The impact of galactic outflows on the IGM in the IllustrisTNG and IllustrisQLA simulations

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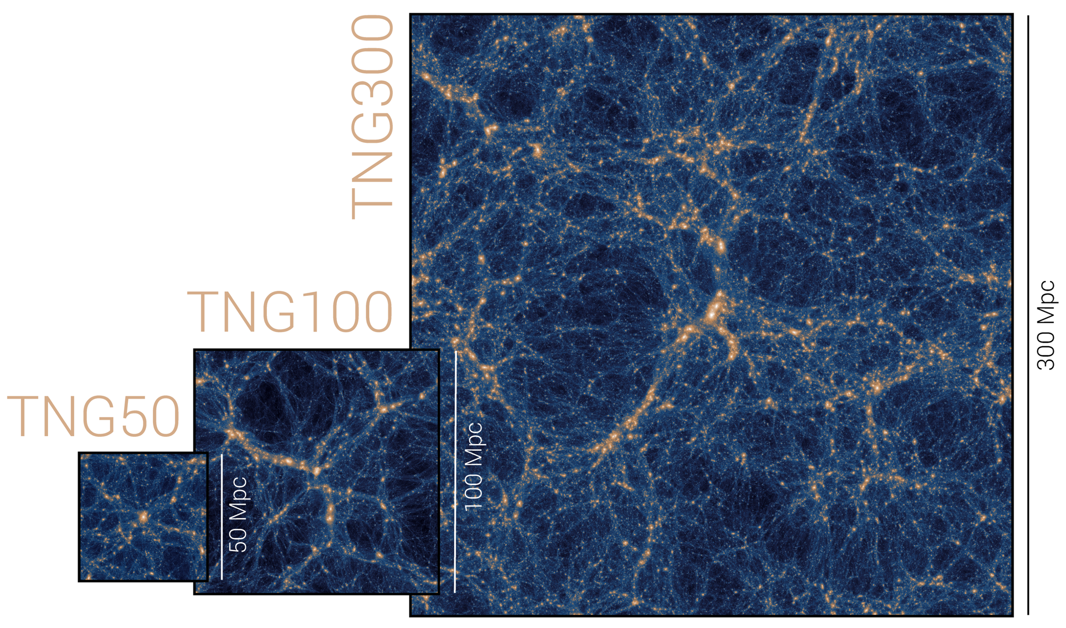
Abstract

We study the impact of galactic outflows on the properties of the intergalactic medium (IGM) at redshifts z=3 and z=2 using simulations of galaxy formation that account for strong feedback effects from galactic winds driven by supernovae and active galactic nuclei (AGN). We have performed a set of simulations with the moving mesh code AREPO evolving several volumes, each with the same initial conditions but once employing the quick Lyman-alpha technique which omits any feedback onto the diffuse gas, and the other time our most advanced physical prescription incorporated in the IllustrisTNG model. Our unique setup allows us to quantify in the most clean way how galactic outflows heat the CGM and IGM, change the density distribution of diffuse gas and its Lyman-alpha forest statistics, and distribute metals across the CGM and IGM. Our results underline the importance of accounting for galaxy formation in precision studies of the IGM.

IllustrisTNG project

The next generation Illustris simulations (IllustrisTNG) is a suite of cosmological magneto-hydrodynamical simulations evolving a representative volume of the universe from initial density perturbations until today with a comprehensive model for galaxy formation. The suite consists of three different volumes, which cover the evolution of structures ranging from dwarf galaxies to galaxy clusters, which allow for a statistical analysis at all mass regimes. IllustrisTNG reproduces the observable properties of galaxies and clusters, and at the same time allows to investigate the impact of galactic feedback on the large scale structure.



dark matter density

Simulations

simulation	volume	initial dm	initial gas
IllustrisTNG	75 Mpc/h	1820^3	1820^3
IllustrisTNG-2	31.648 Mpc/h	768^3	768^3
IllustrisQLA-2	31.648 Mpc/h	768^3	768^3
IllustrisTNG-3	15.824 Mpc/h	384^3	384^3
IllustrisQLA-3	15.824 Mpc/h	384^3	384^3

All Illustris simulations are carried out with the moving mesh code AREPO (Springel, 2010).

IllustrisTNG physics

To mimic the effects of unresolved astrophysical processes, simulations rely on a number of sub-resolution treatments, in particular for the effects of stars and supermassive black holes. The IllustrisTNG galaxy formation physics model is an update of the Illustris model resolving several issues of the original implementation. The most important changes to the original formulation are

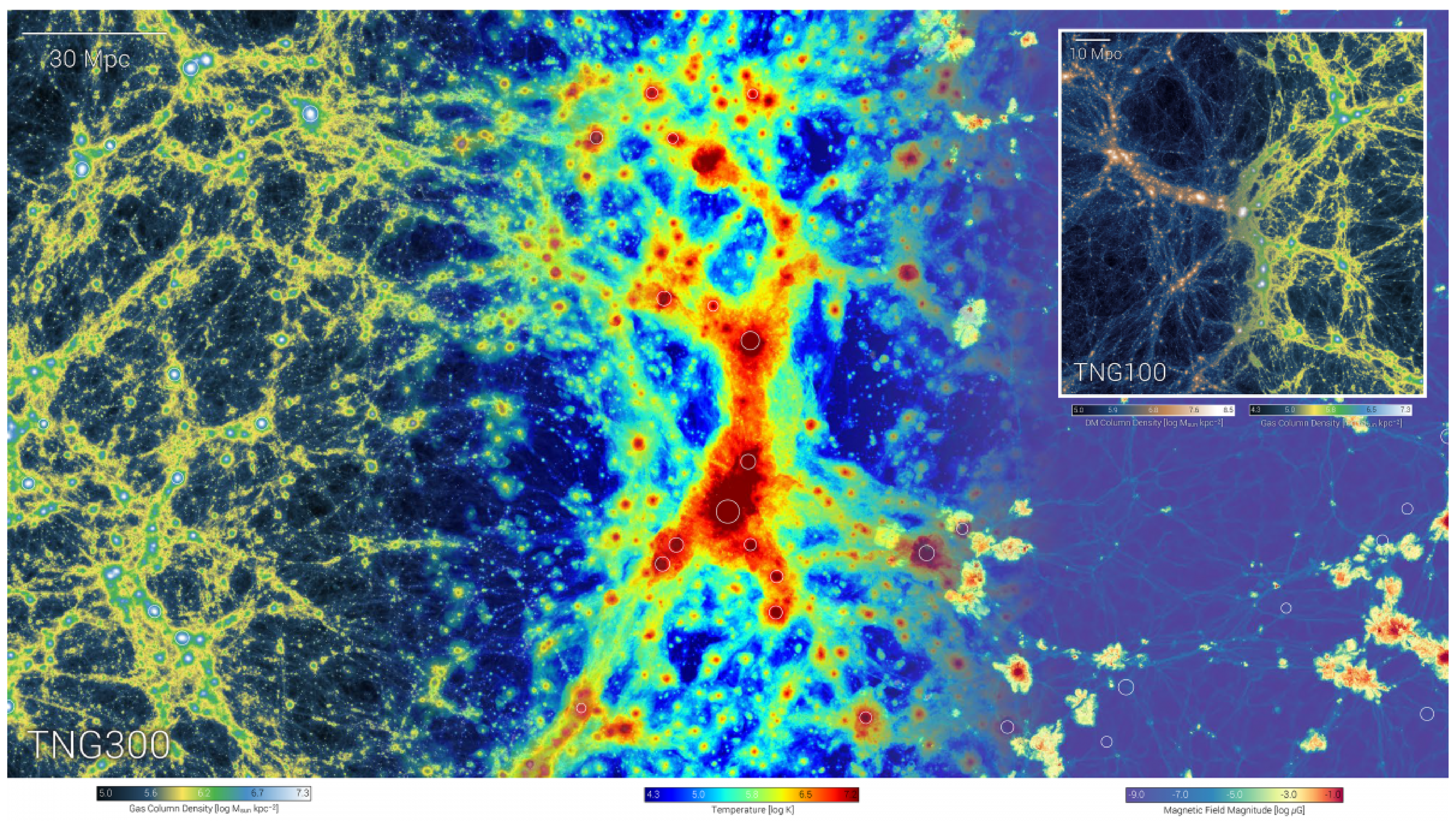
- Planck cosmology
- isotropic star formation-driven galactic winds with improved redshift-dependent scaling (Pillepich et al., 2017)
- kinetic AGN feedback at low accretion states (Weinberger et al., 2017)
- magnetic fields (Pakmor et al., 2014)
- Improved advection of chemical elements

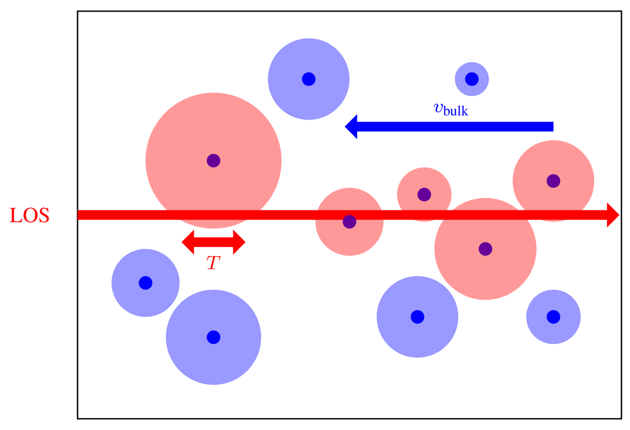
IllustrisQLA ansatz

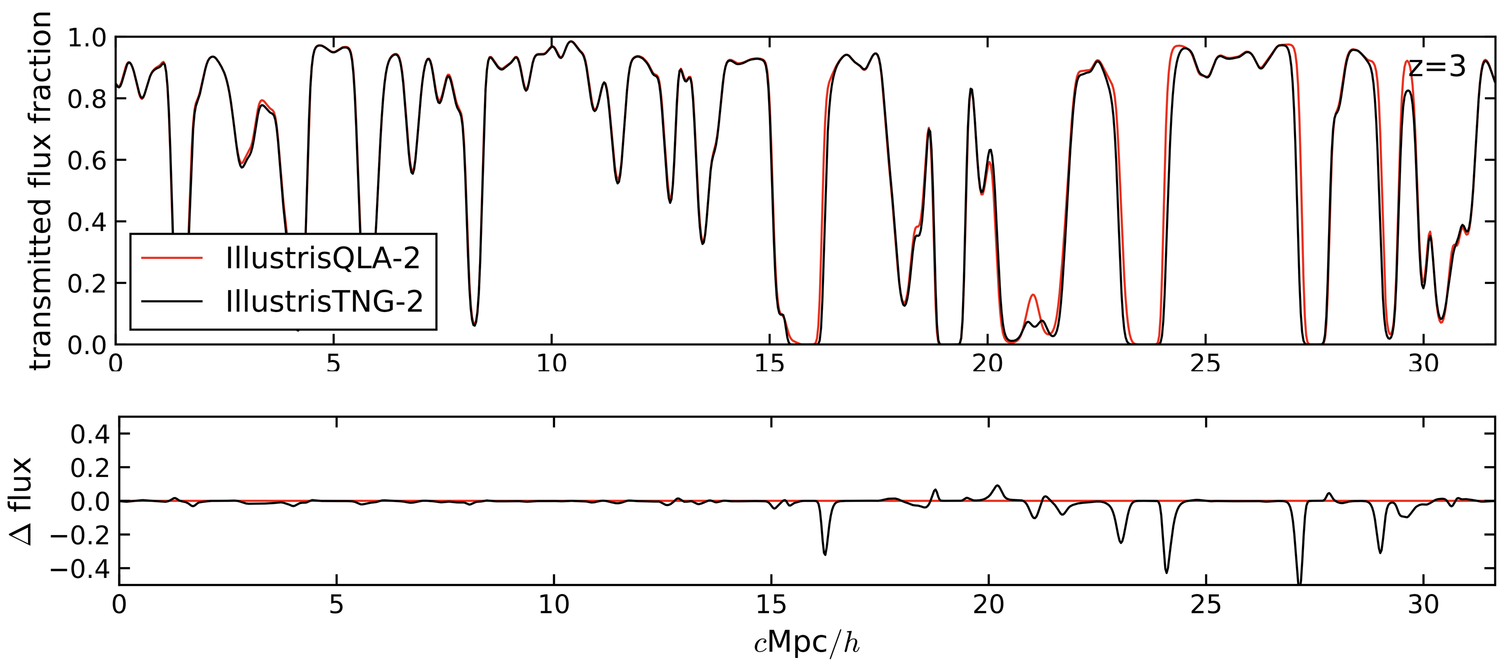
The Quick Lyman-alpha method reduces subgrid physics to gas cooling and a basic starformation prescription in which all gas above a density threshold of $1000 \cdot \rho_{crit}$ is converted into stars. No feedback from galaxies is included leaving the CGM and IGM **unperturbed by galactic outflows**. We have simulated two smaller volumes with the same mass resolution as IllustrisTNG, each with the TNG and QLA physics and identical initial conditions, allowing for direct comparison of the changes introduced into the properties of the gas by outflows.

Lyman-alpha forest as a probe

We probe the IGM with Lyman-alpha forest spectra which we obtain by drawing lines-of-sight (LOS) at random positions through the simulation volume. In our unique setup we can directly compare the same large scale structure as it appears in the Lyman-alpha forest when it is unperturbed (red) and when it is affected (black) by galactic outflows on a line by line basis. The difference in the Lyman-alpha flux shows that there are reoccurring large regions with systematically less transmitted flux and thus higher gas density in the presence of galactic outflows.



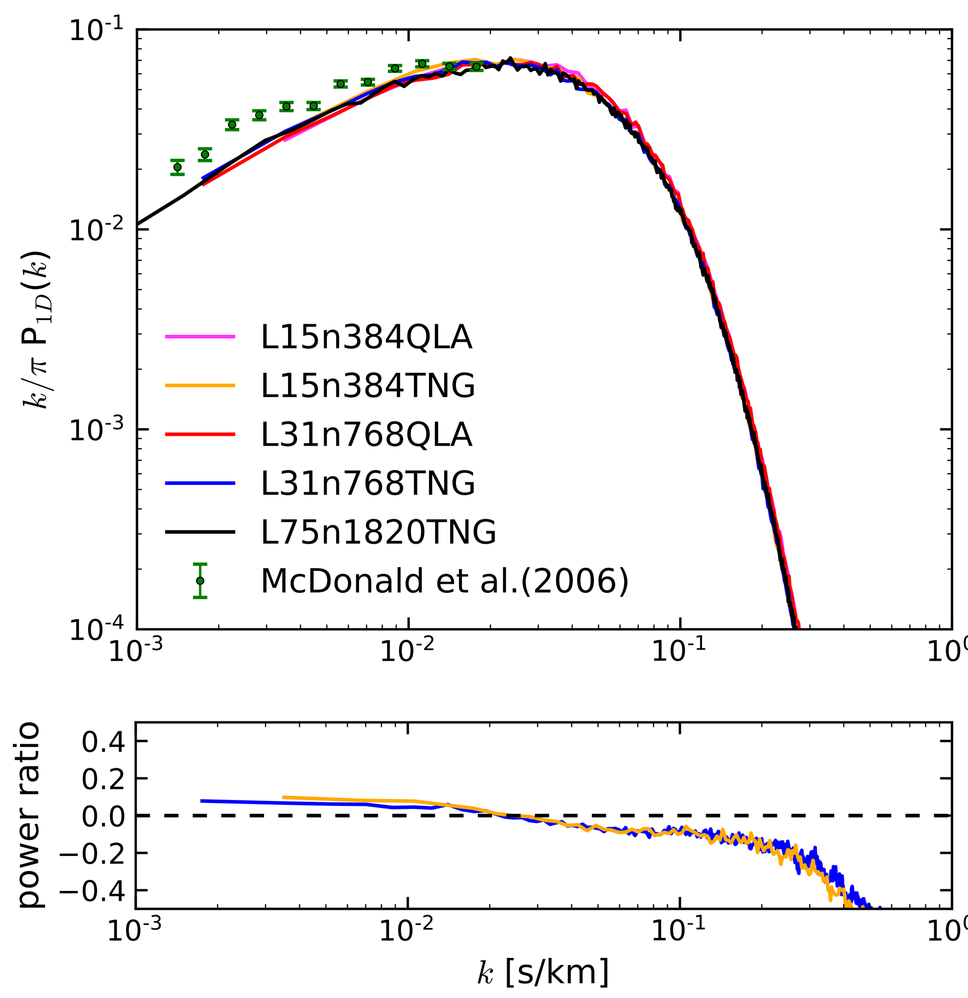




Synthetic Lyman-alpha forest spectra drawn from hydrodynamical simulations accounting for thermal broadening and the bulk velocity of absorbers.

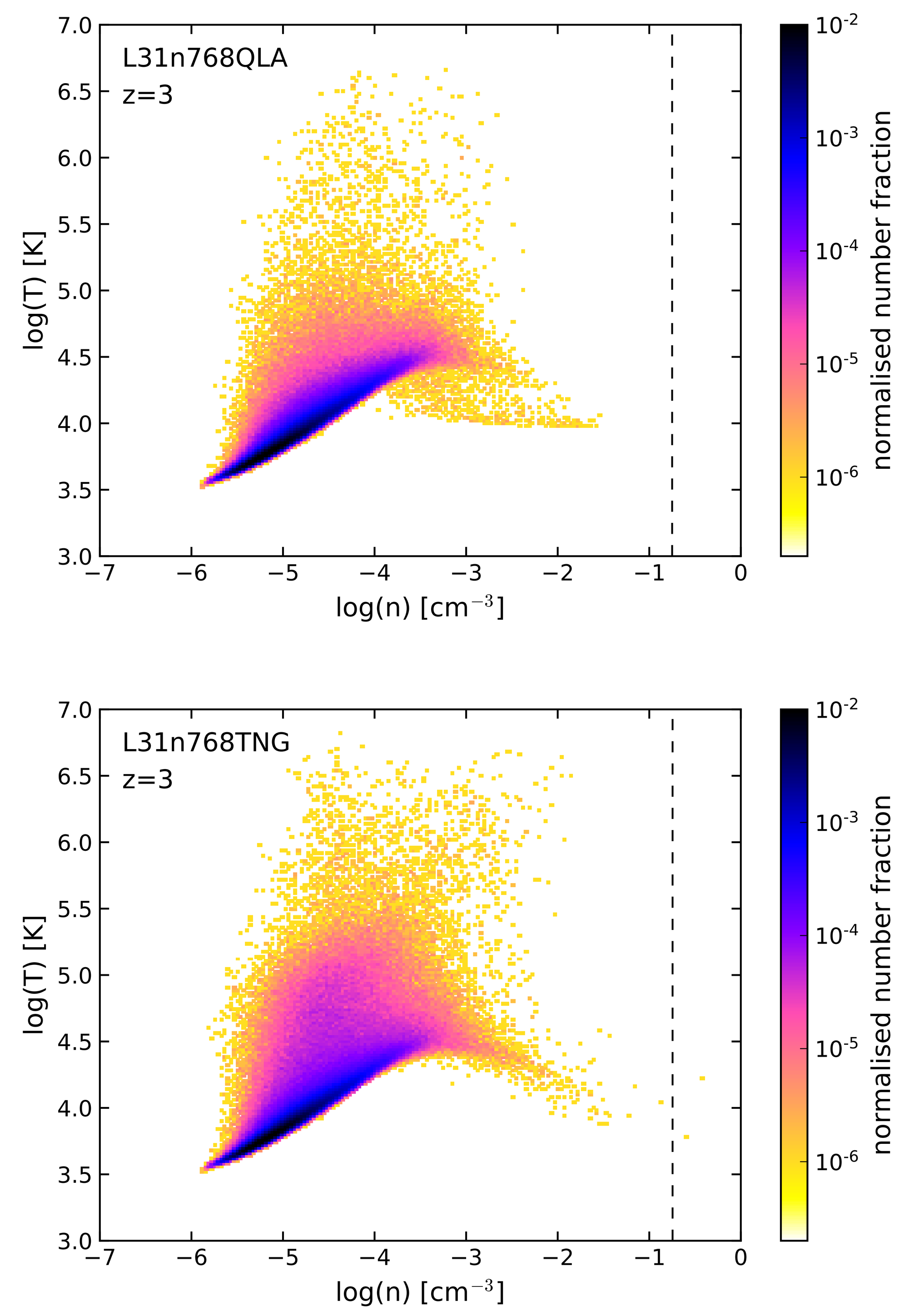
Powerspectrum

One dimensional flux power spectrum tuned to the mean transmission from McDonald et al. (2006). The ratio between the power spectrum from IllustrisTNG (with galactic outflows) and IllustrisQLA (without outflows) is shown in the small panel for volume 3 (yellow) and volume 2 (blue). This shows that galactic outflows transport matter from small scales (∼ 10% less power) to large scales (∼ 10% more power).



Thermal state of the gas

Phasediagram derived from Lyman-alpha lines-of-sight reveals that a significant fraction of the IGM is heated by galactic outflows invalidating the assumption of the IGM being unperturbed by feedback from galaxies.



References

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