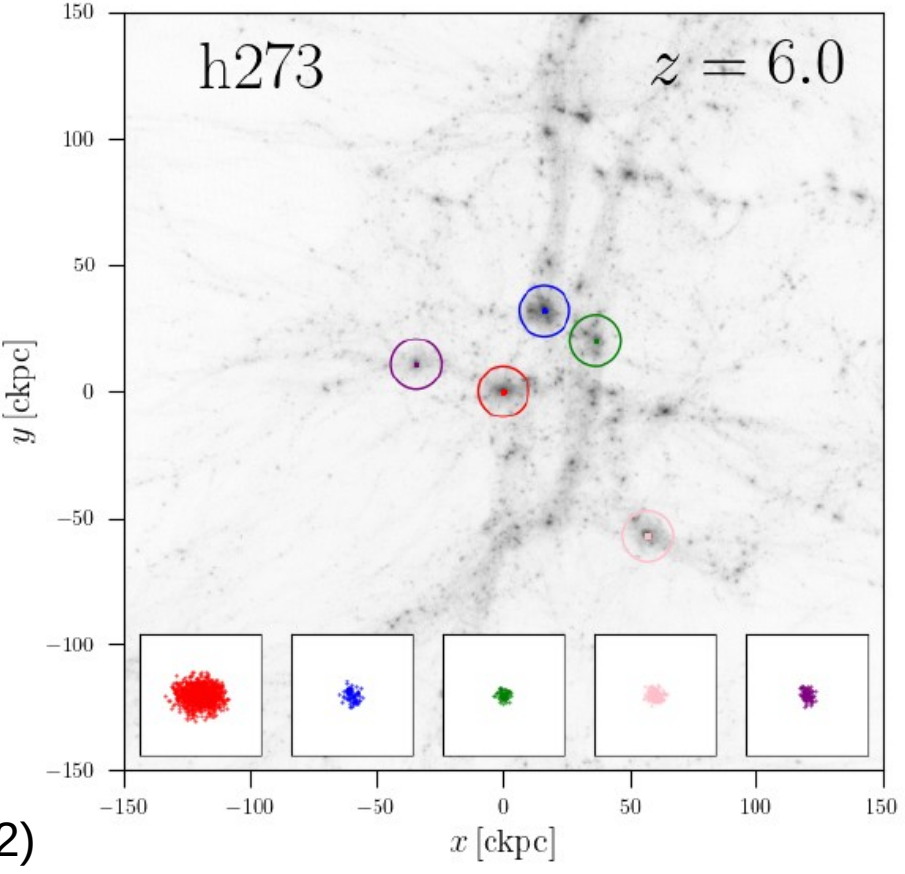
Example dynamic case: h17 (Swift+Grakle+Rahmati)

Study on the UV-Background Model

(Hirling, Bianco & Revaz in prep.)

Apply the RT based UV-background on actual hydro-dynamic simulations:

- How physically motivated is the current UV-background model ?
- Can we improve the model with proper RT simulations ?



Revaz (2022)

Conclusion

- Model the galaxy's neutral hydrogen content with MADE Neural Network
  - Statistical distribution of the M_{halo} – M_{HI} correlation for aplication on large N-body simulation
  - Exploratory analysis of hydro-simulation can lead to a better understanding on how to model the M_{halo} – M_{HI} relation
- Use Radiative Transfer Simulation for a better UV-backgrond model for post-reionization simulations