unimpeded: Cosmological analysis with a re-usable library of machine learning emulators across cosmological models and datasets

Dily Duan Yi Ong
Kavli Institute for Cosmology
University of Cambridge

dlo26@cam.ac.uk

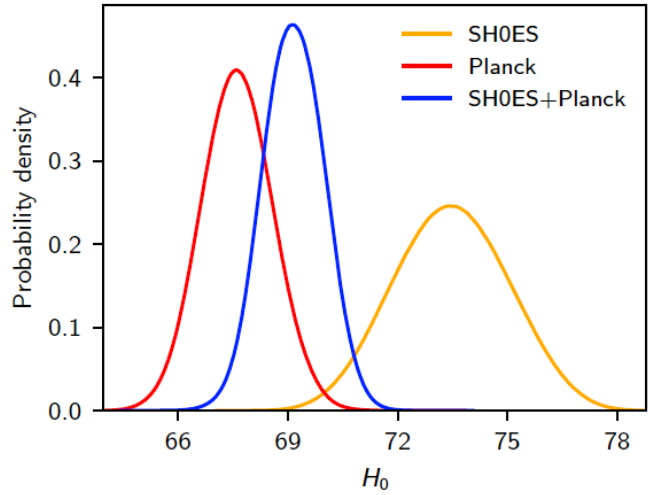
Supervisor: Dr Will Handley

UNIVERSITY OF CAMBRIDGE

Kavli Institute for Cosmology Cambridge KICC

DiRAC High Performance Computing Facility

Motivation: Cosmological Tensions



- Precision cosmology has revealed these anomalies:
  - H_0 Hubble tension (CMB vs supernovae data)
  - σ_8 tension (CMB vs cluster-galaxy weak lensing)
  - Ω_K tension (CMB vs lensing vs BAO)

- Cosmological models:
  - For example: $\Lambda\mathrm{CDM}$, $K\Lambda\mathrm{CDM}$, $n\Lambda\mathrm{CDM}$, $m\Lambda\mathrm{CDM}$, $\mathrm{n_{run}}\Lambda\mathrm{CDM}$, $w\mathrm{CDM}$, $w_0w_\mathrm{a}\Lambda\mathrm{CDM}$, $r\Lambda\mathrm{CDM}$

- Key goals:
  - Systematic exploration across a wide range of models and datasets to accurately quantify cosmological tension
  - Allow model comparison and distinguish new physics from systematics

- The challenge:
  - Unlike parameter estimation (traditionally performed by MCMC methods), model comparison and tension quantification are far more computationally expensive

Introducing `unimpeded`

```
pip install unimpeded
```

- Core idea
  - A re-usable library of MCMC chains, Nested Sampling runs, and ML emulators
  - Turns weeks or months of supercomputer time into seconds on your laptop
- Systematic coverage:
  - 10 cosmological models + 60 datasets & pairwise combinations (to be expanded)
  - MCMC or nested sampling methods

Cosmological models

- ΛCDM : H_0, τ_{reio}, $\Omega_b h^2$, $\Omega_c h^2$, A_s, n_s
- $K\Lambda$CDM : ΛCDM + Ω_K (varying curvature)
- $N\Lambda$CDM : Varying N_{eff} and total mass of 3 degenerate ν's
- $n\Lambda$CDM : Varying total mass of 3 degenerate ν's with N_{eff}=3.044
- $m\Lambda$CDM : Varying N_{eff} with two massless ν and one with m=0.06
- $n_{run}\Lambda$CDM : ΛCDM + n_{run} (running of spectral index $dn_s/d\ln k$)
- wCDM : ΛCDM + w (constant cosmological equation of state)
- $w_0w_a\Lambda$CDM : ΛCDM + w_0 + w_a (varying dark energy equation of state, CLP)
- $r\Lambda$CDM : ΛCDM + r (varying scalar-to-tensor ratio)

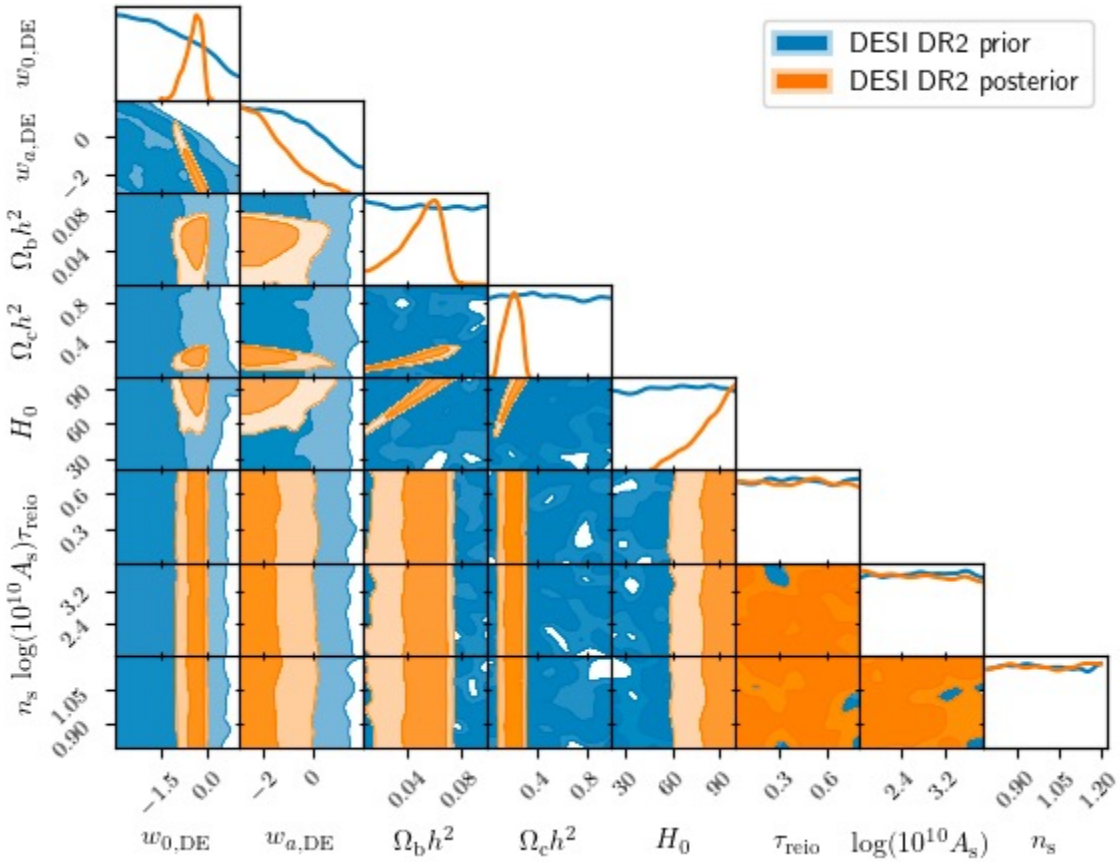
Cosmological datasets

- CMB:(Plik, Camspec, NPIPE, BICEP) ± CMB lensing
- BAO:SDSS, BOSS, eBOSS, Lyα, DESI
- SNe: Pantheon, SH0ES
- WL: DESY1

- Key features & benefits
  - Pip-installable, open-source
  - Easily access pre-computed results with a few lines of Python

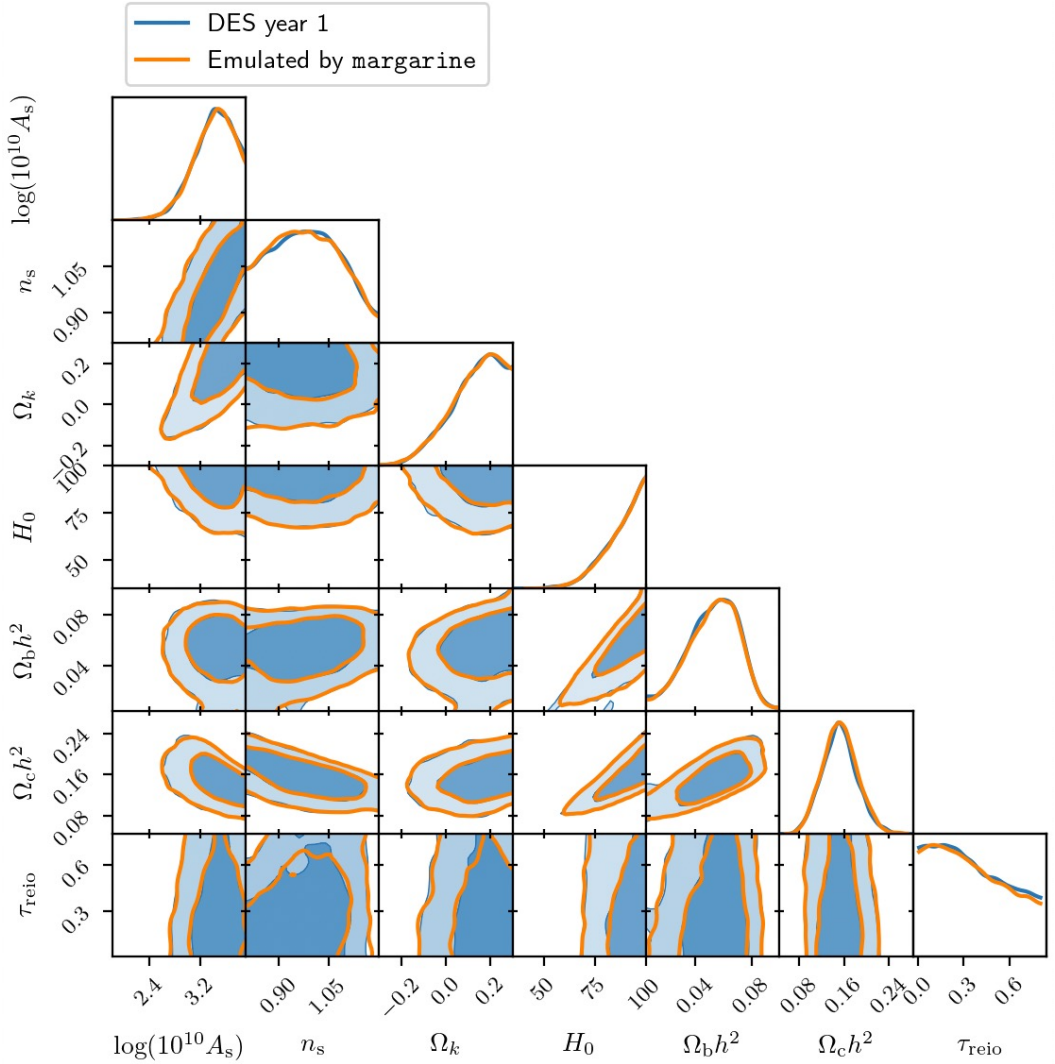
```
samples = unimpeded.download_samples(data='planck_2018_CamSpec',
model='lcdm', method='ns')
```

unimpeded results - Posteriors



- Posteriors from nested sampling runs and MCMC runs
- Pre-computed results by HPC, accessible in your laptop in seconds, not weeks/months!
- Example:
  - DESI DR2 dataset using the $w_0 w_a \Lambda$CDM cosmology model
  - Posteriors are clearly more constrained than the priors for several parameters.

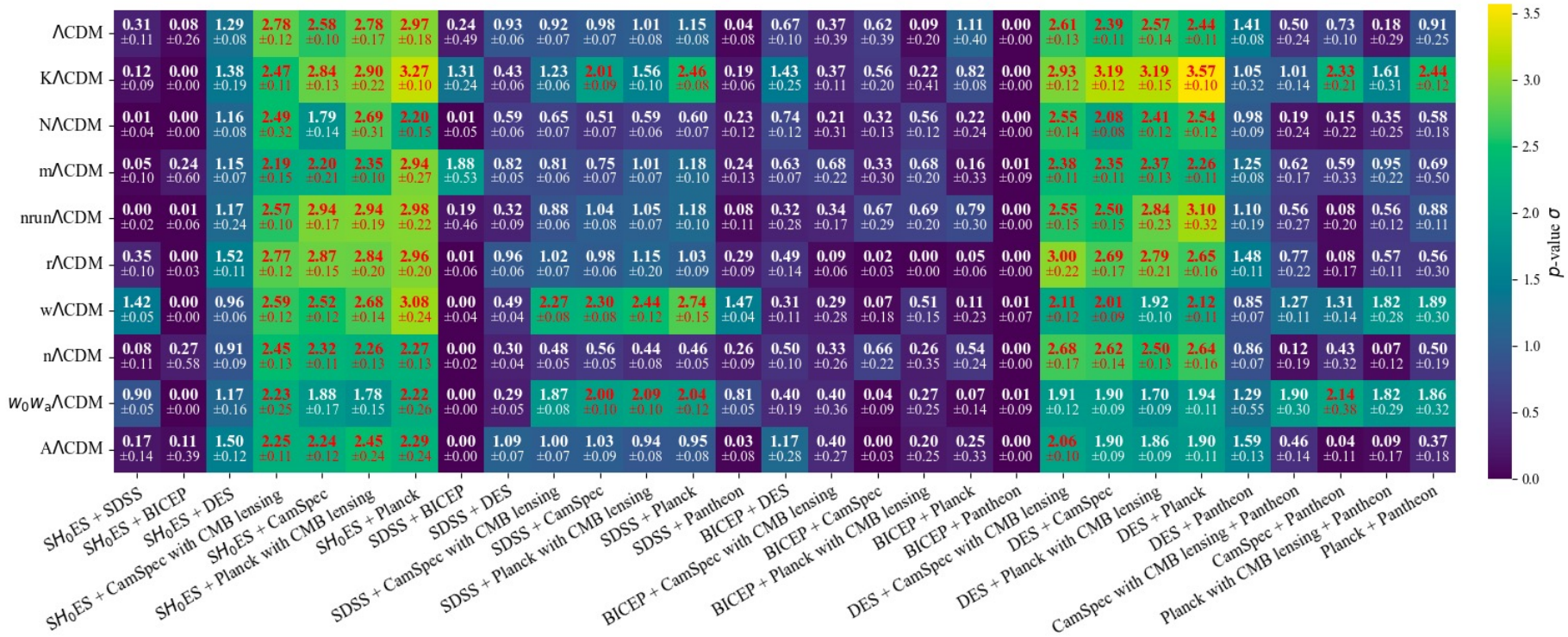
unimpeded results - Emulators



- Machine learning emulators
- Emulate marginalised likelihoods or posteriors.
- Benefits:
  - Dramatically speeds up inference for re-use in new analyses
  - Provides a fast and flexible alternative to full MCMC/NS runs
  - Provides a real 'planck prior' rather than a Gaussian approximation

`unimpeded` results – Tension statistics

- Tension statistics across 10 models (y-axis) and 29 pairwise datasets (x-axis)
- $\sigma > 2$ in red
- Available statistics:
  - p-value
  - R statistic
  - Suspiciousness
  - Information ratio
  - Bayesian model dimensionality



Thank you

- unimpeded is open-source, available on GitHub
- Welcome to chat with me during poster session B tomorrow
- Poster number 130