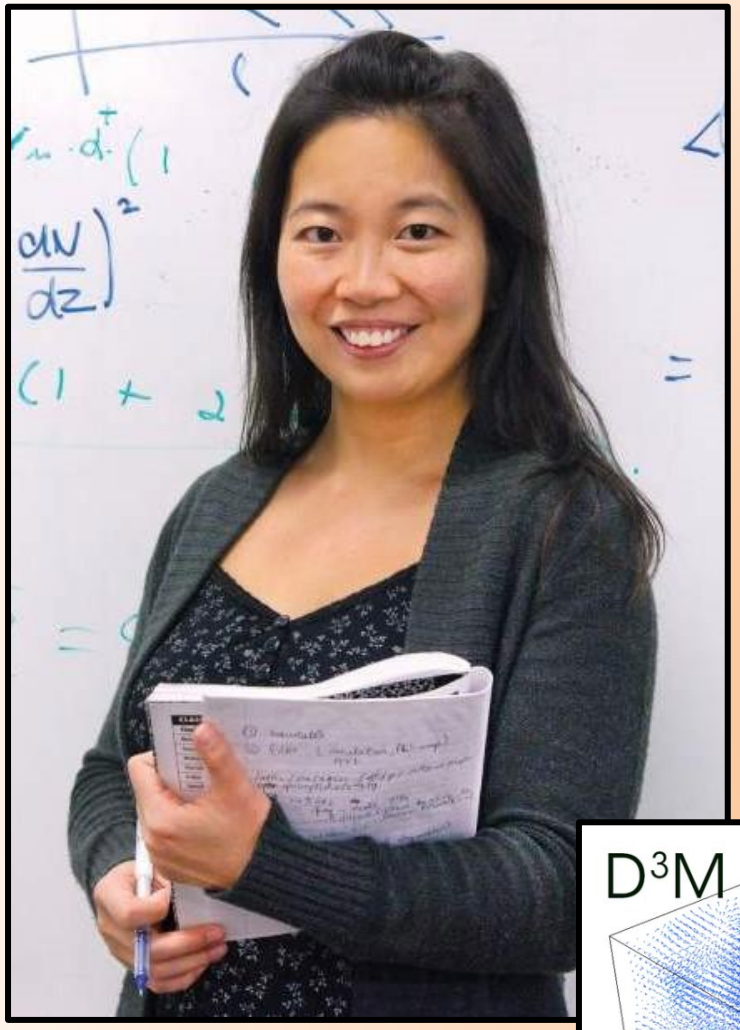
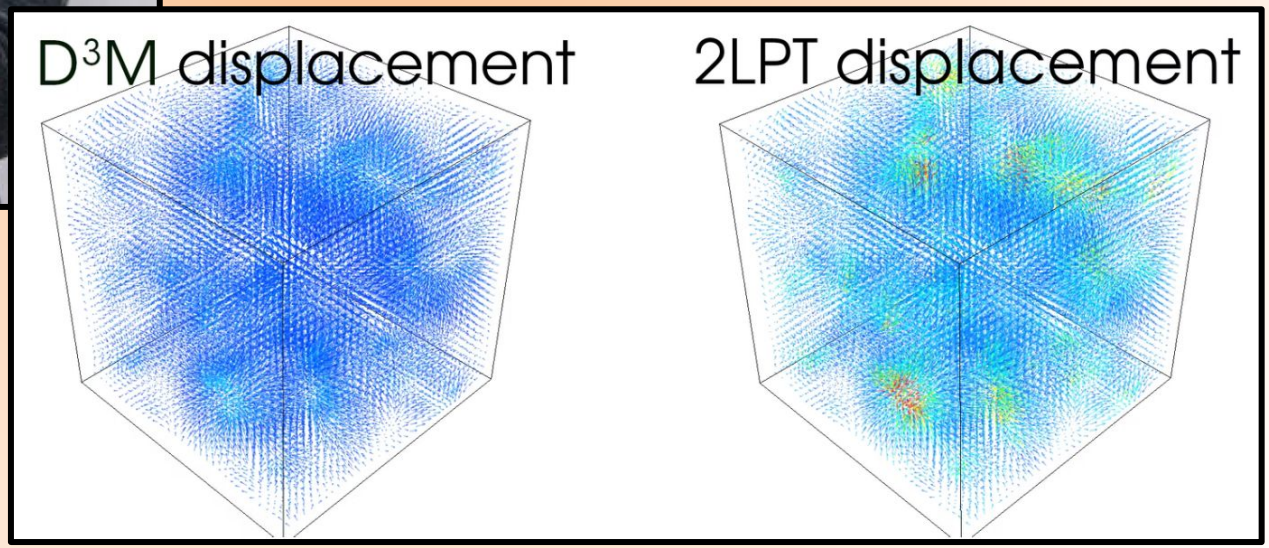


Shirley Ho is a cosmologist and astrophysicist who studies **dark matter**, **dark energy**, and **cosmological models**. She recently led her team in developing a **deep learning algorithm** that simulates the large scale structure of the Universe.



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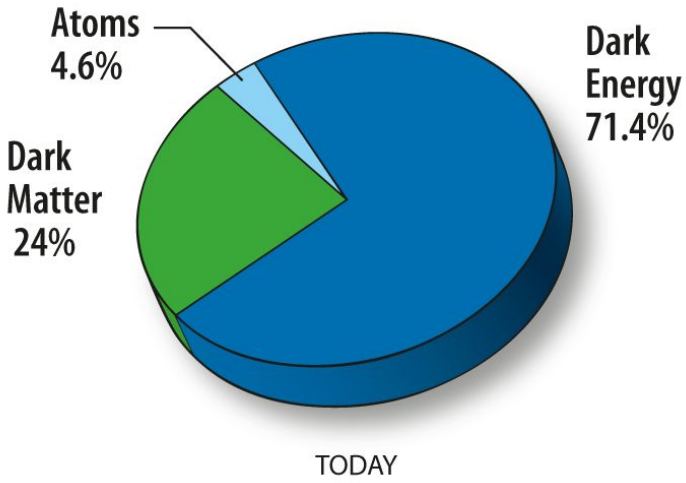
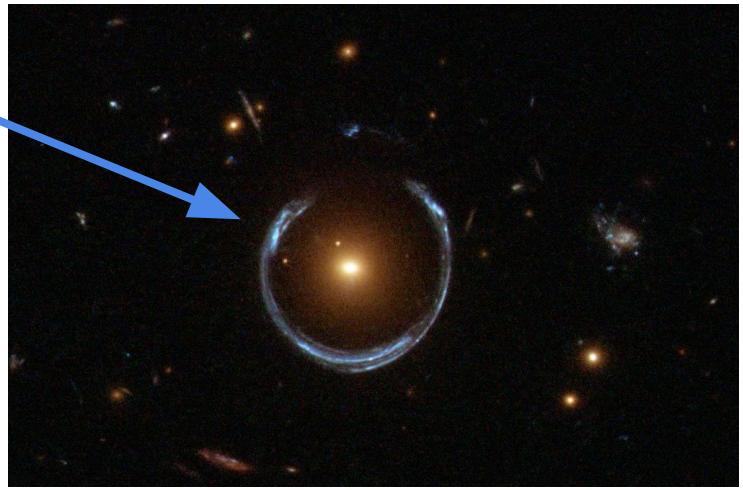
The Universe is made up of **baryonic matter**, **dark matter**, and **dark energy**.

Dark matter is believed to only interact gravitationally with baryonic matter.



Einstein ring



Weak gravitational lensing can be used to determine the background distribution of of **dark matter**.

Observations of **supernovae** in the 1990s showed that the Universe's expansion is accelerating. **Dark energy** is the name given to the unknown force that drives this.

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Cosmologists want to compare the **Observed Universe** to the **Predicted Universe** from simulations.

If the models behind simulations are correct, they should be able to predict **cosmological parameters**, such as the densities of dark matter and dark energy.

Uchuu, for example, is the largest simulation of the Universe and it cost 20 million **CPU hours** (the time it takes for a single CPU to run).

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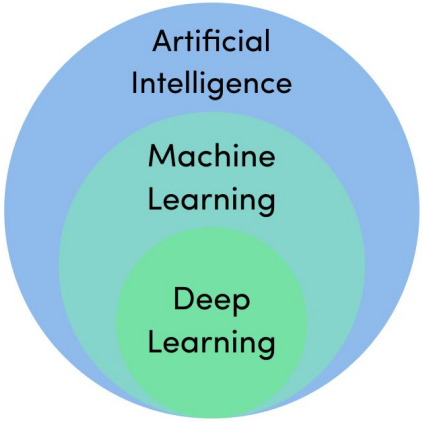
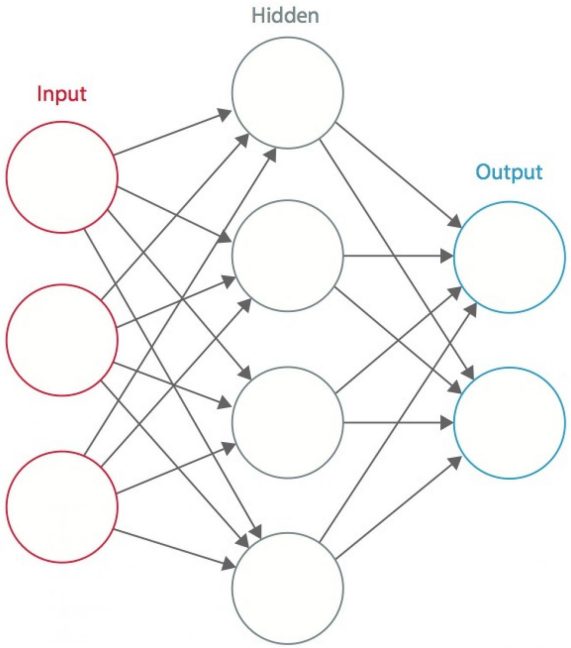
Deep learning algorithms can significantly cut the computational cost of analytical simulations.

Neural networks are a type of machine learning algorithm made up of artificial **neurons** (or nodes) that process information.





The simplest neural network consists of an **input**, a **hidden layer** that performs functions on the input, and an **output**.

The connections between neurons are given by **weights**, which are used to **linearly combine** inputs to a neuron.

A **non-linear activation function** controls the amplitude of the output.

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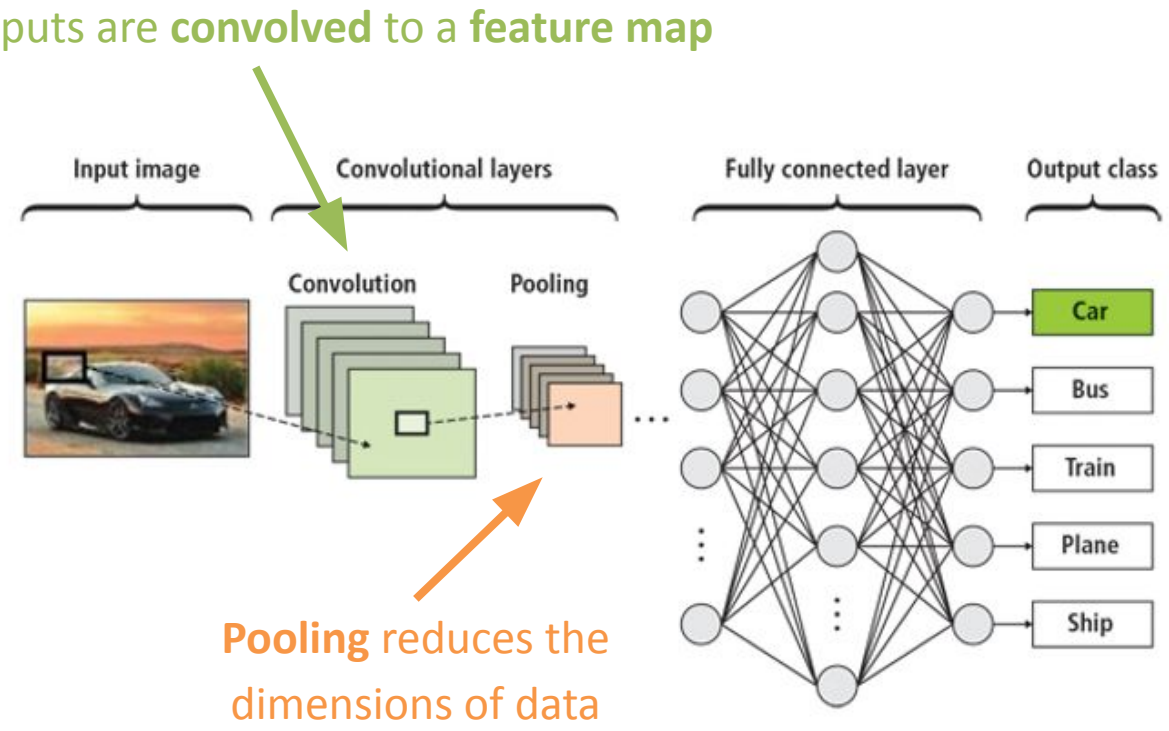
Convolutional neural networks (CNNs) are type of neural network where some of the hidden layers **convolve** their inputs before passing information to the next layer.

CNNs useful for **image classification** because of their abilities to detect patterns.

The algorithm "learns" by adjusting the **biases and weights** in the functions performed in each layer.



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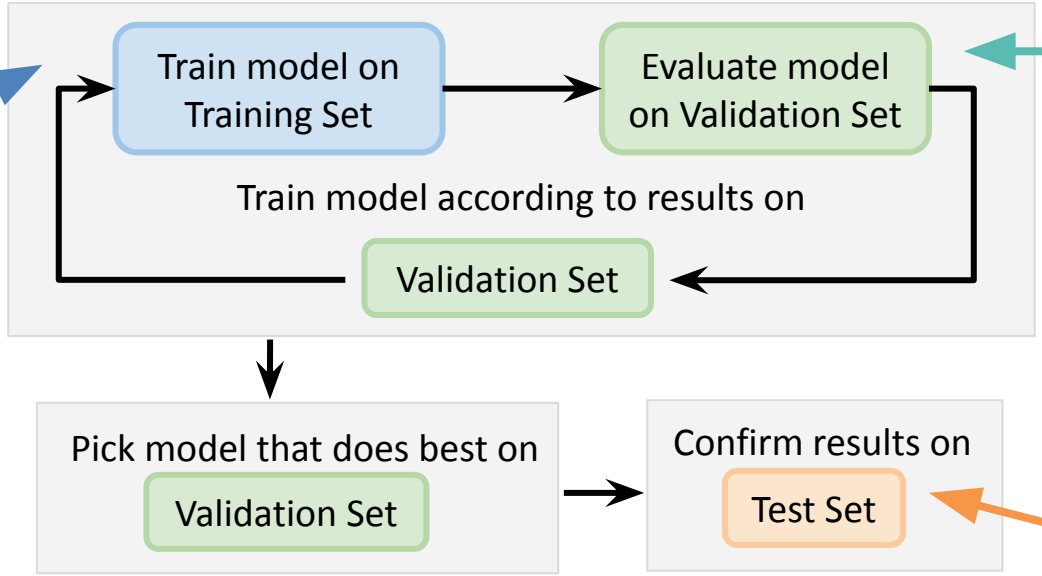
Machine learning algorithms build a mathematical **model** using data divided into three subsets.

The model is trained on **training data** which has paired inputs and **target** outputs. This tunes the model's **parameters**.



Testing the model on **validation data** tunes the model's **hyperparameters**.

The final model is tested on **test data** that it has not seen before.

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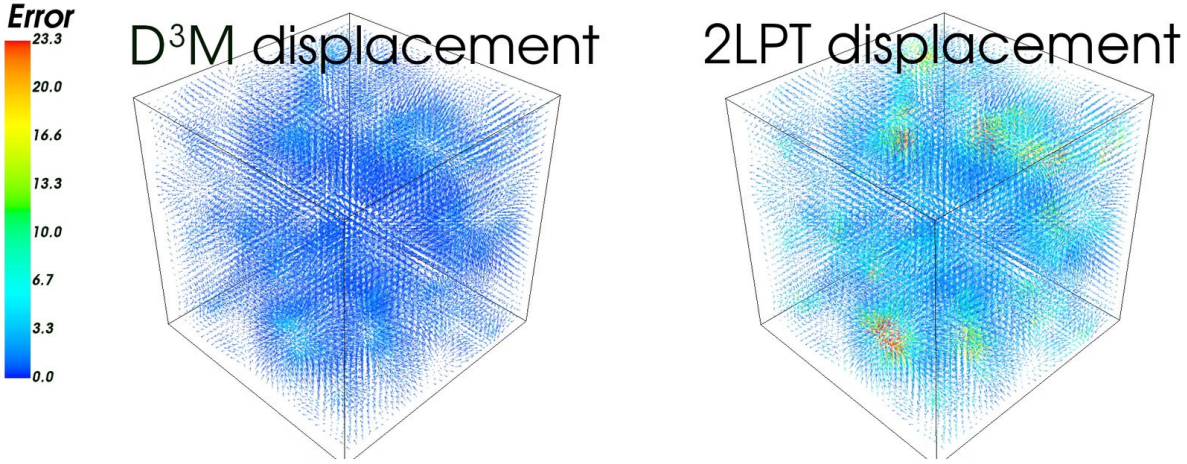
N-body simulations are a way of predicting **structure formation** in the Universe. The simulations generate data that are snapshots of the simulated Universe at various times and they can be extremely computationally expensive to produce.

Ho's group used a CNN called the "**Deep Density Displacement Model**" (D^3M) to simulate a dark matter-only Universe evolved under gravity.



D^3M outperforms the popular **benchmark model** used by cosmologists: "**second order Lagrangian perturbation theory**" (2LPT). It does this at a lower computational cost.

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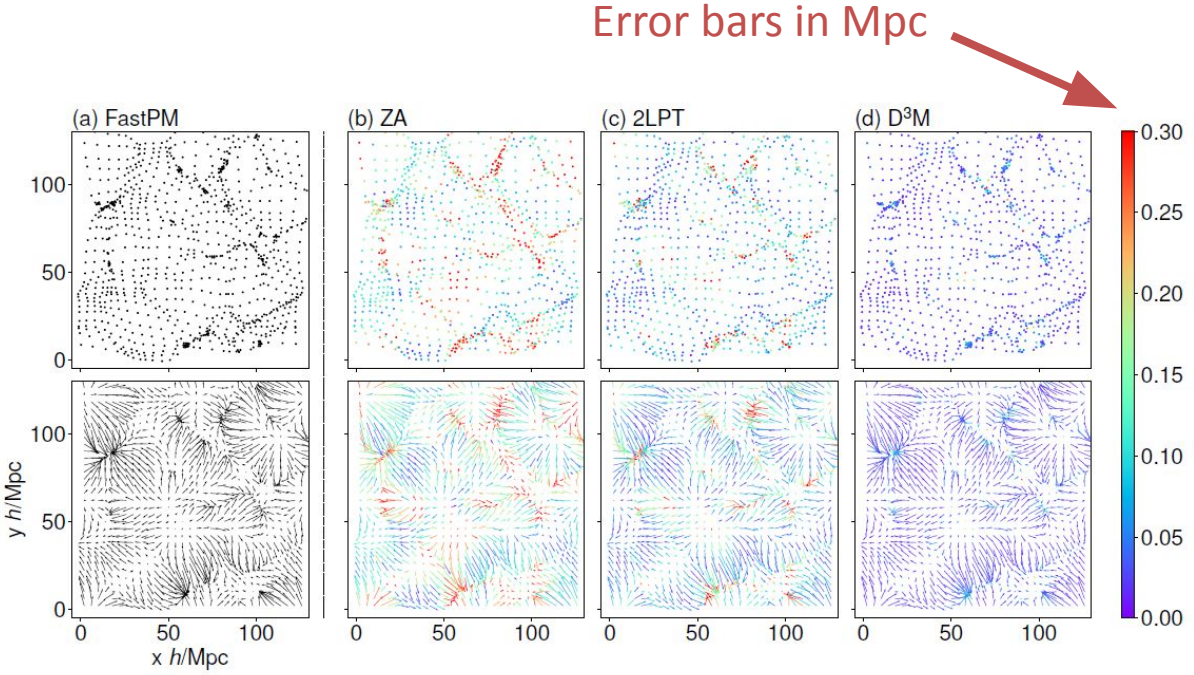
The input data are generated using a **linear** analytical model: the **Zel'dovich Approximation** (ZA).

FastPM generates the **target** output. It takes the displacement field from ZA and **evolves** the particles under gravity.



The displacement fields show structures like **filaments**, **clusters**, and **voids**.

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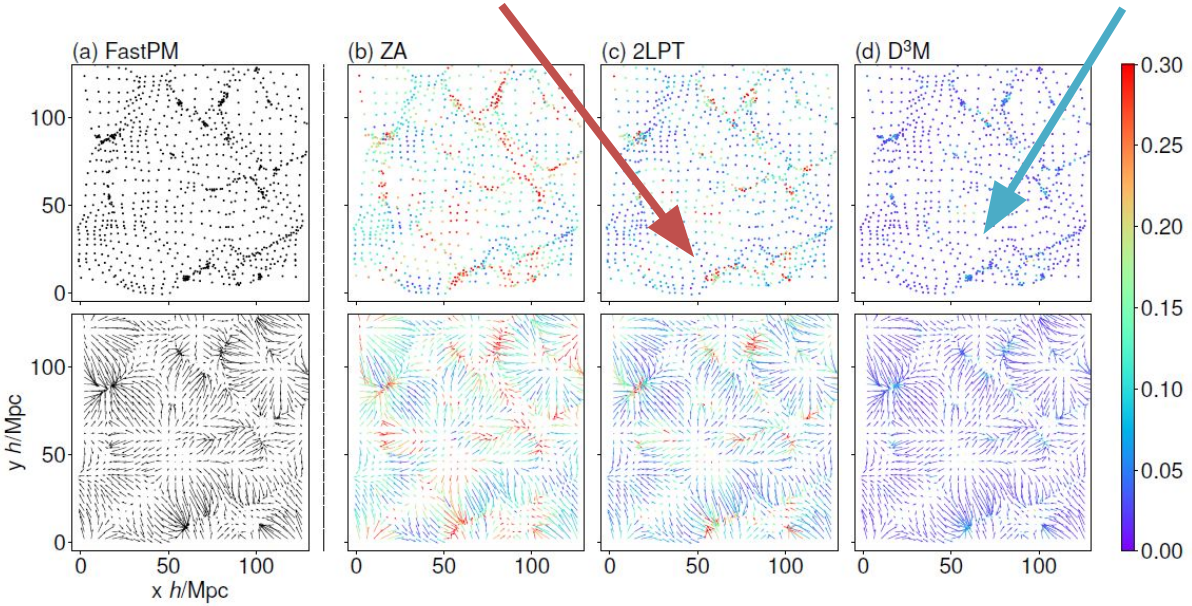
Ho's group used "**second order Lagrangian perturbation theory**" (2LPT) as a **benchmark** to compare with D^3M.

They found that D^3M **outperformed** 2LPT for a lower computational expense.

Maximum errors from 2LPT are higher than those from D3M



D^3M is also able to **predict structure formation** beyond its training data