GlobalTomo: A global dataset for physics-ML seismic wavefield modeling and FWI

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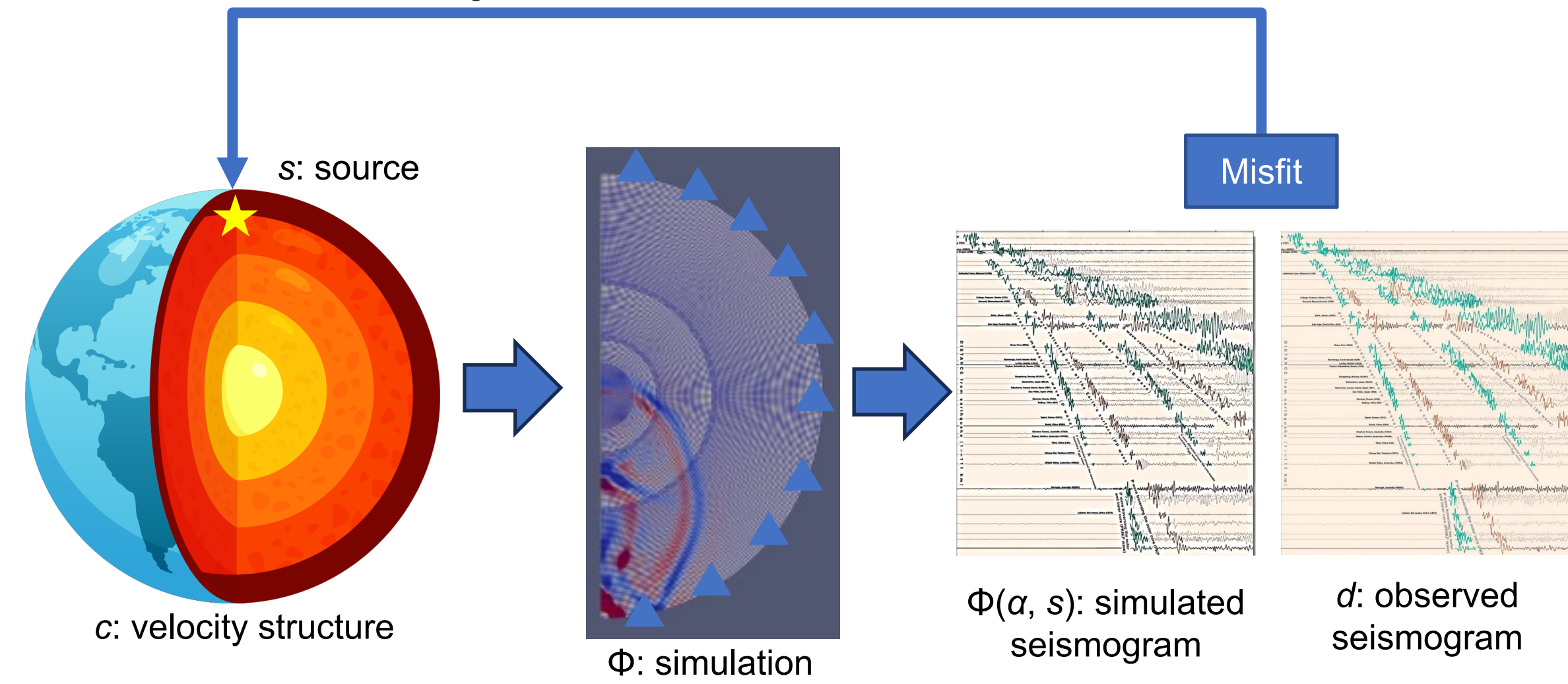
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Overview

Understanding the earth's internal structure is a long-standing scientific question.

Two typical steps to uncover the earth:
- Forward modeling
- Full waveform inversion (FWI)

$$c^* = \arg\min_c J(\mathbf{d}, \Phi(c,s)) + \lambda F(c,s)$$

$F(c,s)$: regularization

s: source

Misfit

c: velocity structure

Φ: simulation

$\Phi(\alpha, s)$: simulated seismogram

d: observed seismogram

Challenges

Limitations of traditional methods.

- Traditional numerical simulations for forward modeling are highly computationally intensive (up to 10^7 CPU hours).
- Adjoint-based FWI methods are prone to local minima, often leading to ill-posed solutions.
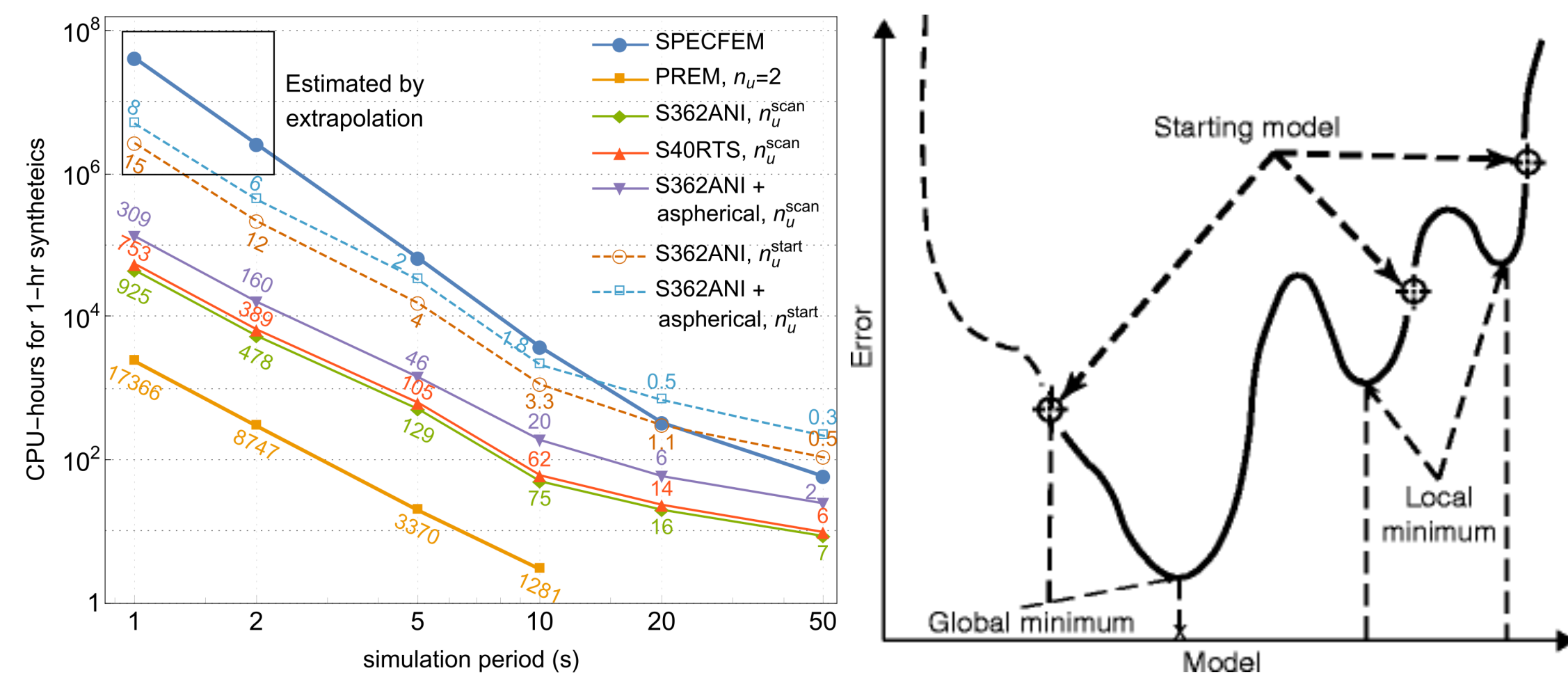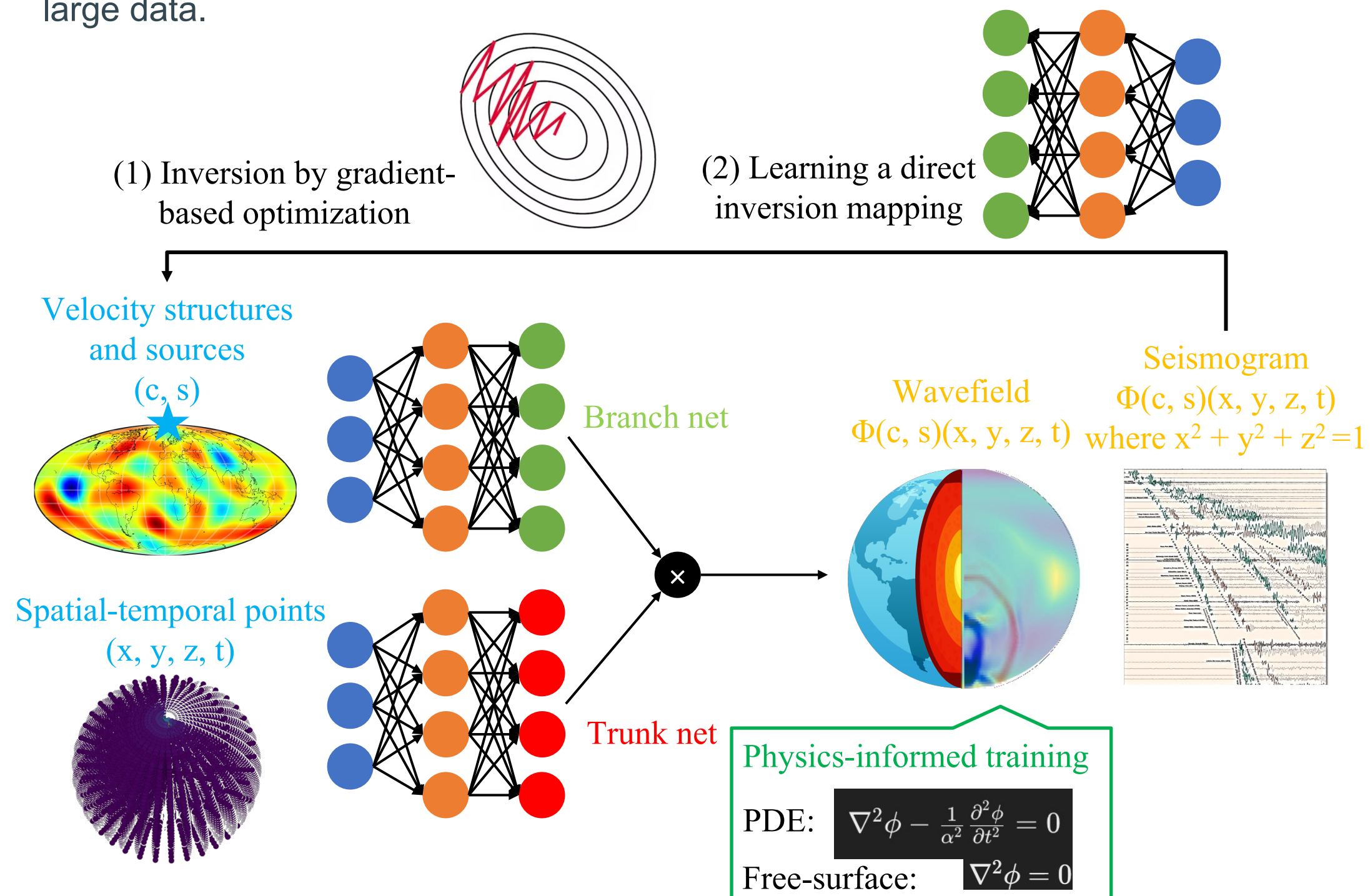

GlobalTomo Dataset

The first 3D global synthetic dataset tailored for ML-based seismic wavefield modeling and full-waveform tomography.

Velocity structure

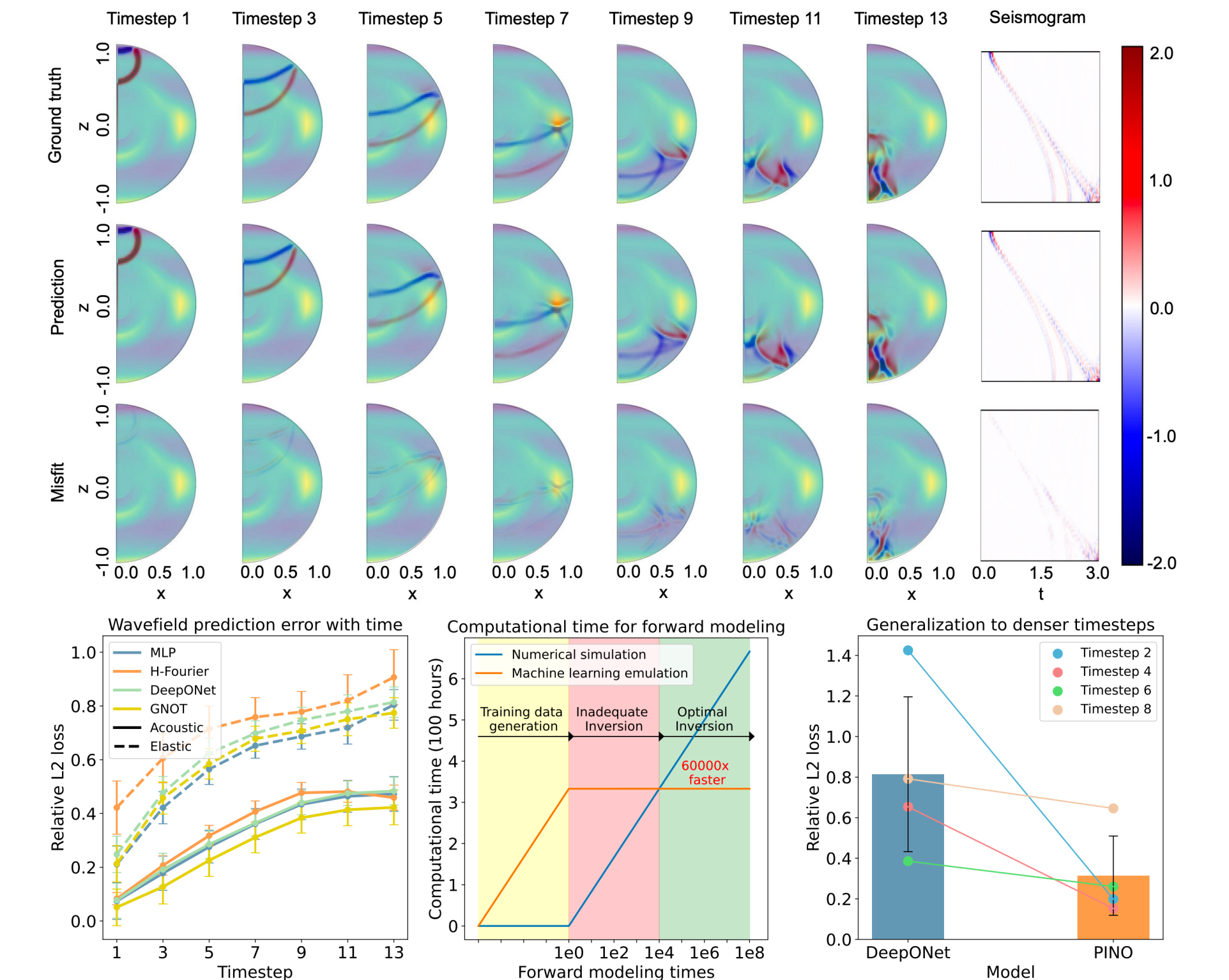Acoustic | Elastic | Real Earth

AxiSEM3D
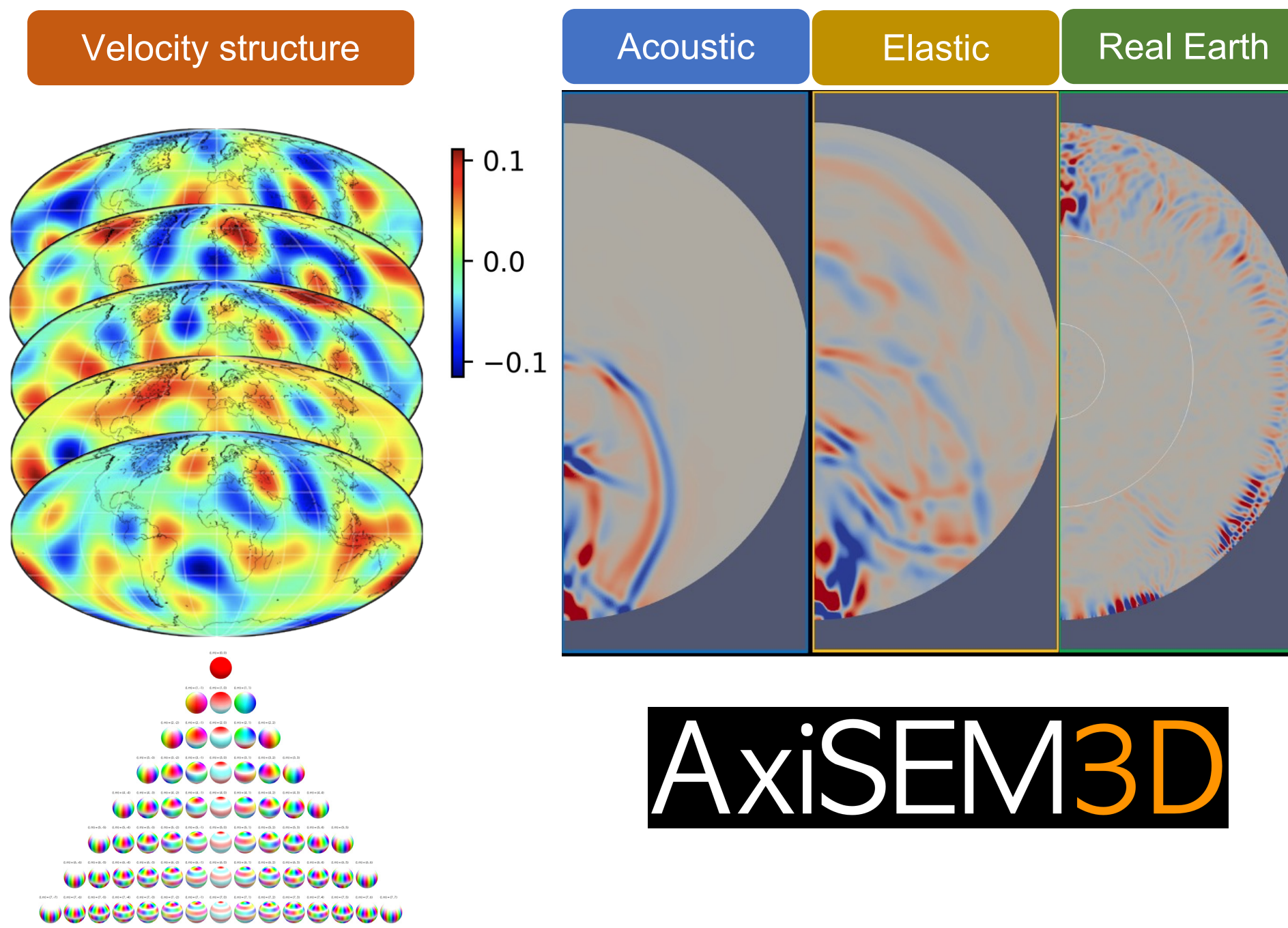
Neural operator learning

Learning a fast neural proxy to solve underlying PDEs.

- ML methods may accelerate forward modeling using neural operators running on GPUs.
- ML methods may alleviate the ill-posed problem in FWI by learning from large data.

(1) Inversion by gradient-based optimization

(2) Learning a direct inversion mapping

Velocity structures and sources (c, s)

Branch net

Spatial-temporal points (x, y, z, t)

Trunk net

Wavefield $\Phi(c, s)(x, y, z, t)$

Seismogram $\Phi(c, s)(x, y, z, t)$ where $x^2 + y^2 + z^2 = 1$

Physics-informed training

PDE: $\nabla^2 \phi - \frac{1}{\alpha^2}\frac{\partial^2 \phi}{\partial t^2} = 0$

Free-surface: $\nabla^2 \phi = 0$

Results: Forward modeling

Results: Inversion

Gradient-based inversion, direct inversion mapping

This section is an example of a paragraph. When creating sections, regardless of whether you're putting in text or images, always try to align to the edges of the yellow guidelines.

Ground truth | Inverted structure | Ground truth | Inverted structure

Degree 4

Degree 6

Degree 8

Velocity perturbation

Ground truth | Inverted structure

Checkboard 1

Checkboard 2

Model	R ↑	MAE ↓	RMSE ↓
MLP+L-BFGS	0.415	0.437	0.528
DeepONet+L-BFGS	0.225	0.482	0.569
H-Fourier+L-BFGS	0.161	0.618	0.750
InversionNet-3D	0.794	0.272	0.356
InversionMLP	**0.826**	**0.253**	**0.335**