Dark Scattering: accelerated constraints from KiDS-1000 with REACT and COSMOPOWER

Alessio Spurio Mancini

with K. Carrion, P. Carrilho, A. Pourtsidou, C. Hidalgo

ROYAL HOLLOWAY UNIVERSITY OF LONDON

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Based on Carrion+ 2024, MNRAS in press, arXiv:2402.18562

Karim Carrion

ROYAL HOLLOWAY UNIVERSITY OF LONDON

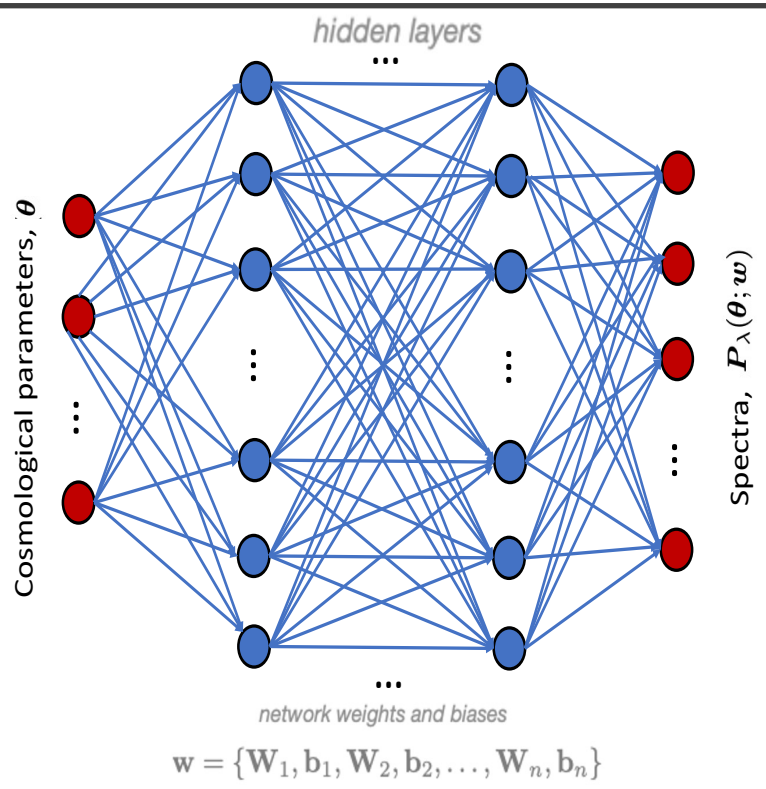
COSMOPOWER

Spurio Mancini+ 2022

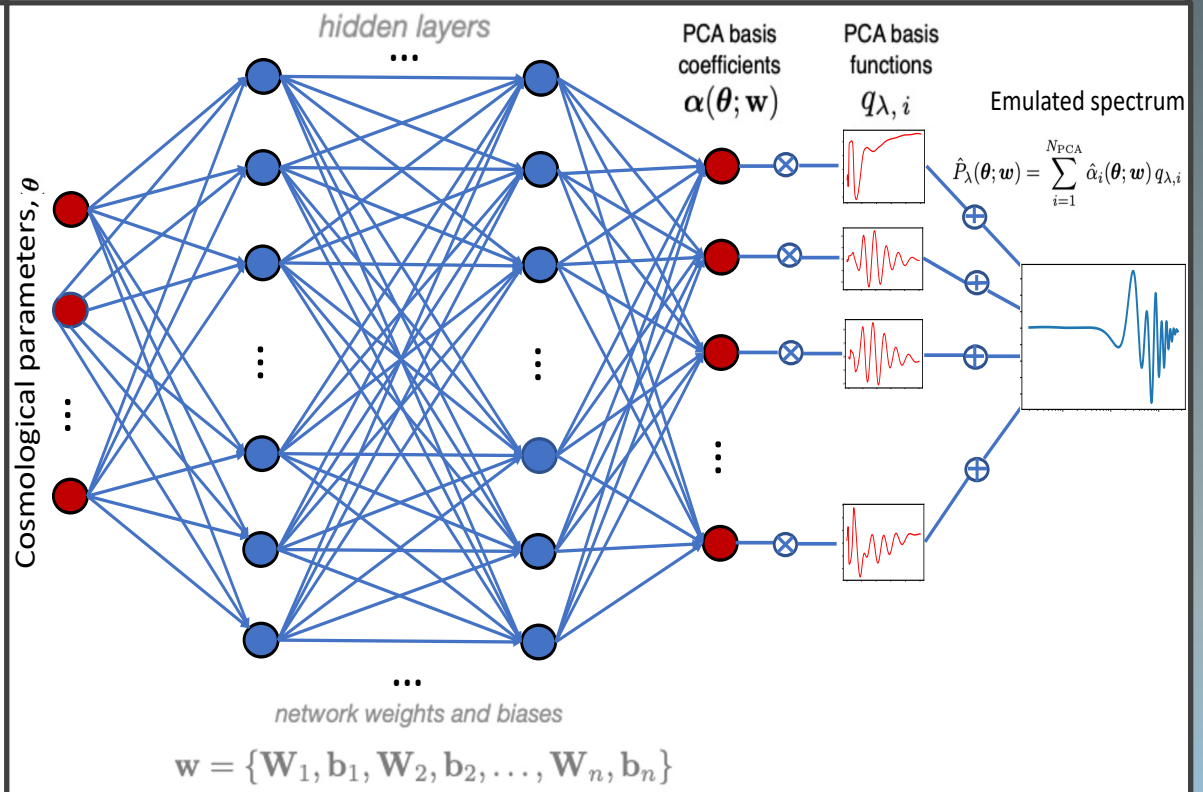
We introduce a suite of
neural cosmological power spectrum emulators
covering both CMB (temperature, polarization and lensing),
and large-scale structure power spectra

COSMOPOWER

Spurio Mancini+ 2022



NEURAL NETWORK



NEURAL NETWORK + PCA

python

GitHub

alessiospuriomancini/cosmopower

Piras & Spurio Mancini 2023

PolyChord+CAMB, 48 cores, ~4 months
PolyChord+CosmoPower, 48 cores, ~8 days
NUTS+CosmoPower-JAX, 3 GPUs, ~1 day

Label	Plot range	Name
P_1	[0.019, 0.024]	ω_b
P_2	[0.10, 0.16]	ω_cdm
P_3	[0.64, 0.75]	h
P_4	[0.84, 1.04]	n_s
P_5	[2.74, 3.26]]	$\ln 10^{10} A_\mathrm{s}$
P_6	[2.3, 3.1]	c_min
P_7	[0.66, 0.75]	η_0
P_8	[0.87, 0.93]	$A^{\mathrm{S1}}_{\mathrm{IA},1}$
P_9	[0.77, 0.84]	$A^{\mathrm{S1}}_{\mathrm{IA},2}$
P_{10}	[0.66, 0.74]	$A^{\mathrm{S1}}_{\mathrm{IA},2}$
P_{11}	[0.56, 0.64]	$A^{\mathrm{S1}}_{\mathrm{IA},3}$
P_{12}	[0.45, 0.55]	$A^{\mathrm{S1}}_{\mathrm{IA},5}$
P_{13}	[0.34, 0.46]	$A^{\mathrm{S1}}_{\mathrm{IA},6}$
P_{14}	[0.22, 0.38]	$A^{\mathrm{S1}}_{\mathrm{IA},7}$
P_{15}	[0.07, 0.34]	$A^{\mathrm{S1}}_{\mathrm{IA},8}$
P_{16}	[−0.16, 0.44]	$A^{\mathrm{S1}}_{\mathrm{IA},9}$
P_{17}	[−0.8, 0.8]	$A^{\mathrm{S1}}_{\mathrm{IA},10}$
P_{18}-P_{27}	$[-4\cdot10^{-4}, 4\cdot10^{-4}]$	$D^{\mathrm{S1}}_{z_i,\mathrm{source}} i = 1,\ldots,10$
P_{28}-P_{37}	$[-1\cdot10^{-2}, 3\cdot10^{-2}]$	m^{S1}_i $i = 1,\ldots,10$

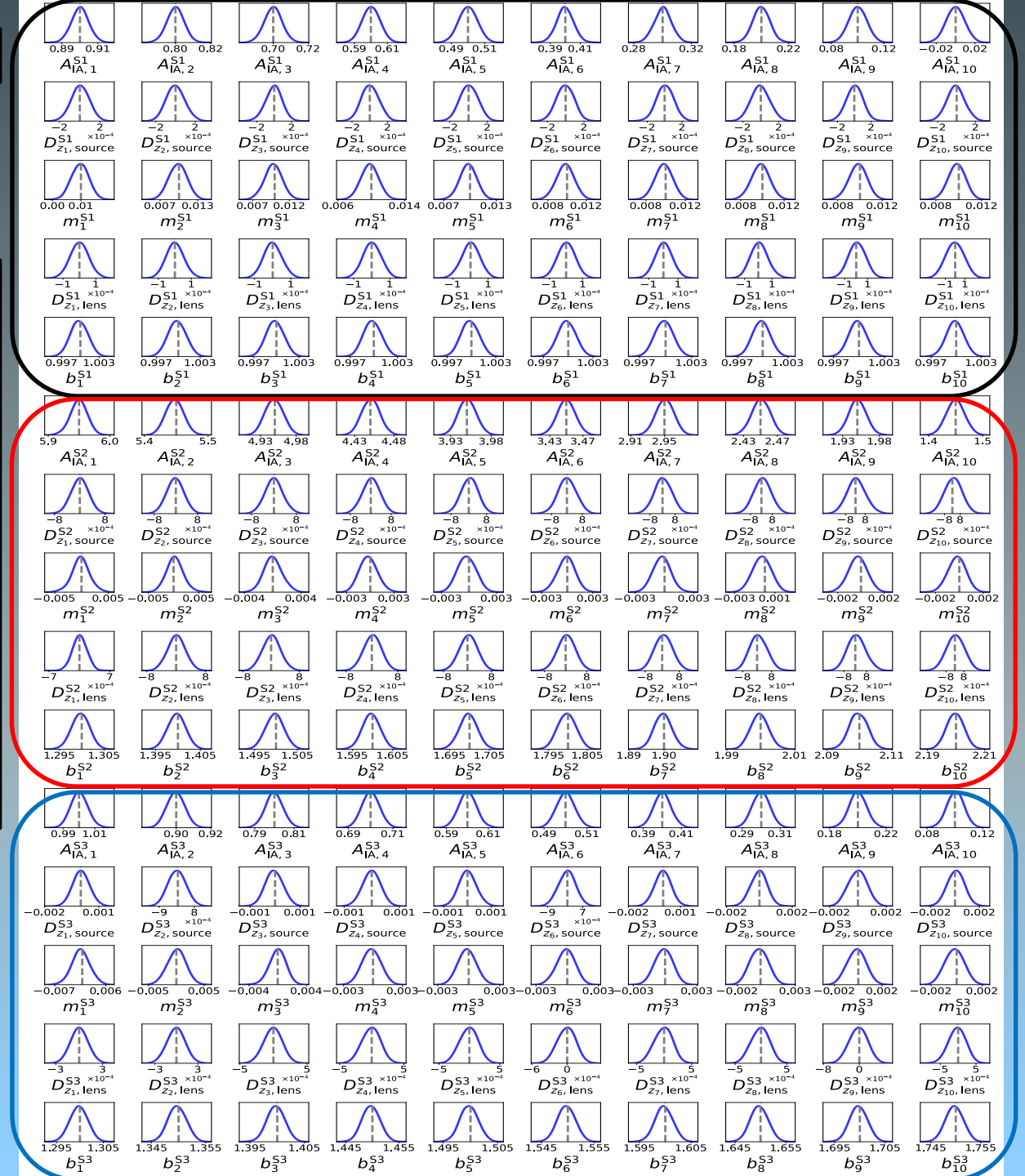
Piras & Spurio Mancini 2023

- COSMOPOWER-JAX
(Piras & Spurio Mancini 2023)
+ JAX-COSMO (Campagne + 2023)

- 3 Stage IV surveys → 157 (!) parameters

- 3 days on 3 GPUs with NUTS

- (Optimistic) estimate: 6 years (!!) on 48 CPUs with PolyChord

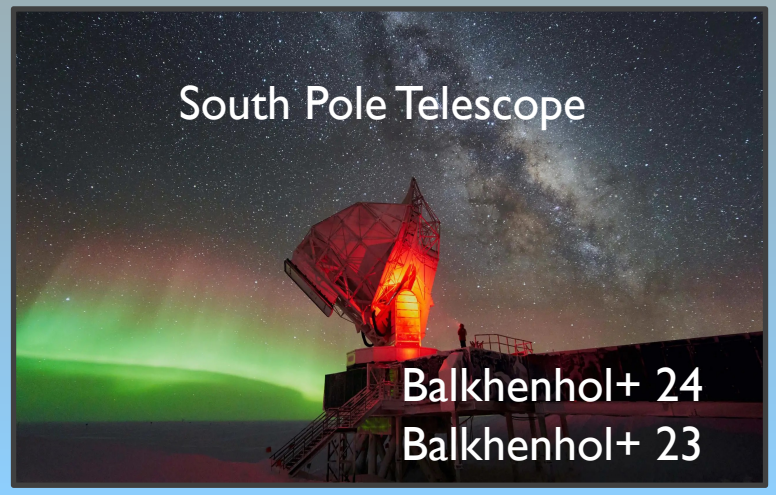


Survey 1

Survey 2

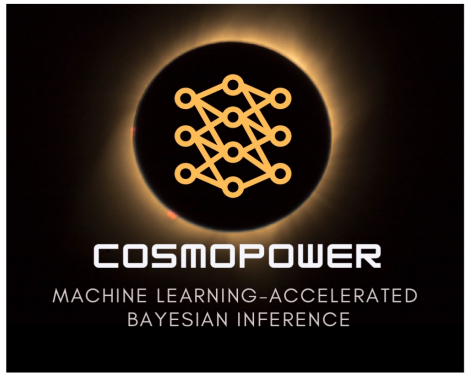
Survey 3

COLLABORATIONS USING COSMOPOWER



https://github.com/alessiospuriomancini/cosmopower

README.md



Python | Tensorflow | License GPLv3 | Author Alessio Spurio Mancini | Installation pip install cosmopower

Overview • Documentation • Installation • Getting Started • Training • Trained Models • Likelihoods • Support • Citation

```
pip install cosmopower
```

```python
import cosmopower as cp

# load pre-trained NN model: maps cosmological parameters to CMB TT log-C_ell
cp_nn = cp.cosmopower_NN(restore=True,
                         restore_filename='/path/to/cosmopower'\
                         +'/cosmopower/trained_models/CP_paper/CMB/cmb_TT_NN')

# create a dict of cosmological parameters
params = {'omega_b': [0.0225],
          'omega_cdm': [0.113],
          'h': [0.7],
          'tau_reio': [0.055],
          'n_s': [0.96],
          'ln10^{10}A_s': [3.07],
          }

# predictions (= forward pass through the network) -> 10^predictions
spectra = cp_nn.ten_to_predictions_np(params)
```

getting_started_with_cosmopower_NN.ipynb

File Edit View Insert Runtime Tools Help Changes will not be saved

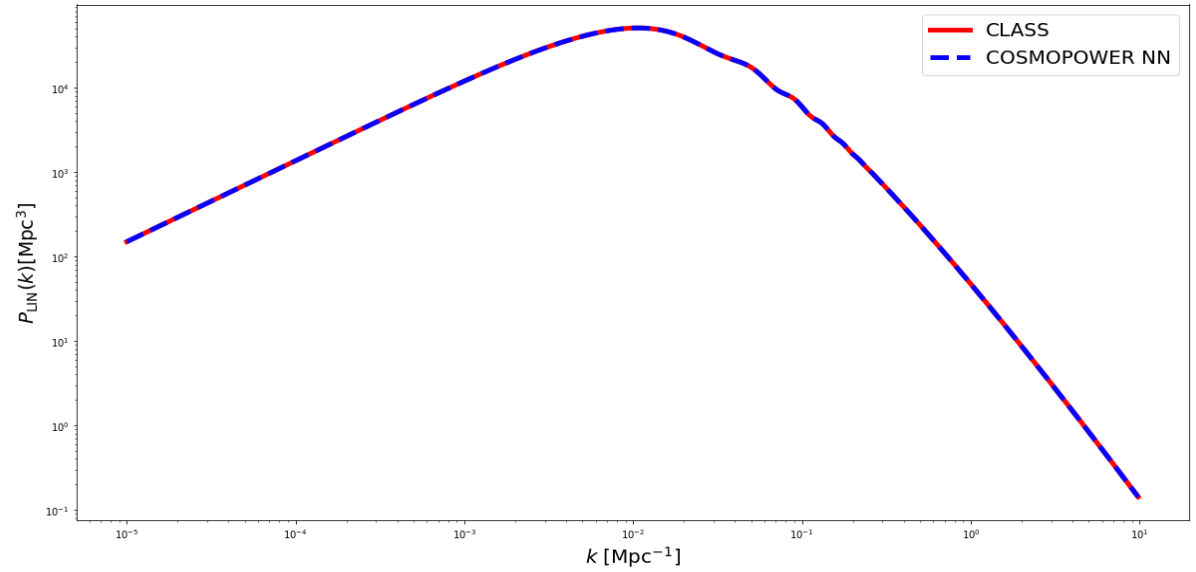
+ Code + Text Copy to Drive

COMPARING with CLASS

```
[ ] k_modes = cp_nn.modes

    cosmo = Class()

    # Define your cosmology (what is not specified will be set to CLASS default parameters)
    params = {'output': 'tCl mPk',
              'z_max_pk': 5,
              'P_k_max_1/Mpc': 10.,
              'nonlinear_min_k_max': 100.,
              'N_ncdm' : 0,
              'N_eff' : 3.046,
              'omega_b': 0.0225,
              'omega_cdm': 0.113,
              'h': 0.7,
              'n_s': 0.96,
              'ln10^{10}A_s': 3.07,
              }

    # Set the parameters to the cosmological code
    cosmo.set(params)
    cosmo.compute()

    z = 0.5

    spectrum_class = np.array([cosmo.pk(ki, z) for ki in k_modes])
```

```
pred = spectrum_cosmopower_NN
true = spectrum_class
fig = plt.figure(figsize=(20,10))
plt.loglog(k_modes, true, 'red', linewidth=5, label = 'CLASS')
plt.loglog(k_modes, pred, 'blue', label = 'COSMOPOWER NN', linewidth=5, linestyle='--')
plt.xlabel('$k$ [Mpc$^{-1}]$', fontsize=20)
plt.ylabel('$P_{\mathrm{LIN}}(k) [\mathrm{Mpc}^3]$', fontsize=20)
plt.legend(fontsize=20)
```

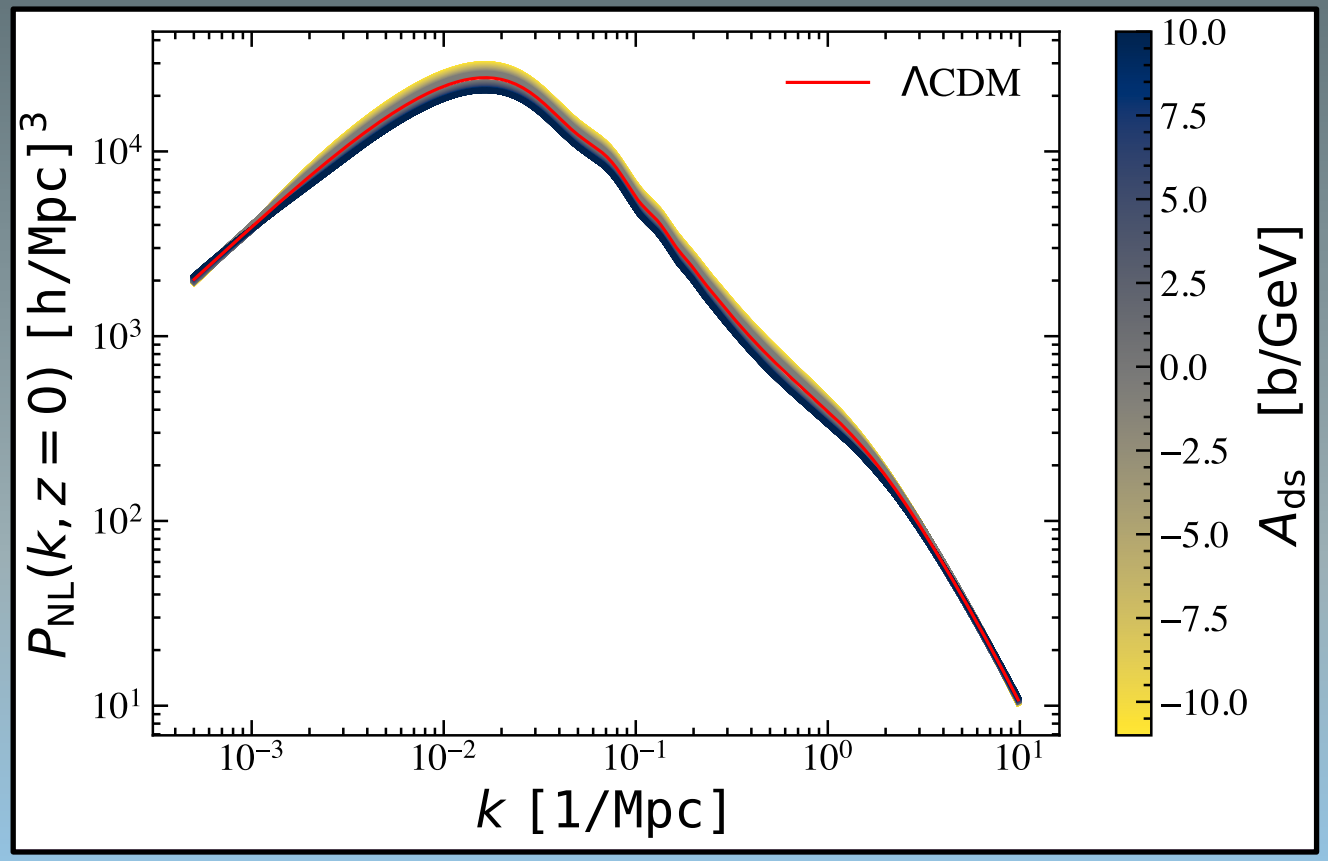
```
<matplotlib.legend.Legend at 0x7f25dd360fd0>
```



Dark Scattering

- Interacting dark sector $\nabla_\mu T^{\mu\nu}_{\rm DM} = J^\nu \iff \nabla_\mu T^{\mu\nu}_{\rm DE} = -J^\nu$
- Inspired by Thomson scattering between electrons and photons
- Interaction parameterized by free parameter $A_{\rm ds}$ (related to cross section $\sigma_{\rm DS}$)
- Pure momentum exchange between dark energy and dark matter
- Details: Simpson 2010, Pourtsidou+ 2013

Matter power spectrum



Depending on sign of interaction parameter $A_{\rm ds}$ can get enhancement or suppression of matter power spectrum

ReACT: nonlinear massive neutrinos and modified gravity

$$P_{\rm NL}^{\rm MG}(k,z) = \mathcal{R}(k,z) \times P_{\rm NL}^{\rm pseudo}(k,z)$$

ΛCDM cosmology whose initial conditions are $P_{\rm L}^{\rm MG}(k,z) = P_{\rm L}^{\Lambda{\rm CDM}}(k,z)$

1-loop perturbation theory + halo model

Cataneo et al. 2019

Bose et al. 2021

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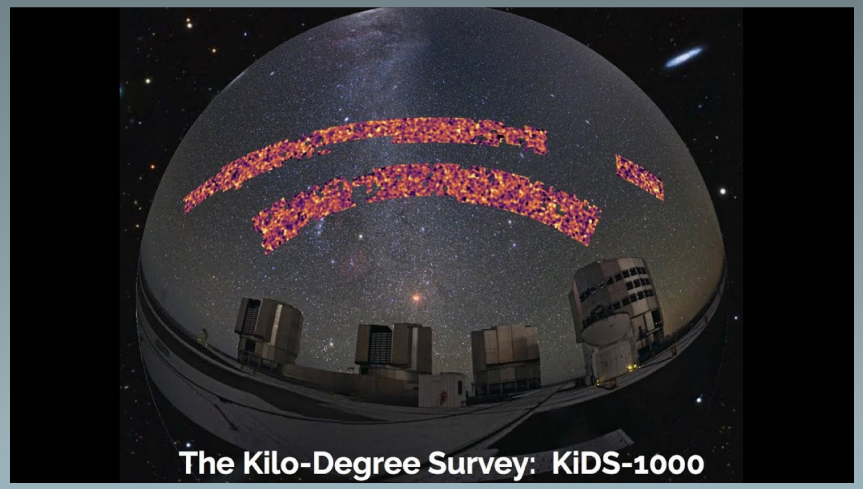
COSMOPOWER + ReACT

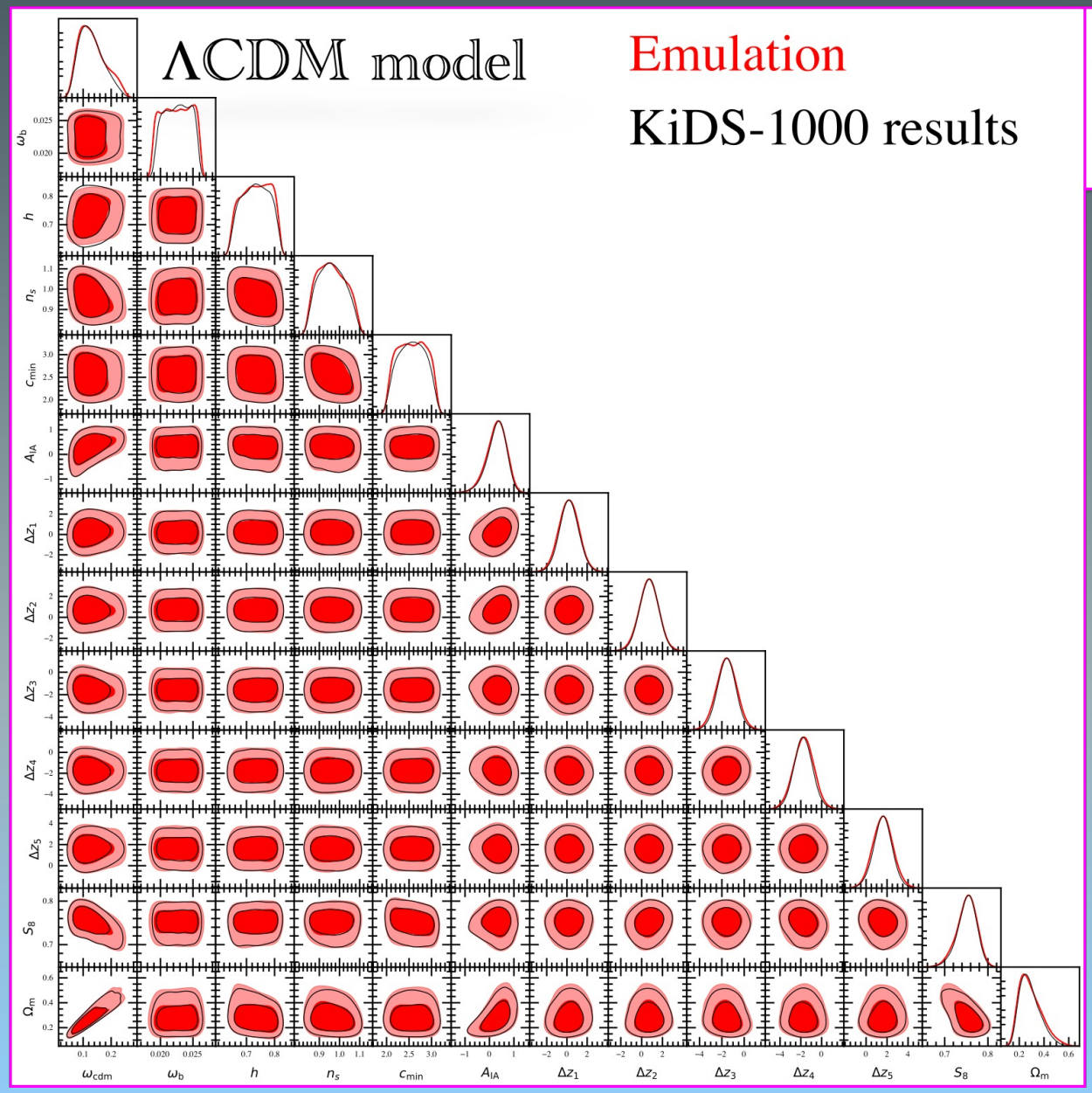
`karimpsi22/DS-emulators` GitHub

Example speed-up: producing 1000 spectra takes 0.19s with emulator, 8.3h with original code

Kilo-Degree Survey (KiDS)

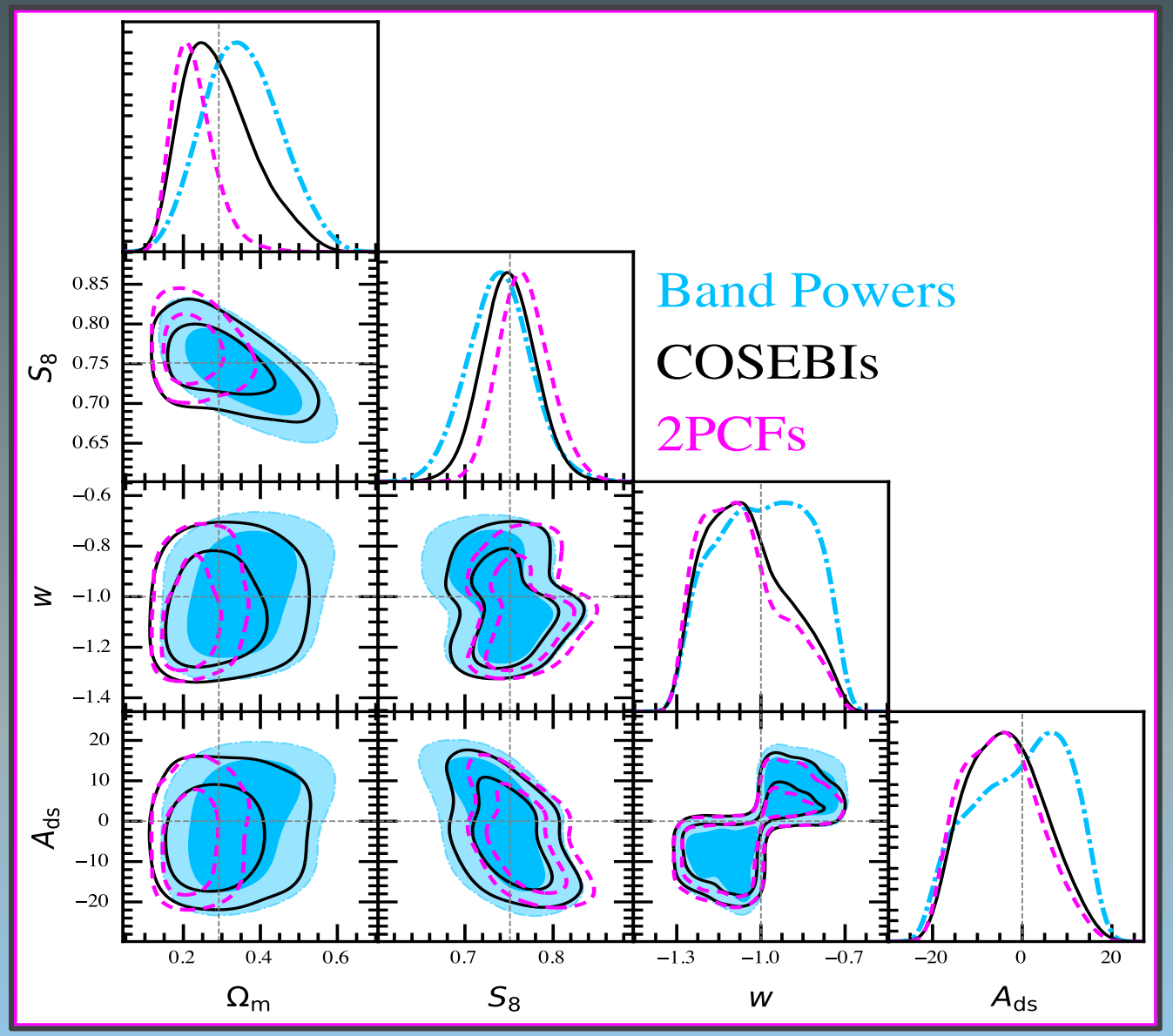


We analyze the IV data release of the Kilo-Degree Survey (KiDS-1000, ~1000 deg^2)

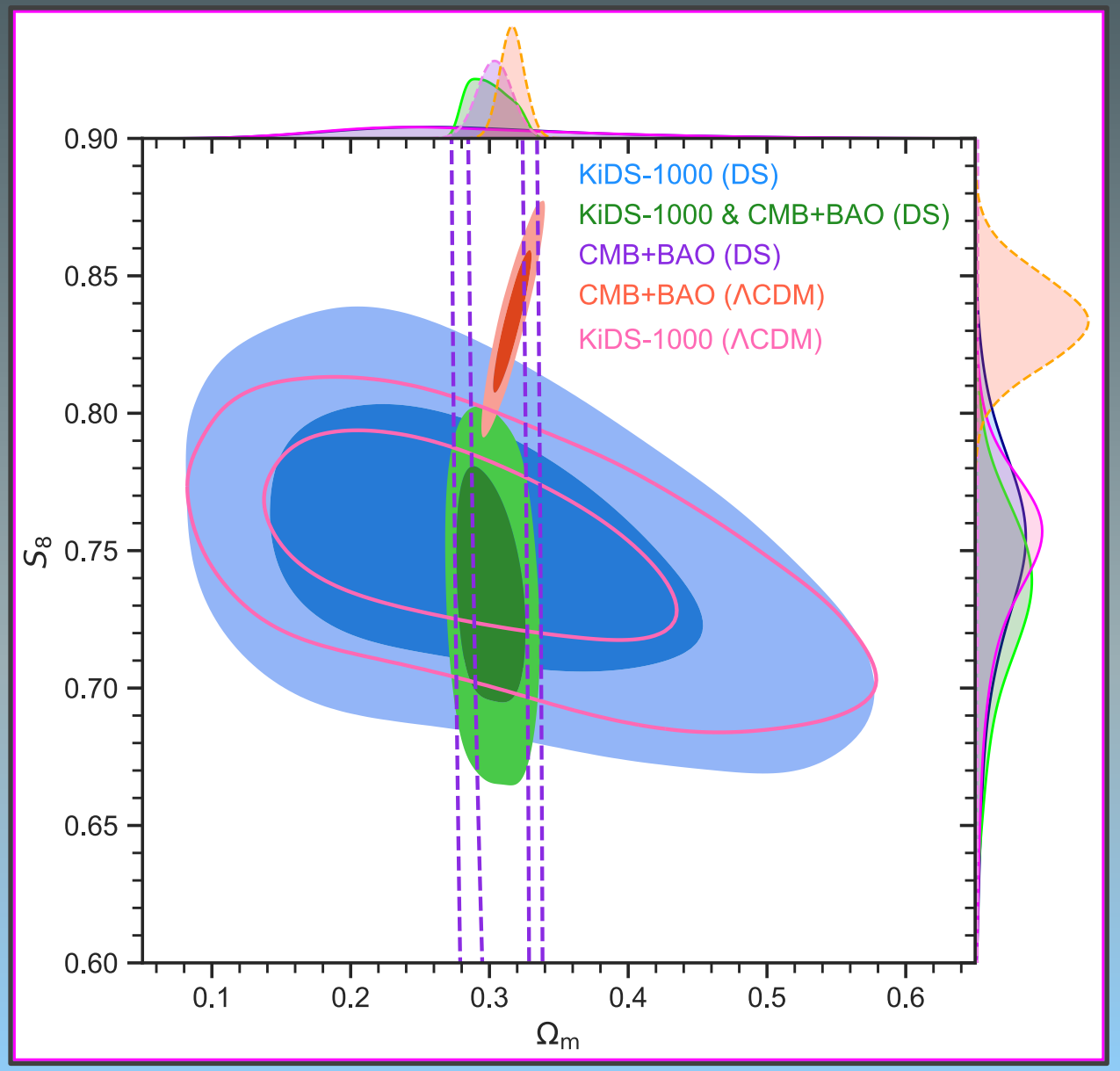


~ 1 hour (24 CPU cores)

~ 5 days (24 CPU cores)



KiDS-1000 data constrain the parameter $|A_{\rm ds}| \lesssim 20\,{\rm b/GeV}$


KiDS-1000 (DS)
KiDS-1000 & CMB+BAO (DS)
CMB+BAO (DS)
CMB+BAO (ΛCDM)
KiDS-1000 (ΛCDM)
0.90
0.85
0.80
0.75
0.70
0.65
0.60
S_8
0.1
0.2
0.3
0.4
0.5
0.6
Ω_m

CONCLUSIONS

- Dark Scattering offers promising alternative to solve σ_8 tension
- Developed REACT nonlinear predictions including baryon feedback, ready for Stage IV analyses
- COSMOPOWER emulation accelerates analysis by orders of magnitude
- Ongoing work: forecasts for Stage IV galaxy surveys

`alessiospuriomancini/cosmopower`
`karimpsi22/DS-emulators`

`alessio.spuriomancini@rhul.ac.uk`