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Weak Lensing ML Uncertainty Challenge

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One of the **NeurIPS 2025 Competitions**

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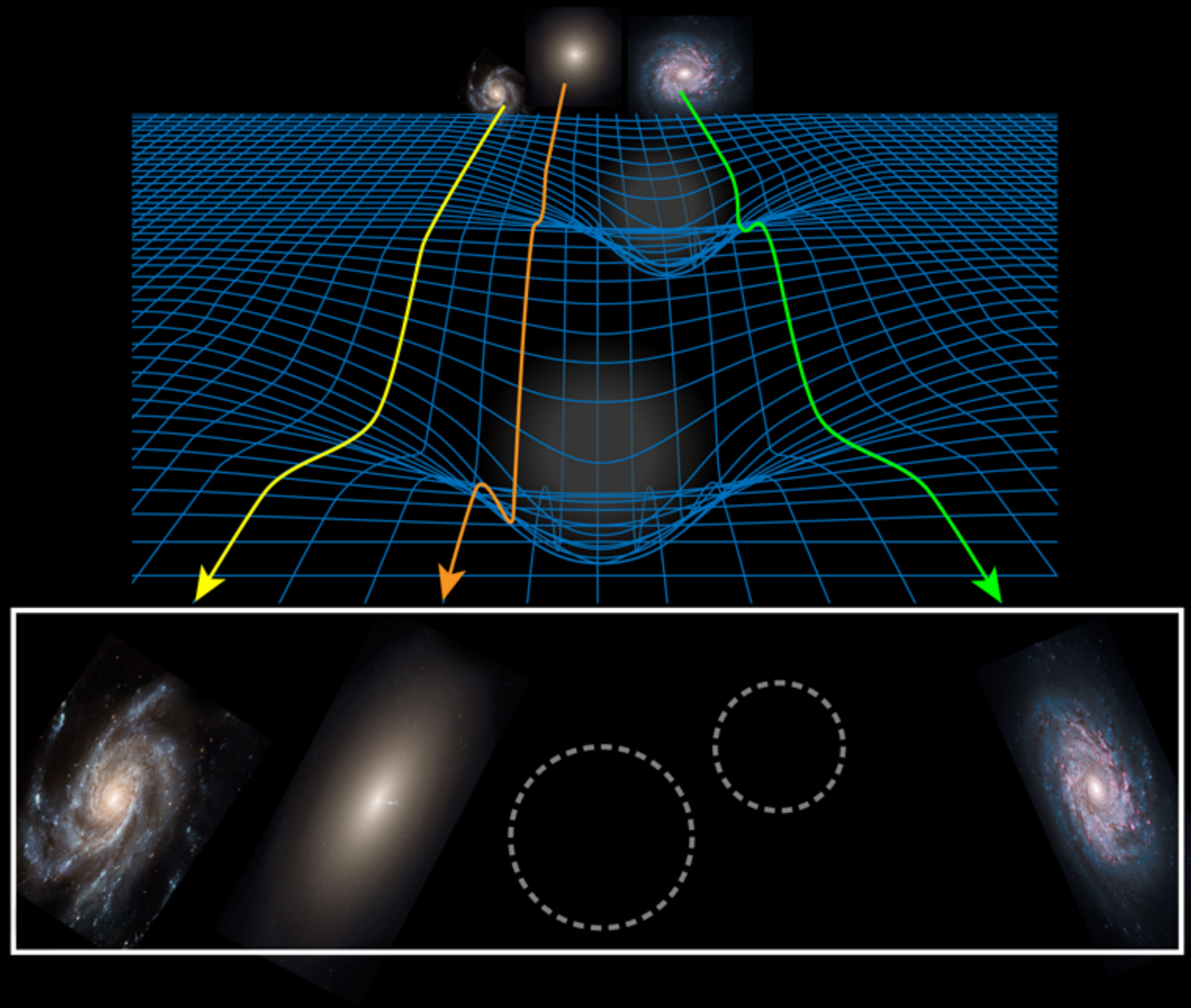
Overview

Weak gravitational lensing

- The gravity of matter warps the surrounding space-time and causes distortions in the observed shapes of the background galaxies.
- Powerful probe of the matter distribution in our universe from coherent patterns of galaxy shapes.
- Numerous current and upcoming WL surveys: DES, HSC, Euclid, Rubin LSST, Roman, etc.
- Traditional analysis based on two-point correlation functions can only capture limited amount of information from the weak lensing data.
- **AI/ML-based approaches could capture more information hidden in higher-order correlations!**
  WE NEED YOU!



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Competition tasks

The competition tasks will be structured into **2 phases**:

- **Phase 1: Cosmological Parameter Estimation**

  Participants will develop models that:

  - Accurately infer cosmological parameters $(\hat{\boldsymbol{\Omega}}_{\mathbf{m}}, \hat{\mathbf{S}}_{\mathbf{8}})$ from the weak lensing image data.
  - Quantify uncertainties via the 68% confidence intervals of the parameters of interest. $(\hat{\boldsymbol{\sigma}}_{\boldsymbol{\Omega}_{\mathbf{m}}}, \hat{\boldsymbol{\sigma}}_{\mathbf{S}_{\mathbf{8}}})$.

Scoring metrics:

KL divergence between the true Gaussian-like posterior distribution and the Gaussian with the predicted mean and standard deviation:

$$\text{score}_{\text{ inference}} = -\frac{1}{N_{\text{test}}}\sum_{i}^{N_{\text{test}}}\left\{\frac{\left(\hat{\Omega}_{m,i}-\Omega_{m,i}^{\text{truth}}\right)^2}{\hat{\sigma}^2_{\Omega_m,i}}+\frac{\left(\hat{S}_{8,i}-S_{8,i}^{\text{truth}}\right)^2}{\hat{\sigma}^2_{S_8,i}}\right.$$
$$\left.+\log\left(\hat{\sigma}^2_{\Omega_m,i}\right)+\log\left(\hat{\sigma}^2_{S_8,i}\right)+\lambda\left[\left(\hat{\Omega}_{m,i}-\Omega_{m,i}^{\text{truth}}\right)^2+\left(\hat{S}_{8,i}-S_{8,i}^{\text{truth}}\right)^2\right]\right\}$$

$\lambda \equiv 10^3$: penalty factor for bad point estimates

- **Phase 2: Out-of-Distribution Detection**

  Some test data will be generated with different physical models (OoD), leading to some distribution shifts with respect to the test data in Phase 1. Participants will develop models that:

  - Identify test data samples inconsistent with the training distribution (OoD detection).
  - Provide probability estimates indicating data conformity to training distributions.

Binary cross-entropy:

$$\text{score}_{\text{OoD}} = \frac{1}{N_{\text{test}}}\sum_{i}^{N_{\text{test}}}\left[y_i \log\left(p_i\right) + \left(1-y_i\right)\log\left(1-p_i\right)\right]$$

where $y_i = 1$ if the dataset is InD; $y_i = 0$ if the dataset is OoD, and p_i is the probability estimates predicted by the model.

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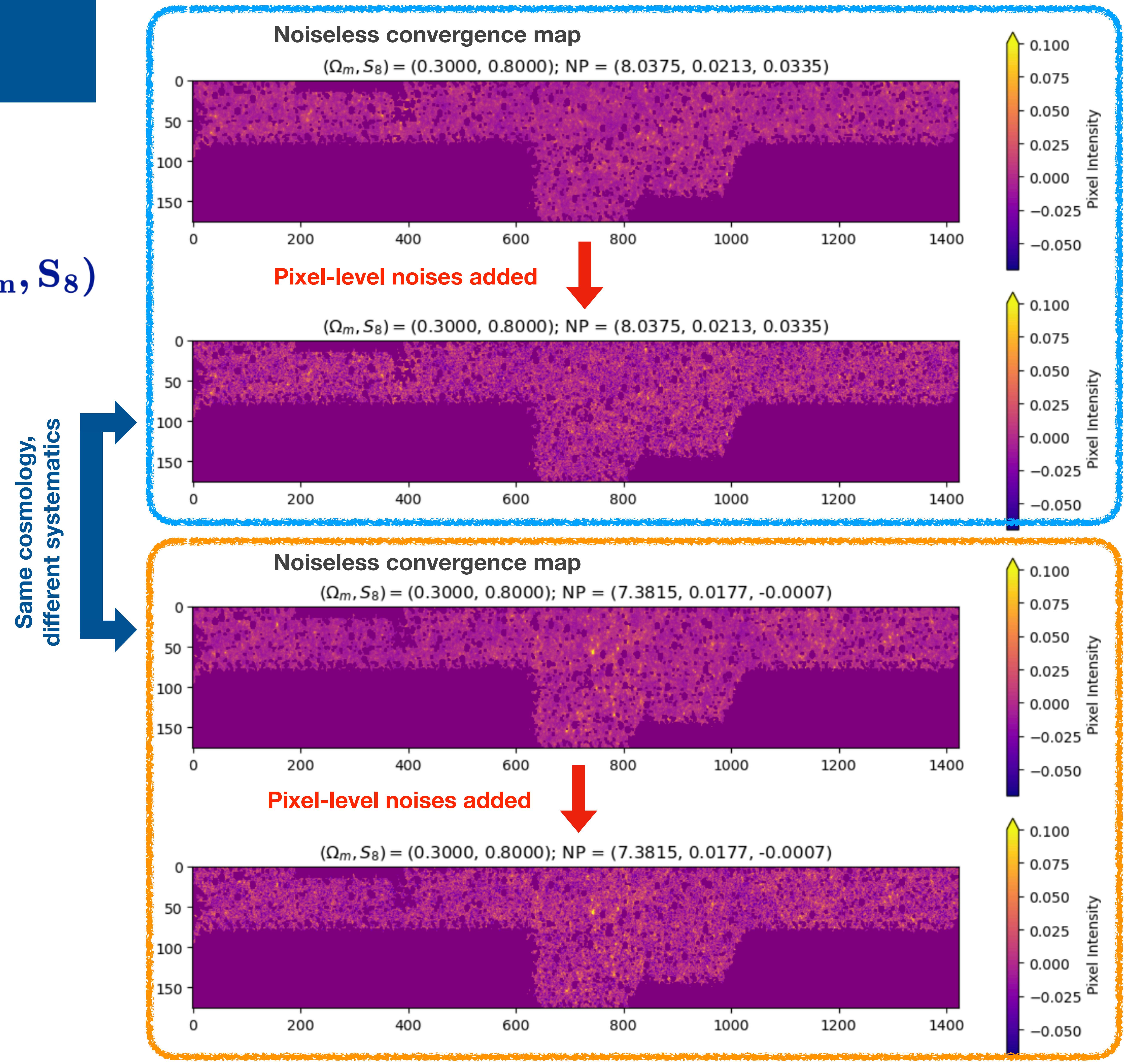
Dataset

- Mock galaxy catalogs predicted with N-body simulations and lens algorithms at 101 cosmological parameters $(\boldsymbol{\Omega_m, S_8})$
- Pixelized 2D weak lensing images: convergence maps
- The model must take into account the systematic uncertainties from **3 realistic systematic effects**

  2 **baryonic effect uncertainties**

  1 **photometric redshift uncertainty**

  along with tunable **pixel-level noises**



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Dataset

The participants will be provide with:

- **Public training set:**
  - Image data; shape = (101, 256, 1424, 176)
  - Label shape = (101, 256, 5)

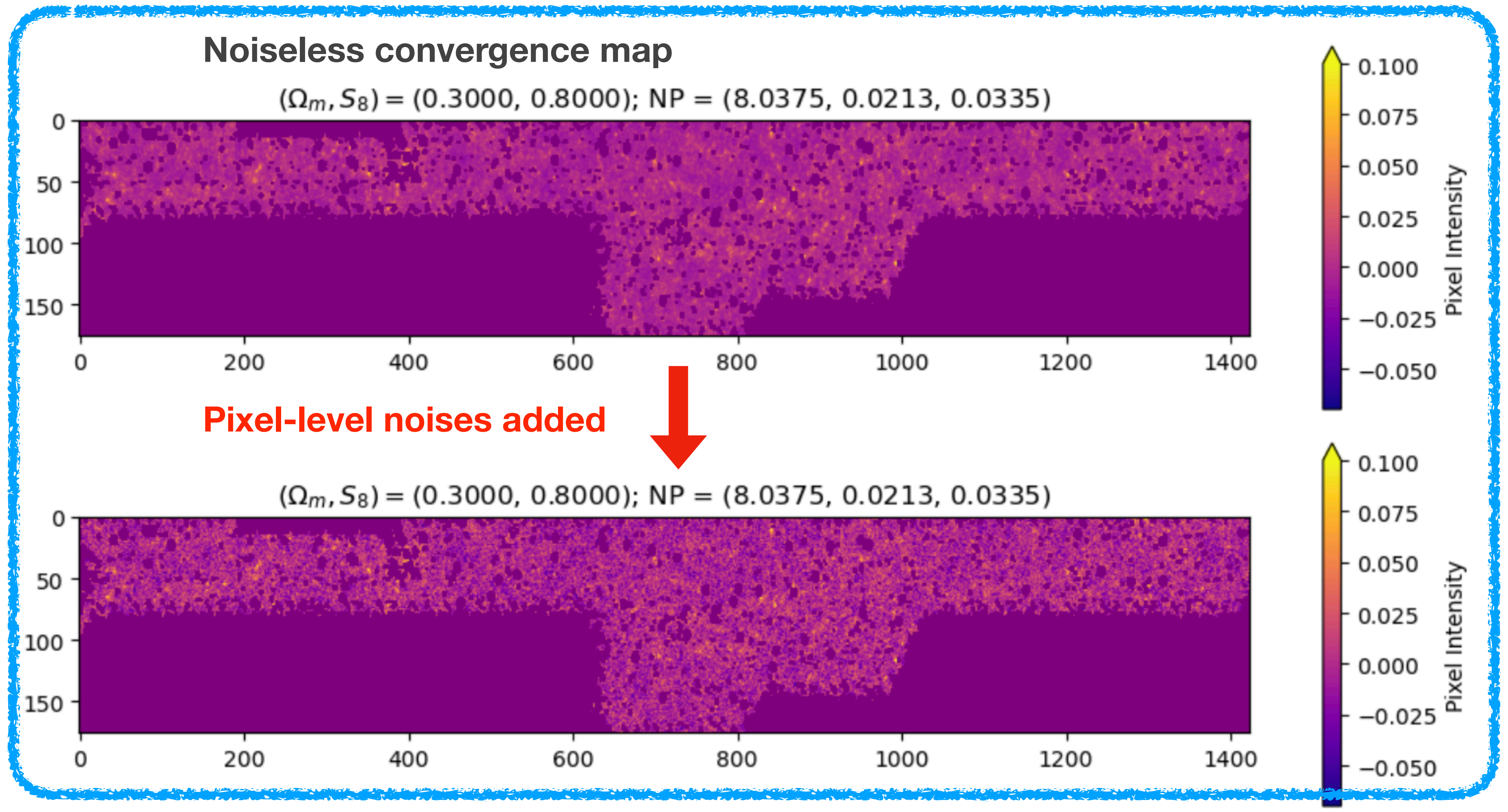
101 = Realizations of cosmological models; each characterized with 2 parameters of interest $(\mathbf{\Omega_m}, \mathbf{S_8})$

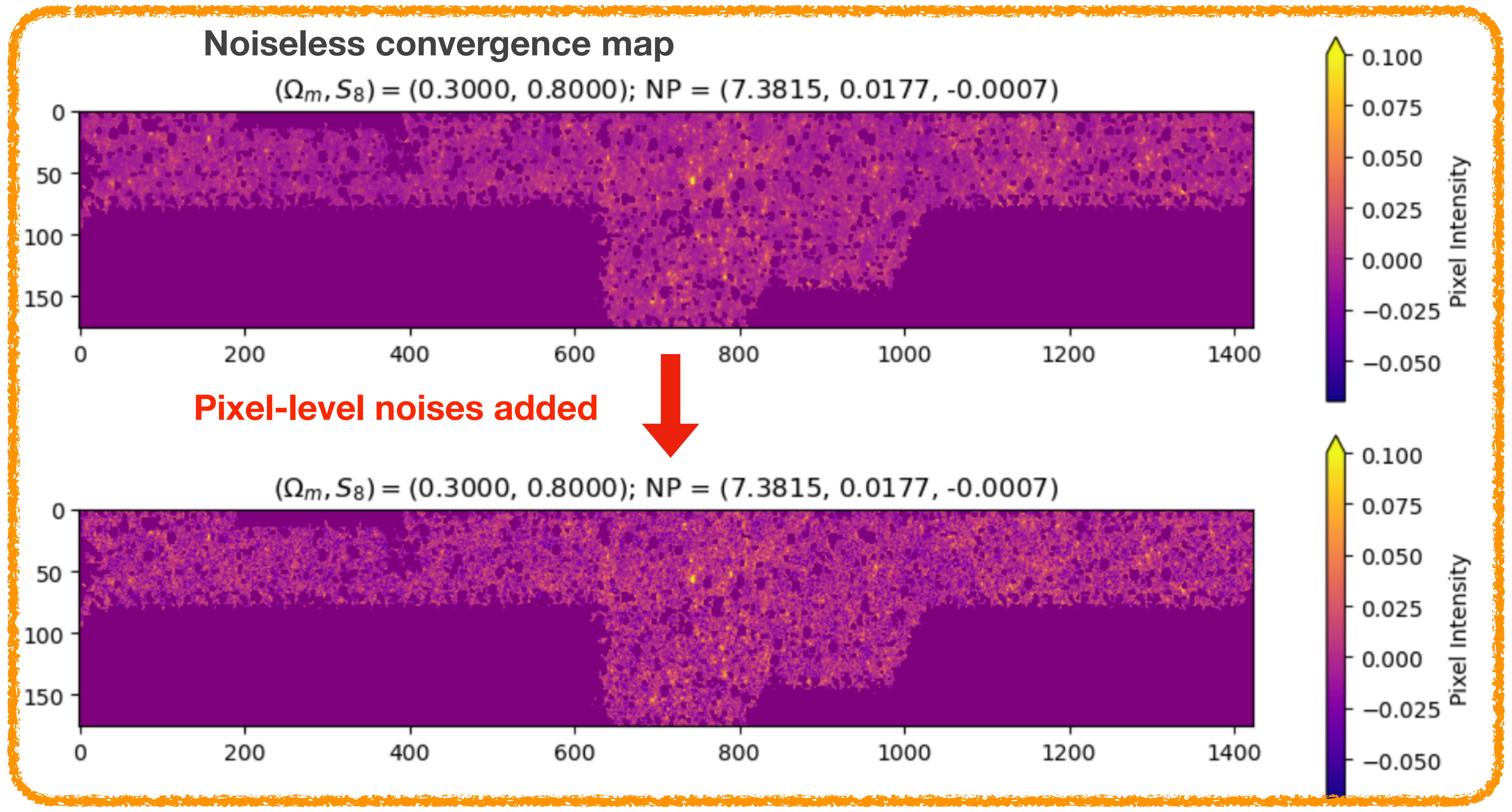
256 = Realizations of 3 nuisance parameters for systematics (1) and (2)

(1424, 176) = Image dimension

5 = 2 parameters of interest $(\mathbf{\Omega_m}, \mathbf{S_8})$ + 3 nuisance parameters for systematics (1) and (2)

- **The provided training set is noiseless.** Participants can generate **pixel-level noise** to augment their training data using a simple `add_noise` function we provide





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Phase 1 Dataset

The participants will be provide with:

- **Public test set:**
  - Image data; shape = (4000, 1424, 176)

    4000 = Number of test images

    (1424, 176) = Image dimension
  - The test images are generated with random cosmological parameters, random nuisance parameters, and random pixel-level noises.

Phase 1 Evaluation

The true parameters $(\Omega_m^{\mathrm{truth}}, S_8^{\mathrm{truth}})$ of the public test set are unknown to the participants.

Participants will submit predictions of

- **Cosmological parameters** $(\hat{\Omega}_m, \hat{S}_8)$
- **Their uncertainties** $(\hat{\sigma}_{\Omega_m}, \hat{\sigma}_{S_8})$

to Codabench, our competition platform.

The model performance will then be evaluated with the hidden ground truth based on our scoring metrics.

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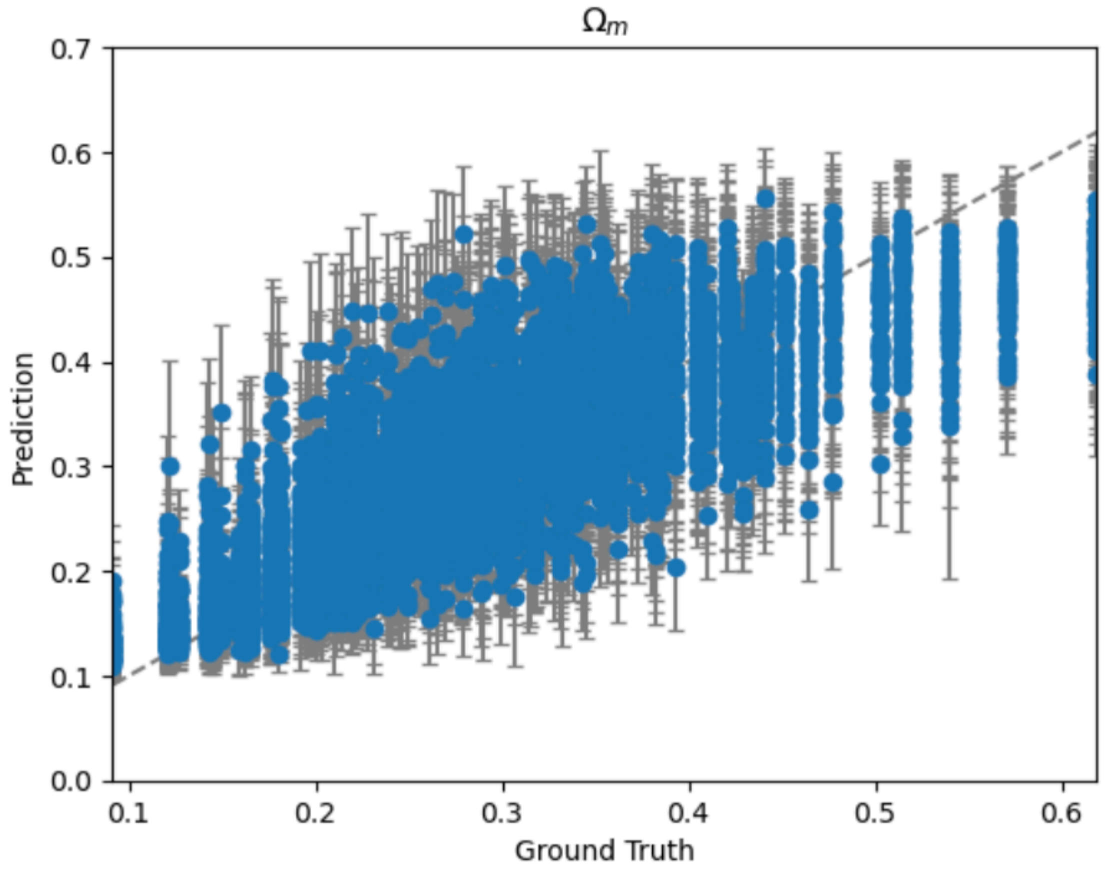
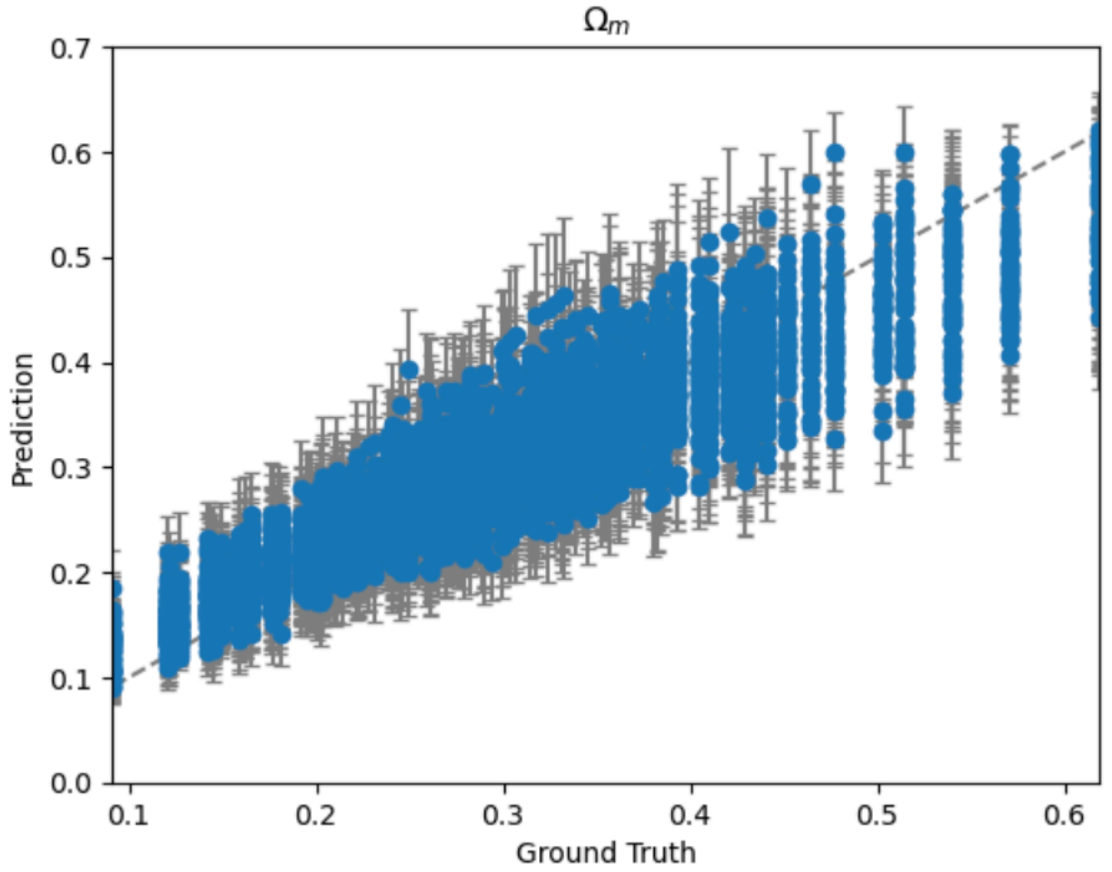
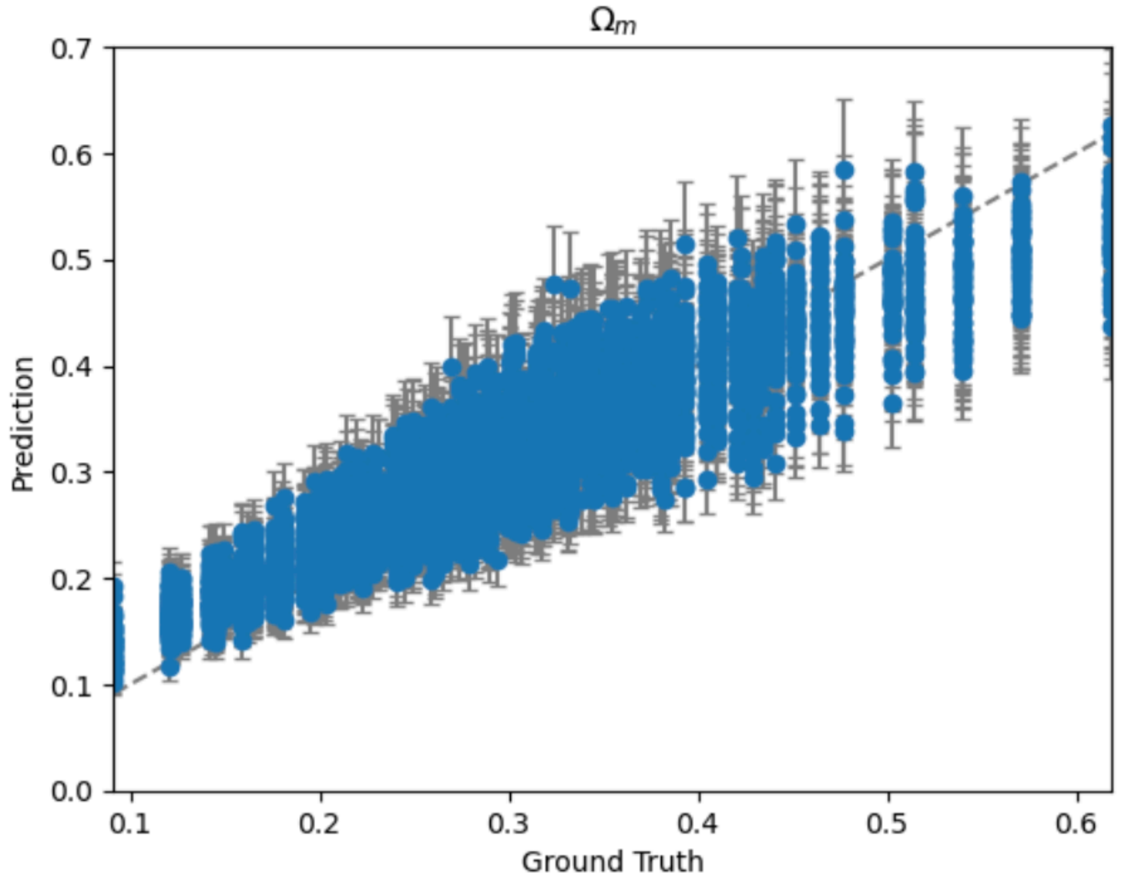
Phase 1 Baseline solutions (tested on validation data)

	Power spectrum analysis w/ MCMC	CNN predictions w/ MCMC	CNN direct predictions

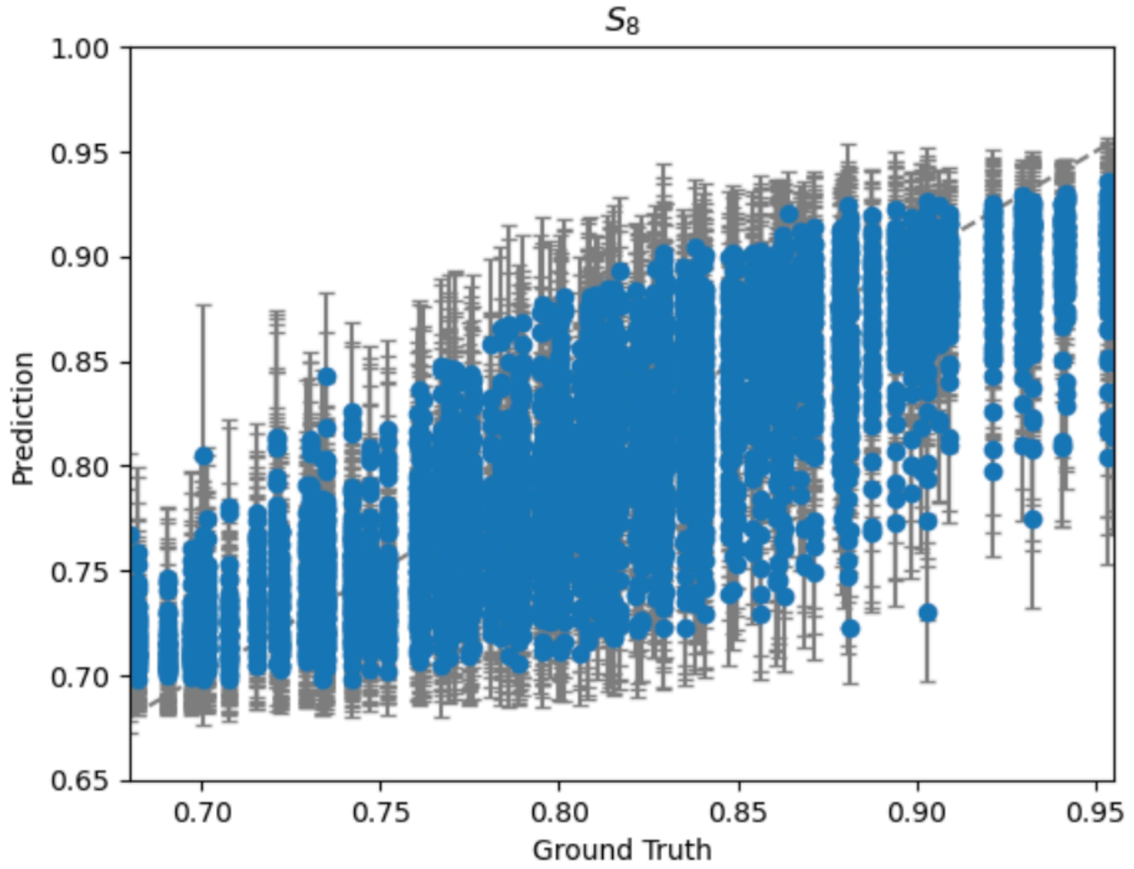
Ω_m

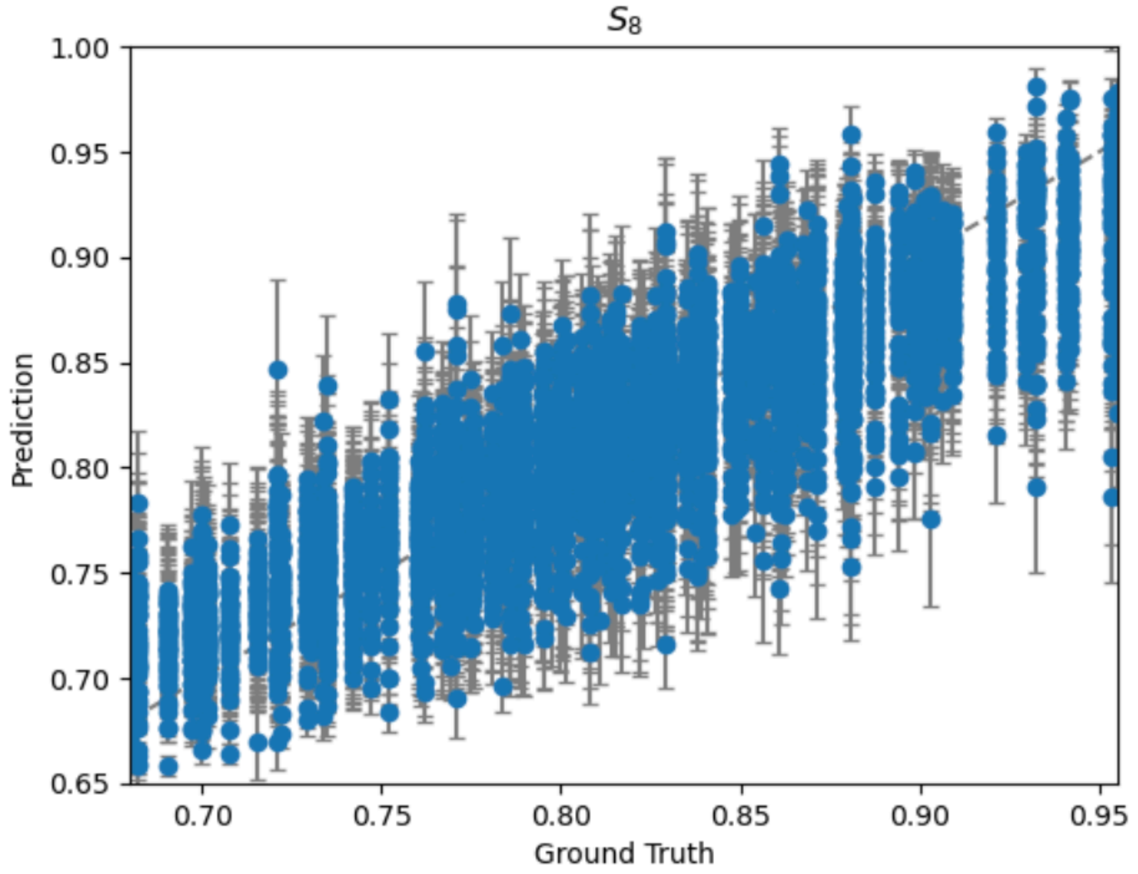


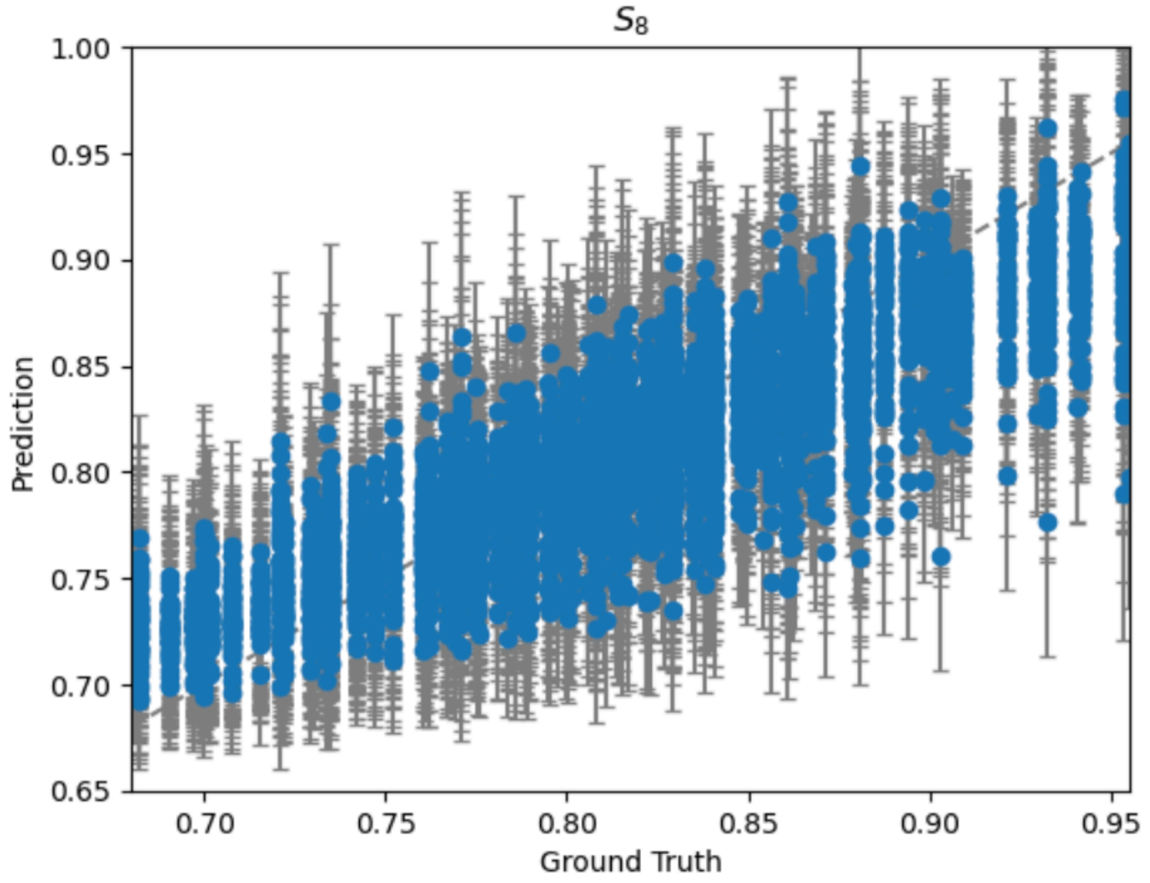




S_8







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Phase 1 Baseline solutions (tested on validation data)

Phase 1 Competition leaderboard (in the final phase of testing)

#	Participant	Date	ID	Method Name	Score	MSE	R^2	Coverage
1	pwchang	2025-08-14 09:52	353450	Baseline_CNN_MCMC_it100k_006_new_data_score **CNN predictions w/ MCMC**	**8.6995**	0.1924	0.804	0.7278
2	pwchang	2025-08-14 09:52	353451	Baseline_CNN_direct_new_data_score **CNN direct predictions**	**8.2667**	0.1957	0.8006	0.734
3	pwchang	2025-08-14 10:34	353466	Baseline_PSA_MCMC_it100k_002_new_data_score **Power spectrum analysis w/ MCMC**	**4.5766**	0.349	0.6446	0.6726

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Phase 1 Baseline solutions (tested on validation data)

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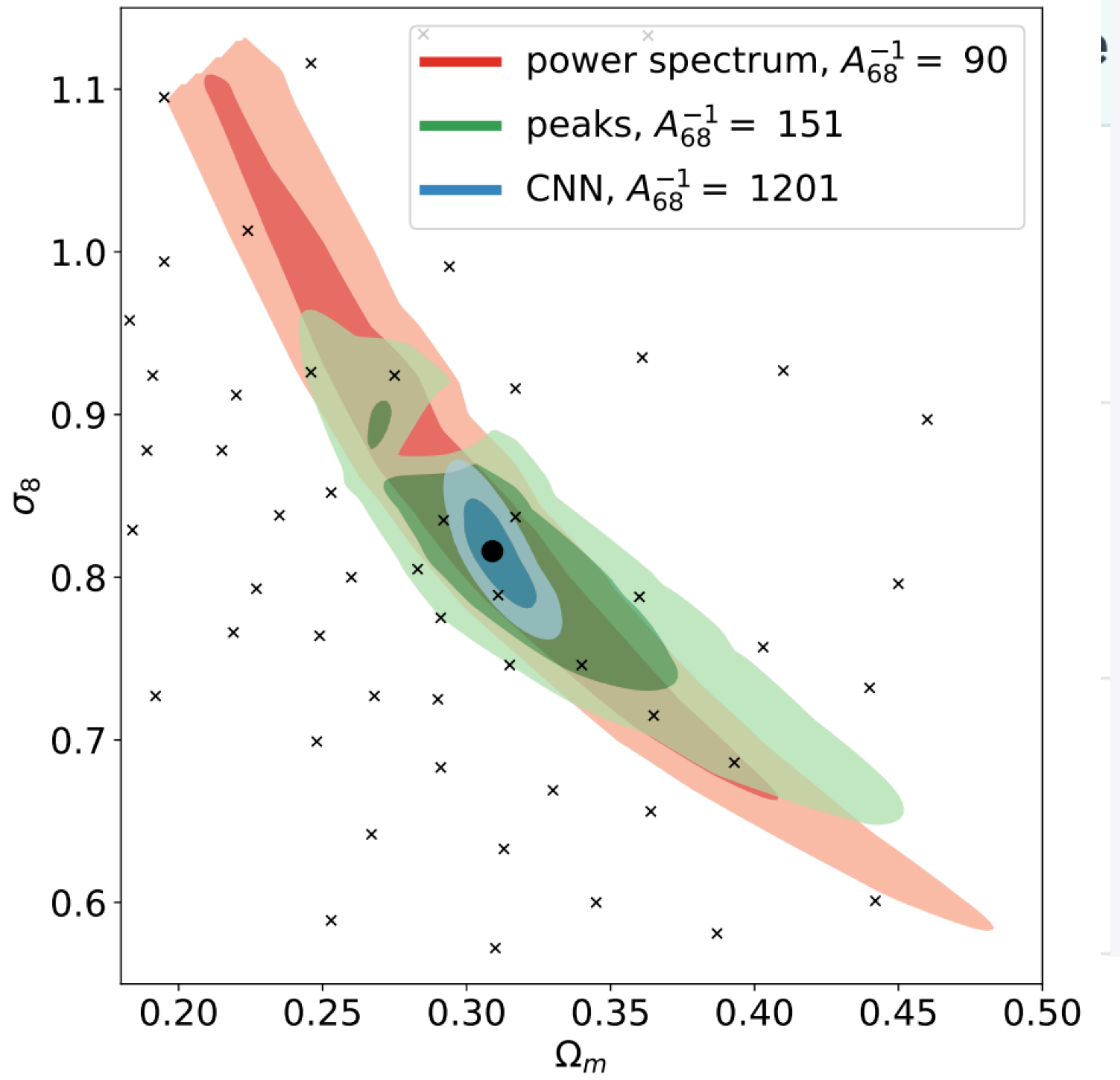
1	pwchang	2025-08-14 09:52	353450	Baseline_CNN_MCMC_it100k_006_new_data_score	8.6995
2	pwchang	2025-08-14 09:52	353451	Baseline_CNN_direct_new_data_score	8.2667
3	pwchang	2025-08-14 10:34	353466	Baseline_PSA_MCMC_it100k_002_new_data_score	4.5766

CNN predictions w/ MCMC

CNN direct predictions

Power spectrum analysis w/ MCMC

Taken from Ribli et al. 1902.03663



A **starting kit** of the power spectrum analysis baseline solution for the Phase 1 competition is now available on our **GitHub repository** or **Google Colab**

Prizes

The Phase 1 and Phase 2 of the competition will have separate leaderboards.
We will award the monetory prizes to the top performers in either phases of the competition.

For the **Phase 1**, the top three performers will be awarded the following prizes:

🥇 First Place: $2,000

🥈 Second Place: $1500

🥉 Third Place: $500

We will announce the prize for the **Phase 2** soon.

In addition to monetary prizes, we will invite the participants who come up with top solutions to present at a our competition workshop in NeurIPS 2025.

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Status and timeline

- This challenge is one of the ***NeurIPS 2025 competitions***.

Envisioned competition schedule (UTC)		
Competition Phase	**Date**	**Description**
Phase 1	Aug 27th 2025 – Nov 16th 2025 Nov 17th 2025 – Nov 30th 2025 Dec 1st 2025	Open submissions Evaluating top submissions on hidden dataset Announcement of winners
Phase 2	End Sep – Early Jan 2026 Early Jan 2026 – Mid Jan 2026 Mid Jan 2026	Open submissions Evaluating top submissions on hidden dataset Announcement of winners
NeurIPS 2025	Dec 7th 2025	Winners will be invited to our workshop

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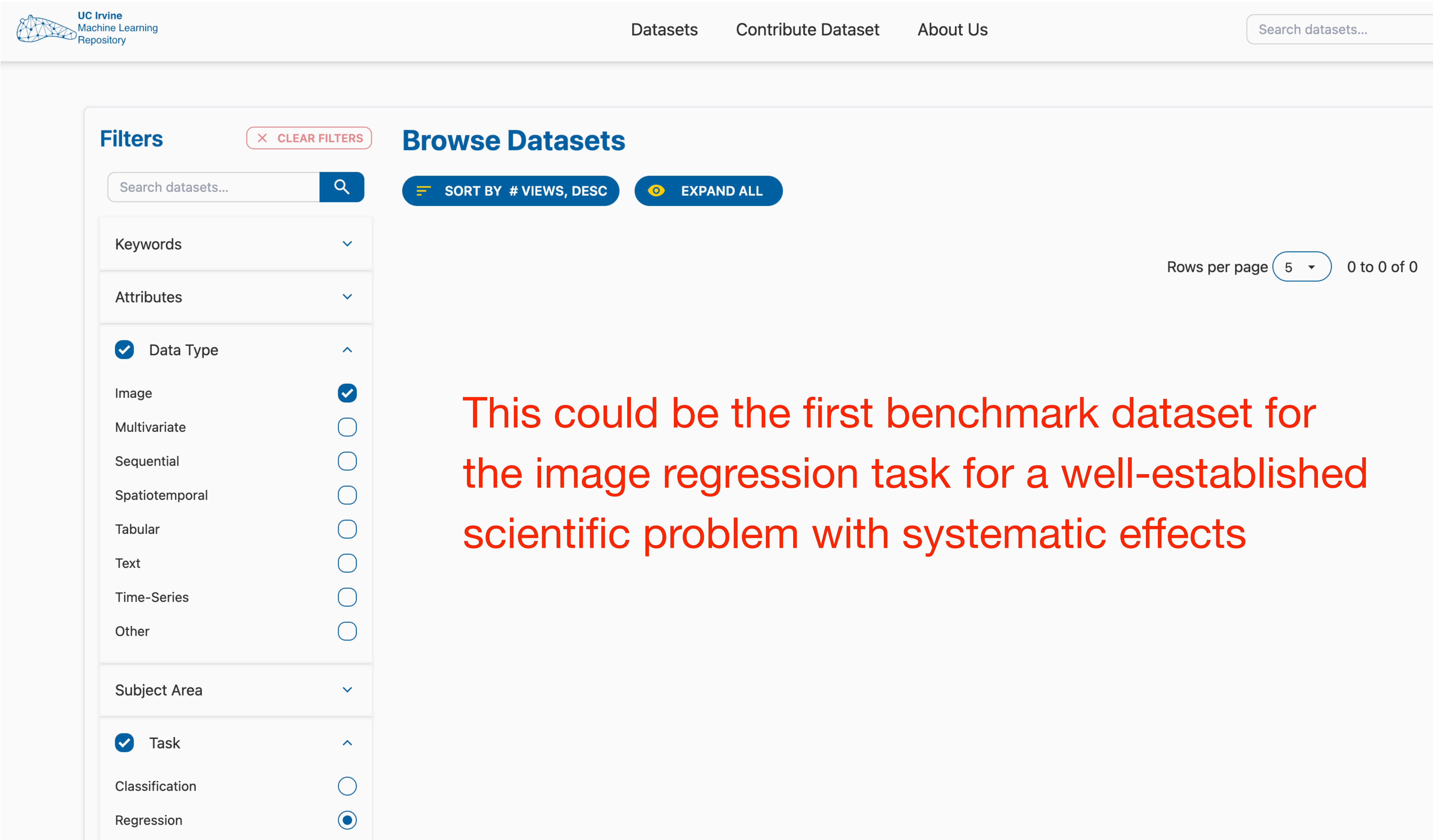
Longterm benchmark

UCI ML Datasets



This could be the first benchmark dataset for the image regression task for a well-established scientific problem with systematic effects