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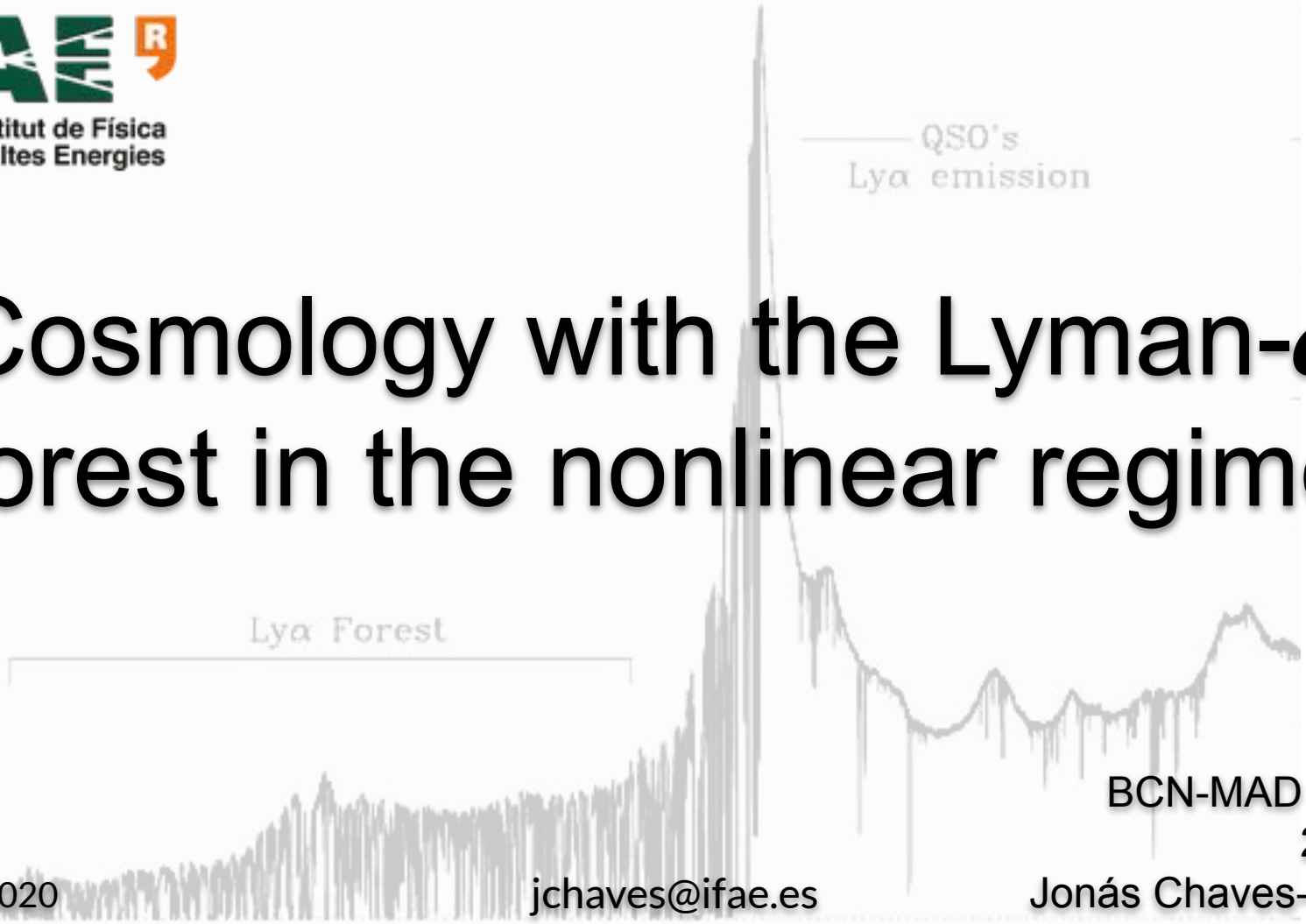


# Cosmology with the Lyman-$\alpha$ forest in the nonlinear regime

BCN-MAD meeting
27/01/25



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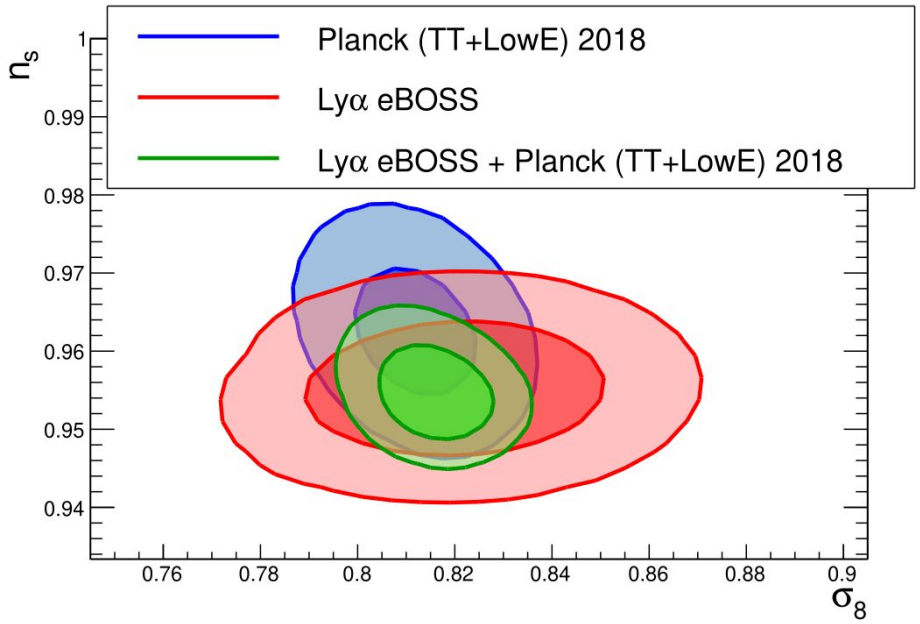
# Cosmology with the Lyman-$\alpha$ forest

On large scales, constraints on the expansion history via BAO measurements

**On small scales**, constraints on the amplitude and slope of the power spectrum:

- Growth history
- Sum of neutrino masses
- Nature of dark matter

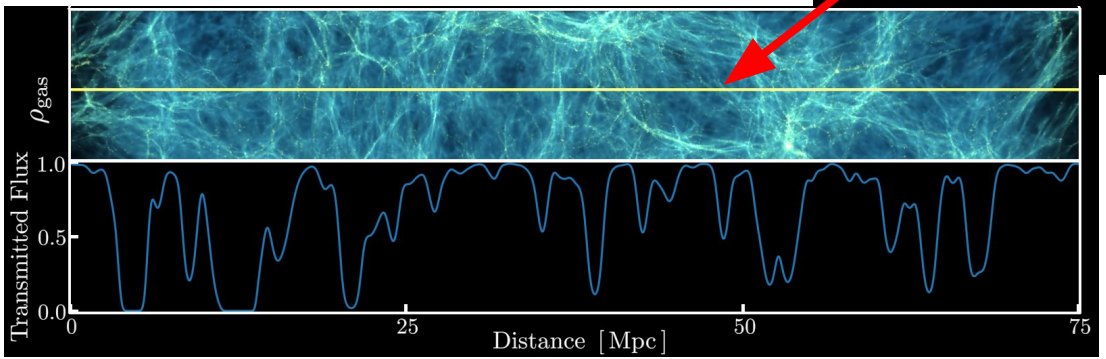


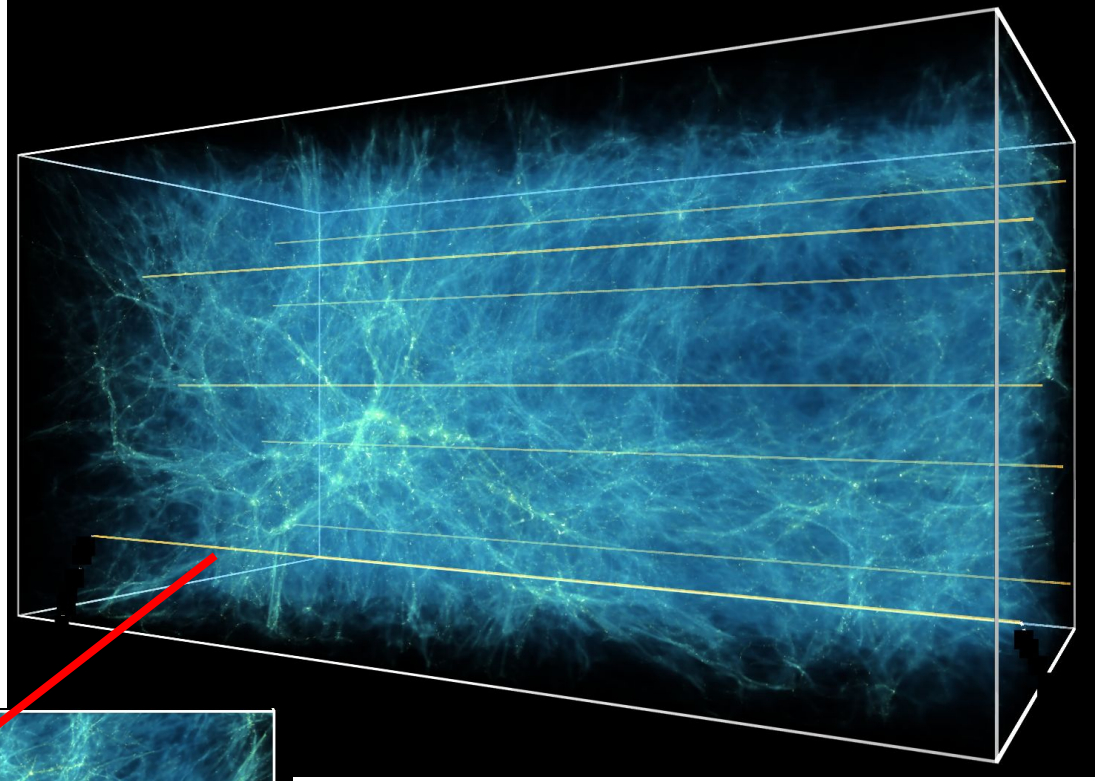

Chabanier+19

# Statistics

Correlation of absorptions:

- Different lines of sight (P3D)
- **Same line of sight (P1D)**



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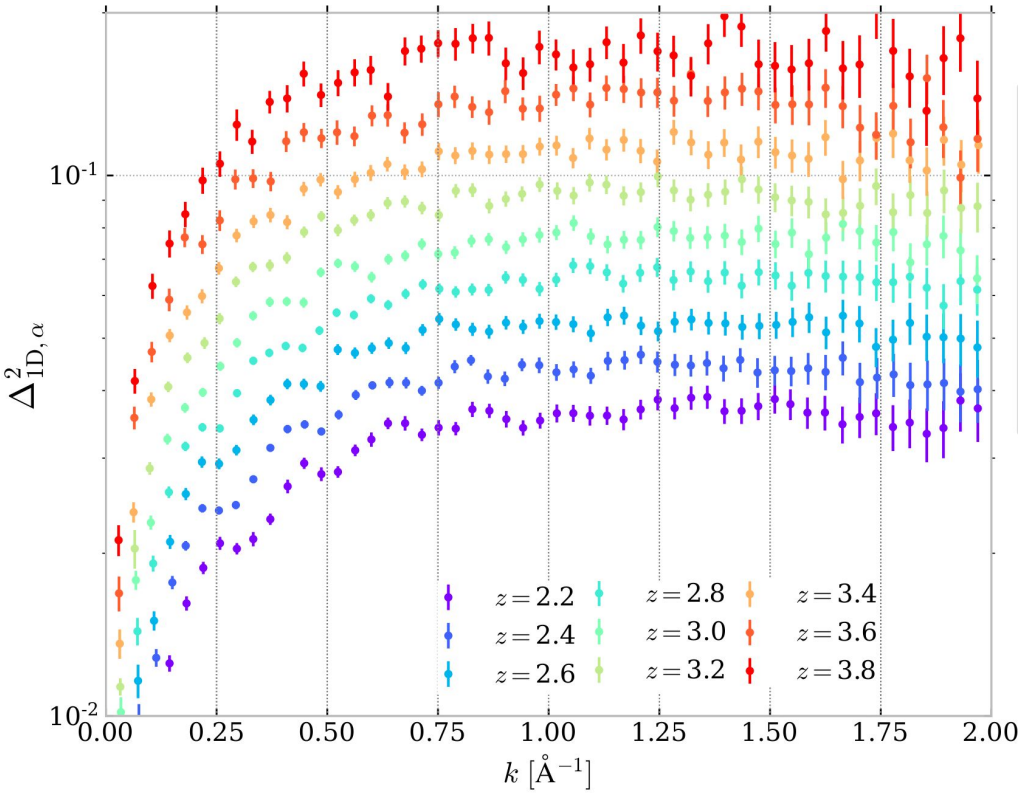
# P1D modeling

Hydrodynamical simulations:

- Nonlinear growth of structure
- Nonlinear peculiar velocities
- IGM ionization state
- Thermal broadening
- Gas pressure

Probes low-density regions of the universe so subgrid physics plays a minor role (Quick-Lya approx)




Ravoux+23 (DESI EDR)

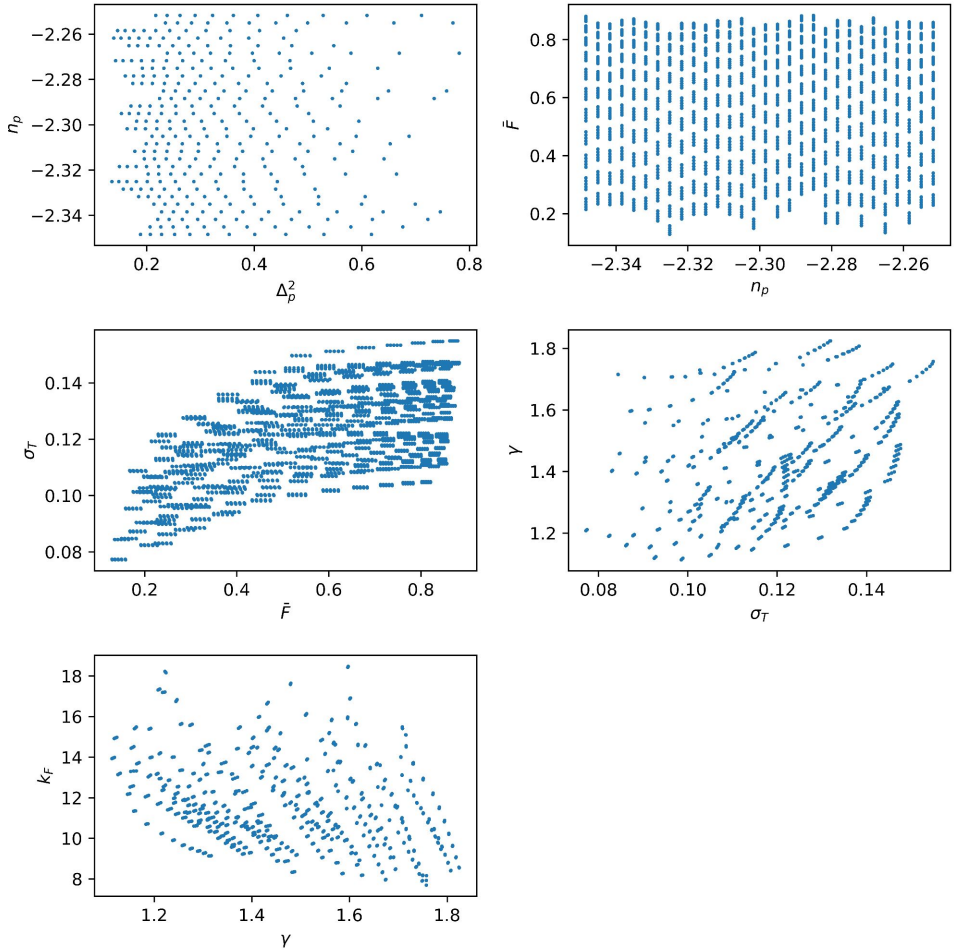
# $P_{1D}$ emulator

In principle, cosmological inference would require running a simulation for each point of MCMC chains

Emulators: surrogate models that “interpolate” between simulations

Training set:

- Gadget: 30 fix-and-paired simulations of 67.5 Mpc on a side
- Nyx: 16 simulations of 120 Mpc on a side (IGM rescalings)




Cabayol-García, **Chaves-Montero**+23

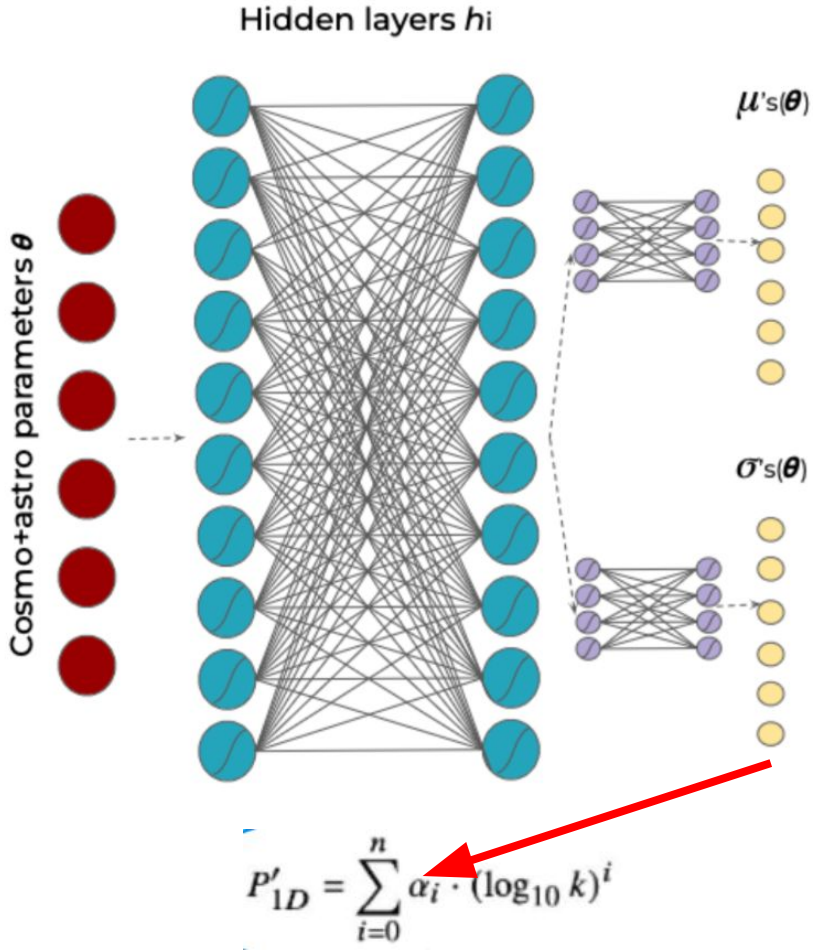
# $P_{1D}$ emulator: design

Parametrize $P_{1D}$ as a function of:

- Cosmology: amplitude and slope of power spectrum at $k_p$=0.7/Mpc ($\Delta^2_p$, $n_p$)
- Astrophysics: ionisation and thermal state of IGM (<F>, $\sigma_T$, $\gamma$, $k_F$)

Multiple strategies to mitigate cosmic variance

Mixture Density Model to predict $P_{1D}$ and uncertainty

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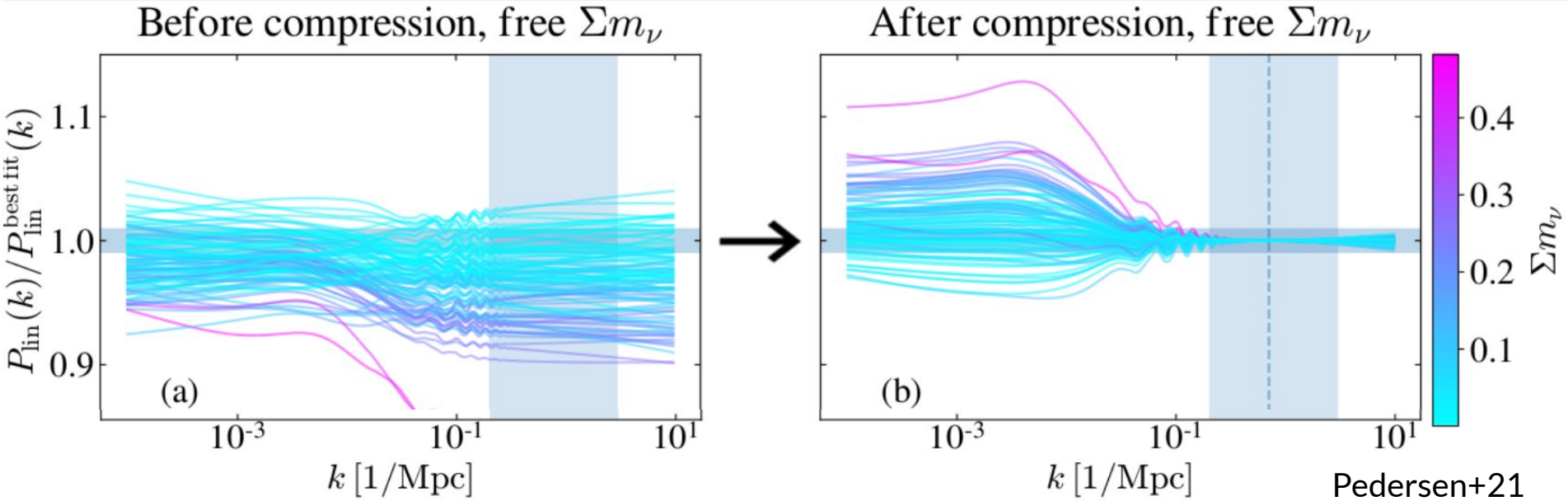
# $P_{1D}$ emulator: cosmology compression ($\Delta^2_p$, $n_p$, ~~z~~)

Universe almost EdS for Lyman-$\alpha$ forest redshifts, $\Omega_M(z>2)>0.9$: similar expansion history, growth rate, and peculiar velocities

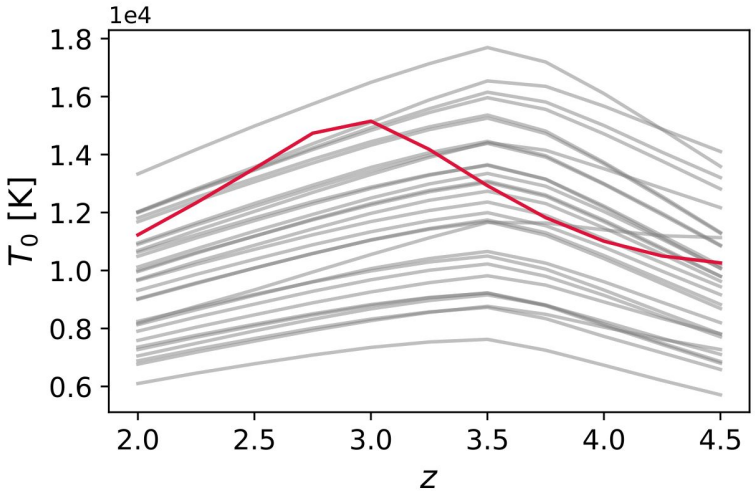


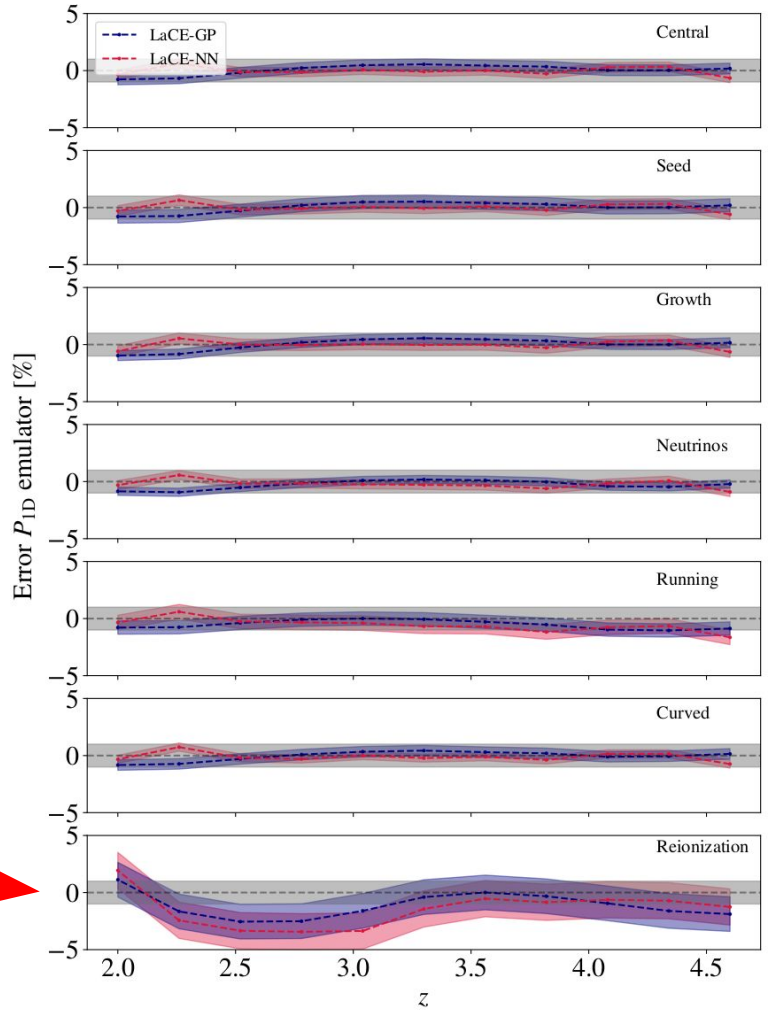

Pedersen+21

# $P_{1D}$ emulator: accuracy

Simulations not in the training set:

- Cosmology: growth history, massive neutrinos, running, curvature
- Astrophysics: reionization history

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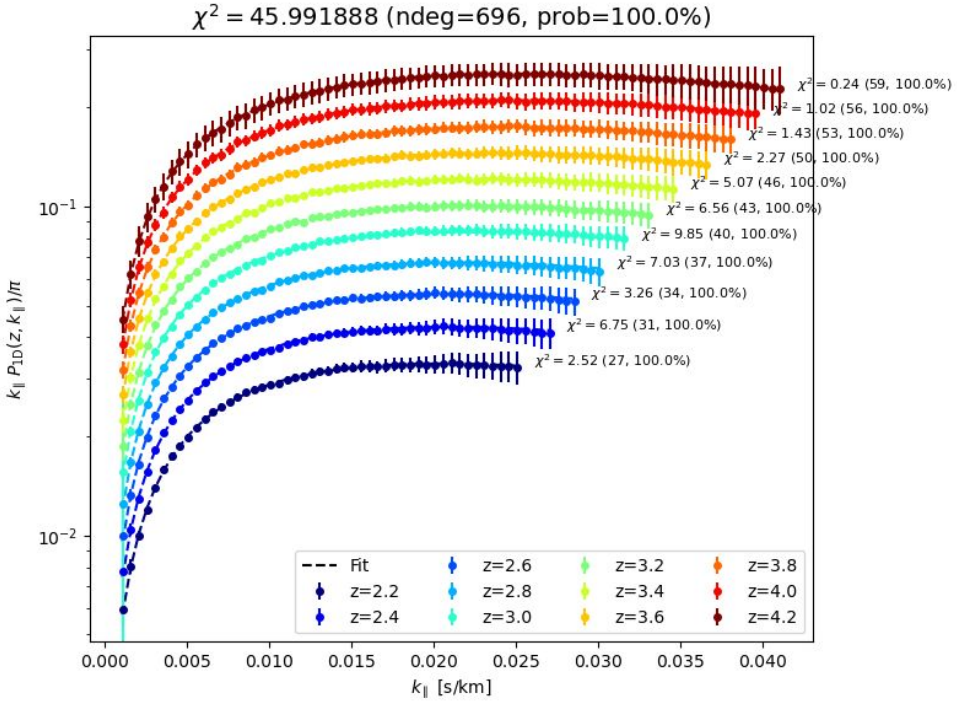
# $P_{1D}$ inference with DESI-DR1

Joint fit of $P_{1D}$ measurements from multiple redshift bins

Parametrized redshift evolution of IGM parameters

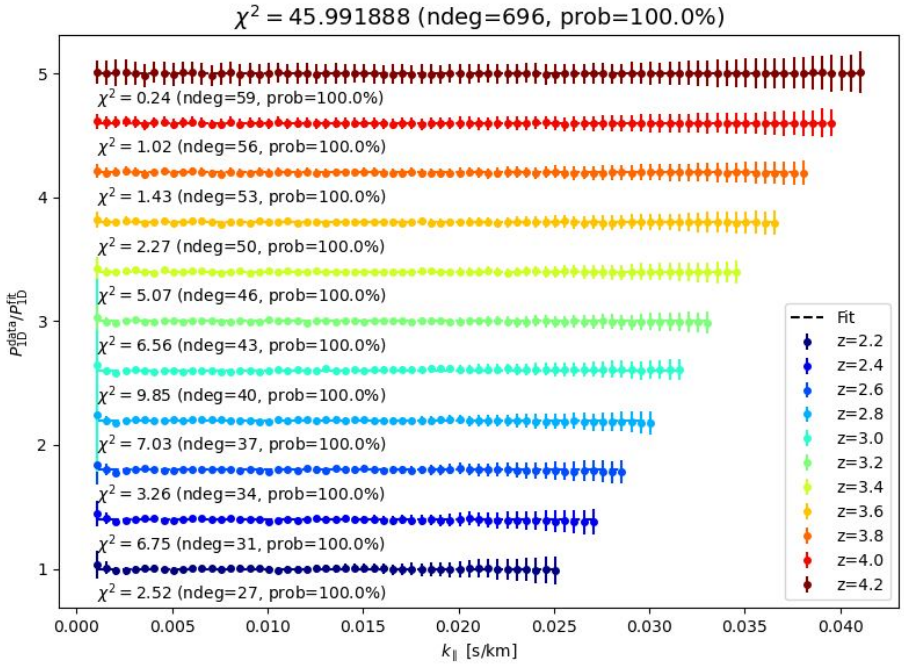
Astrophysical contaminants (metals, DLAs, AGN)

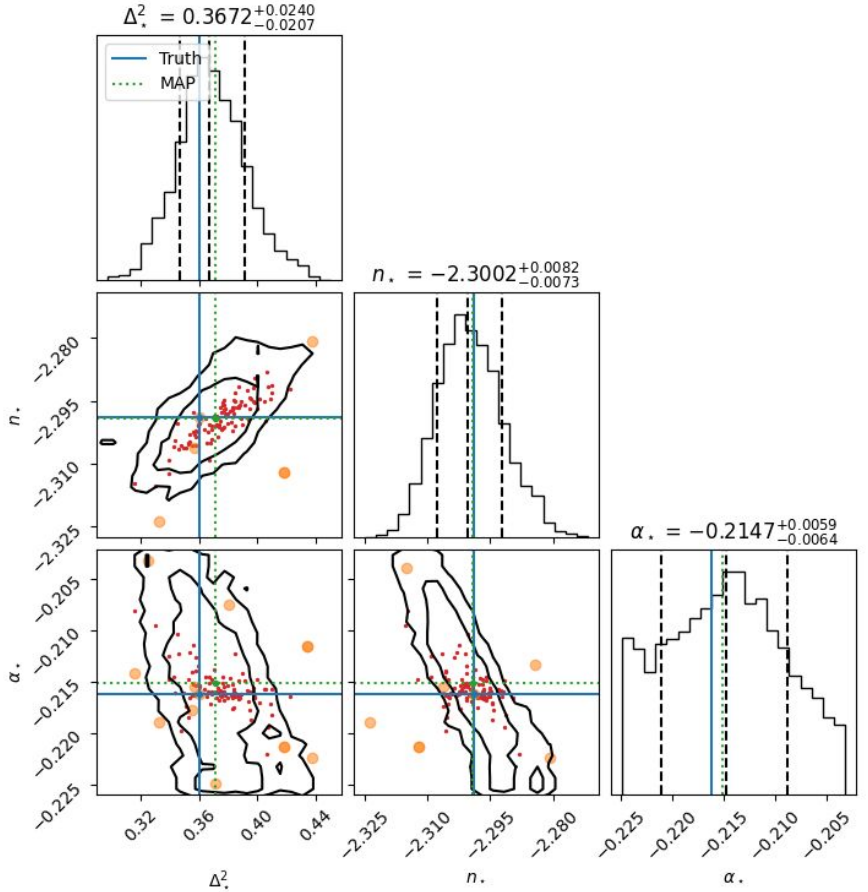
Mock challenge to validate the pipeline (cup1d)




**Chaves-Montero** in prep.

# $P_{1D}$ inference with DESI-DR1




**Chaves-Montero** in prep.