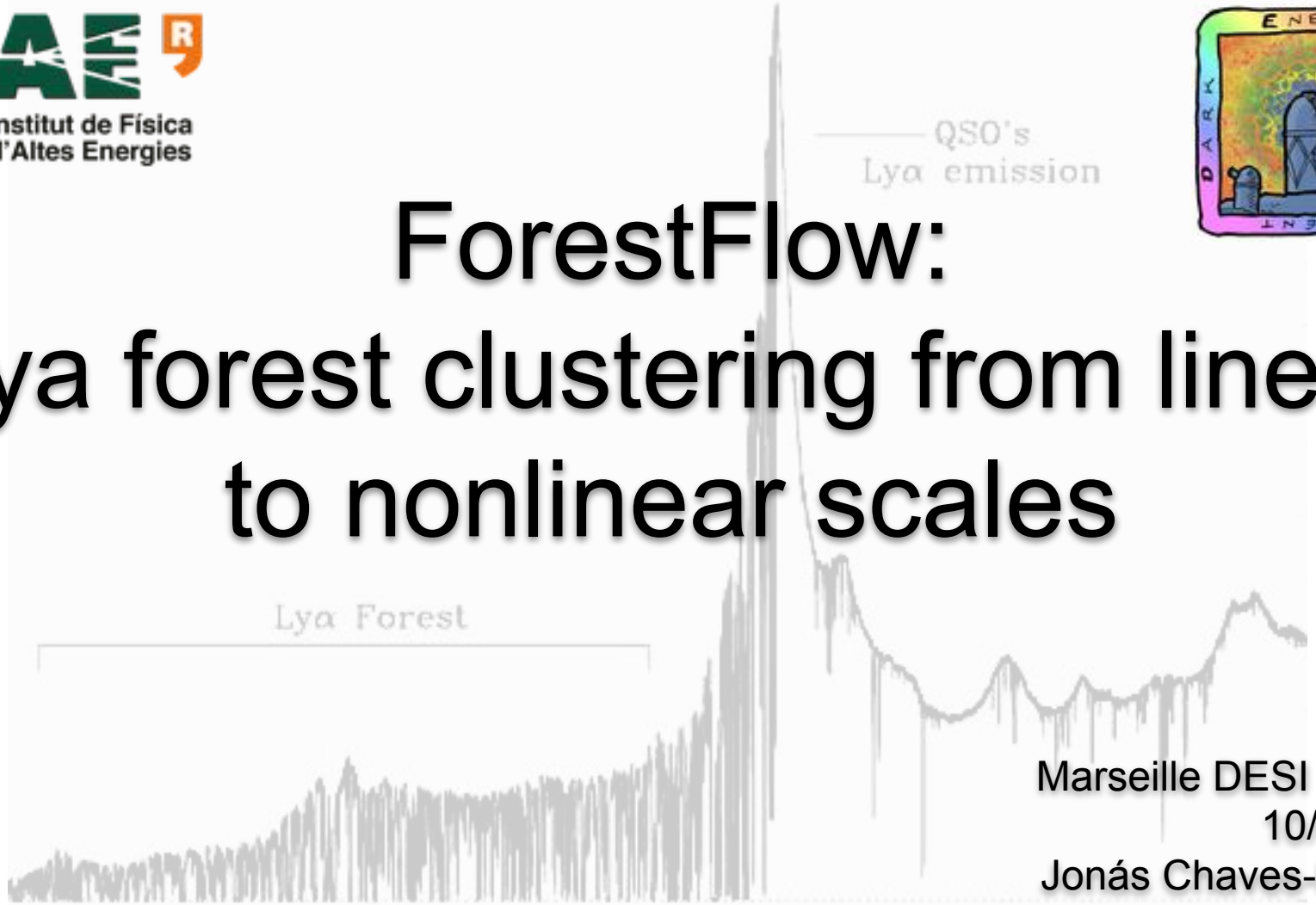
Institut de Física d'Altes Energies

ForestFlow: Lya forest clustering from linear to nonlinear scales



Marseille DESI meeting
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Jonás Chaves-Montero

Members of the project

Project of the DESI Lyman alpha WG, in CWR
The main authors are (IFAE team):

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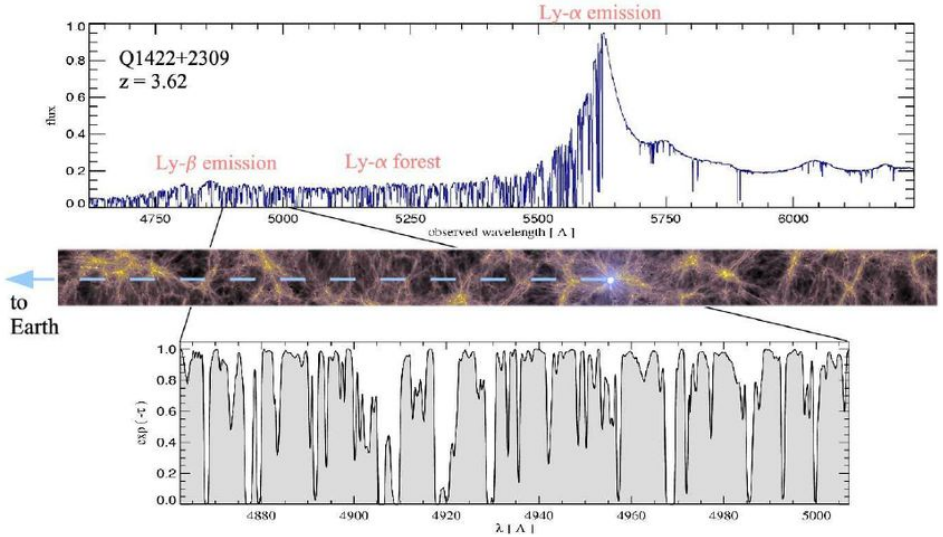
Predicting Lya clustering

Two main approaches:

- **Perturbation theory.** Robust predictions from linear to quasilinear scales at the cost of marginalizing over many free parameters

- **Emulators.** Precise predictions from quasilinear to nonlinear scales at the cost of running cosmological suites of hydrodynamical simulations



Springel+2006

Emulation strategy (I)

Most cosmological emulators predict summary statistics at a set of r- or k-bins

Limitations:

- Big simulations to access large scales
- Interpolations and/or extrapolations to predict derived statistics

For Lya clustering from large to small scales, cosmological suite of hydro sims of (at least) 3 Gpc on a side with excellent resolution. **Unfeasible**

Our approach: emulate the coefficients of a parametric model rather than summary statistics at a set of bins

Emulation strategy (II)

Predict the 2 Lya linear biases and 5 parameters capturing small-scale deviations of P3D from linear theory (Arinyo-i-Prats+15):

$$P_{3D}(k,\mu) = (b_\delta + b_\eta f \mu^2)^2 D_{NL}(k,\mu) P_{lin}(k), \quad D_{NL} = \exp\left\{\left(q_1\Delta^2 + q_2\Delta^4\right)\left[1 - \left(\frac{k}{k_v}\right)^{a_v}\mu^{b_v}\right] - \left(\frac{k}{k_p}\right)^2\right\},$$

large-scale RSD

Boltzmann solver

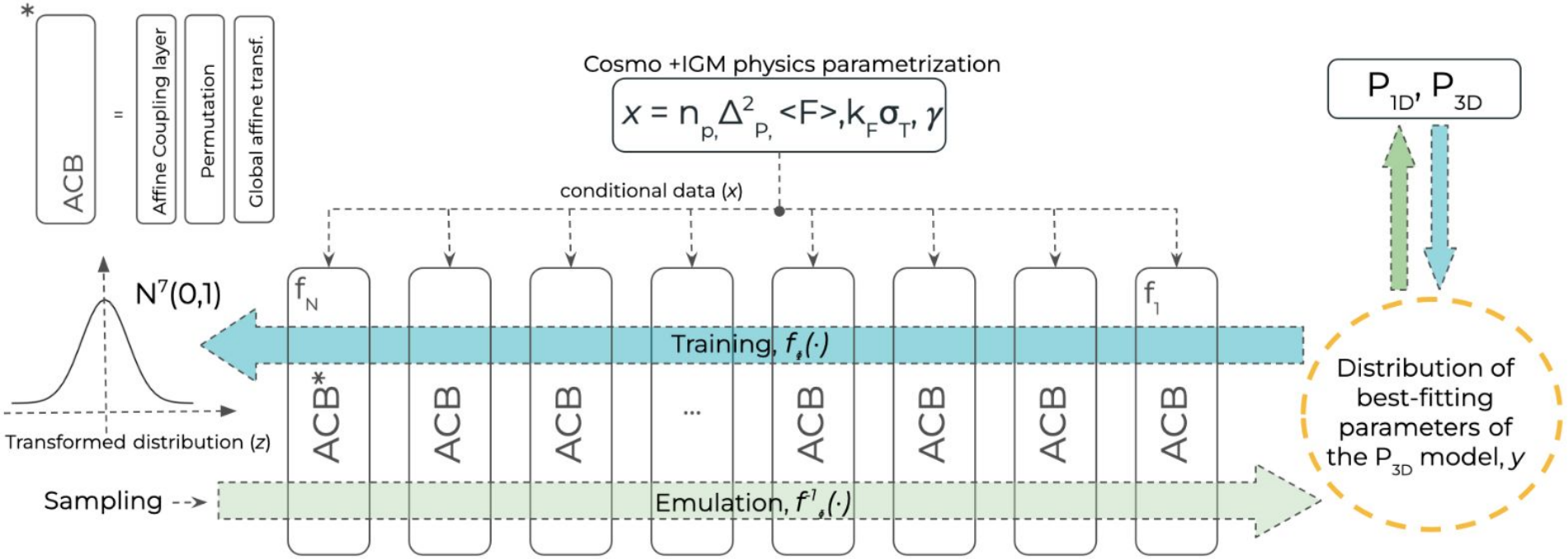
nonlinear growth, small-scale RSD, thermal broadening

gas pressure

Predictions for the 3 main observables of Lya studies:

- ➔ 2pcf for BAO and AP (Fourier Transform)
- ➔ P1D for small scales (integral)
- ➔ Px for full-shape (integral)

ForestFlow: conditional normalizing flows



Returns value and correlations of parameters, propagate these to summary statistics

Conditional data

Parameters for capturing the Lya forest dependence on

- **Cosmology.** Amplitude and slope of the power spectrum on small scales
  Universe almost EdS at Lya redshifts

- **IGM physics.** Mean transmitted flux fraction, amplitude and slope of the temperature-density relation, and pressure smoothing scale

Despite training on a suite only varying As and ns, ForestFlow delivers precise predictions for

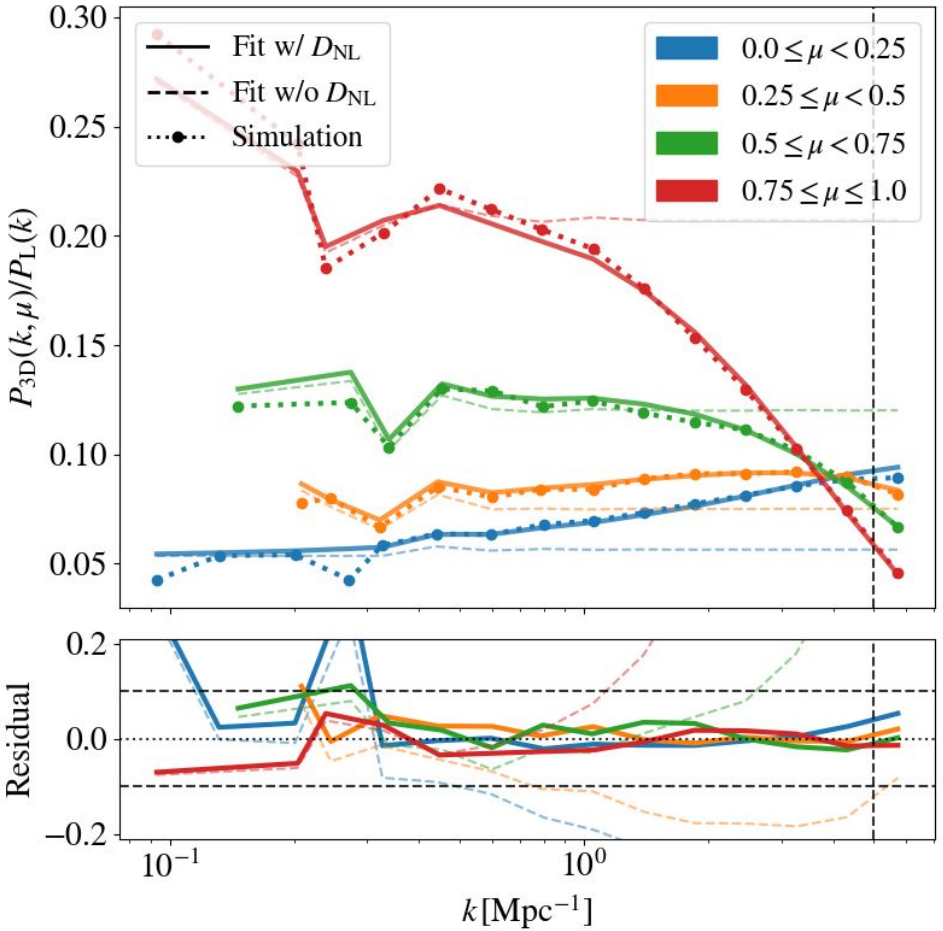
- Any combination of LCDM parameters
- Two LCDM extensions: massive neutrinos and curvature
- Ionization and thermal histories not included in the training set

Target data

Best-fitting parameters to P1D and P3D measurements from suite of cosmological hydrodynamical simulations (Pedersen+2021)

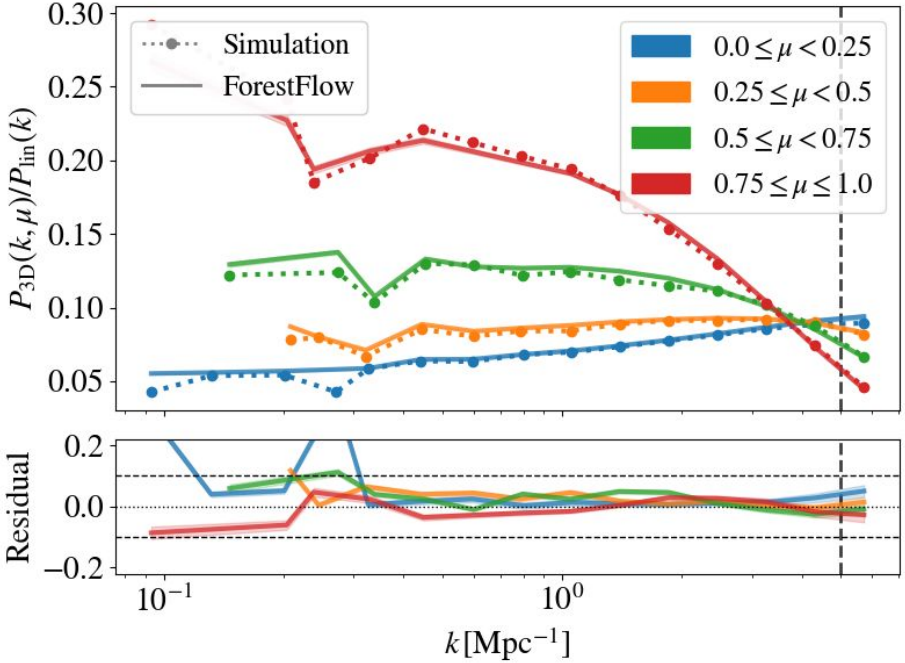
Special care measuring Lya biases:

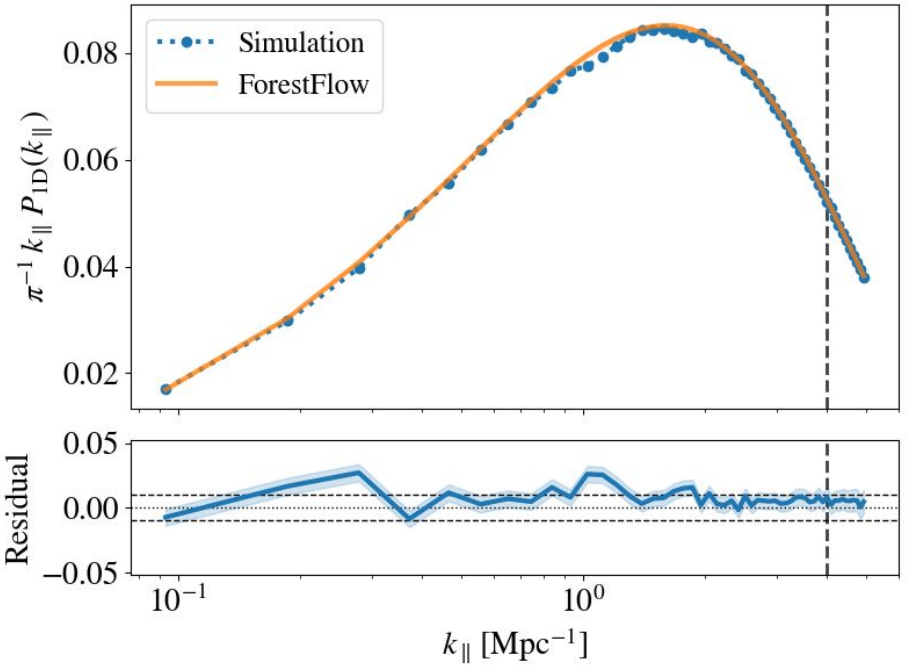
- Fixed-and-paired simulations
- 3 simulation axes
- Joint fit of 11 snapshots from z=2 to 4.5
- Evaluate model for the k-modes sampled by the simulations



Recover Lya statistics

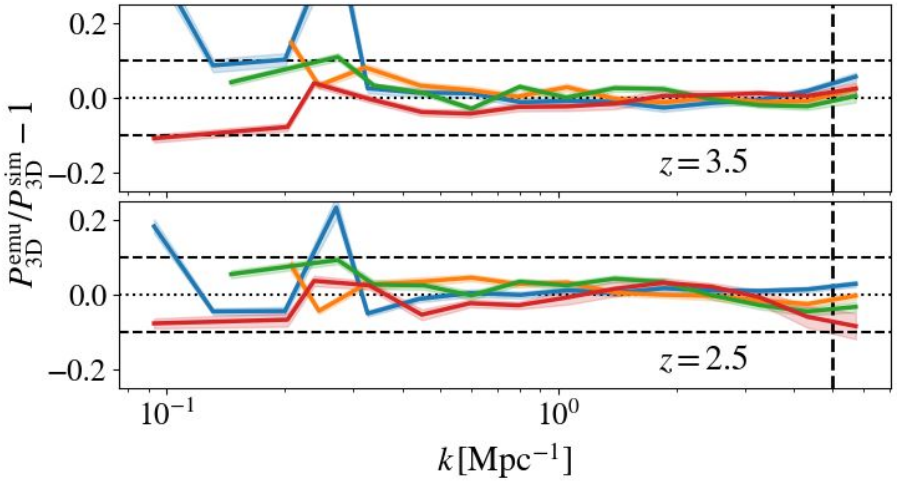
Center of the parameter space

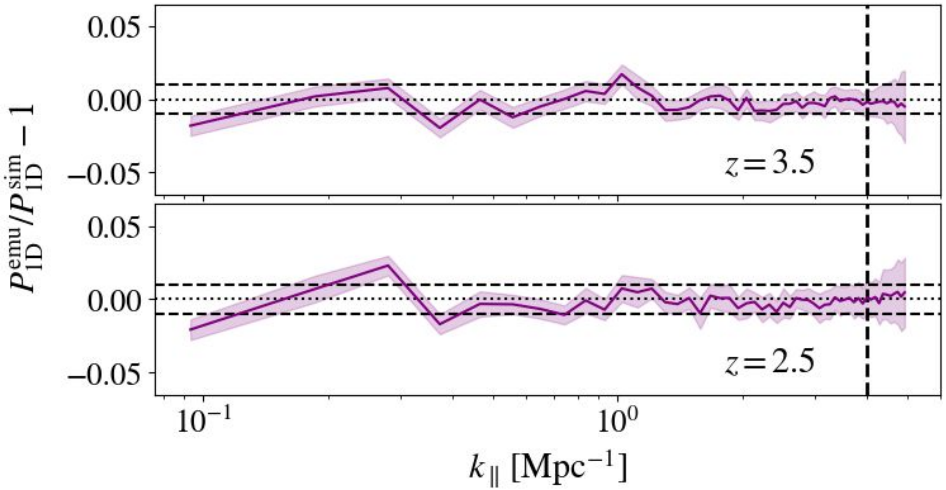




Recover Lya statistics

Across parameter space (leave redshift out)





Other cosmologies and IGM physics

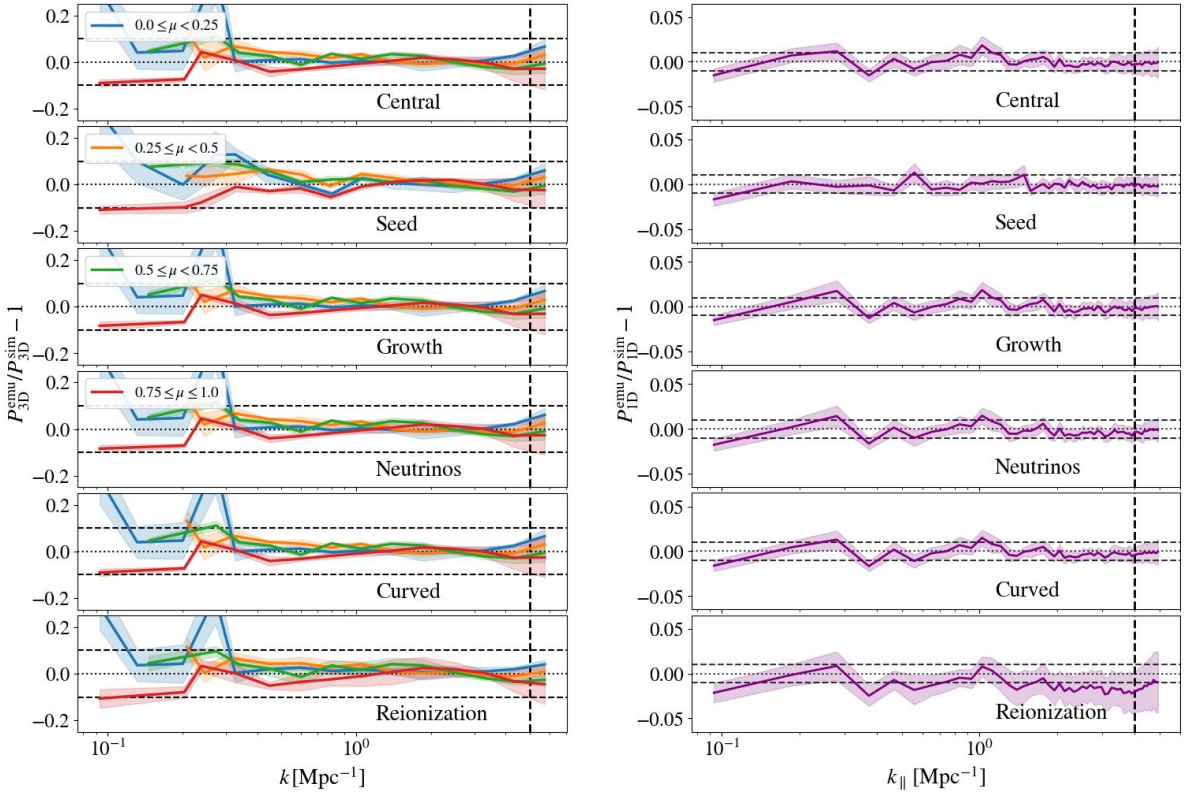
Cosmologies and IGM physics not included in the training set:

Growth. Different Om and h

Neutrinos. Massive neutrinos

Curved. Curvature

Reionization. Different reionization and thermal history



Applications

Some applications (in addition to P1D analyses):

- 2pcf with P1D priors

Lya linear biases from P1D analyses, use these to measure sigma8 and fsigma8 (rather than b_d*sigma8 and b_e*fsigma8)

- AP test with P1D priors

Push towards smaller scales by using priors on Arinyo parameters from P1D analyses

- Small-scale P3D and Px analyses (see next talks)

Summary

ForestFlow is a cosmological emulator bridging the gap between large- and small-scale Lya clustering studies

It emulates the 2 Lya linear biases and 6 parameters capturing deviation of P3D from linear theory as a function of cosmology and IGM physics

- P3D: **3%** precision from linear scales to k=5/Mpc
- P1D: **1.5%** precision down to kpar=4/Mpc

Precise predictions for cosmologies and IGM physics not included in the training set, including LCDM extensions like massive neutrinos and curvature