A Multi-Fidelity Emulator for the Lyman-α Forest Flux
Why is the Lyman-α Forest interesting?

The Lyman-α Forest has been used to study:

- the thermal history of the intergalactic medium and reionization,
- neutrinos and cold dark matter alternatives,
- and cosmological models.
The goal
The simulations

Run using the C code **MP-Gadget**: highly parallelized (OpenMP + MPI) N-body and smoothed particle hydrodynamics, using a TreePM code. Successfully run using ful

<table>
<thead>
<tr>
<th></th>
<th>This Work</th>
<th></th>
<th>Current Project</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Low Fidelity</td>
<td>High Fidelity</td>
<td>Testing</td>
<td>2021 Allocation</td>
</tr>
<tr>
<td><strong>Simulation</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Box side length (Mpc/h)</td>
<td>30*</td>
<td>30*</td>
<td>30*</td>
<td>120</td>
</tr>
<tr>
<td>Particle load</td>
<td>256$^3$</td>
<td>512$^3$</td>
<td>512$^3$</td>
<td>1536$^3$</td>
</tr>
<tr>
<td>Cost per (node-hours)</td>
<td>~10</td>
<td>~150</td>
<td>~150</td>
<td>~6000</td>
</tr>
<tr>
<td>Number of simulations</td>
<td>40</td>
<td>6</td>
<td>10</td>
<td>43</td>
</tr>
</tbody>
</table>

*Too small volume for inference using observations
Simulation inputs include astrophysical and cosmological parameters

- **Cosmology**
- **Astrophysics**
  - Helium, hydrogen reionization, black holes
Gaussian Process & Multi-Fidelity

- Gaussian processes provide function prediction in a Bayesian framework.
- A GP emulator is trained to predict simulation outputs for arbitrary simulation inputs.
- Multi-fidelity emulation allows us to replace some of the training set required in a single-fidelity emulator.
*Single-fidelity emulators: \( \approx 20 \) simulations for 1% accuracy.

Single-fidelity: \( \sim 3000 \) node-hours

Multi-fidelity: \( \sim 1000 \) node-hours
Summary & Future Work

* Constructed a < 1% error emulator for the high fidelity flux power spectrum.


* Coming soon: cosmology inference using an emulator constructed from ~40 simulations with 64x volume.