Probing Feedback Dependence in WHIM Absorption Lines

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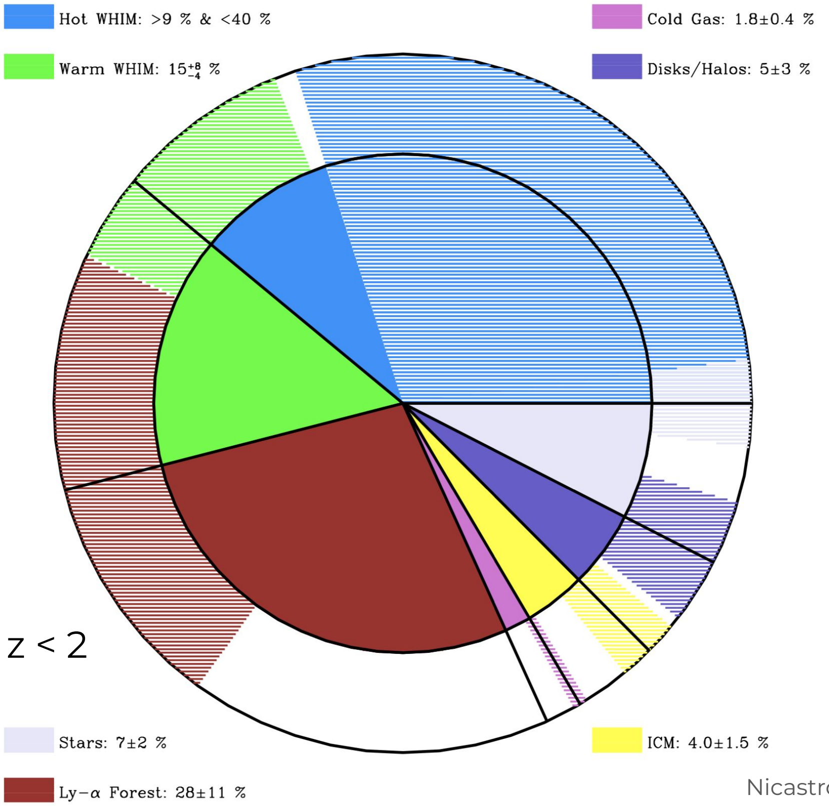
Missing Baryon Problem and the WHIM

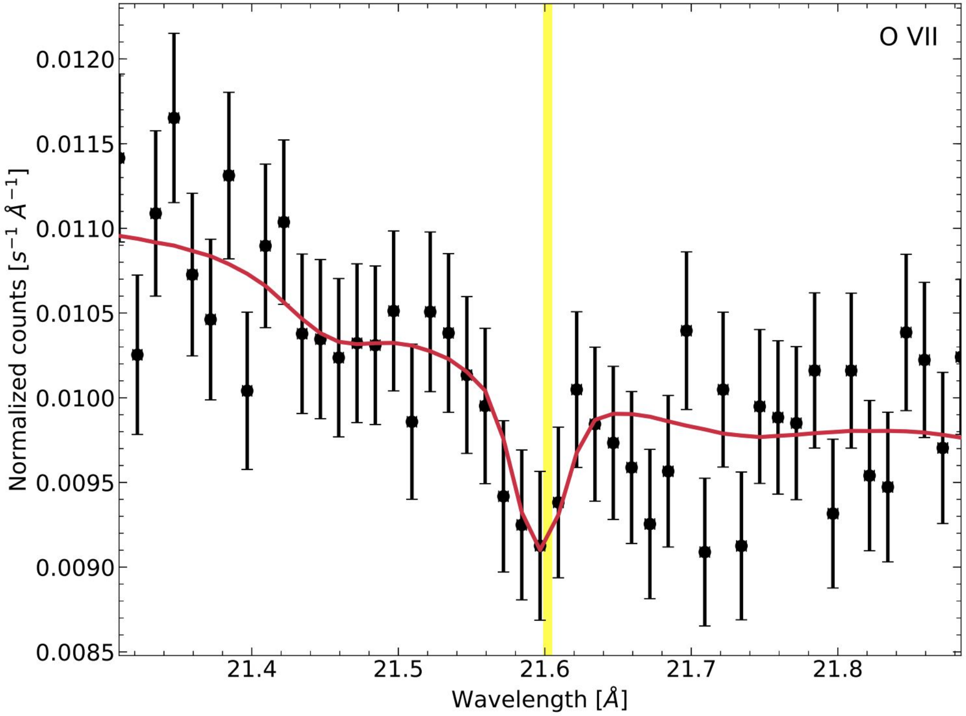


Nicastro+18

The Warm Hot Intergalactic Medium (WHIM)

- Low density (< 10^{-6} cm^{-3})
- Warm hot (10^5 K - 10^7 K)
- Weakly emitting in X-ray

Stacked Chandra Observation of OVII Absorption



Kovács+19

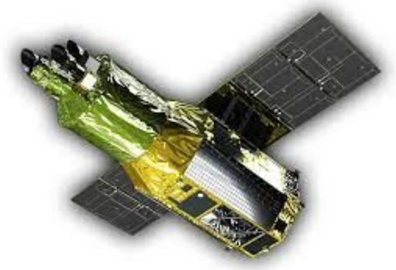
Kovács et al. 2019

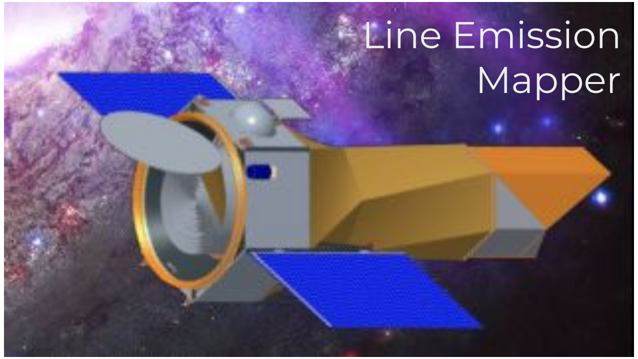
- Stacked spectra of quasar H1821+643 revealed OVII absorption line , using redshifts from HI absorbers (3.3 sigma)
- Inferred OVII column density of 1.4×10^{15} cm^{-2}
- About 40% of total baryonic mass density fraction from WHIM

Goals with CAMELS

- Interpretation Kovács+19 Chandra results.
- Potential dependencies on feedback physics.
- Provide recommendations for WHIM detection in both absorption and emission (cf. Gabriele's talk) with next-era high-res X-ray spectral missions.

XRISM





Column Density Maps from CAMELS

snapshot 030 (z = 0.15)

SIMBA

IllustrisTNG

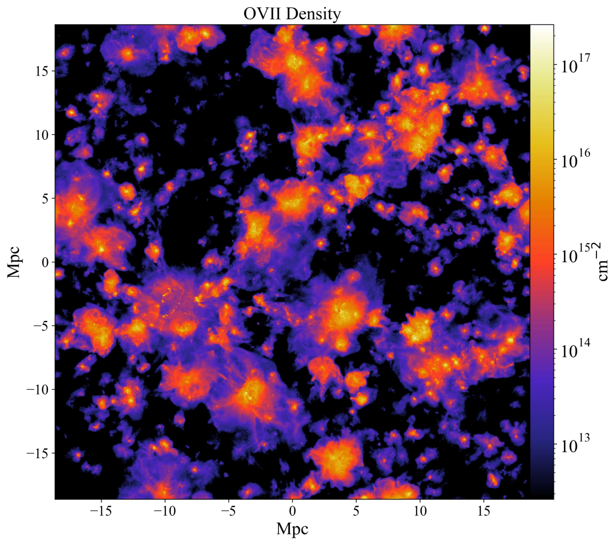
→ Trident →

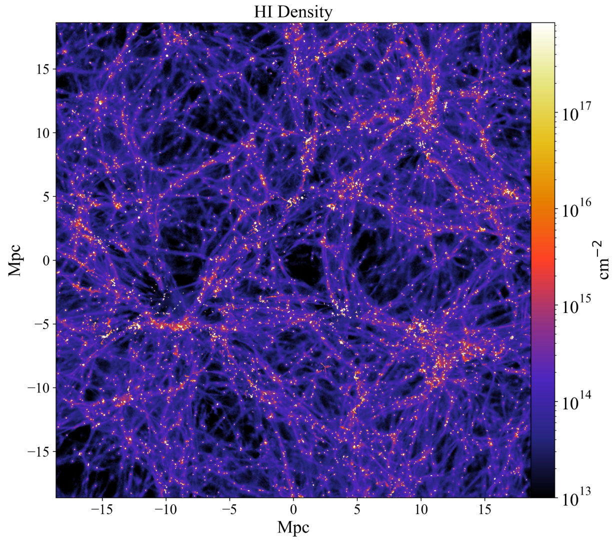
OVII Density

HI Density

→ ÷ 6 →

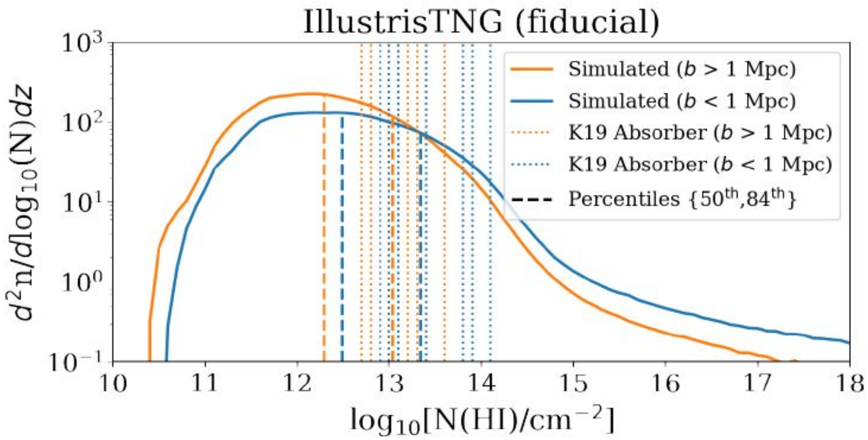
$$g(X) = \int f(x)\, \hat{n} \cdot dx$$

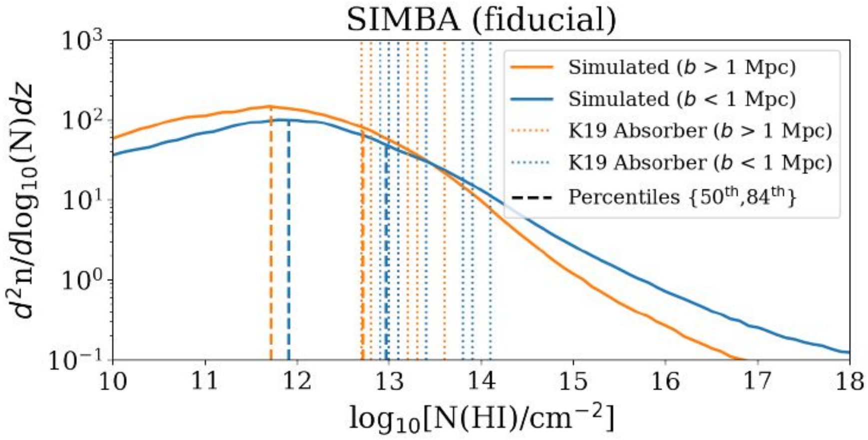




IllustrisTNG fiducial run

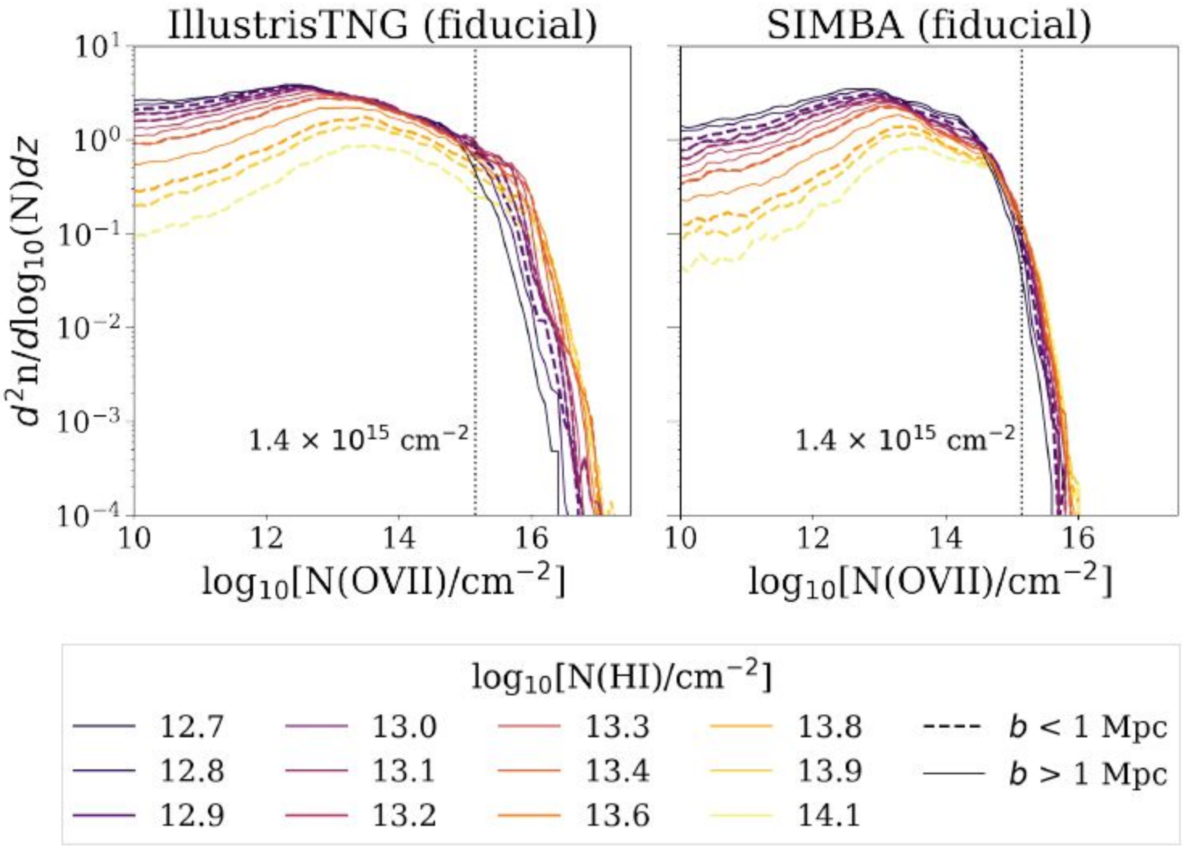
Distributions of HI Absorbers





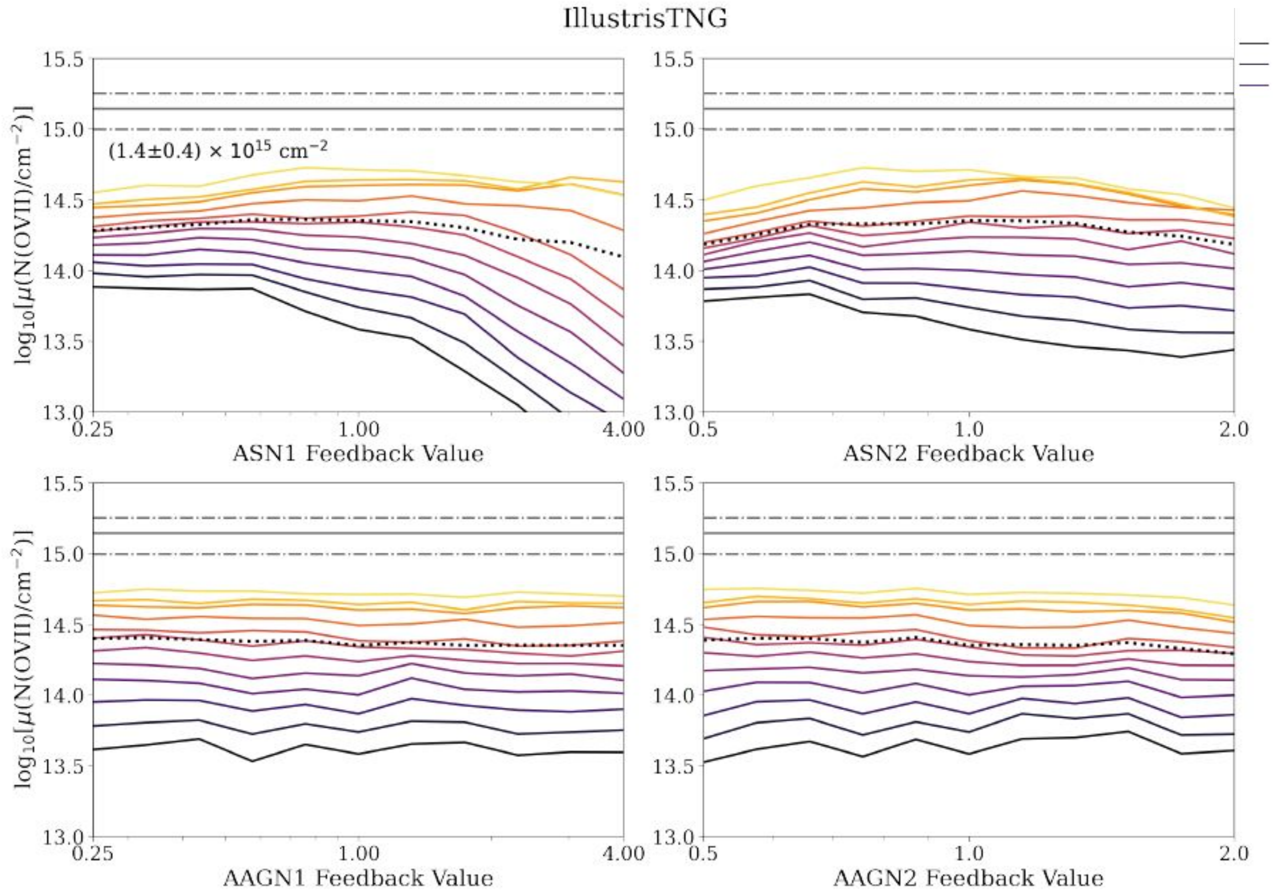
- HI distributions from CAMELS consistent with observation (dotted vertical lines).
- Absorbers near galaxy (impact parameter $b < 1$ Mpc, blue lines) have higher N_{HI} values
- HI column density corrected for feedback dependence in photoionization (cf Megan's talk).

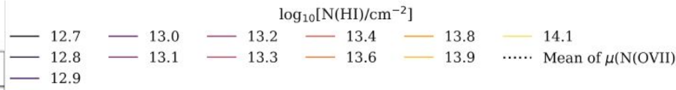
Distribution of OVII Absorbers



- Showing distribution of N(OVII) for each HI sightline with obs. N(HI) values.
- Sightlines with higher N(HI) have higher N(OVII).
- For all sightlines, quite unlikely (>2sigma) to find N(OVII) that matches observation.
- Dependence on feedback physics?

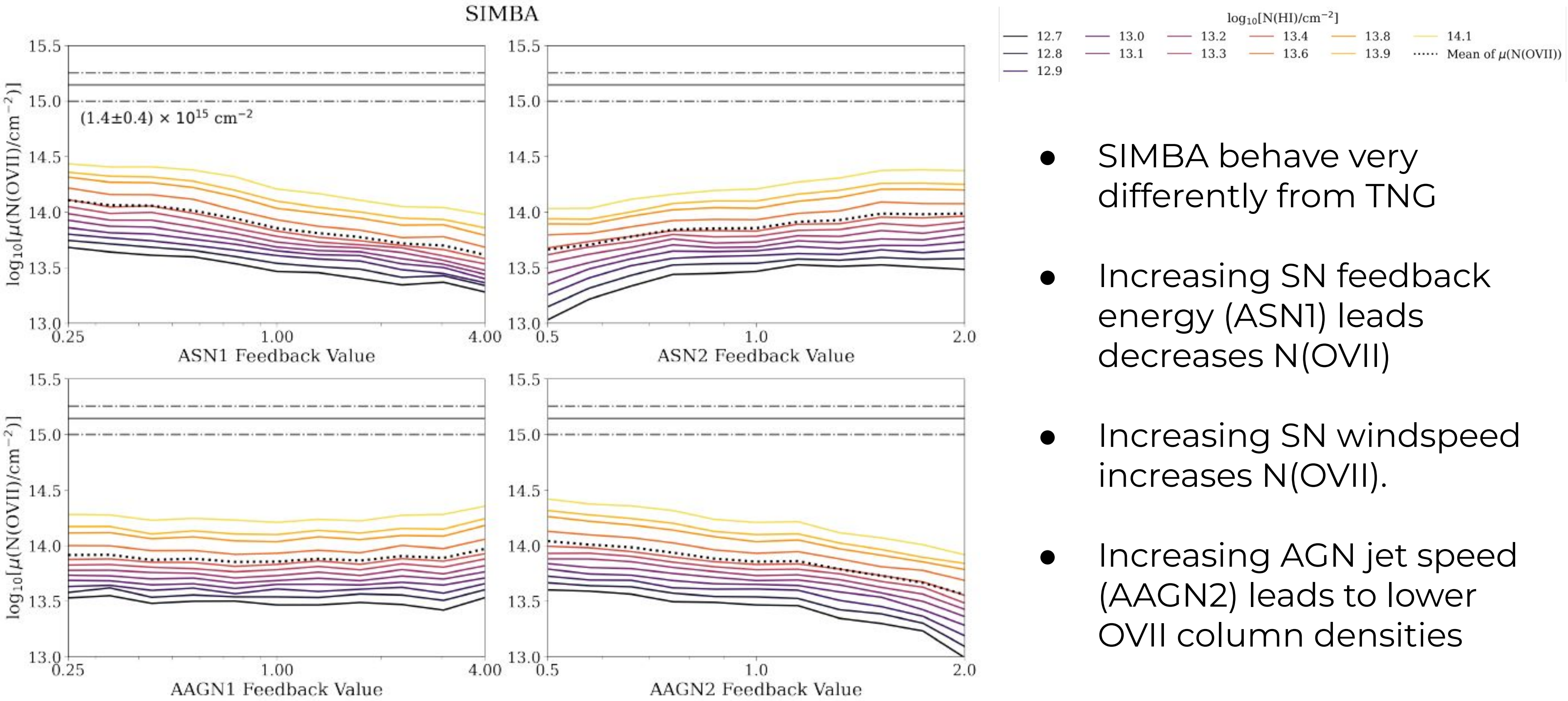
Dependence on SN and AGN Feedback (TNG)





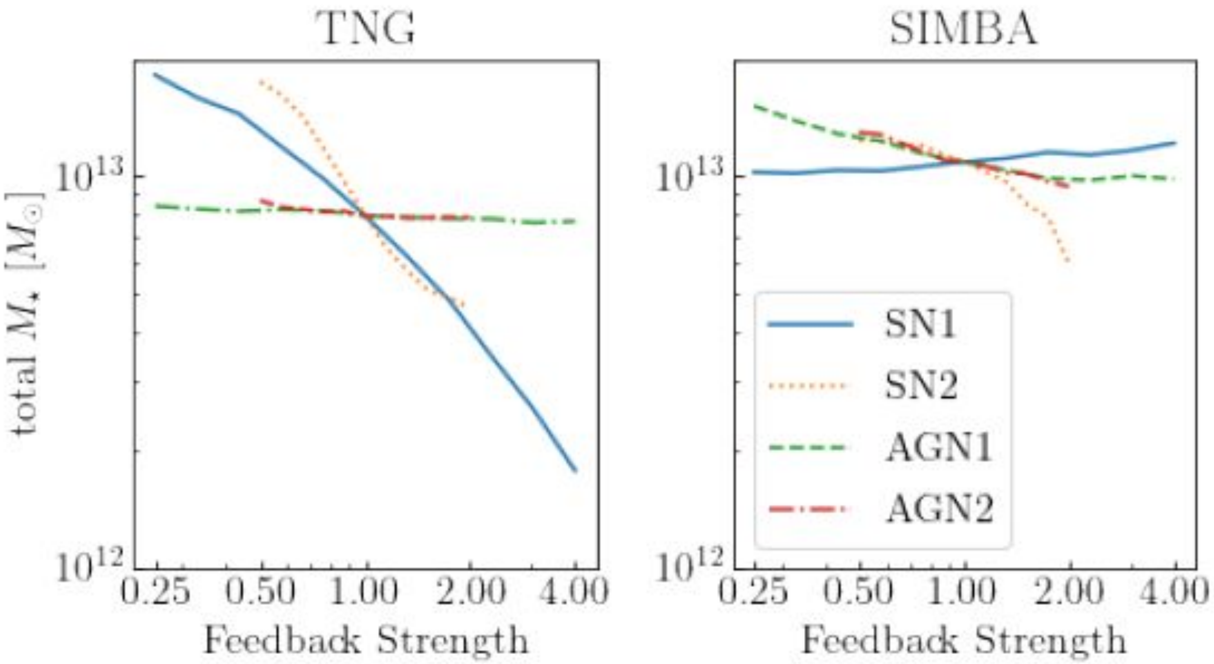
- Increasing SN feedback energy (ASN1) leads to decrease in mean OVII column density for sightlines with low N(HI).
- Independent of AGN feedback

Dependence on SN and AGN Feedback (SIMBA)

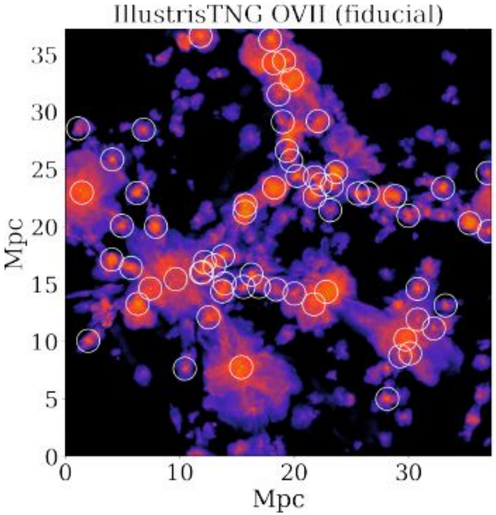


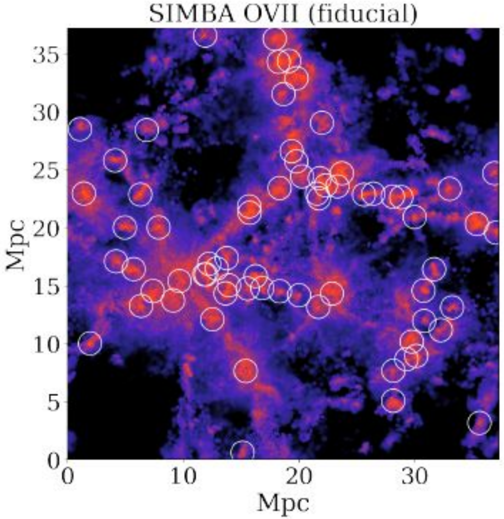
- SIMBA behave very differently from TNG
- Increasing SN feedback energy (ASN1) leads decreases N(OVII)
- Increasing SN windspeed increases N(OVII).
- Increasing AGN jet speed (AAGN2) leads to lower OVII column densities

Origin of the OVII Dependence on Feedback



- Stronger SN feedback leads to less amount of stars form, hence less Oxygen production
- Feedback does not produce noticeable effect on Oxygen ionization states.
- OVII dependence can be partly explained in terms of total star formation (at least for TNG).





Summary:

- WHIM can be detected via absorption lines, complementary to emission (cf Gabriele's talk).
- **All** CAMELS OVII column densities are **lower** than Chandra measurements (>2 sigma) in Kovács+19.
- Dependence on feedback primarily via feedback effects on star formation.
- TNG and SIMBA results are very different!

Outlook:

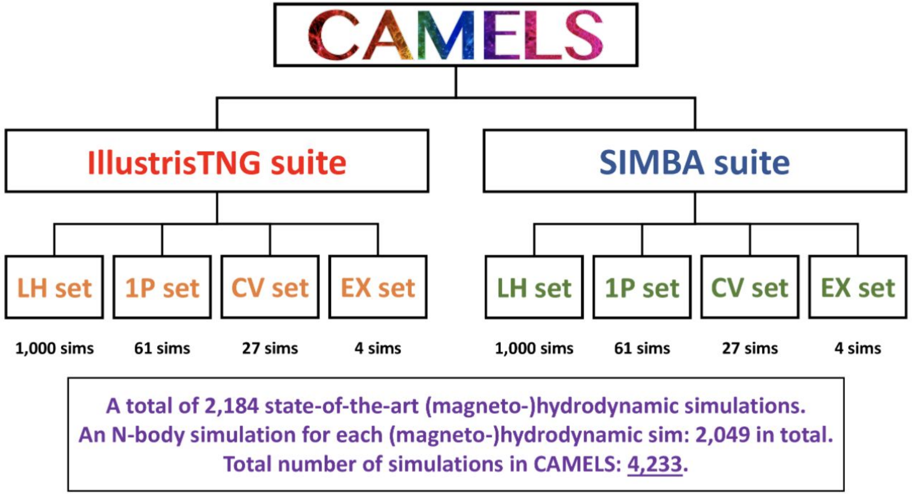
- Chandra archival study underway to understand difference between Kovacs+19 and CAMELS.
- LEM, Athena, XRISM (cluster outskirts) will provide more accurate measurements of OVII absorption line spectra for WHIM detection.
- Future CAMELS are crucial for understanding effects of other gas physics (e.g., TNG-SB28) and cosmic variance on WHIM absorption.

Observations: HI Column Densities

z	equivalent width (mÅ)	N_{HI} (cm^{-2})	0.1 dex bin ($\log_{10} N_{HI}$)
0.05704	87	1.598e+13	13.2
0.06432	62	1.138e+13	13.0
0.08910	47	8.630e+12	12.9
0.11152	66	1.212e+13	13.0
0.11974	102	1.873e+13	13.2
0.12157	353	6.482e+13	13.8
0.12385	35	6.427e+12	12.8
0.14760	229	4.205e+13	13.6
0.16990	523	9.604e+13	13.9
0.18049	75	1.377e+13	13.1
0.19905	29	5.325e+12	12.7
0.22489	739	1.357e+14	14.1
0.24132	79	1.451e+13	13.1
0.24514	79	1.451e+13	13.1
0.25814	134	2.461e+13	13.3
0.26156	163	2.993e+13	13.4
0.26660	163	2.993e+13	13.4

Select HI column density in CAMELS boxes with same values from HST-COS observations (inferred from Lyman Alpha absorption linewidths) as in the Chandra observation in Kovács et al 19.

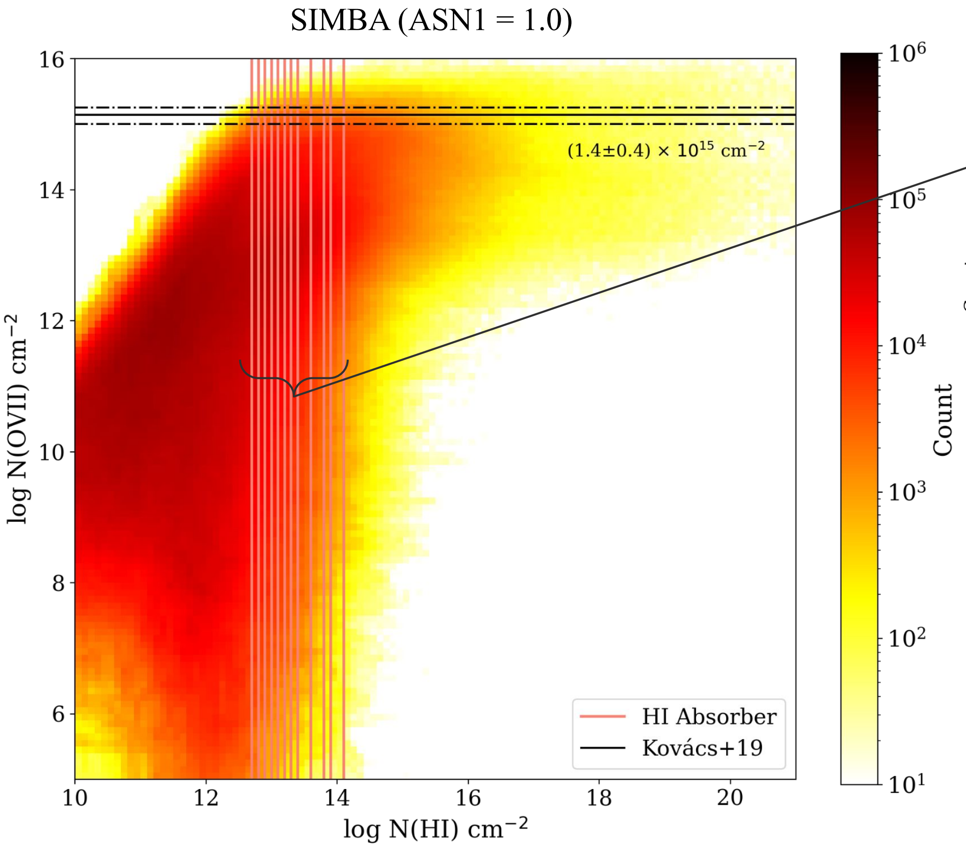
CAMELS Simulations

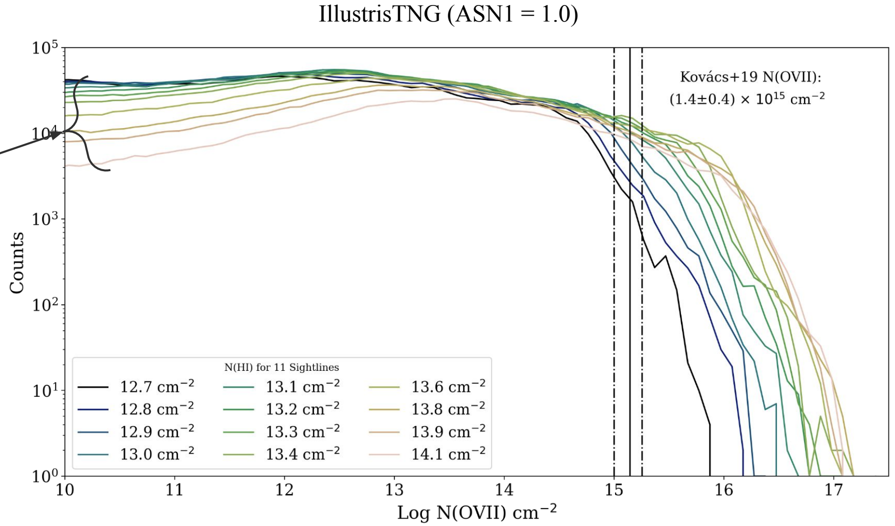


1P Set: varies one parameter at a time

Feedback mode	Value Range	Physical interpretation
SN1	[0.25, 4.0]	normalization factor for flux of galactic wind feedback
SN2	[0.5, 2.0]	normalization factor for speed of galactic winds
AGN1	[0.25, 4.0]	normalization factor for the energy output of AGN feedback
AGN2	[0.5, 2.0]	normalization factor for the specific energy of AGN feedback

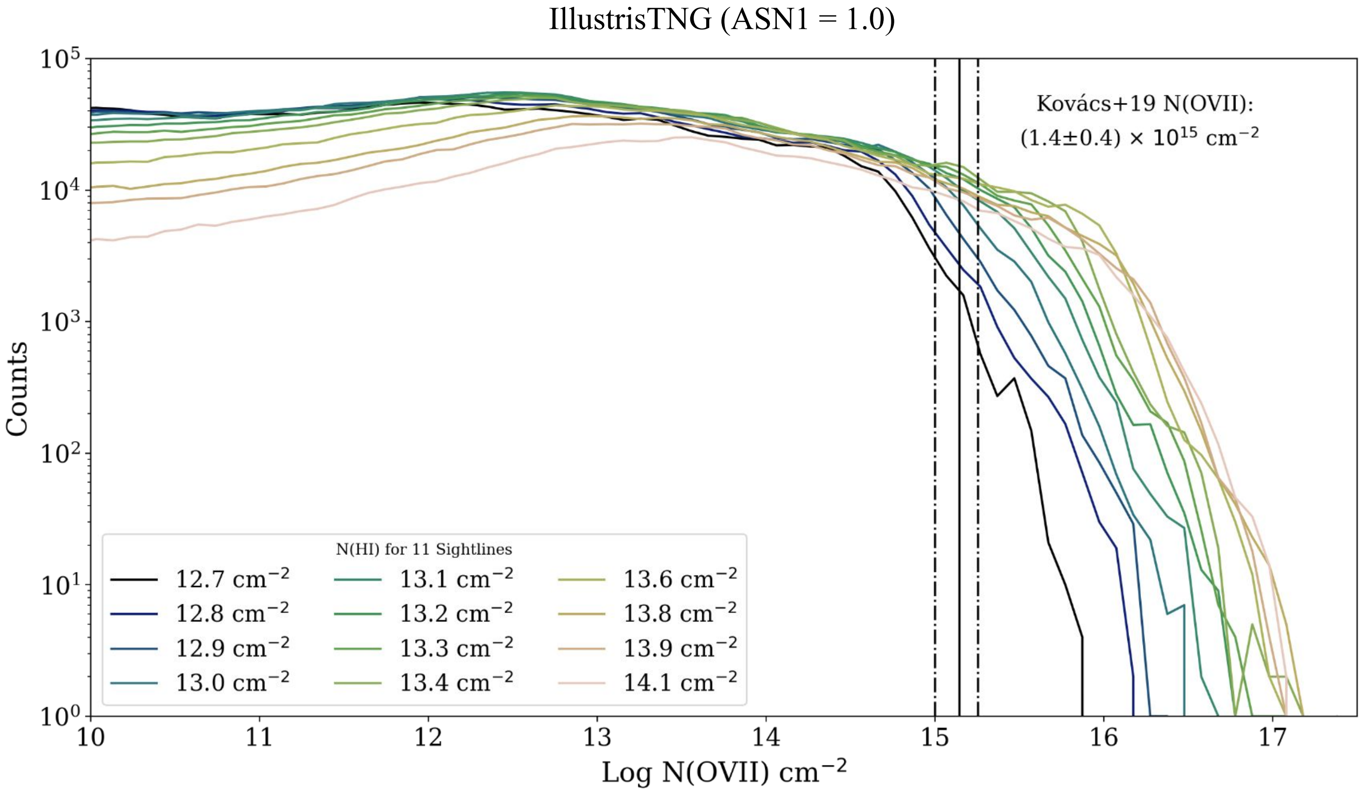
2D Distributions and Region Selection





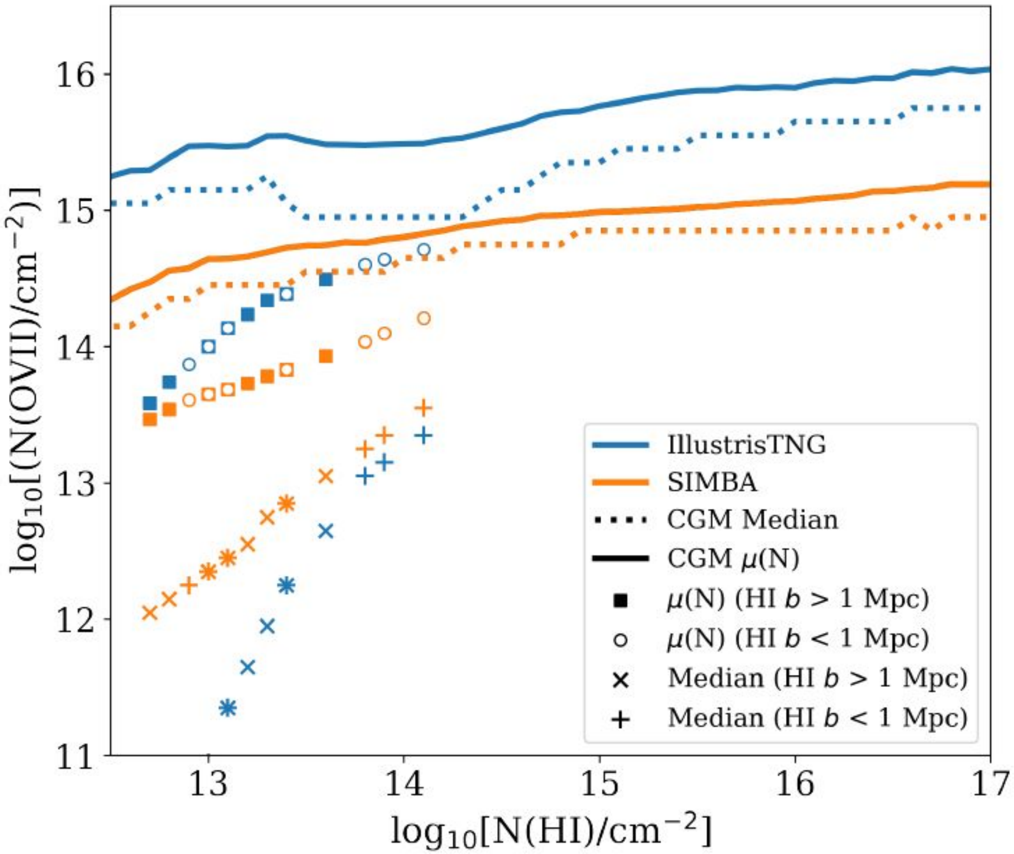
Histograms can be used to uncover interesting internal distributions

Distributions across HI Sightlines



Variations exist across OVII distributions corresponding to different HI lines

N(OVII) vs N(HI)



- Higher N(HI) has higher N(OVII)
- Absorbers closer to halos have higher N(HI) and N(OVII)

Acknowledgments

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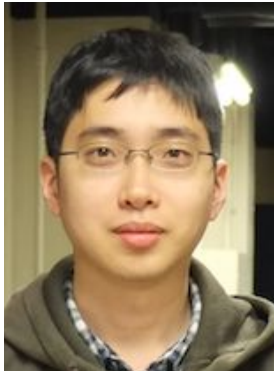

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References

Kovács et al. 2019, ApJ, 872, 83, doi:10.3847/1538-4357/aaef78
Nicastro, et al. 2018, Nature 558, 406–409, doi:10.1038/s41586-018-0204-1
Villaescua-Navarro et al. 2022, arXiv, arXiv:2201.01300
Wijers, et al. 2019, MNRAS, 488, 2947. doi:10.1093/mnras/stz1762