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

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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: ΛCDM , $K\Lambda CDM$, $n\Lambda CDM$, $m\Lambda CDM$, $n_{run}\Lambda CDM$, wCDM, $w_0w_a\Lambda CDM$, $r\Lambda CDM$
- 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	Cosmological datasets									
• Λ CDM : H_0 , τ_{reio} , $\Omega_b h^2$, $\Omega_c h^2$, A_s , n_s • $K\Lambda$ CDM : Λ CDM + 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 : Λ CDM + n_{run} (running of spectral index $dn_s/d \ln k$)	 CMB:(Plik, Camspec, NPIPE, BICEP) ± CMB lensing BAO:SDSS, BOSS, eBOSS, Lyα, DESI SNe: Pantheon, SH0ES WL: DESY1 									
 wCDM : ΛCDM + w (constant cosmological equation of state) w₀w_aΛCDM : ΛCDM + w₀ + w_a (varying dark energy equation of state, CLP) rΛCDM : ΛCDM + r (varying scalar-to-tensor ratio) 	<pre>samples = unimpeded.dow model='lcdm', method='n</pre>									

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

amples = unimpeded.download_samples(data='planck_2018_CamSpec', nodel='lcdm', method='ns')

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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

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ACDM	0.31 ±0.11	0.08 ±0.26	1.29 ±0.08	2.78 ±0.12	2.58 ±0.10	2.78 ±0.17	2.97 ±0.18	0.24 ±0.49	0.93 ±0.06	0.92 ±0.07	0.98 ±0.07	1.01 ±0.08	1.15 ±0.08	0.04 ±0.08	0.67 ±0.10	0.37 ±0.39	0.62 ±0.39	0.09 ±0.20	1.11 ±0.40	0.00 ±0.00	2.61 ±0.13	2.39 ±0.11	2.57 ±0.14	2.44 ±0.11	$\underset{\pm 0.08}{\textbf{1.41}}$	0.50 ±0.24	0.73 ±0.10	0.18 ±0.29	0.91 ±0.25	- 3.5
KACDM	0.12 ±0.09	0.00 ±0.00	1.38 ±0.19	2.47 ±0.11	2.84 ±0.13	2.90 ±0.22	3.27 ±0.10	1.31 ±0.24	0.43 ±0.06	1.23 ±0.06	2.01 ±0.09	1.56 ±0.10	2.46 ±0.08	0.19 ±0.06	1.43 ±0.25	0.37 ±0.11	0.56 ±0.20	0.22 ±0.41	0.82 ±0.08	0.00 ±0.00	2.93 ±0.12	3.19 ±0.12	3.19 ±0.15	3.57 ±0.10	1.05 ±0.32	1.01 ±0.14	2.33 ±0.21	1.61 ±0.31	2.44 ±0.12	- 3.0
NACDM	0.01 ±0.04	0.00 ±0.00	1.16 ±0.08	2.49 ±0.32	1.79 ±0.14	2.69 ±0.31	2.20 ±0.15	0.01 ±0.05	0.59 ±0.06	0.65 ±0.07	0.51 ±0.07	0.59 ±0.06	0.60 ±0.07	0.23 ±0.12	0.74 ±0.12	0.21 ±0.31	0.32 ±0.13	0.56 ±0.12	0.22 ±0.24	0.00 ±0.00	2.55 ±0.14	2.08 ±0.08	2.41 ±0.12	2.54 ±0.12	0.98 ±0.09	0.19 ±0.24	0.15 ±0.22	0.35 ±0.25	0.58 ±0.18	- 25
m∧CDM	0.05 ±0.10	0.24 ±0.60	1.15 ±0.07	2.19 ±0.15	2.20 ±0.21	2.35 ±0.10	2.94 ±0.27	1.88 ±0.53	0.82 ±0.05	0.81 ±0.06	0.75 ±0.07	1.01 ±0.07	1.18 ±0.10	0.24 ±0.13	0.63 ±0.07	0.68 ±0.22	0.33 ±0.30	0.68 ±0.20	0.16 ±0.33	0.01 ±0.09	2.38 ±0.11	2.35 ±0.11	2.37 ±0.13	2.26 ±0.11	1.25 ±0.08	0.62 ±0.17	0.59 ±0.33	0.95 ±0.22	0.69 ±0.50	- 2.5
nrun∧CDM	0.00 ±0.02	0.01 ±0.06	1.17 ±0.24	2.57 ±0.10	2.94 ±0.17	2.94 ±0.19	2.98 ±0.22	0.19 ±0.46	0.32 ±0.09	0.88 ±0.06	1.04 ±0.08	1.05 ±0.07	1.18 ±0.10	0.08 ±0.11	0.32 ±0.28	0.34 ±0.17	0.67 ±0.29	0.69 ±0.20	0.79 ±0.30	0.00 ±0.00	2.55 ±0.15	2.50 ±0.15	2.84 ±0.23	3.10 ±0.32	1.10 ±0.19	0.56 ±0.27	0.08 ±0.20	0.56 ±0.12	0.88 ±0.11	- 2.0
r∧CDM	0.35 ±0.10	0.00 ±0.03	1.52 ±0.11	2.77 ±0.12	2.87 ±0.15	2.84 ±0.20	2.96 ±0.20	0.01 ±0.06	0.96 ±0.06	1.02 ±0.07	0.98 ±0.06	1.15 ±0.20	1.03 ±0.09	0.29 ±0.09	0.49 ±0.14	0.09 ±0.06	0.02 ±0.03	0.00 ±0.00	0.05 ±0.06	0.00 ±0.00	3.00 ±0.22	2.69 ±0.17	2.79 ±0.21	2.65 ±0.16	1.48 ±0.11	0.77 ±0.22	0.08 ±0.17	0.57 ±0.11	0.56 ±0.30	- 1.5
wΛCDM	1.42 ±0.05	0.00 ±0.00	0.96 ±0.06	2.59 ±0.12	2.52 ±0.12	2.68 ±0.14	3.08 ±0.24	0.00 ±0.04	0.49 ±0.04	2.27 ±0.08	2.30 ±0.08	2.44 ±0.12	2.74 ±0.15	1.47 ±0.04	0.31 ±0.11	0.29 ±0.28	0.07 ±0.18	0.51 ±0.15	0.11 ±0.23	0.01 ±0.07	2.11 ±0.12	2.01 ±0.09	1.92 ±0.10	2.12 ±0.11	0.85 ±0.07	1.27 ±0.11	1.31 ±0.14	1.82 ±0.28	1.89 ±0.30	
n∧CDM	0.08 ±0.11	0.27 ±0.58	0.91 ±0.09	2.45 ±0.13	2.32 ±0.11	2.26 ±0.13	2.27 ±0.13	0.00 ±0.02	0.30 ±0.04	0.48 ±0.05	0.56 ±0.05	0.44 ±0.08	0.46 ±0.05	0.26 ±0.09	0.50 ±0.10	0.33 ±0.26	0.66 ±0.22	0.26 ±0.35	0.54 ±0.24	0.00 ±0.00	2.68 ±0.17	2.62 ±0.14	2.50 ±0.13	2.64 ±0.16	0.86 ±0.07	0.12 ±0.19	0.43 ±0.32	0.07 ±0.12	0.50 ±0.19	- 1.0
$w_0 w_a \Lambda \text{CDM}$	0.90 ±0.05	0.00 ±0.00	1.17 ±0.16	2.23 ±0.25	1.88 ±0.17	1.78 ±0.15	2.22 ±0.26	0.00 ±0.00	0.29 ±0.05	1.87 ±0.08	2.00 ±0.10	2.09 ±0.10	2.04 ±0.12	0.81 ±0.05	0.40 ±0.19	0.40 ±0.36	0.04 ±0.09	0.27 ±0.25	0.07 ±0.14	0.01 ±0.09	1.91 ±0.12	1.90 ±0.09	1.70 ±0.09	1.94 ±0.11	1.29 ±0.55	1.90 ±0.30	2.14 ±0.38	1.82 ±0.29	1.86 ±0.32	- 0.5
AACDM	0.17 ±0.14	0.11 ±0.39	1.50 ±0.12	2.25 ±0.11	2.24 ±0.12	2.45 ±0.24	2.29 ±0.24	0.00 ±0.00	1.09 ±0.07	1.00 ±0.07	1.03 ±0.09	0.94 ±0.08	0.95 ±0.08	0.03 ±0.08	1.17 ±0.28	0.40 ±0.27	0.00 ±0.03	0.20 ±0.25	0.25 ±0.33	0.00 ±0.00	2.06 ±0.10	1.90 ±0.09	1.86 ±0.09	1.90 ±0.11	1.59 ±0.13	0.46 ±0.14	0.04 ±0.11	0.09 ±0.17	0.37 ±0.18	
	DSS BI	CEP	DESLEN	sing	Spec	ising Pl	anck	CEP	DESIE	ising Cam	Spec ler	ising Pl	anck	heon +	DES	ising Cam	Spec ler	ising Pl	anck	heon len	sing	Spec ler	ising Pla	unck Pant	neon	neon	neon Panti	Panti	neon	- 0.0
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SHOES+	CamSP	SHOES	+ Plan		5	055+0	amor	SDSS	+ Plan		BI	CEP+C	amor	BICEP	+ Plan	1	DES+C	amor	DES	+ Plan	Cam	Spec wi	th Charles	Inck wi	thCh					

Thank you

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

A0 Poster board

• Poster number 130

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