Relating observations and theory - Exercises

Deanna C. Hooper, 29.05.2024

In these exercises you will:

- Become familiar with some basic `python` functions for reading data and plotting
- Perform a statistical analysis to compare theoretical predictions and observational data
- Reproduce the results from one of the biggest cosmological experiments

Prerequisites

Even though this is a coding-based exercise, no previous knowledge of `python` is required. You will be using a `jupyter` notebook, which provides an easy environment for running and visualising `python` code. All of the functions you need are already shown in examples in the notebook, so you should not need to look anything up. However, you will need to set up a `python` environment with the following packages: `numpy, matplotlib, jupyter`:

1. Open a terminal on linux / mac or command prompt (cmd) on Windows in the directory where you have downloaded the course material
2. In order to keep things self-contained and not affect anything else on your system, you can set up a virtual environment:
    - **Linux/mac**: First run `python3 -m venv course_env` to create the environment, and then `source course_env/bin/activate` to activate the environment
    - **Windows**: First run `py -m venv course_env` to create the environment, and then `course_env\Scripts\activate` to activate the environment
3. Install the the required packages:
    - **Linux/mac**: `python3 -m pip install -r requirements.txt`
    - **Windows**: `py -m pip install -r requirements.txt`
4. Launch the jupyter notebook with `jupyter notebook model_comparison.ipynb` . This will then open a browser with the notebook. You can run individual cells using the play button at the top (or using `shift + enter` on the selected cell)
5. Be sure to deactivate the virtual environment when you are done (`deactivate`)

Exercises

The standard model of cosmology (ΛCDM) is characterised by six parameters. We can use these six parameters to calculate the power spectrum of the Cosmic Microwave Background (CMB), which is the oldest light in the universe. This power spectrum was measured very accurately by the Planck satellite in 2018.

You are given 10 different realisations of the CMB power spectrum, defined by different values of the ΛCDM parameters. The main objective is to find which of these 10 models provides a best fit to the Planck 2018 data, and therefore recover the ΛCDM parameters. In reality, we would need to test as many different parameter combinations as possible, but here we do a simplified example.

The values measured by Planck (making use of only the temperature data)[1], and which you need to reproduce, are:

$$\begin{aligned} \omega_b &= 0.02212 \pm 0.00022 \\ \omega_{cdm} &= 0.1206 \pm 0.0021 \\ h &= 0.6688 \pm 0.0092 \\ 10^9 A_s &= 2.092 \pm 0.034 \\ n_s &= 0.9626 \pm 0.0057 \\ z_{reio} &= 7.50 \pm 0.82 \end{aligned}$$

Work through the provided `jupyter` notebook `model_comparison.ipynb`. Read the instructions and hints in the notebook carefully: there will be a couple of issues along the way common to data analysis, and you will be guided through how to solve them.

[1] Table 2, first column, of Planck 2018 results. VI. Cosmological parameters.