Constraining cosmology and baryonic physics via deep learning from weak lensing

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Introduction

The history, shape and constituents of our Universe can be described by the so-called ΛCDM cosmological model with a few parameters. One method to infer these parameters from astronomical observations is weak gravitational lensing (WL). WL is a general relativistic phenomenon which predicts that the shapes of distant galaxies appear distorted, because their light is bent as it passes through the inhomogeneous foreground Universe. We can measure the shapes of the galaxies, compute a resulting lensing convergence (κ) map of the sky, and use it to infer the evolution and structure of the Universe.

In this work[1], we expand our earlier work on deep learning[2] to extract information from κ maps. We investigate how deep learning performs in the presence of baryons[1], which are distributed differently from the dominant dark matter component, and influence the small-scale lensing features.

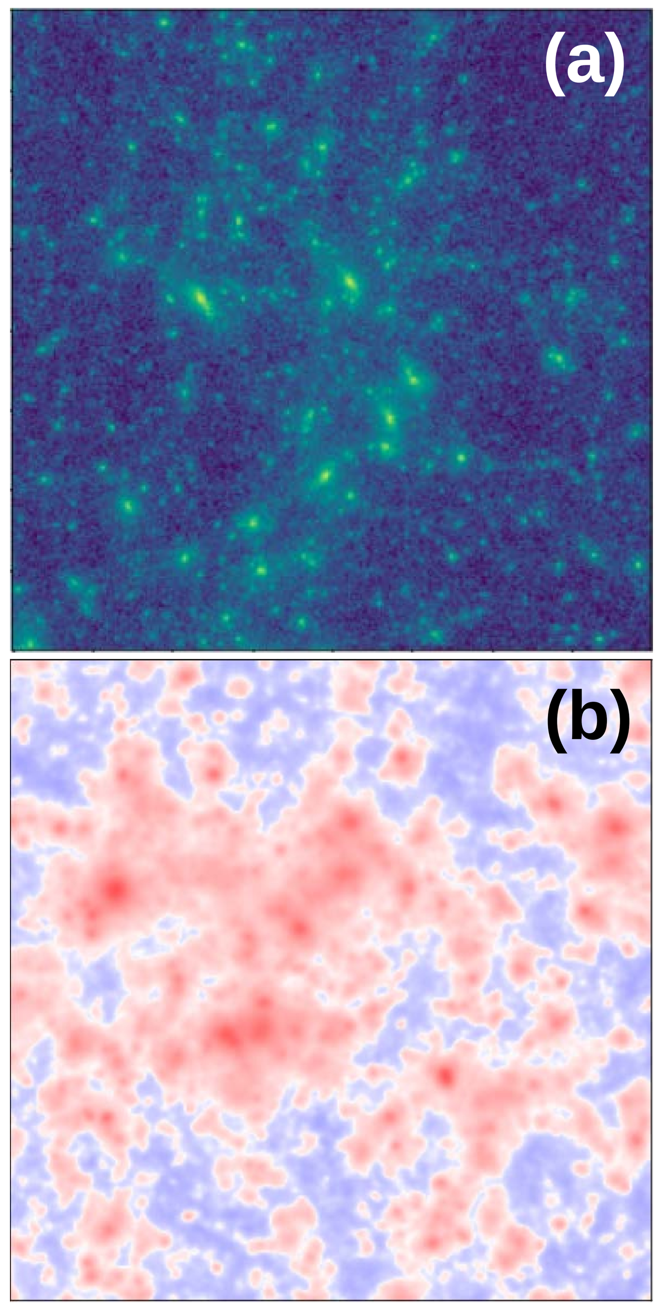

Figure 1. (a) Large-scale structure of the universe from a simulation, (b) a mock weak lensing κ map.

Methods

- Generate 150,000 κ maps with different cosmological and baryonic[3] parameters from *N*-body simulations.
- Noise is added to the κ maps according to the target galaxy number density.
- Build neural networks (with 10–40 convolution layers) predicting parameters from κ maps.
- Train the networks on the κ maps augmented with random rotation and translation (only half of the maps are used).
- Test the accuracy of the networks on the other half of the κ maps.

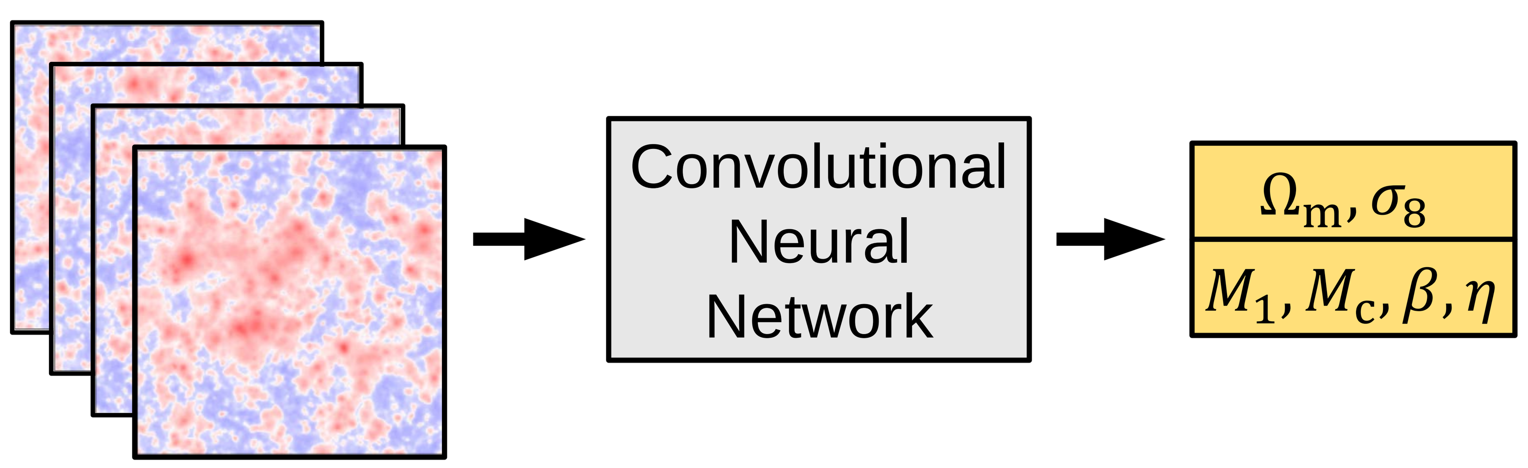

Figure 2. Training neural networks on κ maps to predict cosmological and baryonic parameters

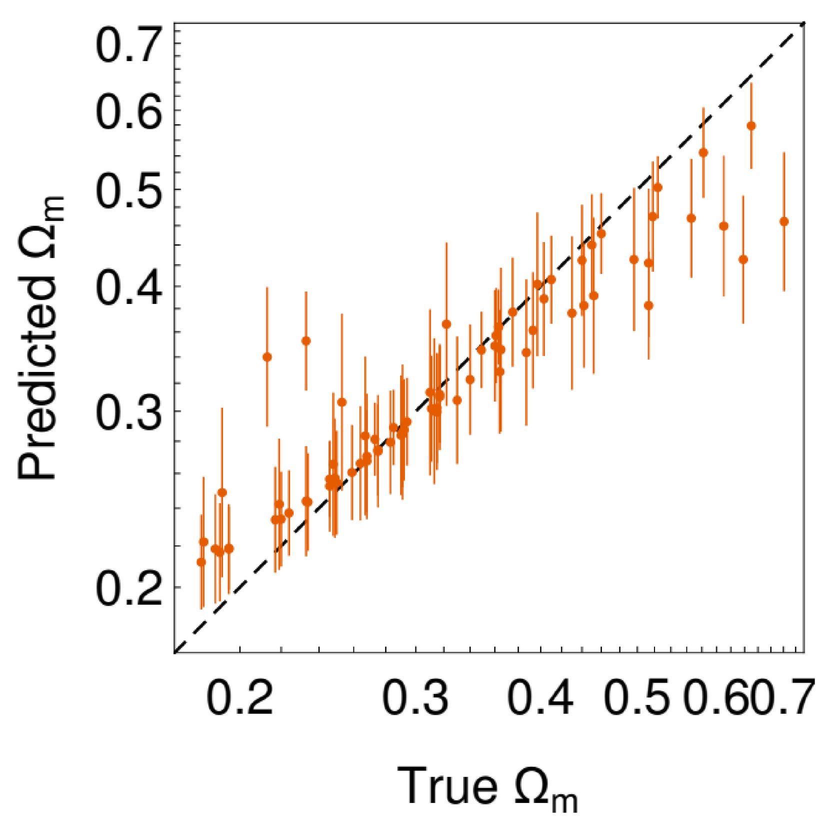

Figure 3. The predictions of Ω_m by the best network at 20 galaxies/arcmin²

Results

With Bayesian inference, we sample the posterior distribution of the parameters with MCMC, which shows the uncertainty of the inferred parameters of the input fiducial model.

Our network achieves a 1.7× tighter constraint on the two cosmological parameters (Ω_m, the matter density, and σ_8, the matter fluctuation amplitude) for a future WL survey[4] with a 1,500 deg² sky area and a 20 gal/arcmin² galaxy density. Combing the predictions by the neural network with the κ power spectrum improves the cosmological constraint by a factor of ~2, and it also improves the estimation of the baryonic model.

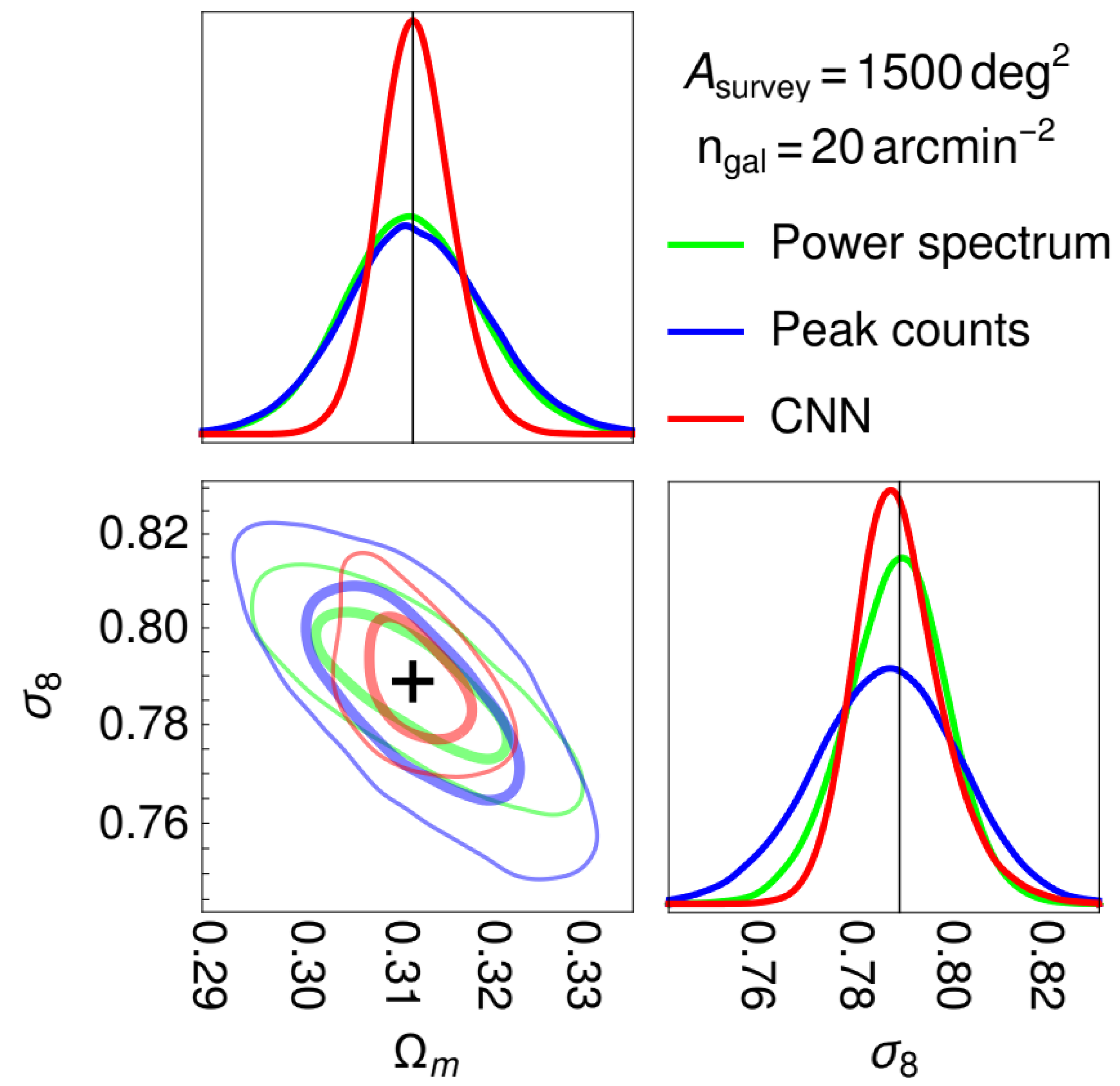

Figure 4. Posteriors (1σ and 2σ contours) of the CNN and two other methods

Method	Area of 1σ contour $\Omega_m - \sigma_8$	Area of 1σ contour $M_1 - \eta$
Power spectrum	1.00	1.00
Peak counts	1.71	2.94
CNN	0.60	1.25
CNN+Power spectrum	0.28	0.44

Table 1. Comparison of posterior areas between the methods

Conclusions

We have built a convolutional neural network to learn from weak lensing convergence maps and to predict the parameters of the ΛCDM cosmological model. We measure the performance of the network under the influence of uncertain baryonic effects, and we find that it performs 1.7× better in terms of the constraint in the $\Omega_m - \sigma_8$ parameter space. We also find this improvement to be stable across various galaxy number densities, which makes it a promising method for current and future lensing surveys.

Acknowledgments

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