Artificial Neural Networks to investigate the geometry and dynamics of the Universe

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AlmaHAI: Hard Sciences

KICK-OFF WORKSHOP

28 APRIL 2021

Overview

The **huge amount of data** available today has drastically changed the way we do science. **Cosmology** is not an exception, it is indeed one of the most revolutionized scientific branches. Research in this field therefore represents an ideal context in which to **test the most innovative data analysis techniques**.

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- The **large-scale structure of the Universe** and the **Standard Cosmological Model**

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- The **large-scale structure of the Universe** and the **Standard Cosmological Model**
- The common data analysis methods: the **two-point correlation function**
- **Artificial Neural Networks** for Cosmology, in particular to study **the properties of Dark Energy**, the enigmatic form of energy that we believe to be responsible for the accelerated expansion of the Universe

The large-scale structure of the Universe

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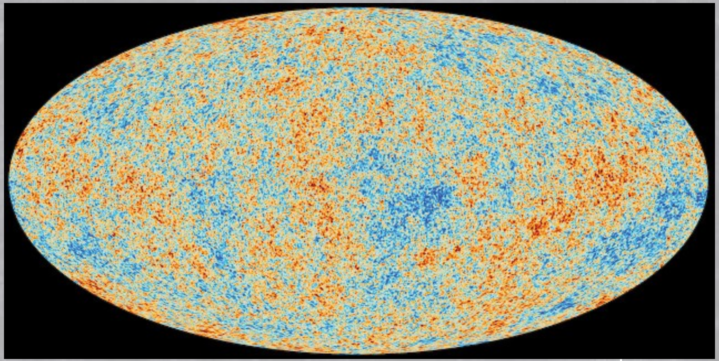

All-sky picture of the oldest light in our Universe, imprinted on the sky when it was just 380 000 years old. According to the standard model of cosmology, the fluctuations arose immediately after the Big Bang and were stretched to cosmologically large scales during a brief period of accelerated expansion, known as inflation.

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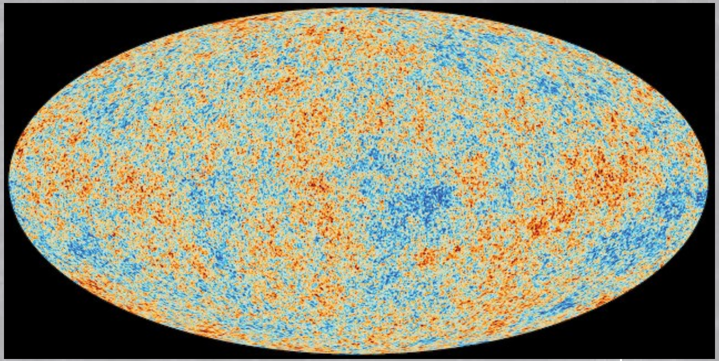

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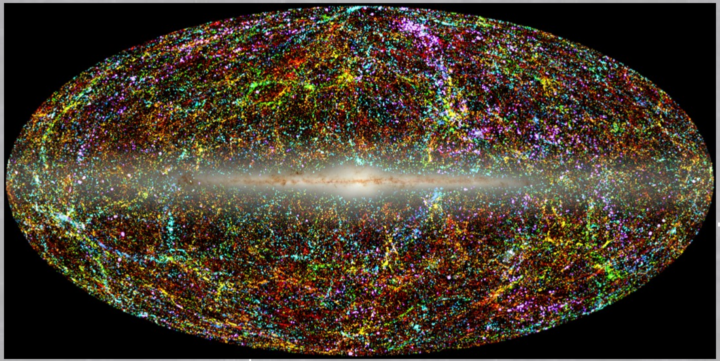
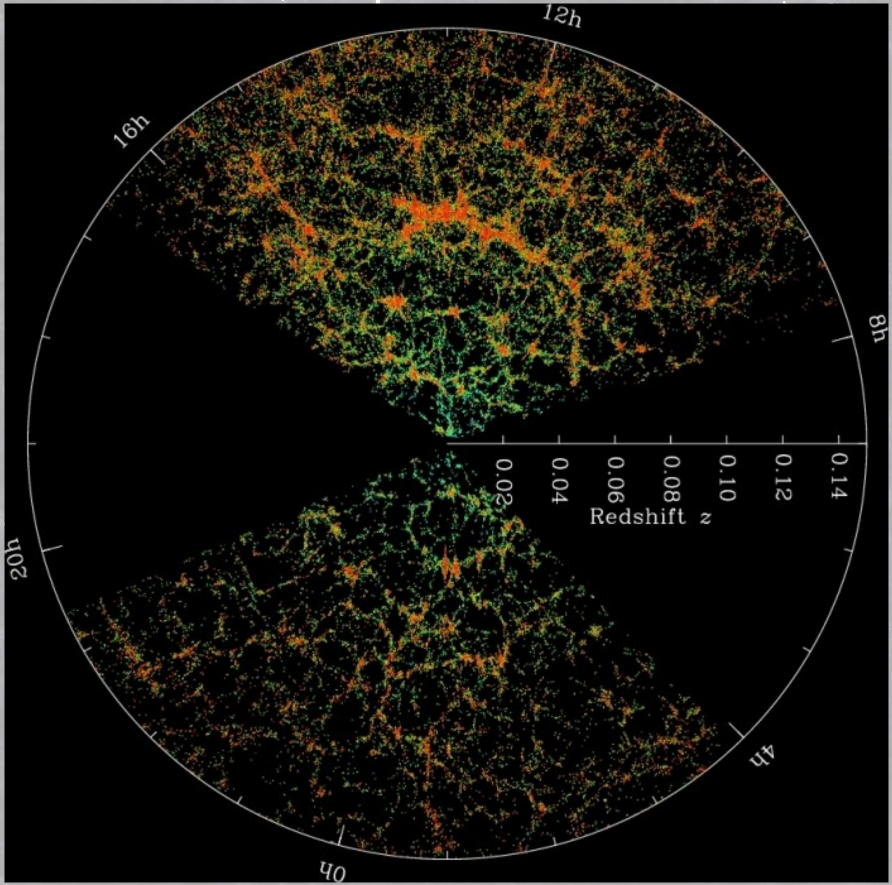


Panoramic view of the entire near-infrared sky reveals the distribution of galaxies beyond the Milky Way. The image is derived from the 2MASS Extended Source Catalog (XSC) – more than 1.5 million galaxies.

The large-scale structure of the Universe



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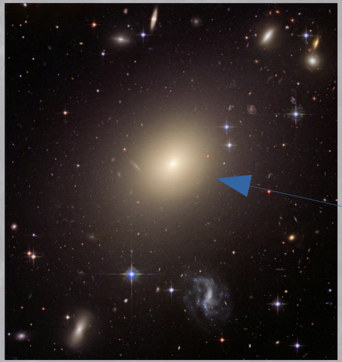
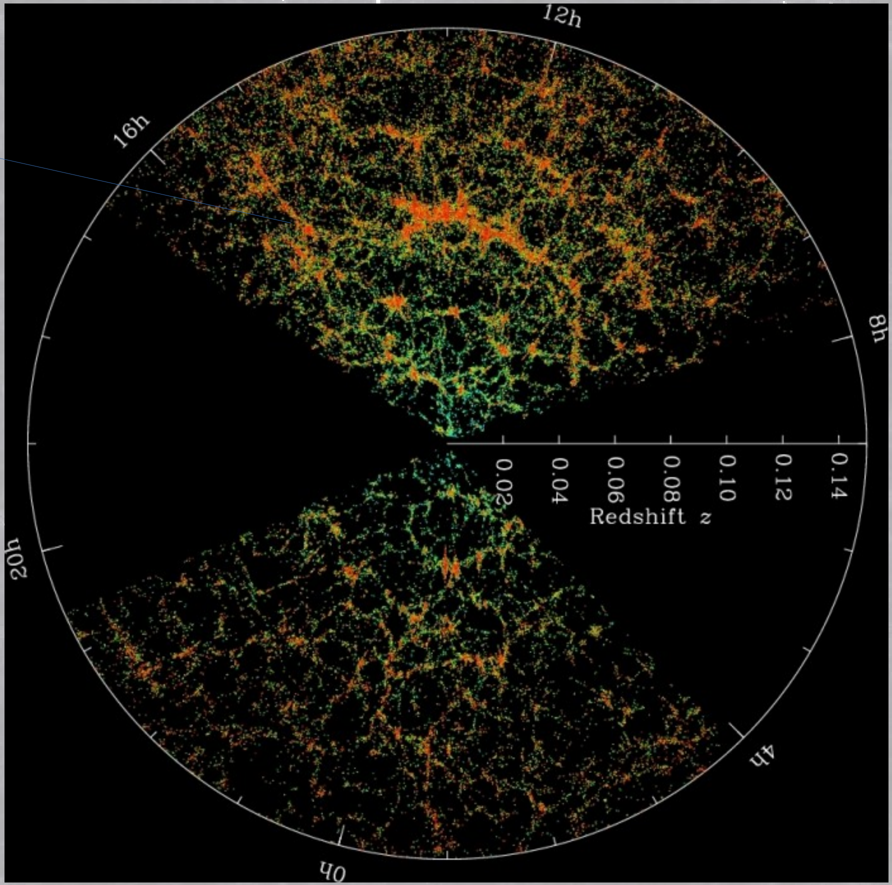


elliptical galaxy



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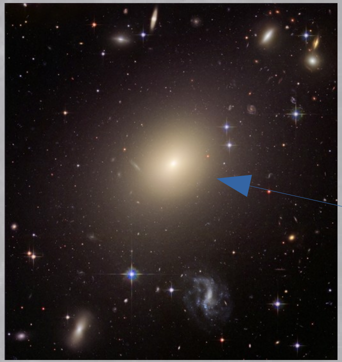

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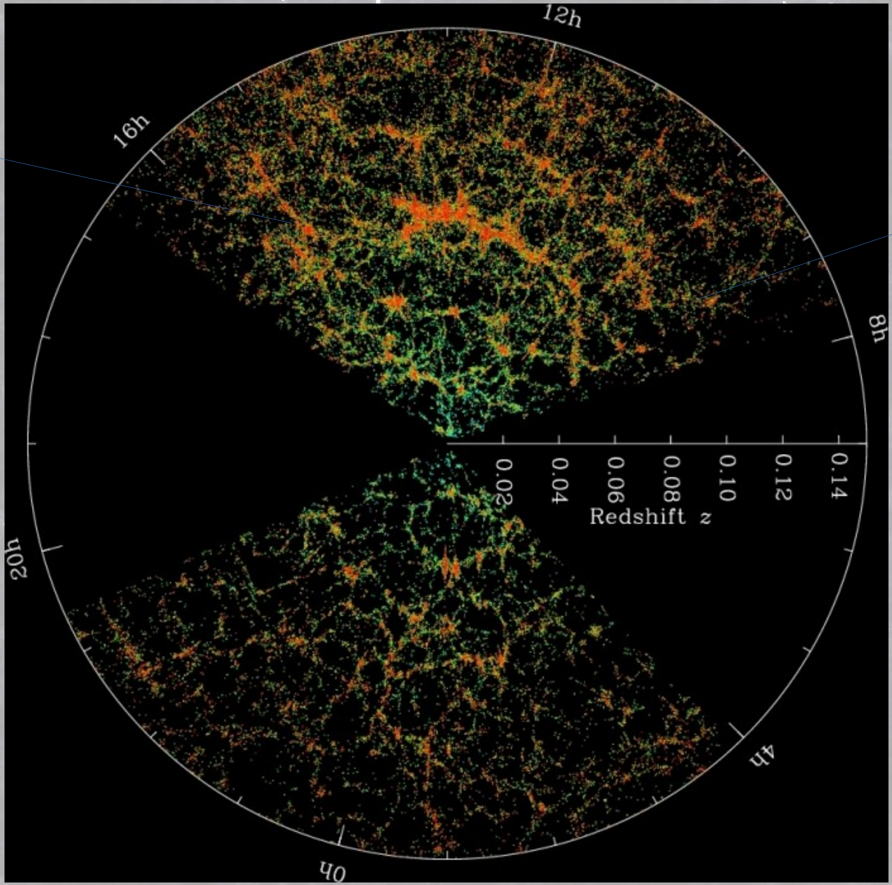

spiral galaxy

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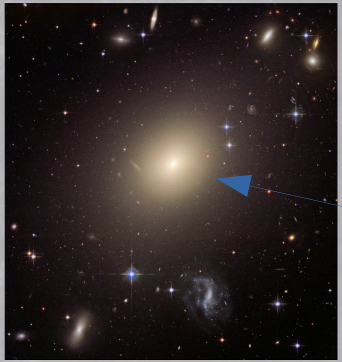

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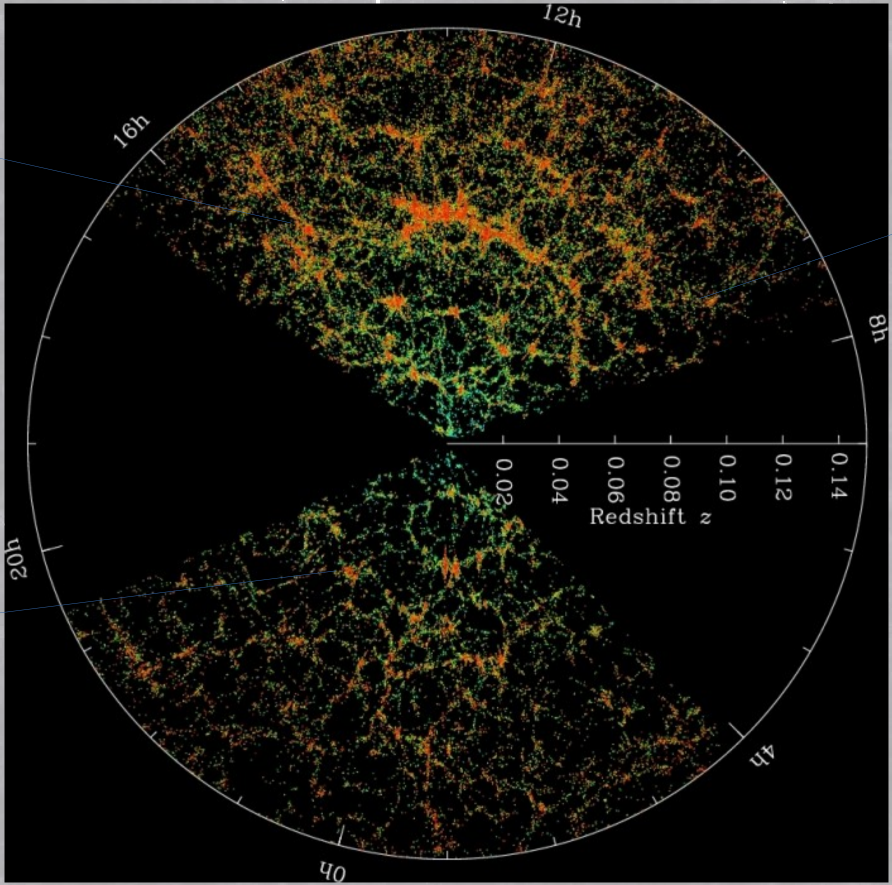

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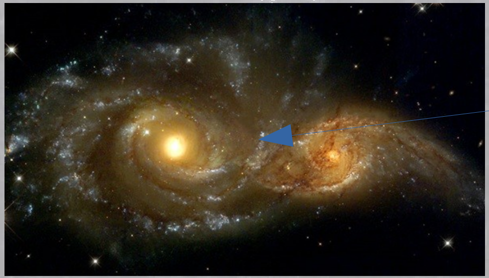

interacting galaxies

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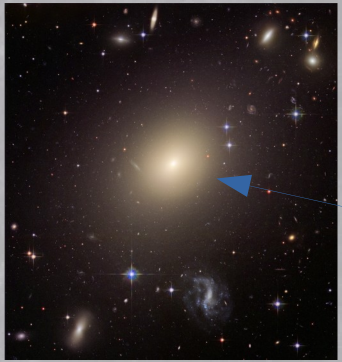

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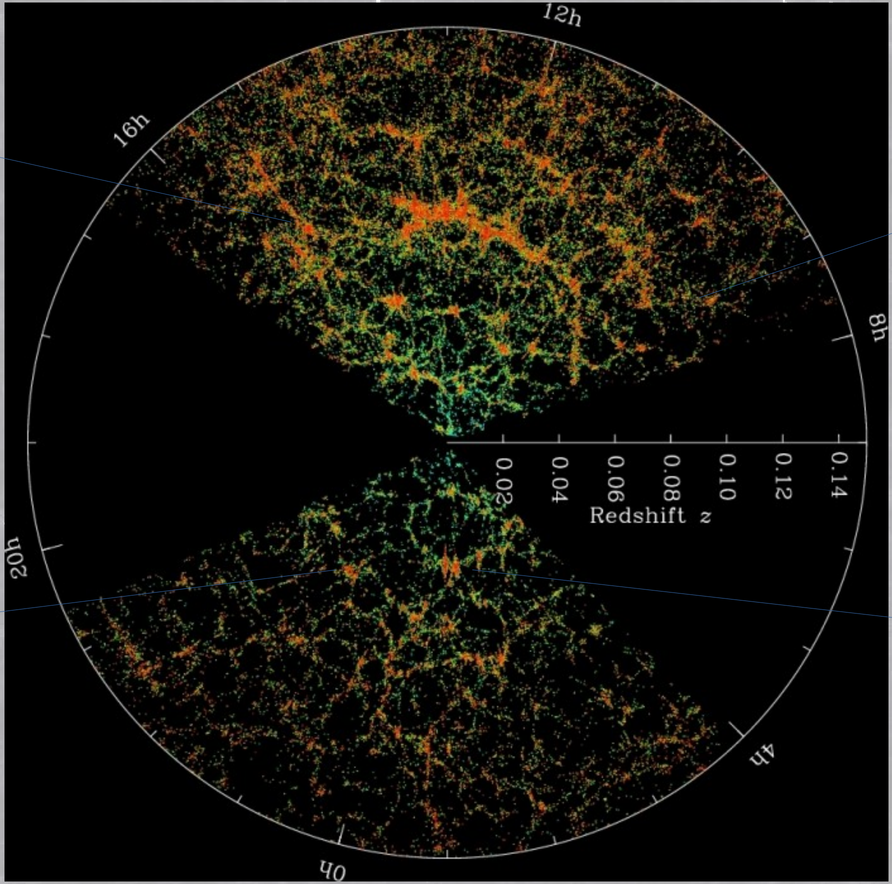

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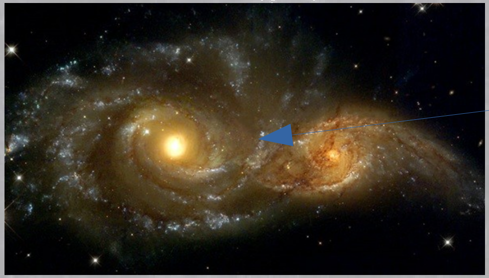
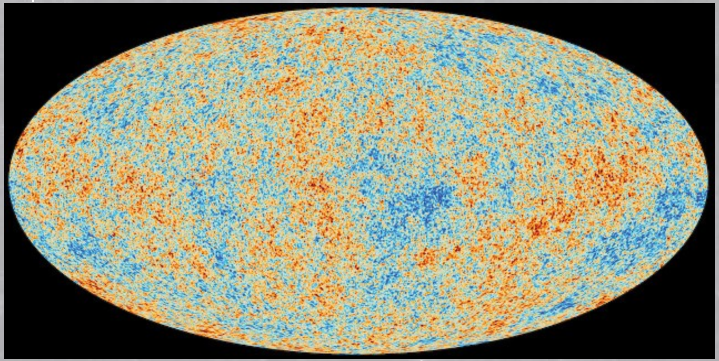


interacting galaxies

galaxy cluster

The Standard Cosmological Model



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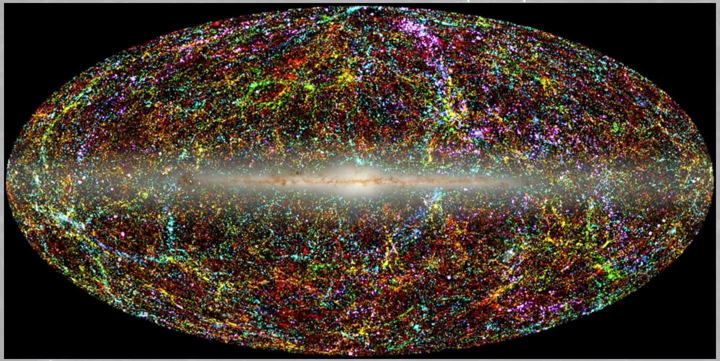

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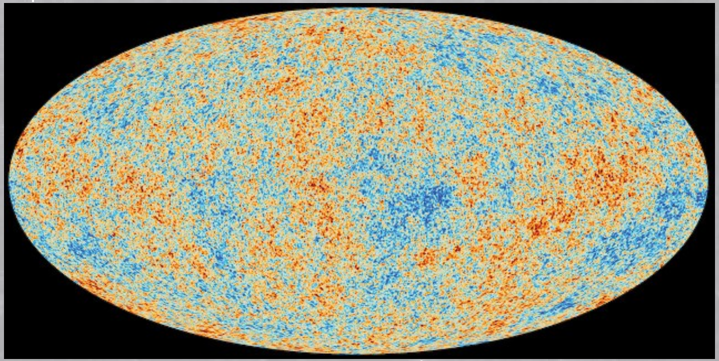

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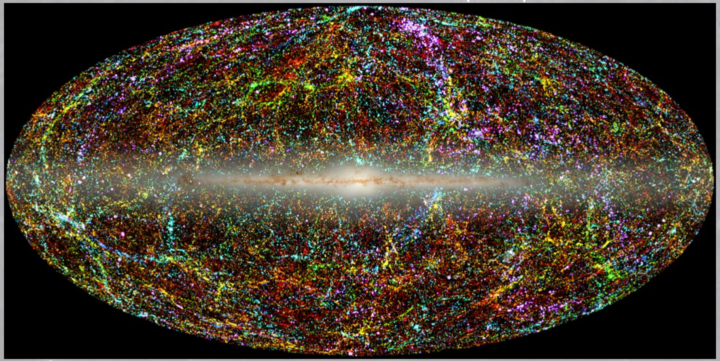

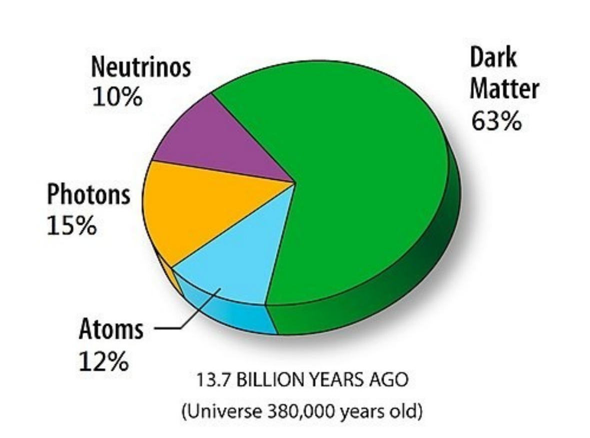

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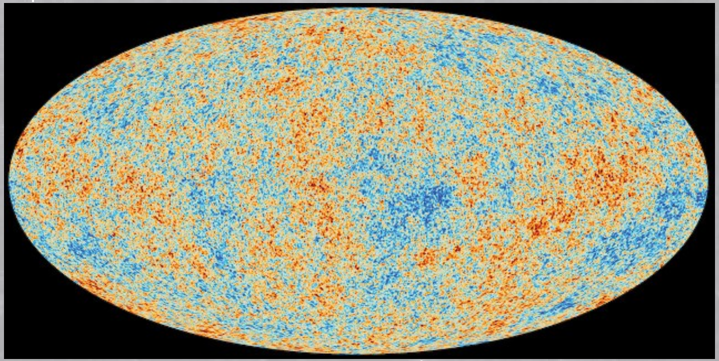

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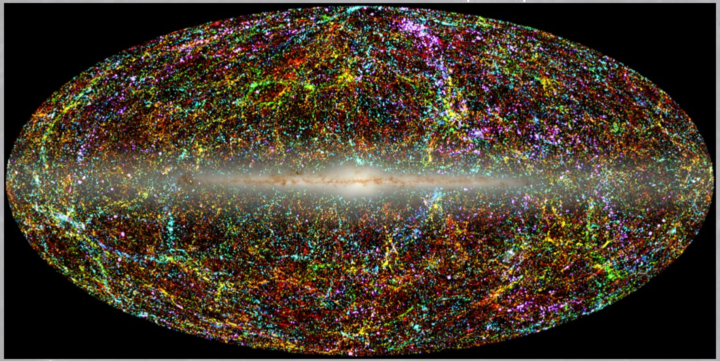
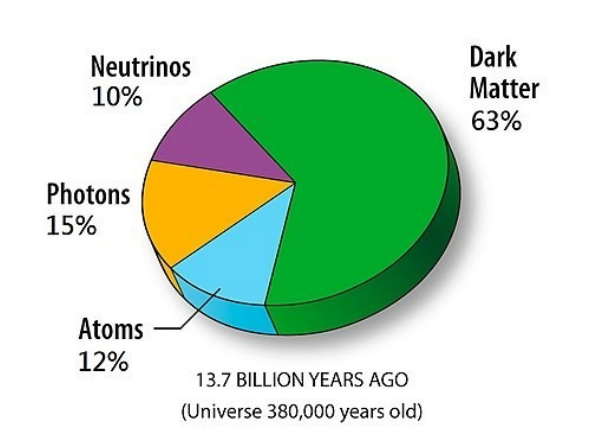
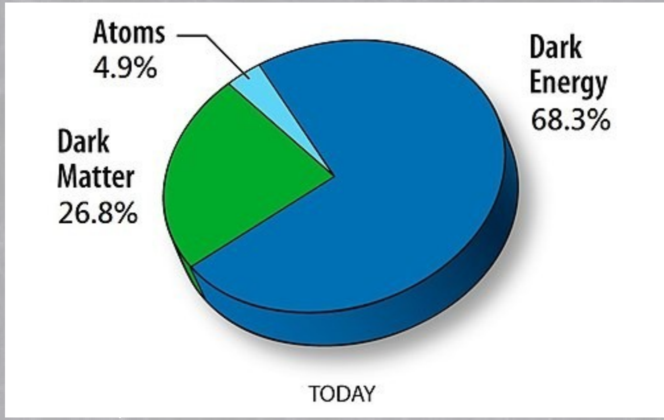
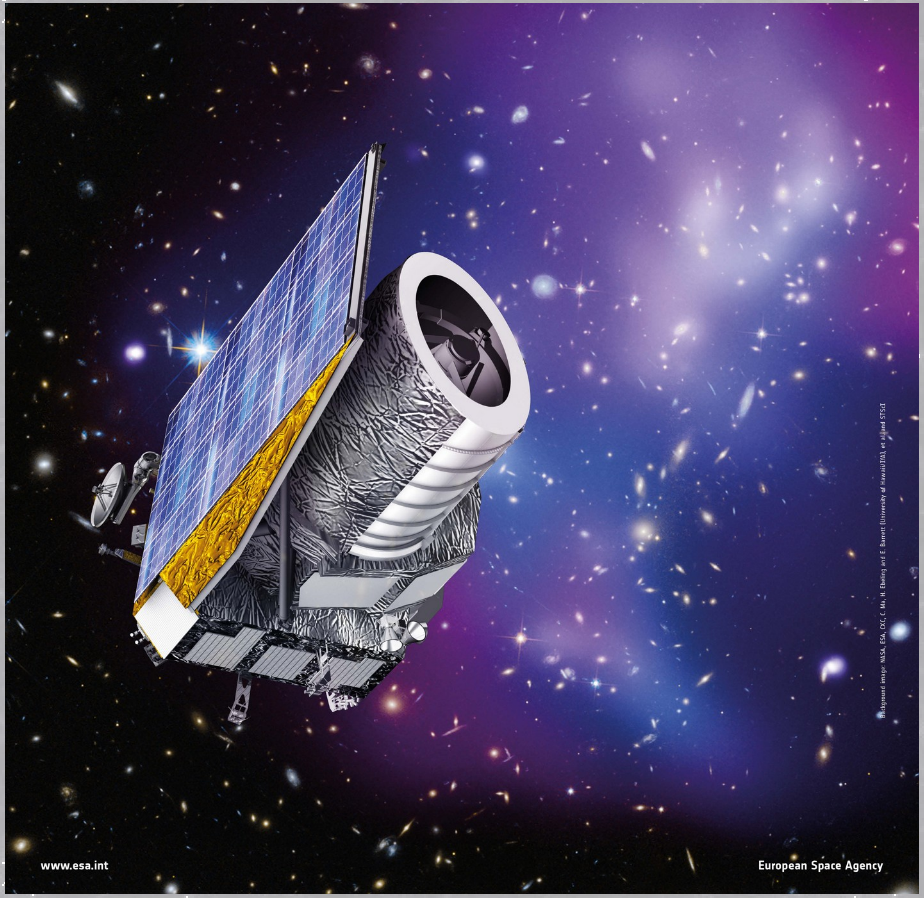






The Euclid Mission



Euclid is an ESA medium class space mission, selected in October 2011. Its launch is planned for 2022.

The Euclid Mission aims at understanding why the expansion of the Universe is accelerating and what is the nature of the source responsible for this acceleration.

Euclid will address questions related to fundamental physics and cosmology on the nature and properties of dark energy, dark matter and gravity, testing Einstein's General Relativity.

The complete Euclid survey represents hundreds of thousands images and several tens of Petabytes of data. About 10 billion sources will be observed!

The two-point correlation function

The two-point correlation function is defined as the **excess of probability of finding a pair of objects** (e.g. galaxies) with a relative comoving distance r with respect to the case these objects were distributed randomly:

$$\delta P(r) = n^2 \left[1 + \xi(r) \right] \delta V_1 \delta V_2$$

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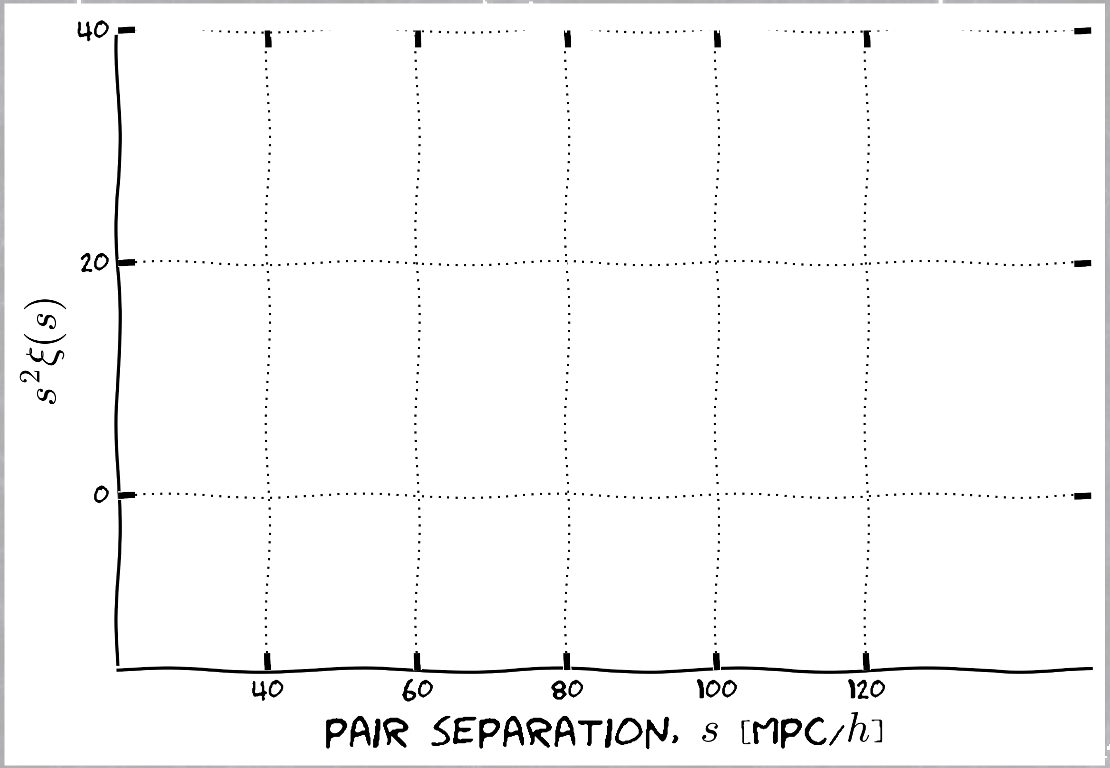
The **standard way** to put constraints on cosmological parameters from the two-point correlation function is by fitting the measured statistic through a likelihood which should account for all kinds of distortions and uncertainties.

The two-point correlation function

Observe the Universe and construct a **map of galaxies**



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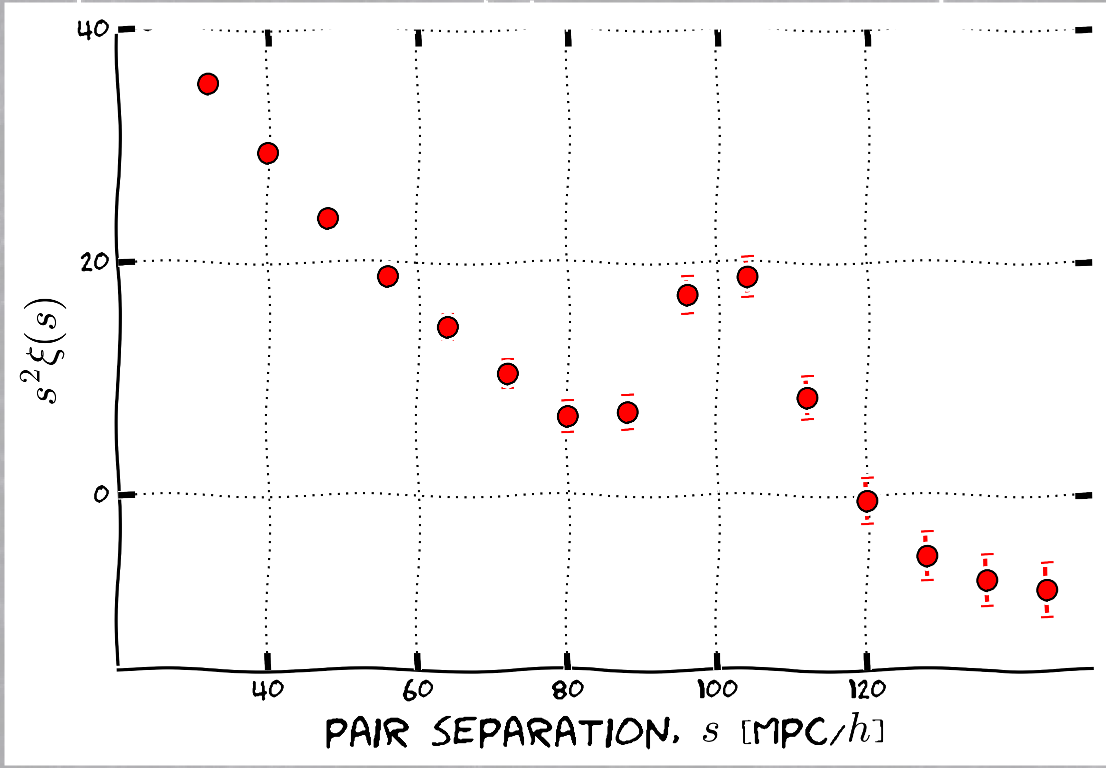
Measure the **two-point correlation function**



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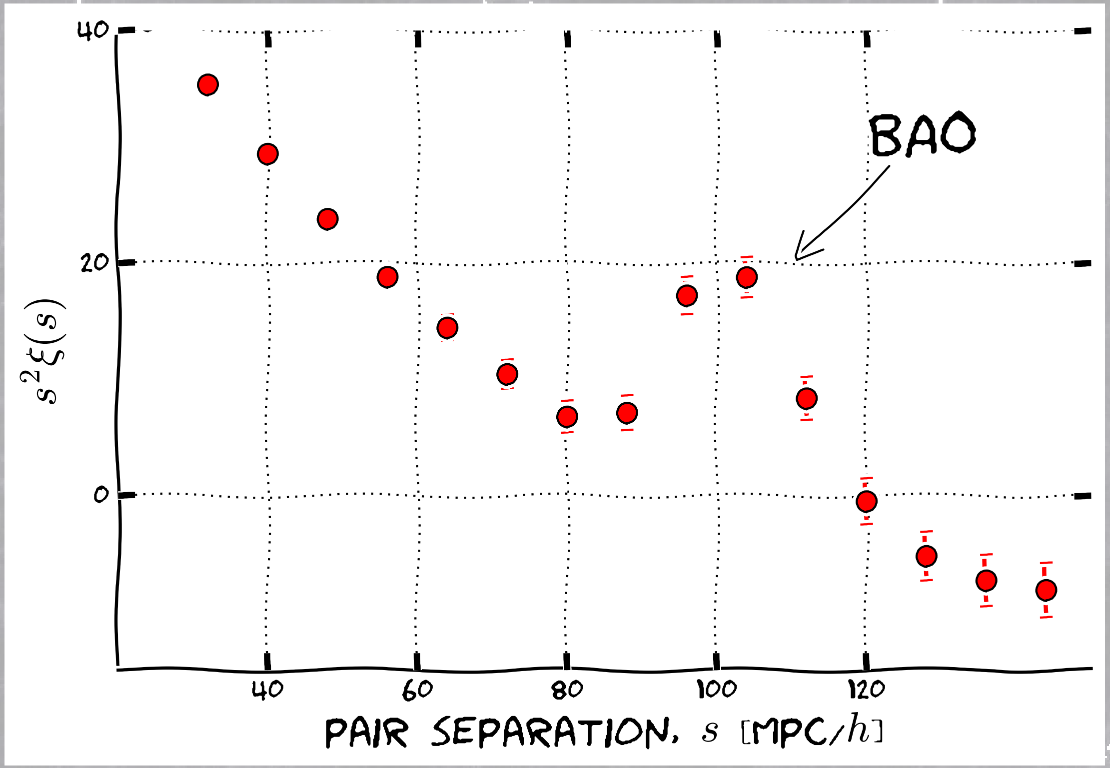
Focus on some interesting scales, e.g. the **Baryon Acoustic Oscillations**



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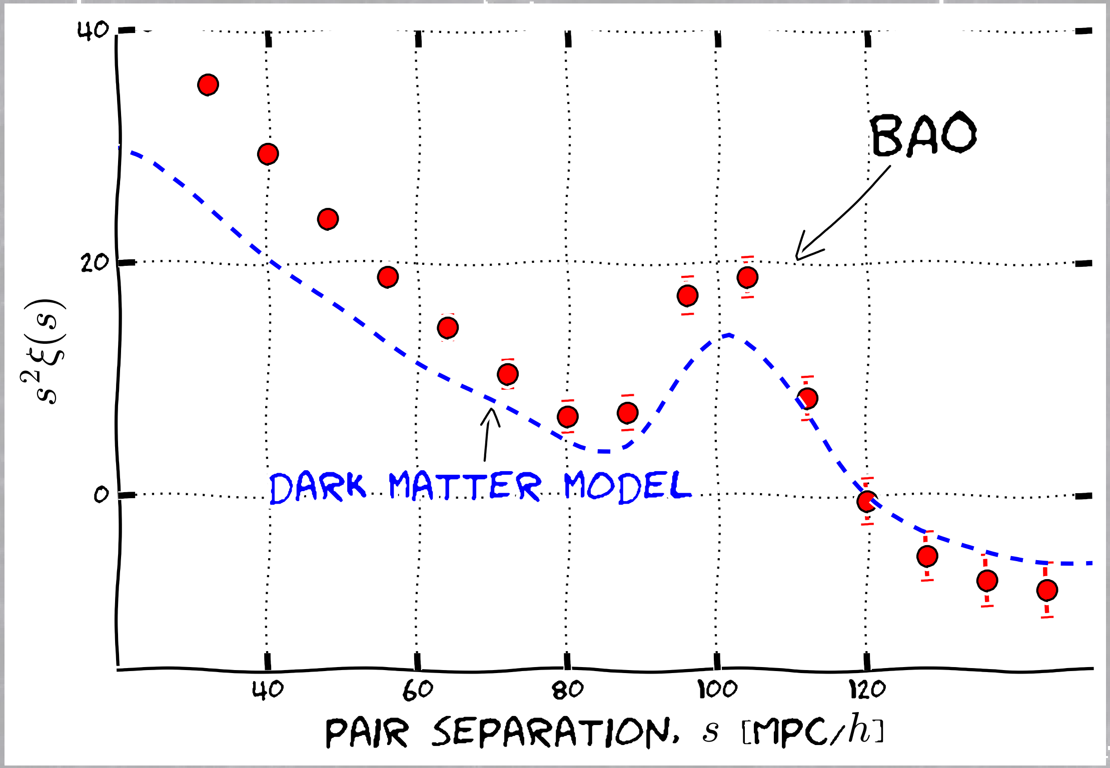
Model the dark matter clustering



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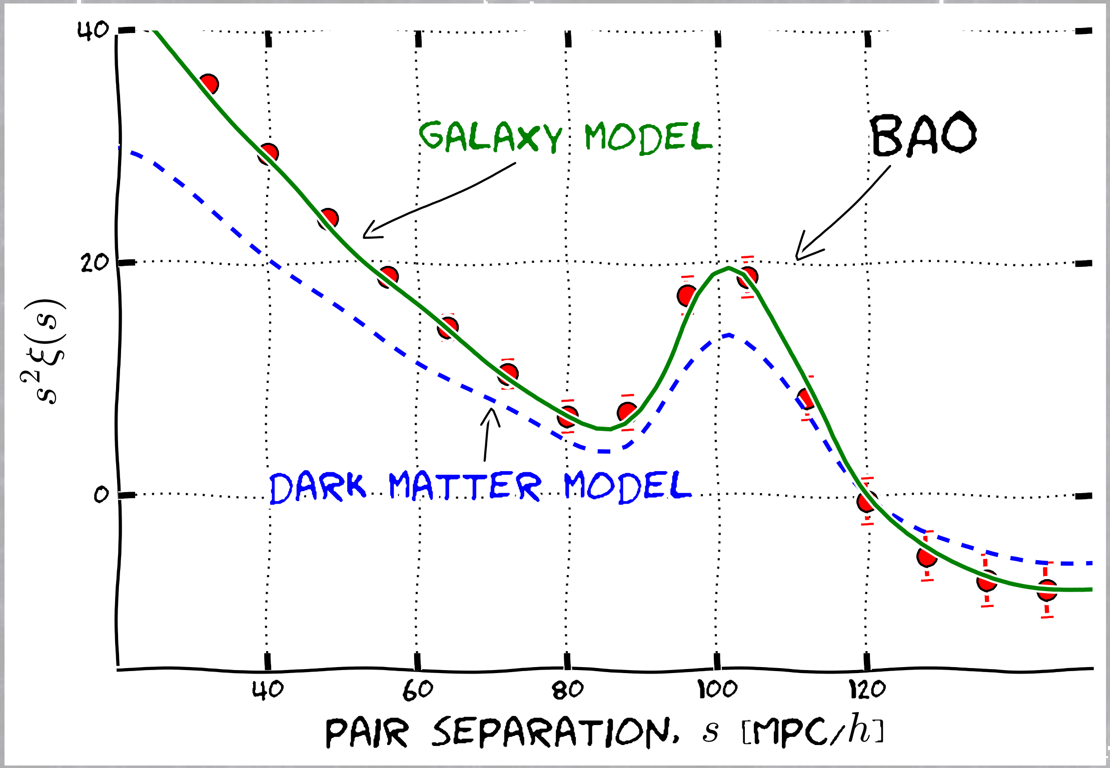
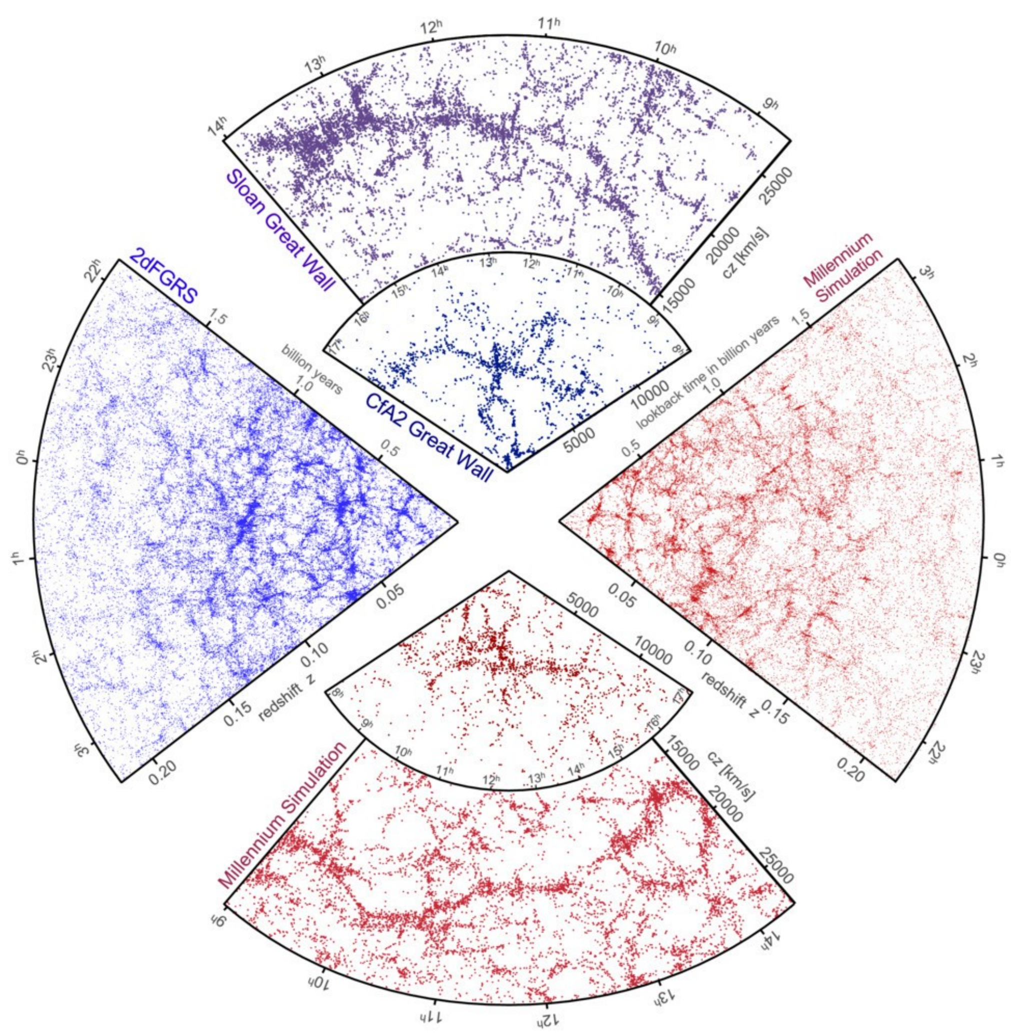


Numerical simulations

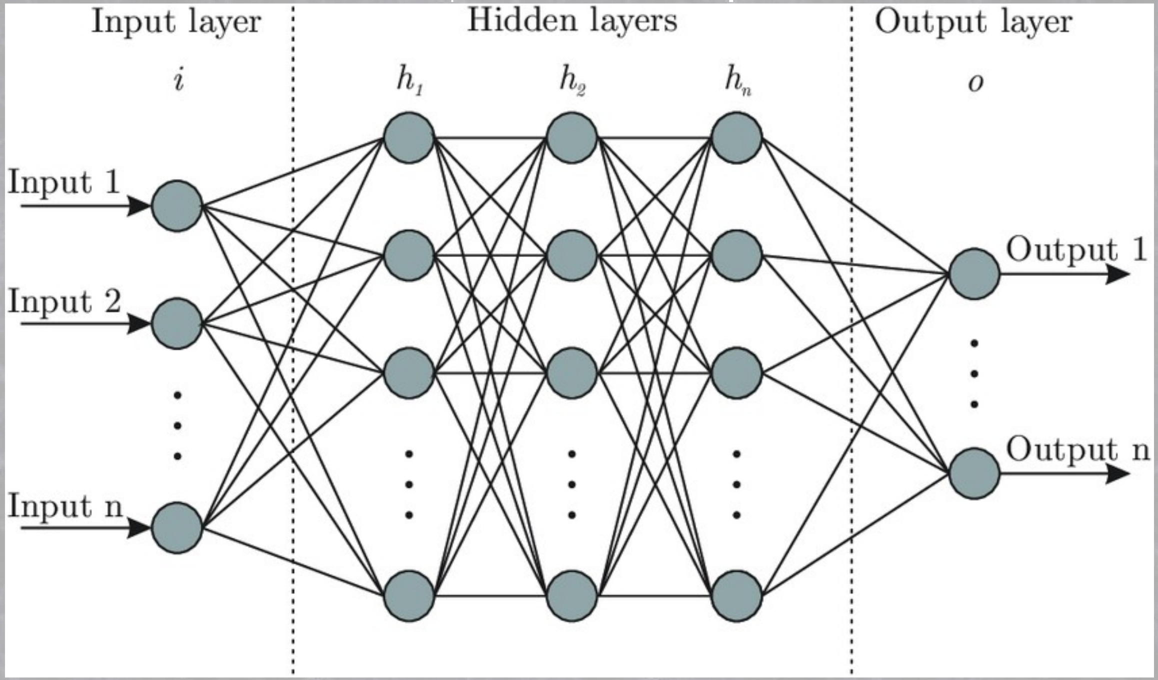
real Universe



simulated Universe

We can **model** directly the large-scale structure of the Universe with N-body **simulations** in different cosmological frameworks

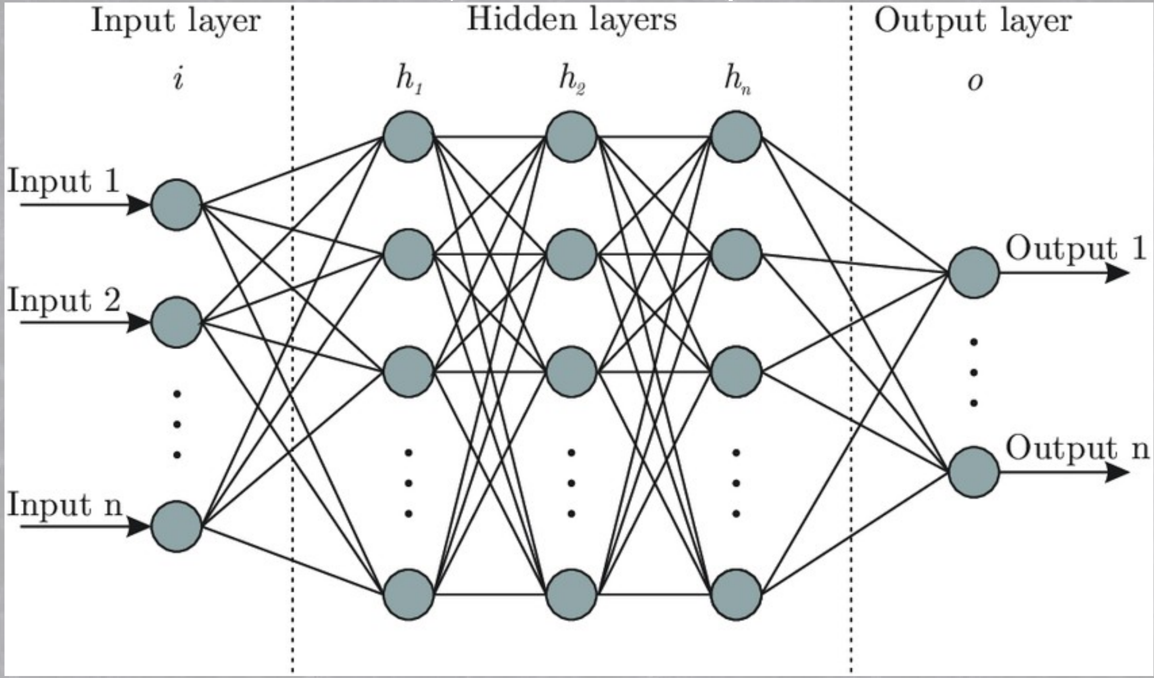
Artificial Neural Networks



Artificial Neural Networks for Cosmology

Galaxy maps
(coordinates, stellar masses, luminosities, etc.)

Two-point correlation functions and higher-order statistics



Dark Energy density

Dark Energy parameters

Dark Matter density

Neutrino masses

etc.

Artificial Neural Networks for Cosmology

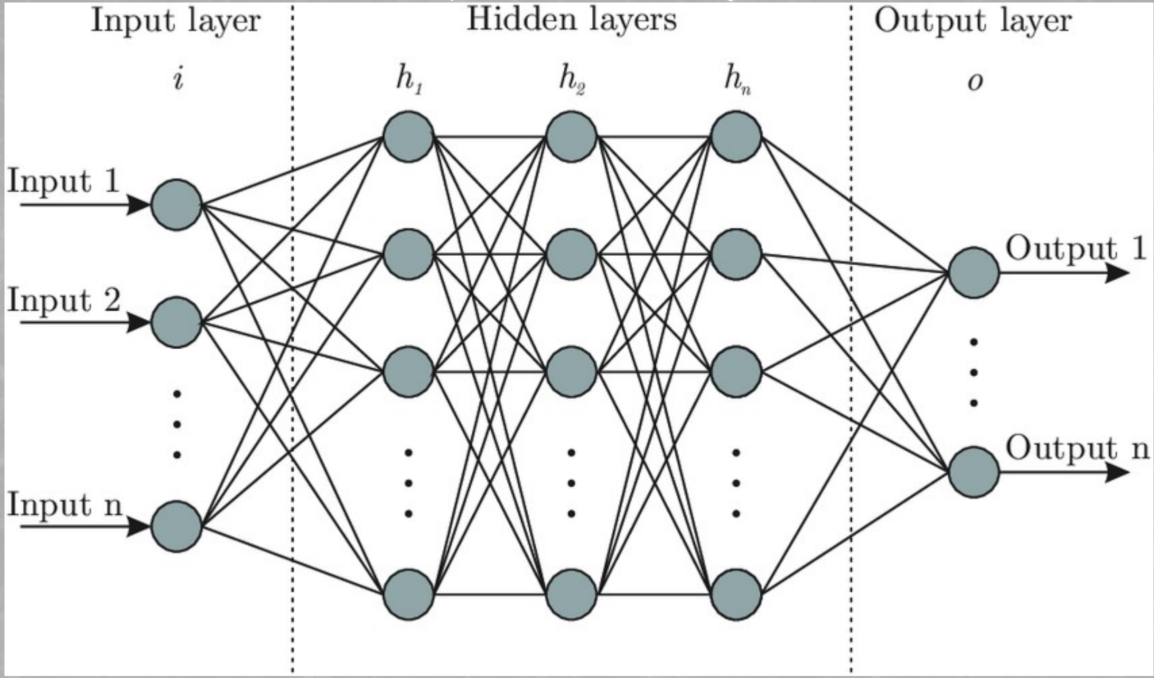
open issues

Which kind of training set to use? (maps, spatial statistics, other probes?)

Which method to quickly construct mock catalogs? (which features are needed?)

How many input examples?

Which network architecture? (e.g. Bayesian Networks, auto-encoders, etc.?)



Which astrophysical and cosmological parameters to constrain?

Which cosmological model to constrain?

Cosmological projects with Machine Learning

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- Farida Farsian "Big Data exploration with Artificial Intelligence: from Cosmology to practical applications"
  [Alte competenze Regione Emilia Romagna 2020]

Main scientific objectives

- The primary scientific goals of these projects are to provide independent constraints on the **dark energy equation of state parameters** and to test Einstein's **General Theory of Relativity**

- The newest **machine learning techniques** for data mining have been investigated for the first time **in a cosmological context**

First results

(Veronesi et al. in prep.)

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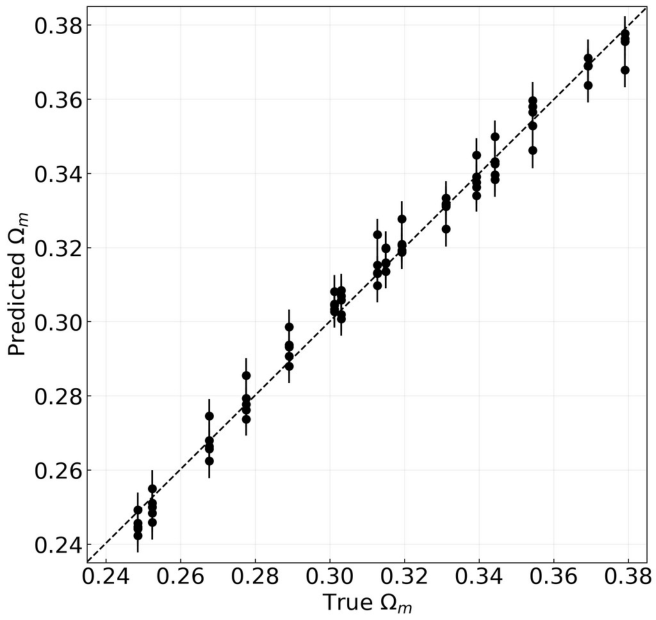

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- **Results**: new constraints: Ω_M **=0.307 ± 0.006**