Symbolic Regression for Learning Scale Transition Equations in Synthetic Fractal Surface Roughness

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Motivation

- Surface roughness exhibits multiscale, fractal structure.
- Modeling transitions across scales is essential for accurate physical simulation.
- Existing ML models are black-box and lack interpretability for scientific use.

Method

- We generate synthetic fractal roughness with multiscale perturbations.
- Apply coarse-graining (mean, median filters) to produce large-scale descriptors.
- Symbolic regression (PySR) discovers compact, interpretable equations mapping fine-scale features to coarse-scale behavior.

$R^2 = 0.999997$ MSE = 3e-6   RMSE = 0.00185
Prediction aligns closely with ground truth (see plot →)

Symbolic regression captures interpretable scale transitions, offering a transparent alternative to black-box ML.

Symbolic Regression Predictions with Bootstrap Uncertainty