IllustrisTNG:

The abundance, distribution, and physical nature of highly ionized oxygen OVI, OVII, and OVIII

Dylan Nelson

MPA

Intergalactic Interconnections, Marseille
10 July, 2018

Take home messages

- The abundance of oxygen in the circumgalactic medium of galaxies can provide a nice constraint on the baryon cycle & feedback models
- Recent hydro sims in the past few years have had issues with OVI (too low)
- For the first time, the IllustrisTNG simulations produce an OVI abundance in the CGM of ~L* galaxies in statistical agreement with e.g. COS-Halos (+eCGM)
- TNG predicts that: there is more OVI around star-forming vs. quiescent galaxies (blue vs. red), at **fixed** stellar (or halo) mass
- Fundamental driver: high-velocity BH driven outflows (at low accretion rates)
- Can provide predictions for OVII and OVIII for future x-ray observatories (& OVI in as of yet unobserved regimes)

Ions of Oxygen

oxygen is the most abundant element in the universe after H and He,
and is the dominant metal in the ISM, CGM, and IGM

Low ionization states
(OI, OII, OIII)

galaxies <

> galaxies

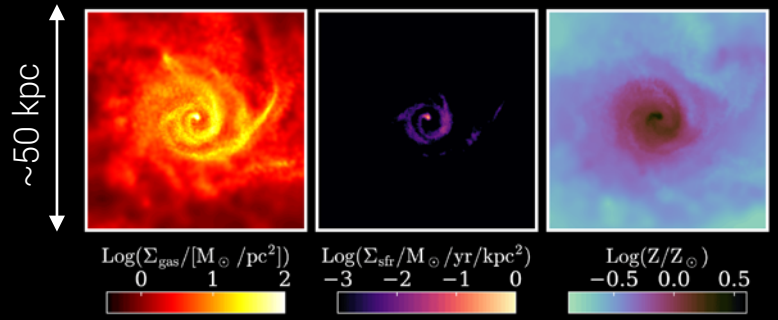
High ionization states
(OVI, OVII, OVIII)

e.g. OII doublet at 496, 501 nm (optical)

e.g. OVI doublet at 103 nm (UV)

Photoionized gas around young stars:

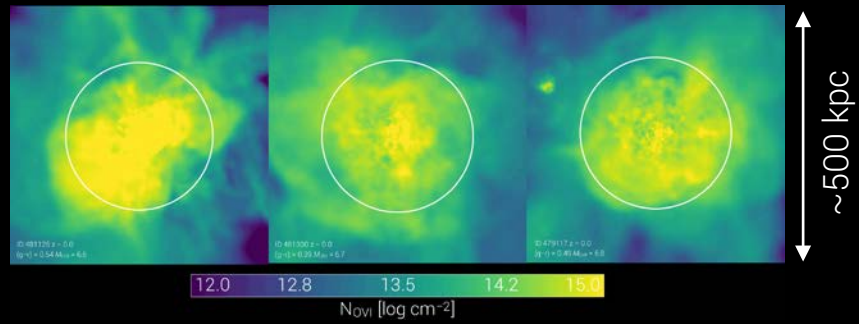
- Optical emission lines
- In the dense ISM of SF galaxies



TNG: Torrey, ..., Nelson+ (2018)

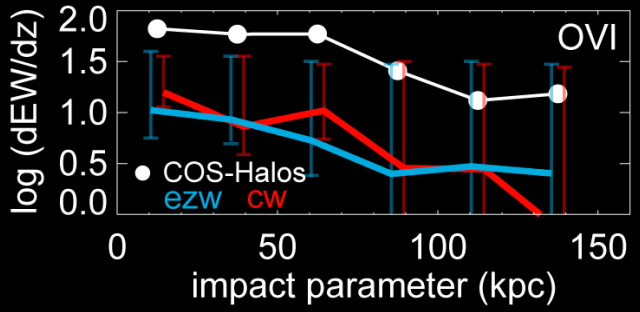
Relatively hot/low-density gas:

- Ultraviolet to x-ray transitions
- In low-density plasmas outside gals

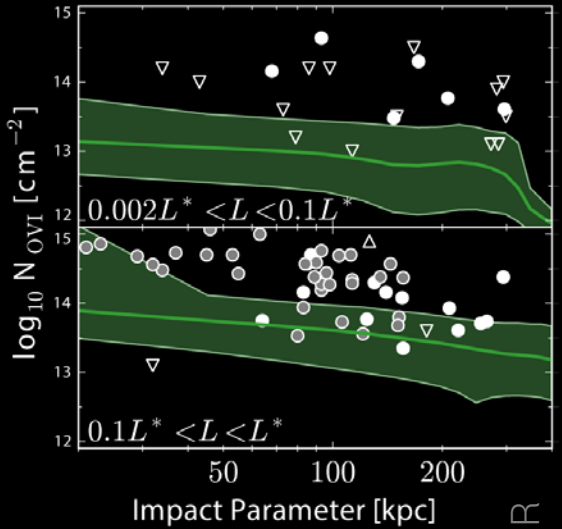


TNG: Nelson+ (2018)

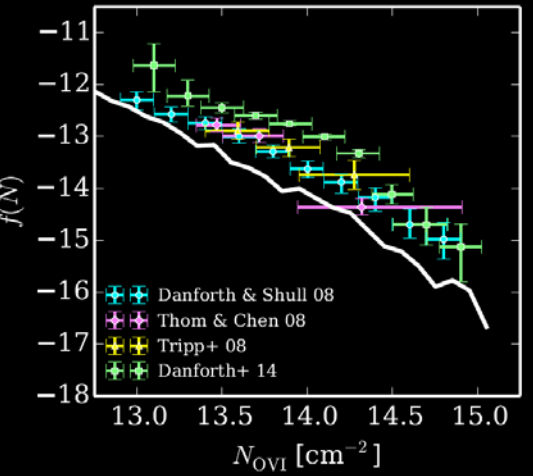
Does OVI represent a challenge to galaxy formation models?



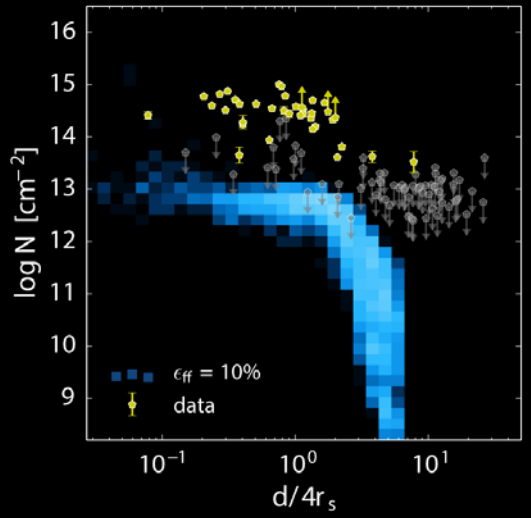
Ford+ (2016), pre-MUFASA



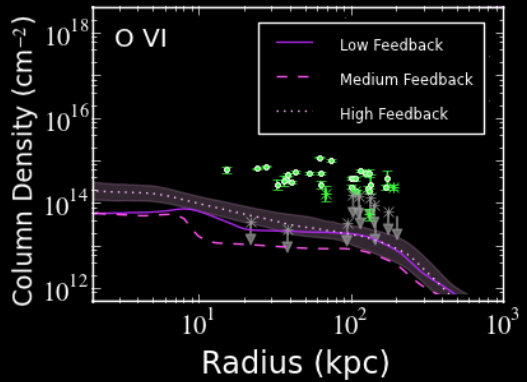
Gutcke+ (2016), NIHAO



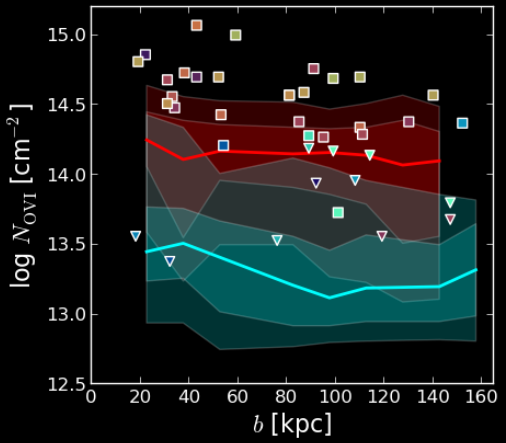
Suresh+ (2017), Illustris



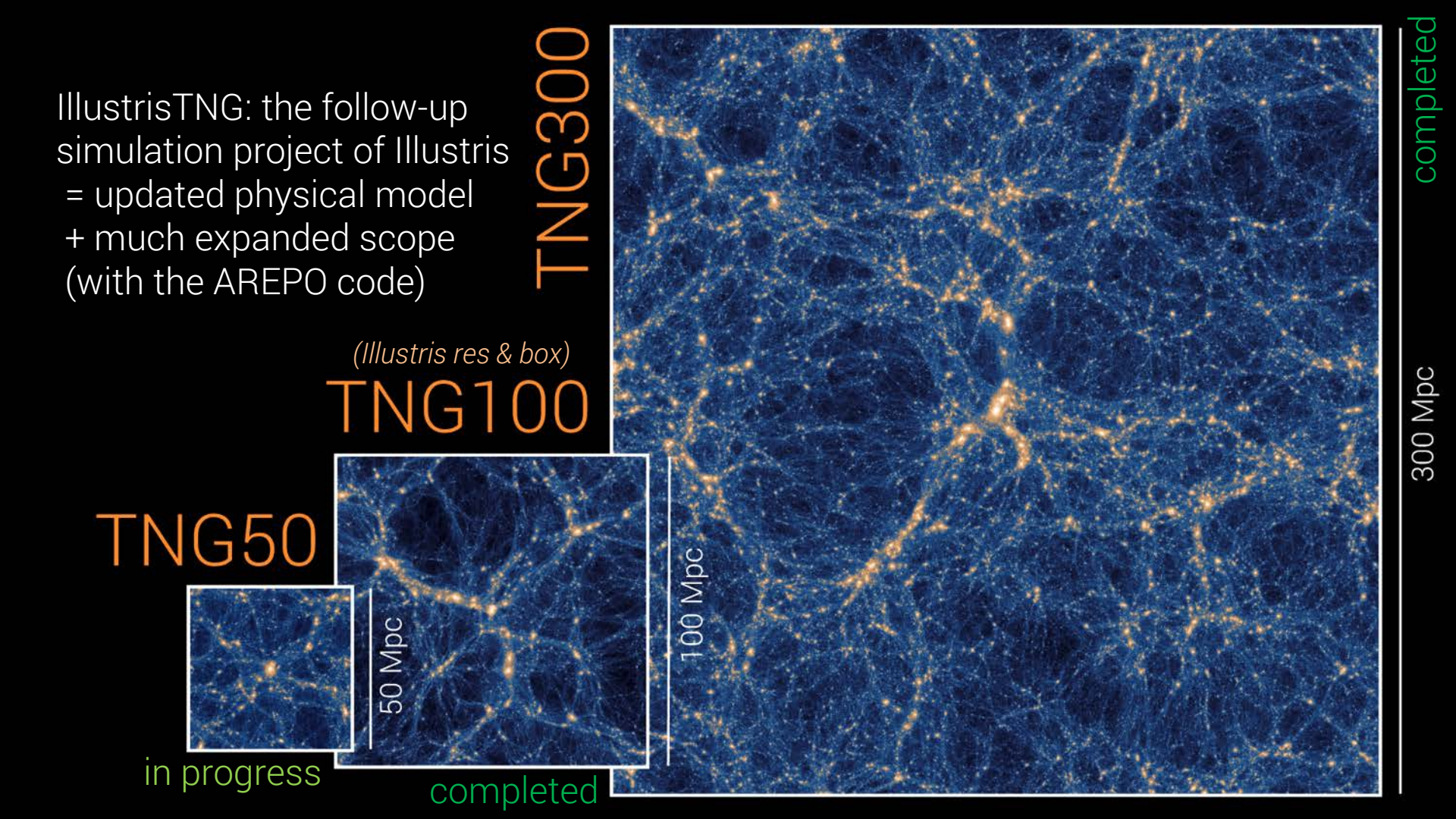
Liang+ (2016), AMR



Hummels+ (2013), AMR



Oppenheimer+ (2017), EAGLE

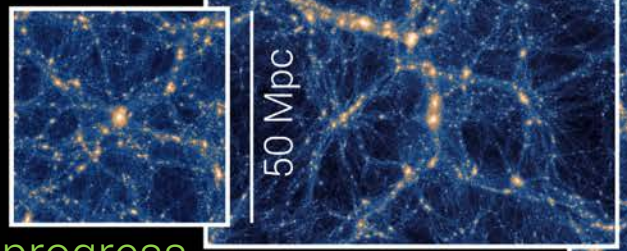

IllustrisTNG: the follow-up simulation project of Illustris
= updated physical model
+ much expanded scope
(with the AREPO code)
TNG300
completed
300 Mpc
(Illustris res & box)
TNG100
100 Mpc
TNG50
50 Mpc
in progress
completed

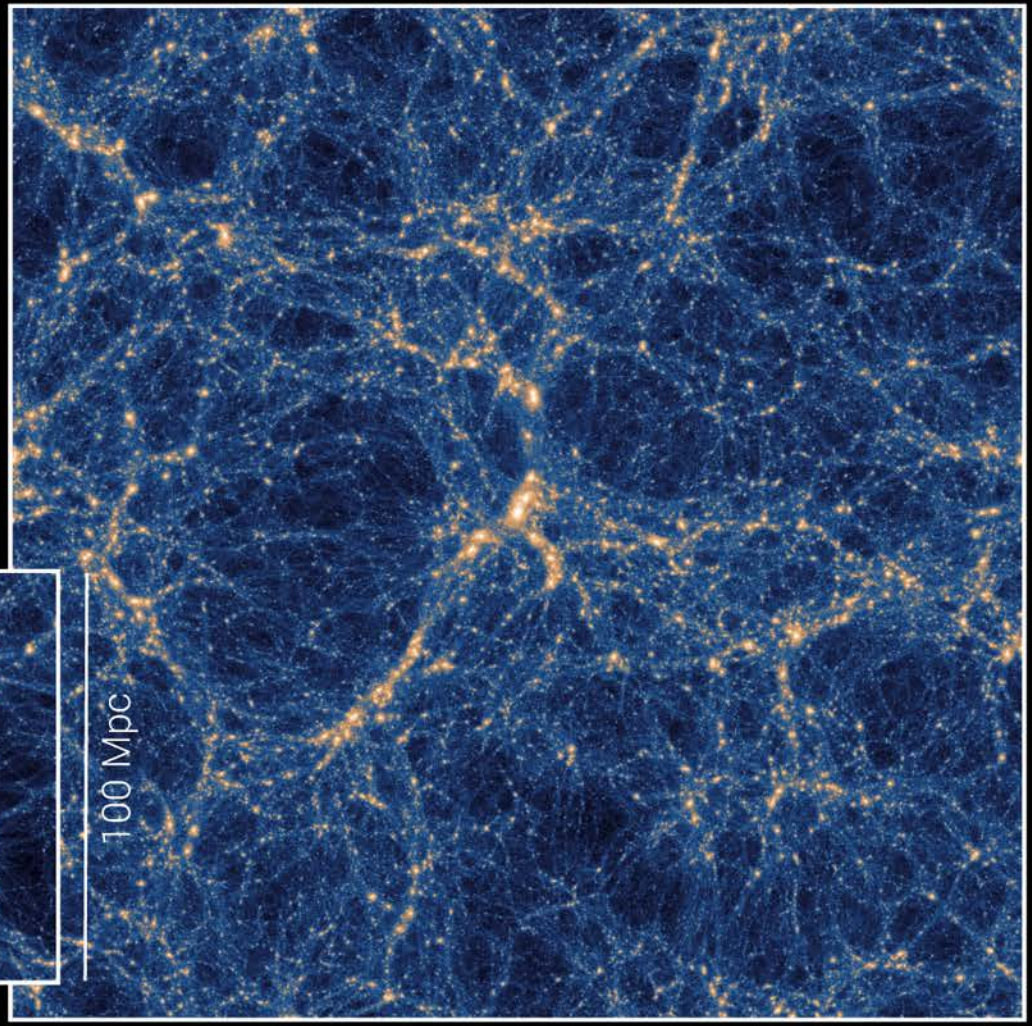
Run Name		TNG100	TNG300
Volume	[Mpc^3]	110.7^3	302.6^3
L_{box}	[Mpc/h]	75	205
N_{GAS}	-	1820^3	2500^3
N_{DM}	-	1820^3	2500^3
N_{TRACER}	-	2×1820^3	1×2500^3
m_{baryon}	[$\mathrm{M}_\odot$]	1.4×10^6	1.1×10^7
m_{DM}	[$\mathrm{M}_\odot$]	7.5×10^6	5.9×10^7
$\epsilon_{\mathrm{gas,min}}$	[pc]	185	370
$\epsilon^{z=0}_{\mathrm{DM,stars}}$	[kpc]	0.74	1.48
$\epsilon_{\mathrm{DM,stars}}$	[ckpc/h]	$1.0 \rightarrow 0.5$	$2.0 \rightarrow 1.0$

TNG300

TNG100

TNG50

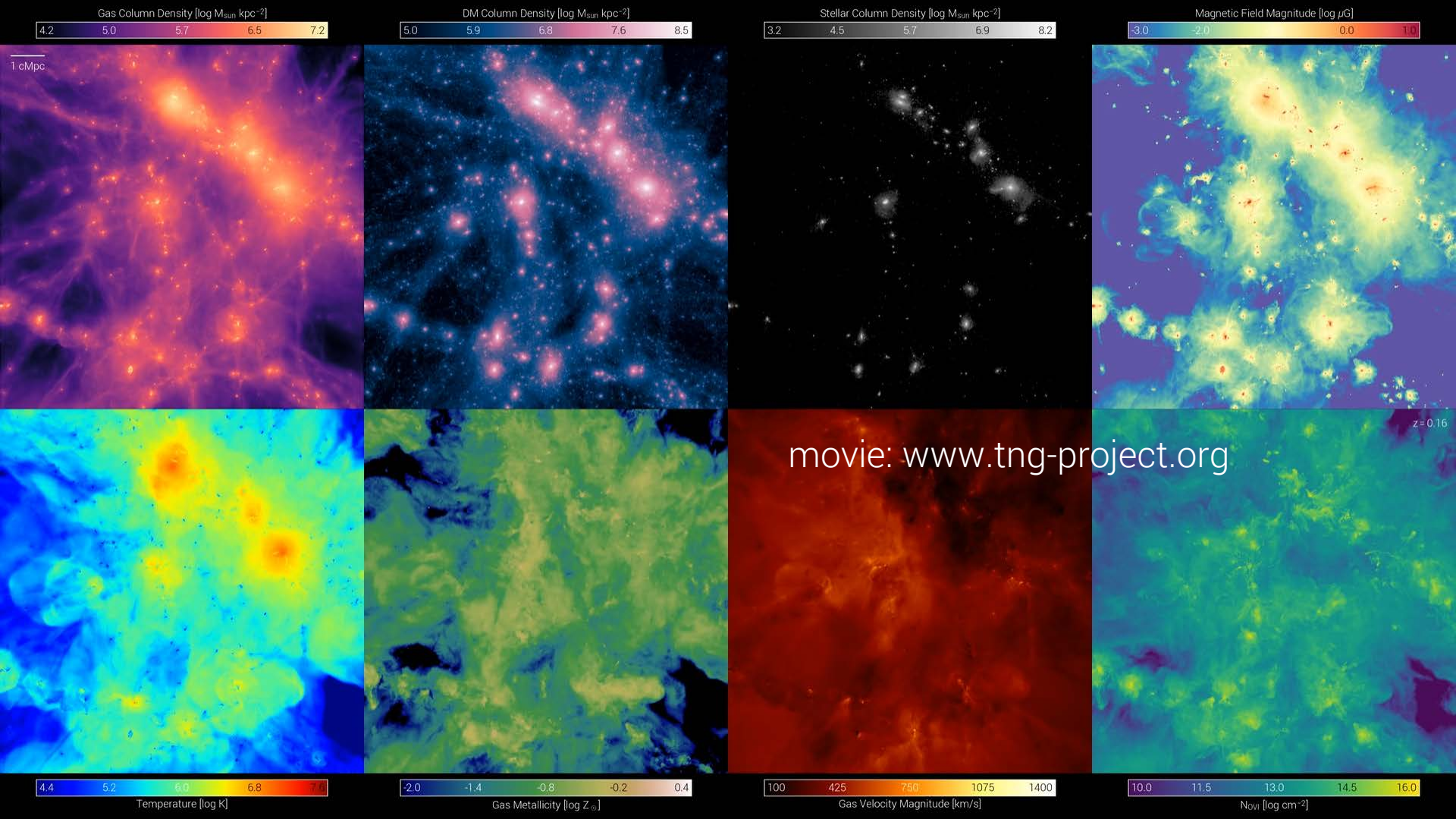




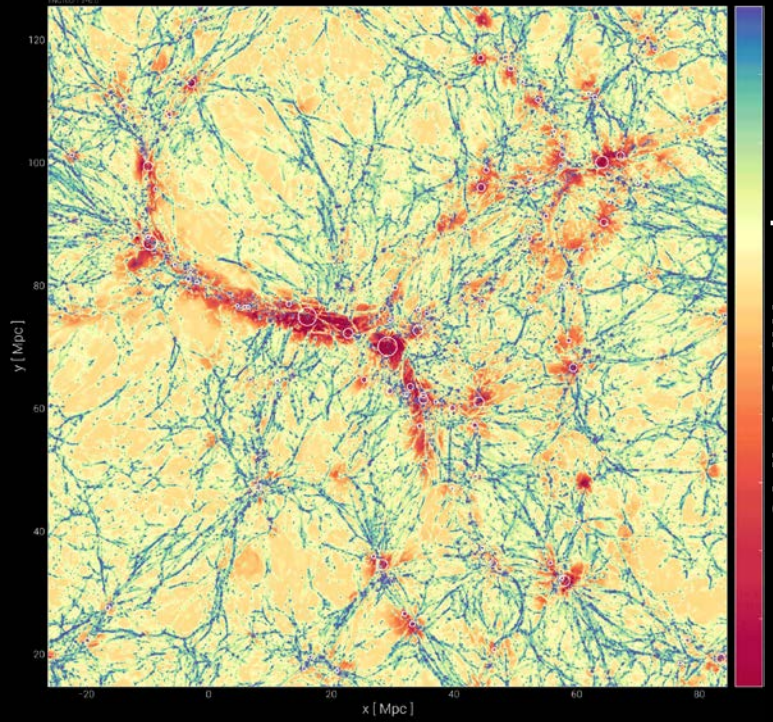
in progress

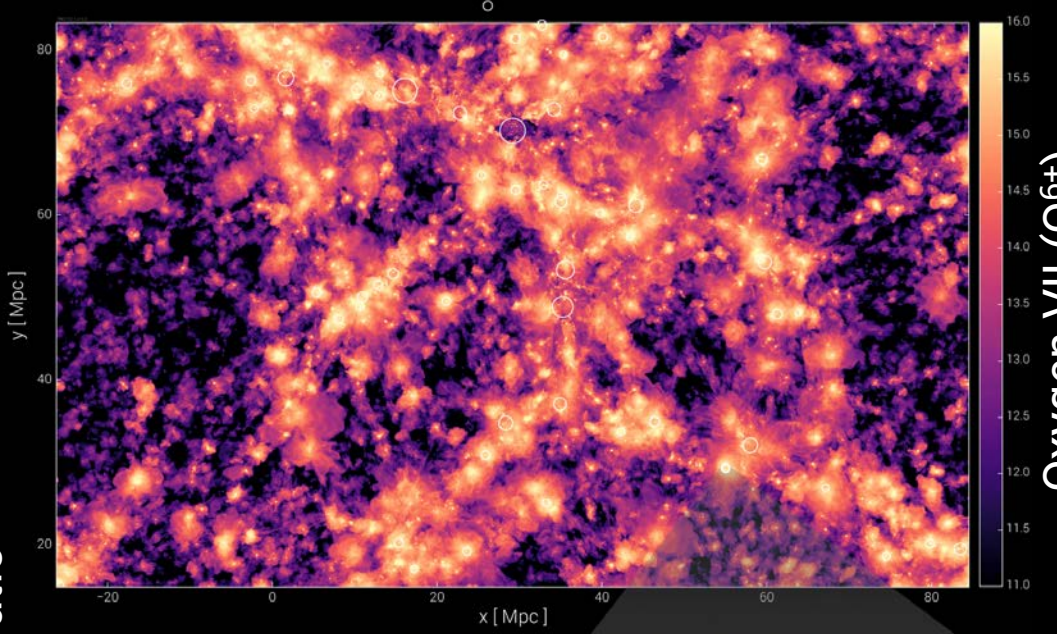
completed

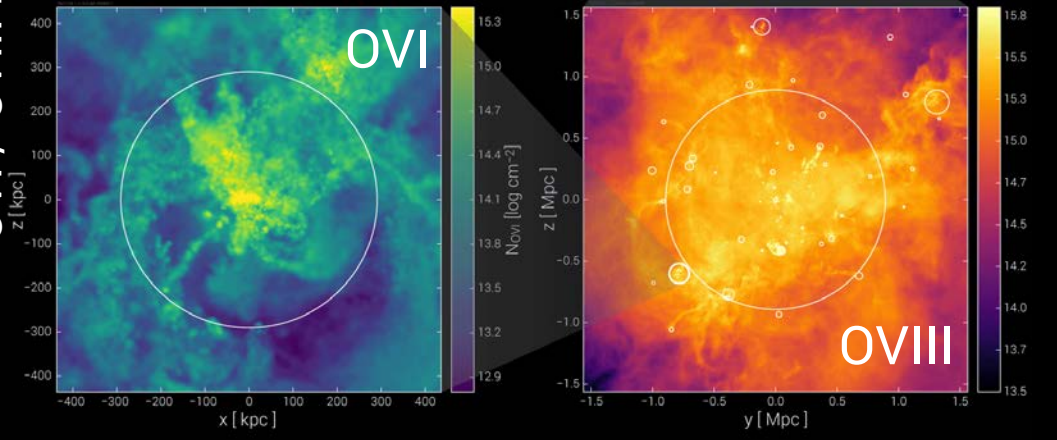
completed

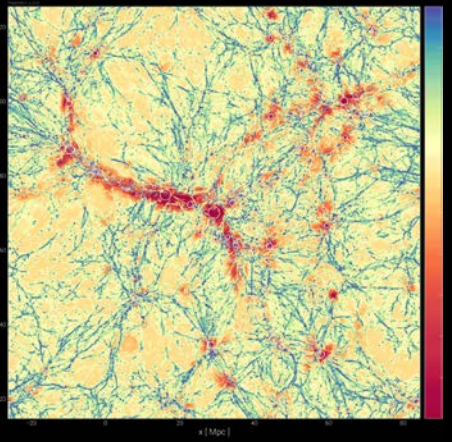

Gas Column Density [log M_{sun} kpc^{-2}]
4.2 5.0 5.7 6.5 7.2
DM Column Density [log M_{sun} kpc^{-2}]
5.0 5.9 6.8 7.6 8.5
Stellar Column Density [log M_{sun} kpc^{-2}]
3.2 4.5 5.7 6.9 8.2
Magnetic Field Magnitude [log μG]
-3.0 -2.0 0.0 1.0
1 cMpc
z = 0.16
movie: www.tng-project.org
4.4 5.2 6.0 6.8 7.6
Temperature [log K]
-2.0 -1.4 -0.8 -0.2 0.4
Gas Metallicity [log $Z_{\odot}$]
100 425 750 1075 1400
Gas Velocity Magnitude [km/s]
10.0 11.5 13.0 14.5 16.0
N_{OVI} [log cm^{-2}]

Modeling metal ions (CGM/WHIM): UV quasar absorption studies (HST COS, high-z ground/JWST), predictions for upcoming x-ray missions (Athena, Lynx).



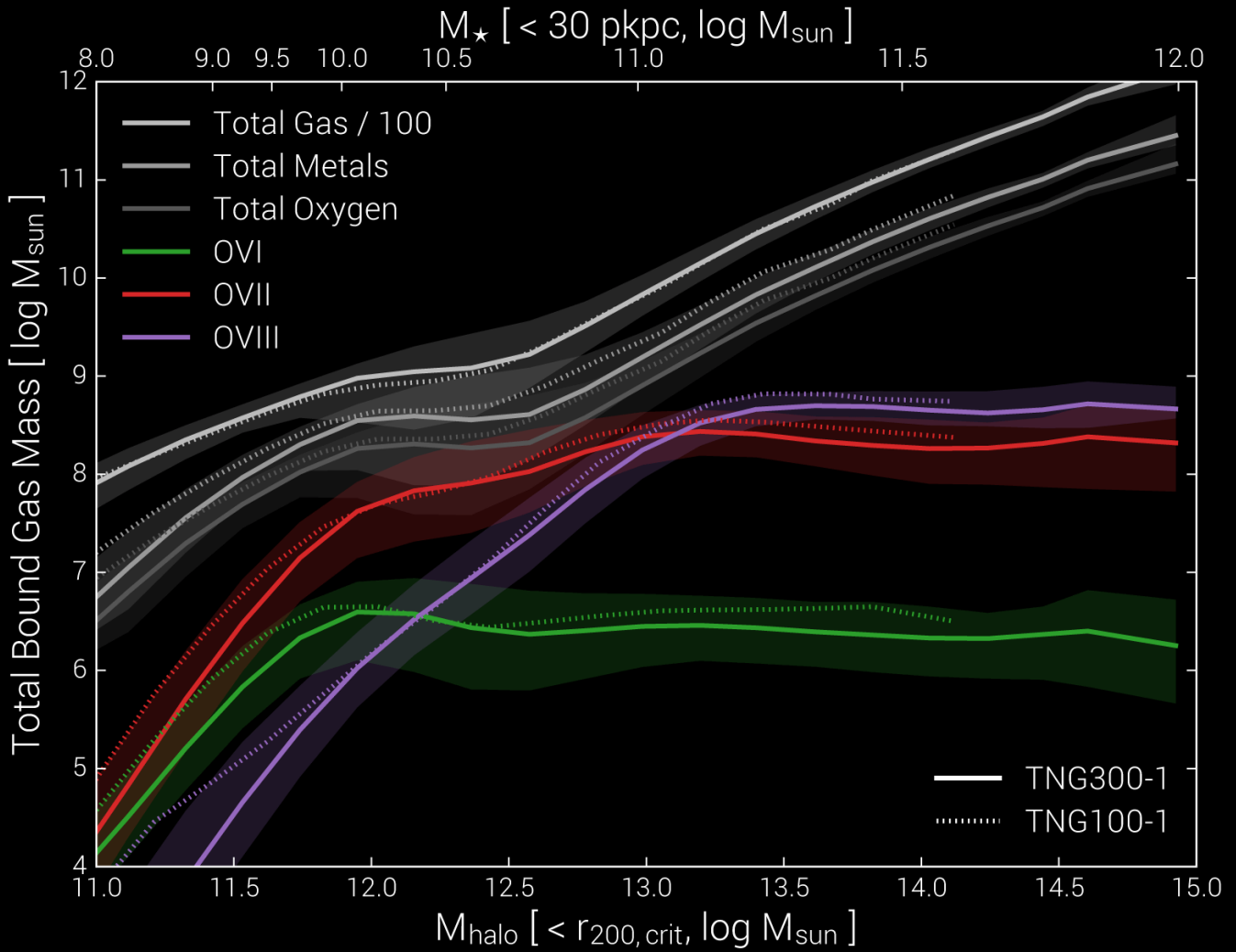


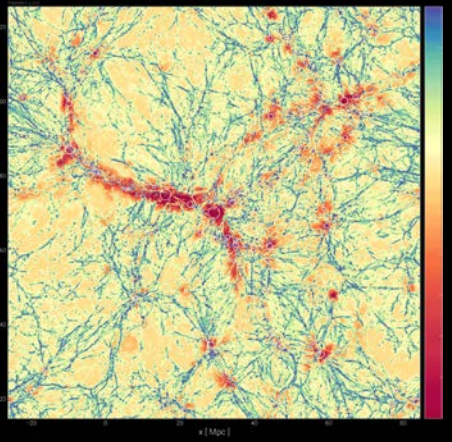




O6 ~ $10^{5.5}$ K
O7 ~ $10^{6.0}$ K
O8 ~ $10^{6.5}$ K

O6 always < O7

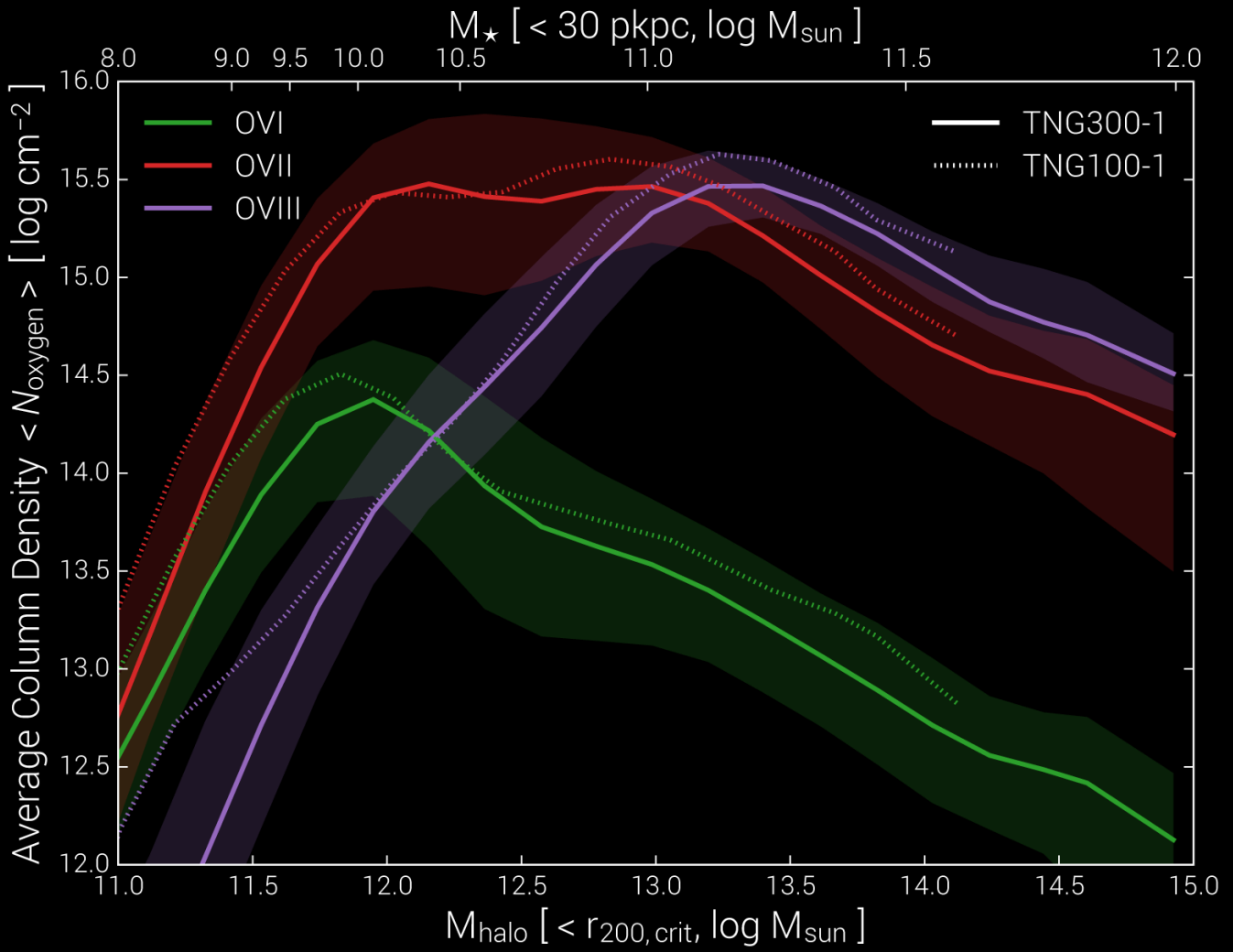




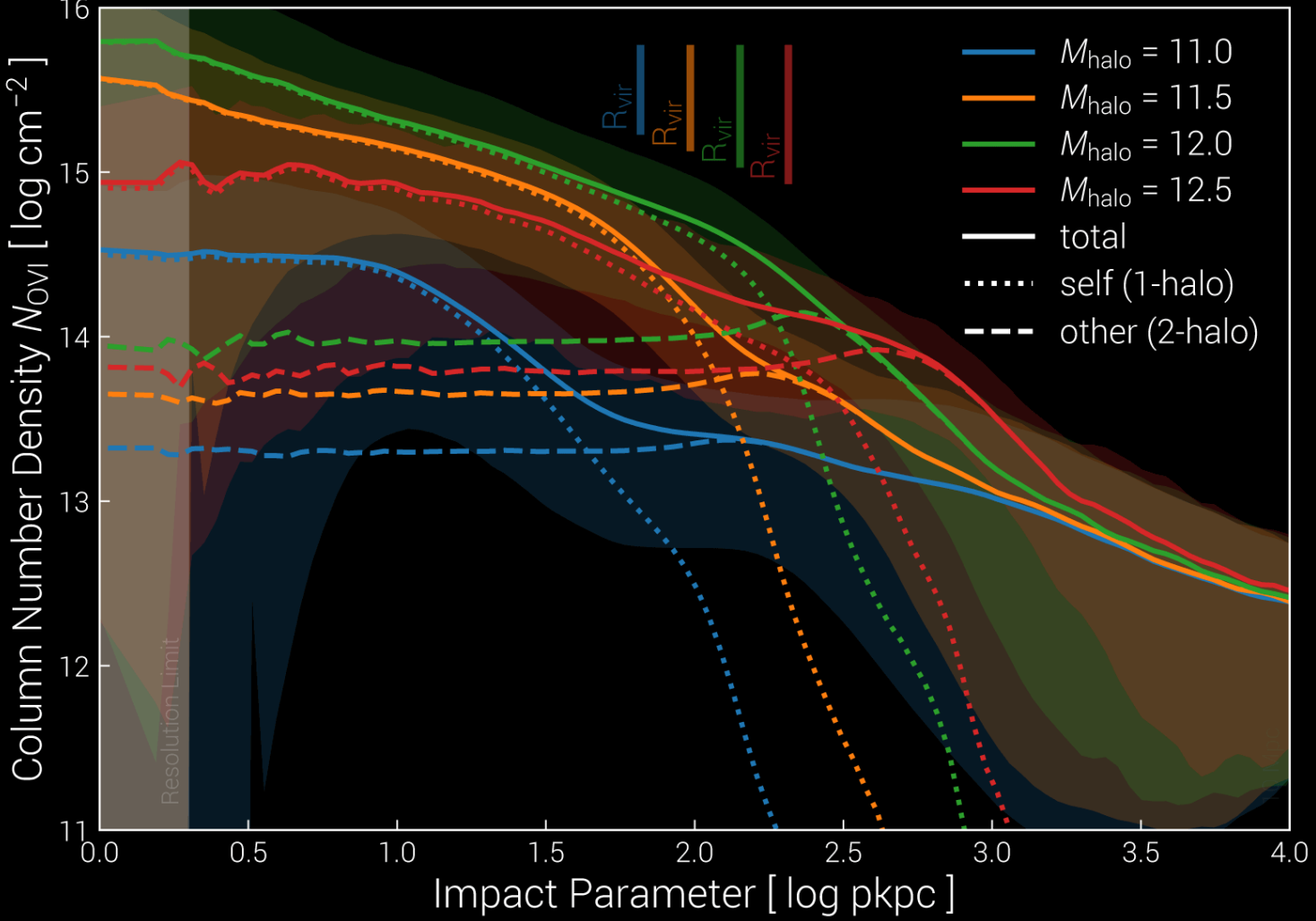
O6 ~ $10^{5.5}$ K
O7 ~ $10^{6.0}$ K
O8 ~ $10^{6.5}$ K

O6 ~ $10^{12.0}$ M_{sun}
O7 ~ $10^{12.5}$ M_{sun}
O8 ~ $10^{13.0}$ M_{sun}

O6 always < O7



OVI

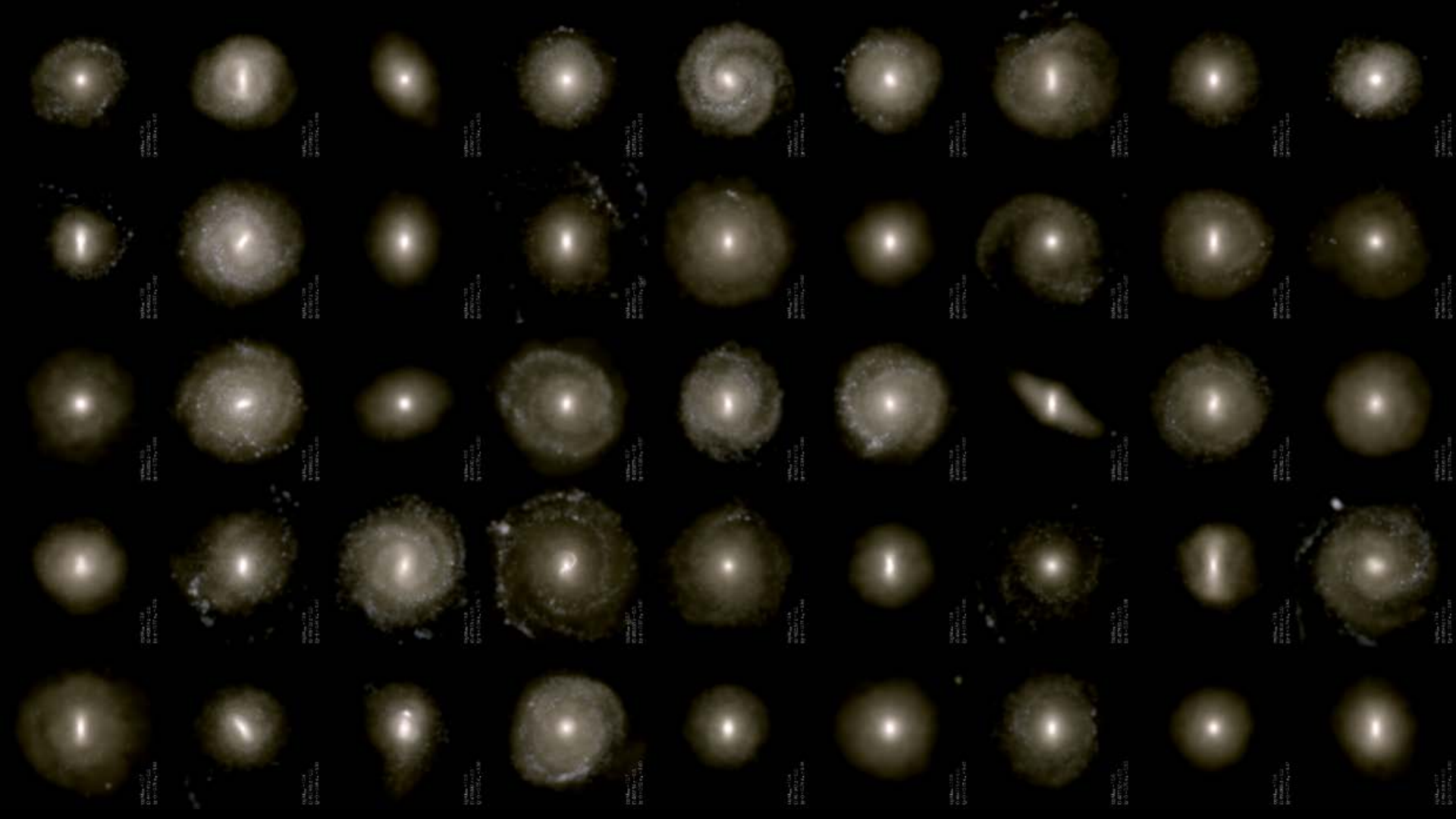


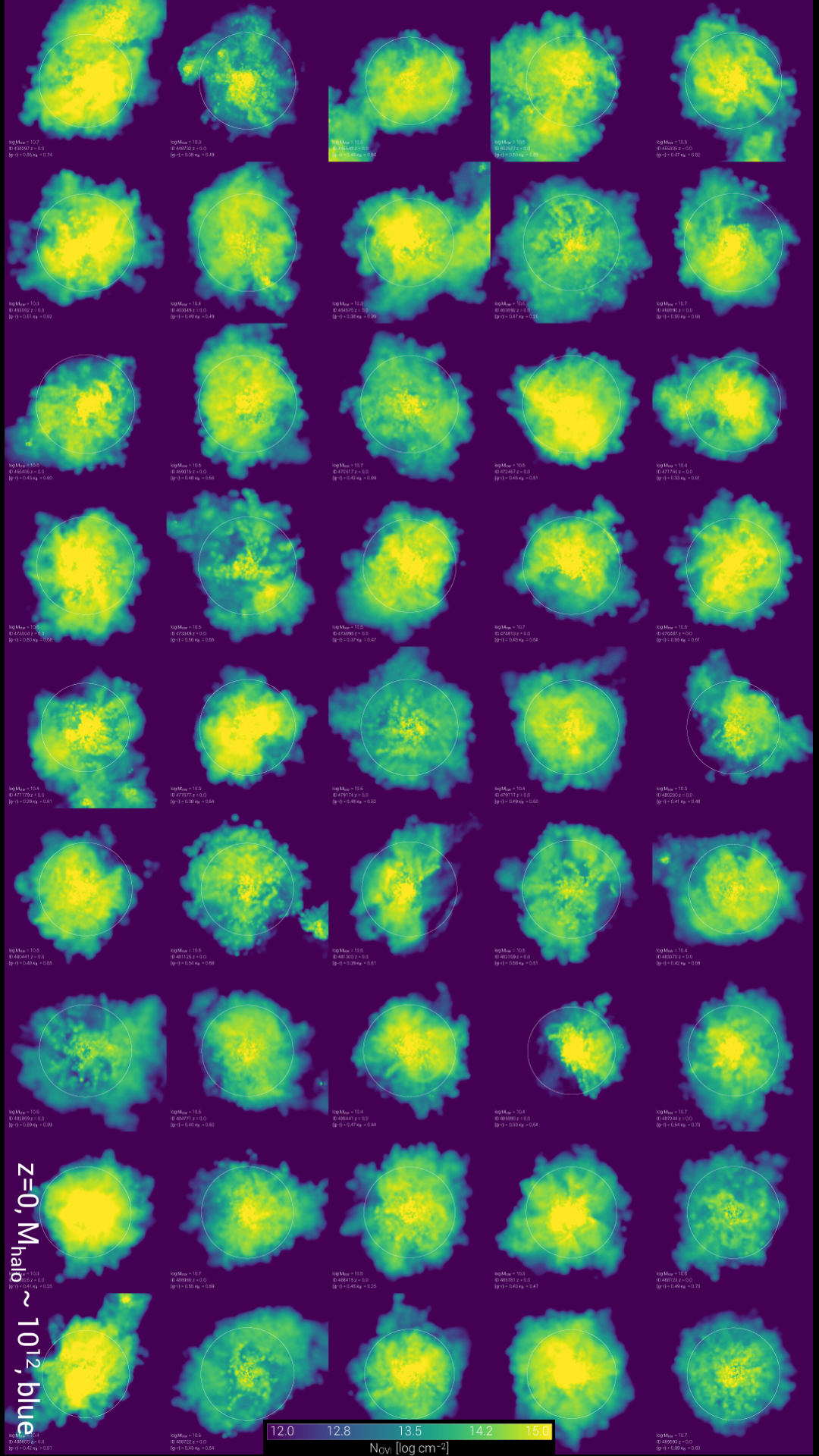
Average radial profile of OVI column density:

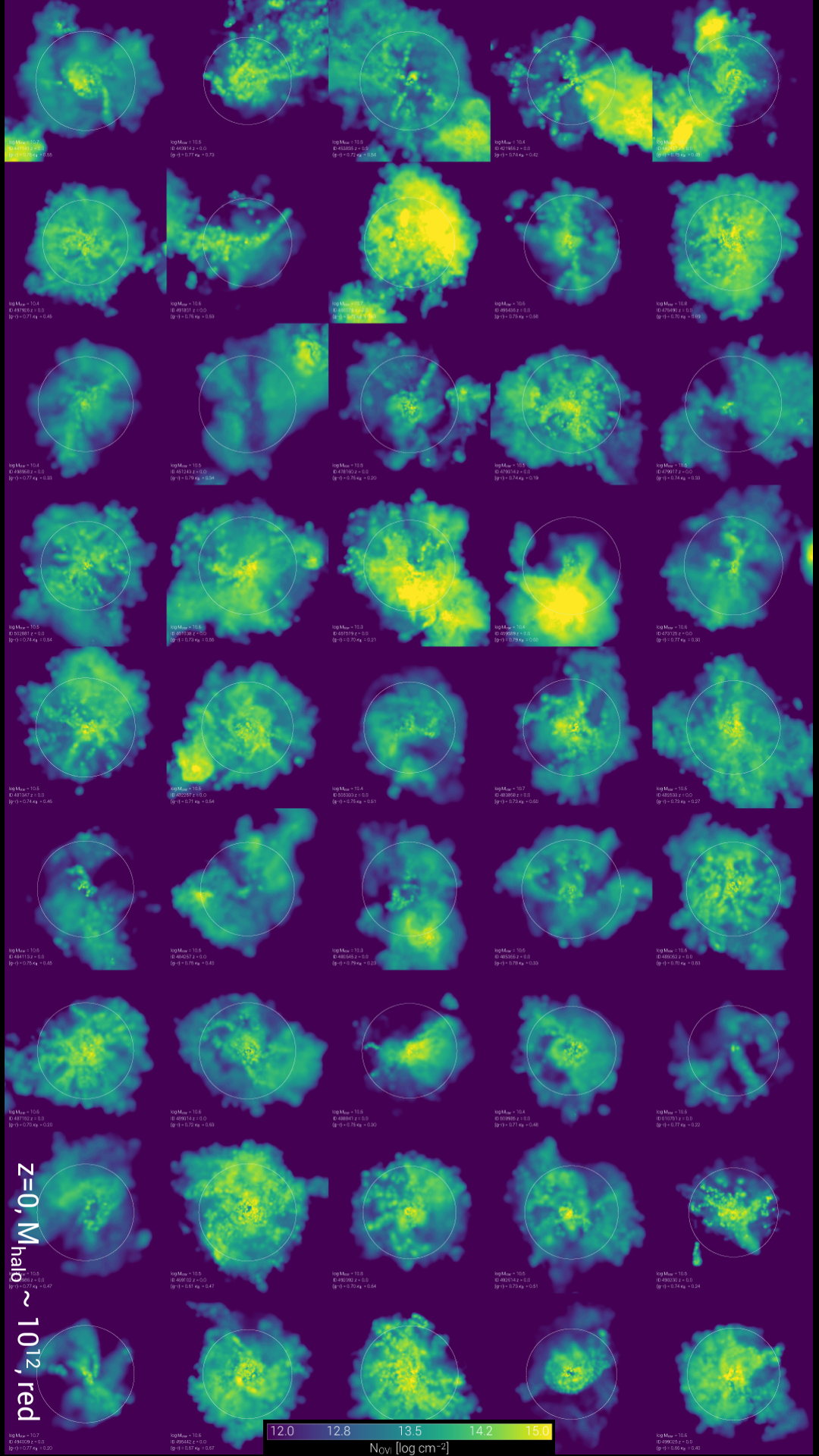
LOS contribution can be significant even within r_{vir}

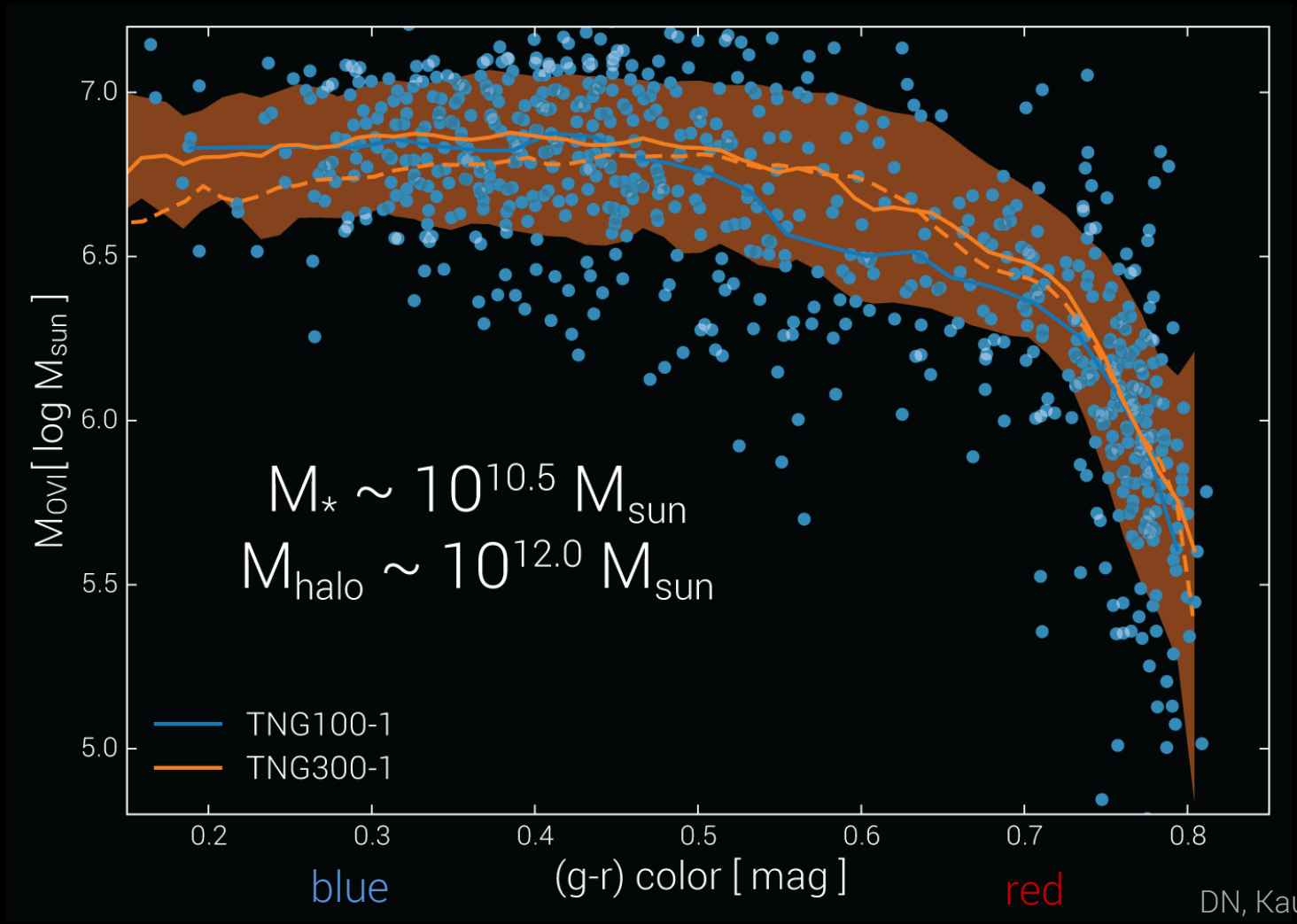
Higher mass: OVI halos more extended & w/ higher columns

($N \sim 10^{15.5}$ cm^{-2} at maximal $M_{halo} \sim 10^{12}$)




z=0, M$_{halo}$ ~ 10^{12}, blue
12.0
12.8
13.5
14.2
15.0
N$_{OVI}$ [log cm^{-2}]


12.0
12.8
13.5
14.2
15.0
N_{OVI} [log cm^{-2}]
z=0, $M_{halo} \sim 10^{12}$, red



Quantitative prediction of the TNG model:

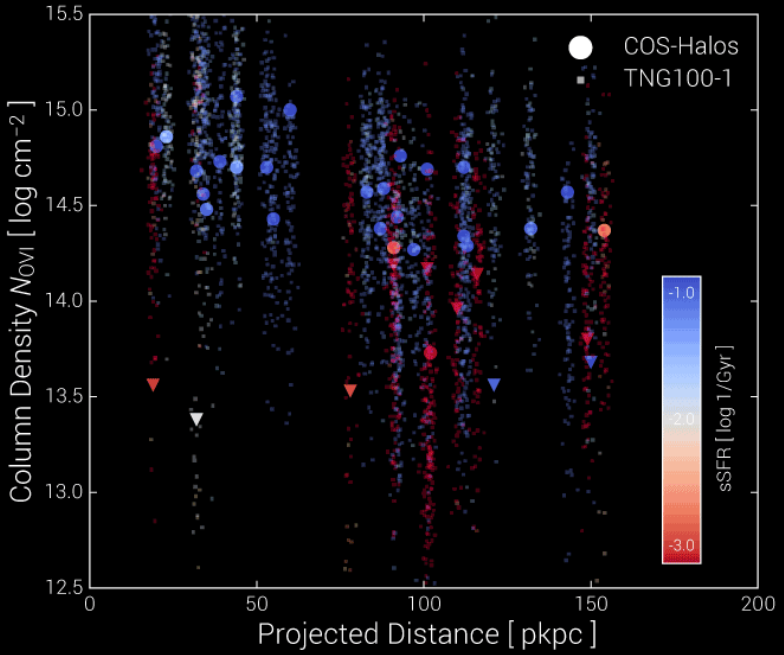
a correlation between the halo OVI mass and galaxy color at fixed M_*

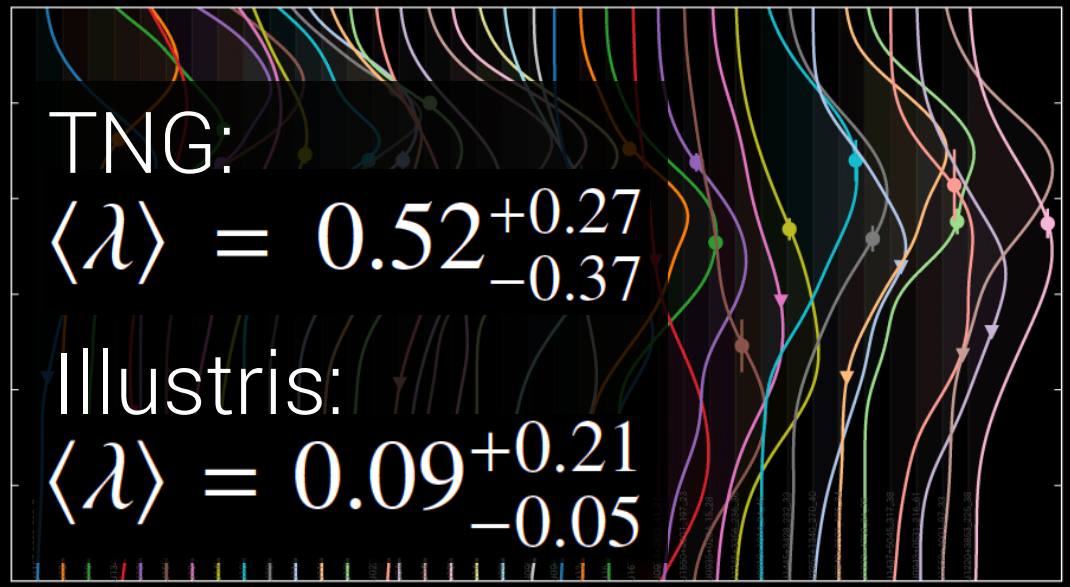
From both:

(i) Physical redistribution of metal mass

(ii) Modification of the CGM thermal state

DN, Kauffmann, Pillepich+ (2018)



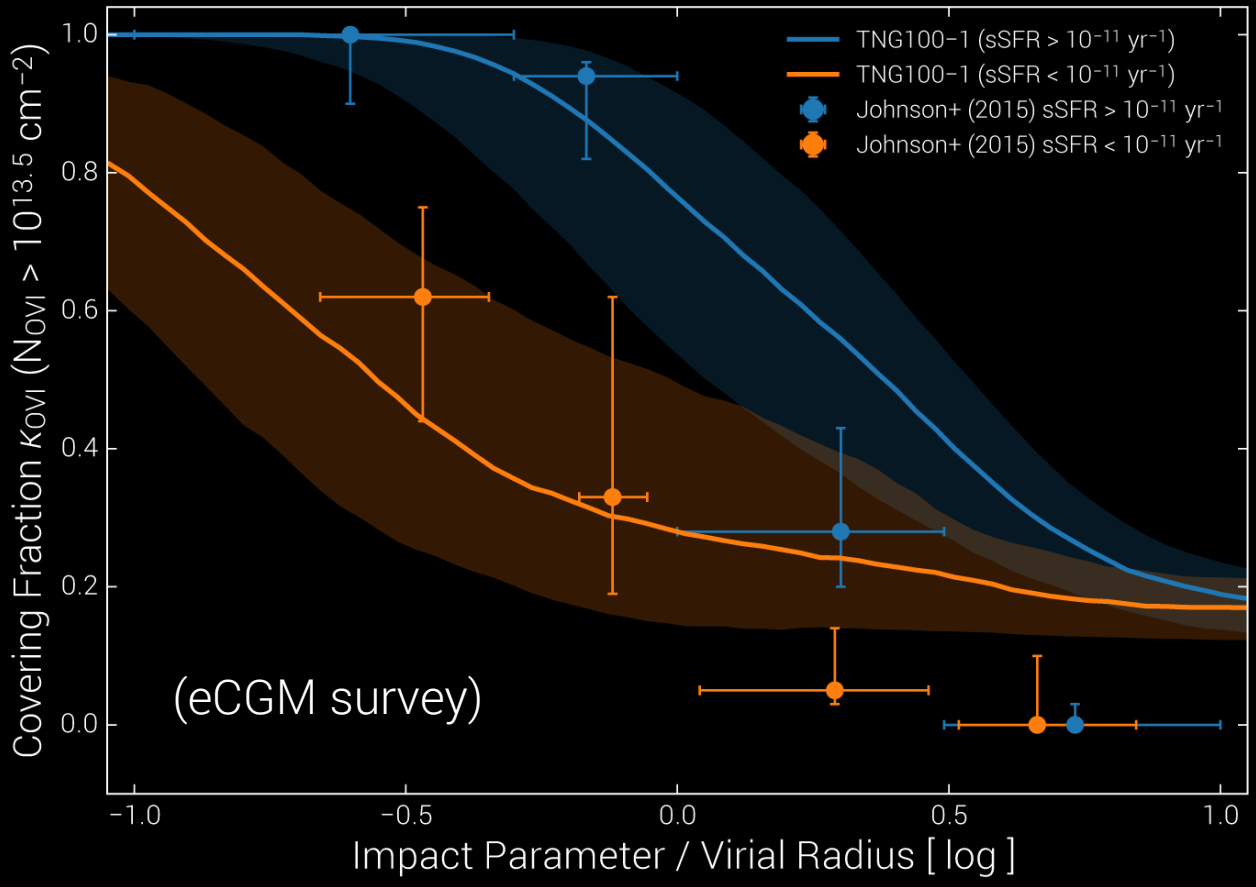


- Step 1: create mock galaxy sample matched in (M*, sSFR, env, z) + errors
- Step 2: draw random sightline at the matching impact parameter (b)
- Step 3: repeat 100x, compare each mock PDF of N_{OVI} vs. single obs data point
- Step 4: compute some statistic (λ) and its mean over the population

TNG seems fully consistent with low-z OVI data.

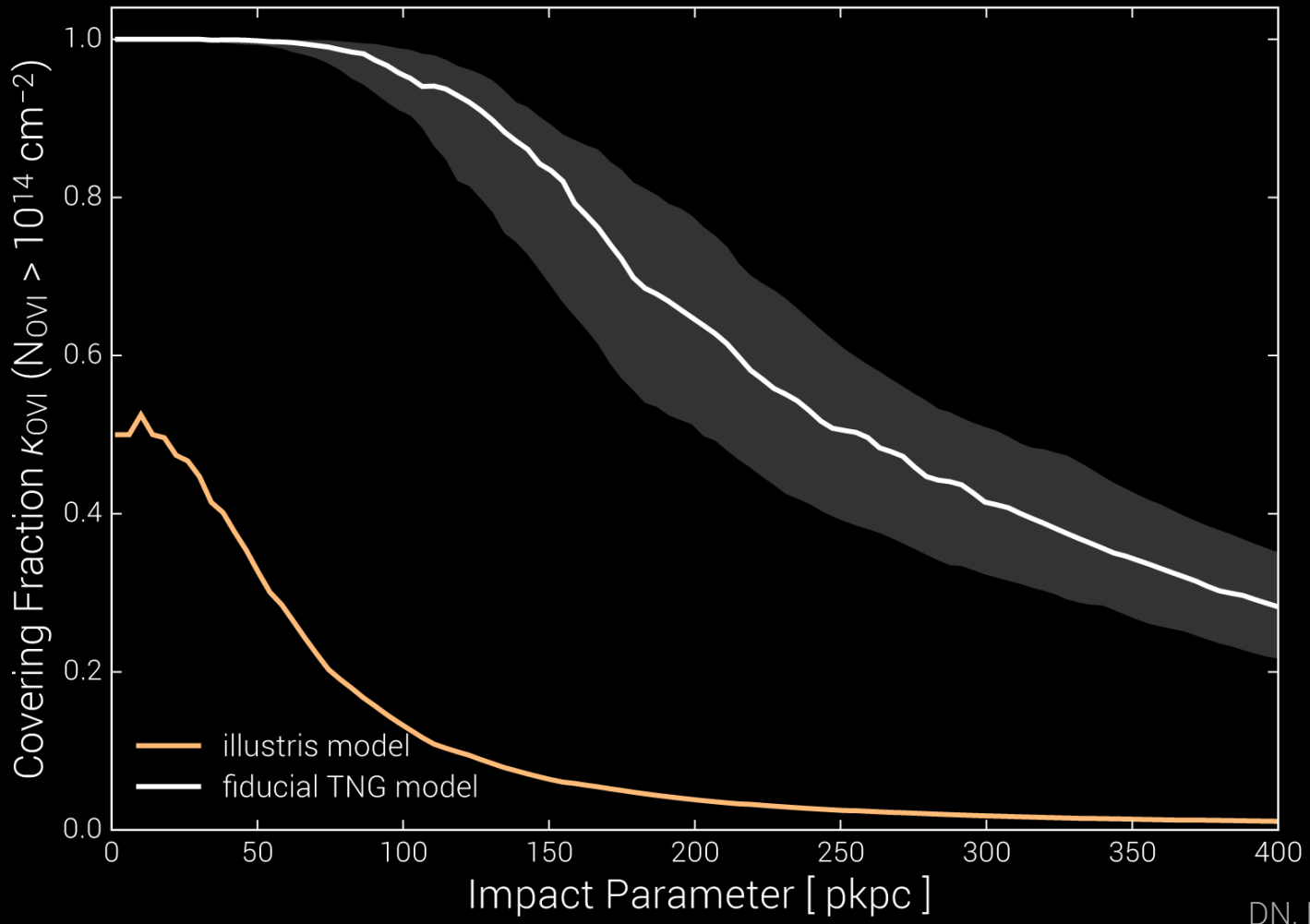
DN, Kauffmann, Pillepich+ (2018)

TNG seems fully consistent with low-z OVI data.



Why the improvement in TNG vs. original Illustris?

DN, Kauffmann, Pillepich+ (2018)

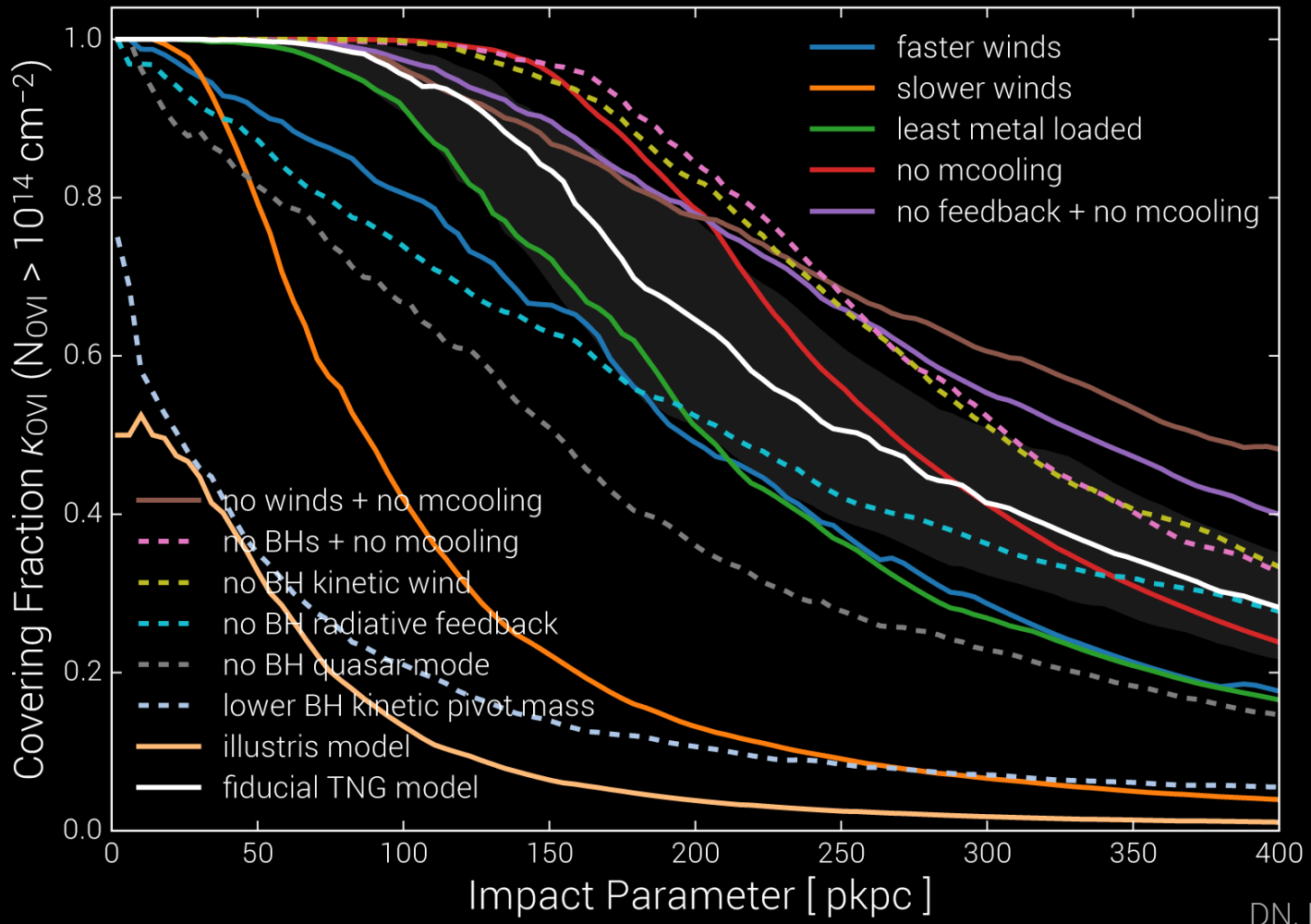


Why the improvement in TNG vs. original Illustris?

$M_{halo} \sim 10^{11.5}$ - $10^{12.5}$

(about 200 galaxies in a ~37 Mpc test volume)

DN, Kauffmann, Pillepich+ (2018)



Why the improvement in TNG vs. original Illustris?

$M_{halo} \sim 10^{11.5}$ - $10^{12.5}$

(about 200 galaxies in a ~37 Mpc test volume)

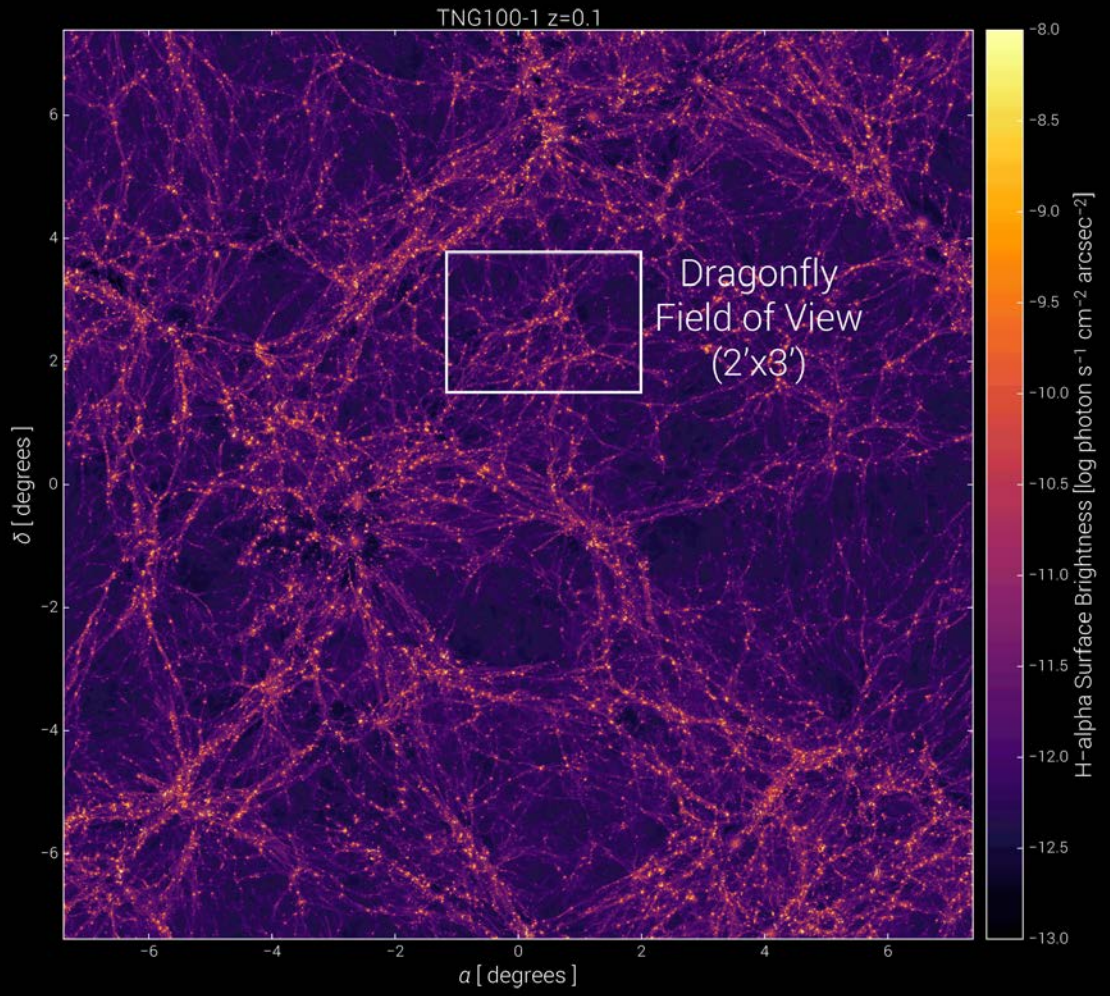
~100 variants exploring all relevant TNG model and parameter value choices

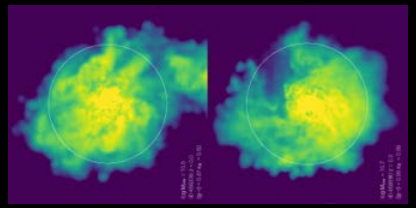
DN, Kauffmann, Pillepich+ (2018)

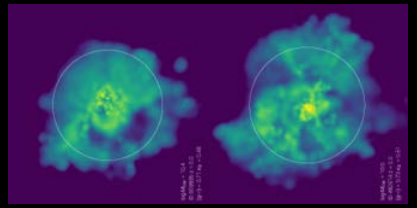
Random aside:

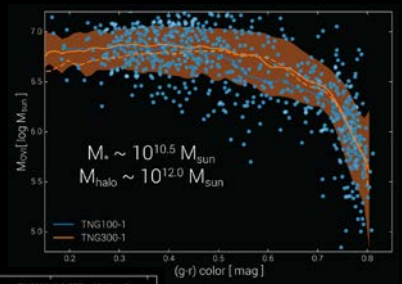
‘direct imaging’

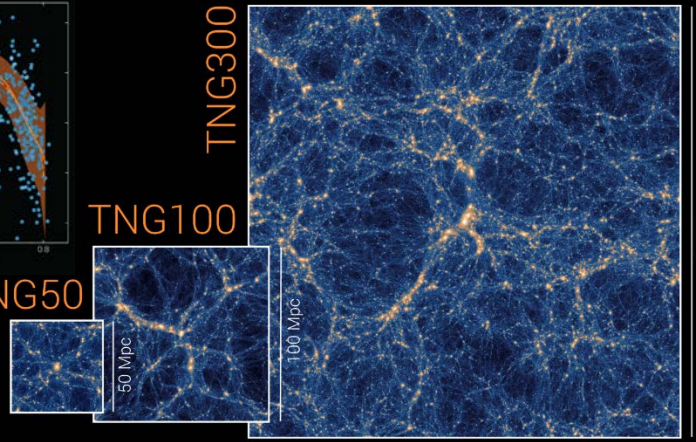
The cosmic web in emission instead of absorption: there’s more Hα than just the component inside galaxies.

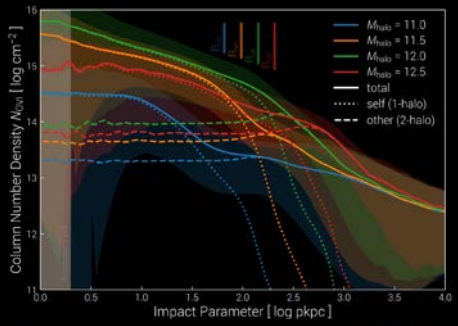


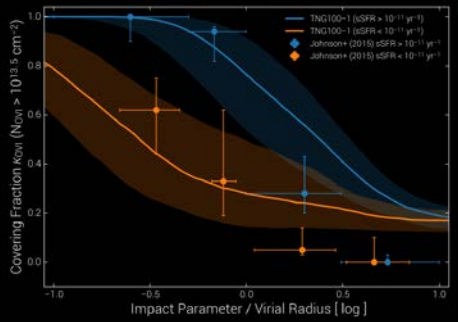


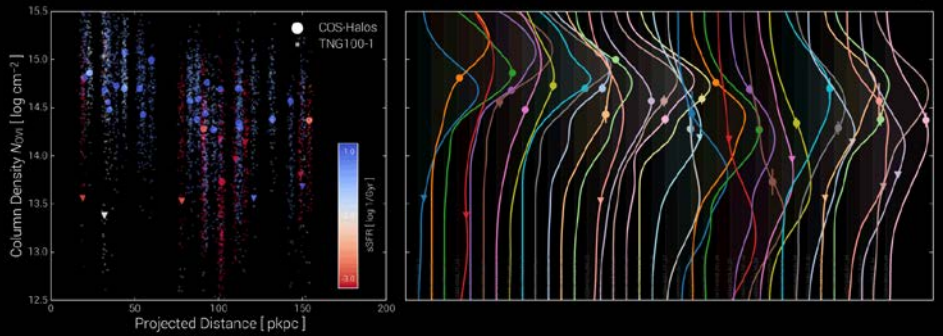












The TNG team:

Volker Springel


Lars Hernquist


Annalisa Pillepich


Rüdiger Pakmor


Dylan Nelson


Rainer Weinberger


Federico Marinacci


Jill Naiman


Mark Vogelsberger


Shy Genel


Paul Torrey

HITS CfA Max-Planck-Institut für Astrophysik MIT SIMONS CCA