Thesis and M2 internship proposal

Inflationary non-Gaussianities in the CMB and large-scale structure

Guillaume Patanchon (APC) & Bartjan van Tent (IJCLab)

Inflation is an important theory of the primordial universe that explains amongst other things the origin of the fluctuations observed in the cosmic microwave background (CMB) and of the large-scale structure of the galaxy distribution. However, there are many different inflation models and one of the challenges of modern cosmology is to find ways to distinguish these models at the level of their predictions for observables, in order to confront them with experimental data. A very important way to do this is based on studying the amplitude and the type of the non-Gaussianities that are produced during inflation due to second-order perturbations. With the results of the Planck satellite, non-Gaussianities have become a quantitative and topical area of research.

The main subject of this thesis proposal is extending the non-Gaussian estimators developed for Planck both to future CMB experiments like LiteBIRD and CMB-S4, and to future large-scale structure experiments like Euclid and LSST-Vera Rubin. However, further non-Gaussian analyses of the existing Planck data and conclusions for inflation can also be part of the project. Here is a list of some issues that need to be tackled for this purpose. Regarding the internship proposal, it consists of project no. 1.

1. **Extend the existing binned bispectrum code to include B-mode polarization.** B. van Tent and his collaborators have developed an estimator (the binned bispectrum estimator; the bispectrum being the three-point correlator, the principal non-Gaussian statistic) and the associated computer code to determine the primordial non-Gaussianities from the Planck data using both temperature and E-mode polarization. Future CMB experiments will also observe B-mode polarization, hence the code needs to be generalized for that. This is a good starting project, as it allows the student to get familiarized with the estimator and related concepts as well as the code. Moreover, the same changes should also be useful for large-scale structure data, where we do not have different polarizations but different redshift slices.

2. **Extend the existing know-how about bispectrum analysis from the CMB to large-scale structure experiments.** While extracting information about primordial non-Gaussianity from large-scale structure data (i.e. galaxy surveys) will be harder than for the CMB, because the fluctuations cannot be treated as a small perturbation, the reward is potentially much larger, as these experiments probe a 3D volume of data instead of a 2D surface. It will be very interesting and important to study how our knowledge about CMB bispectrum analysis, and the binned bispectrum method, can be translated to this new field. While we have ideas about this, it will be important to get everything on a solid theoretical footing. This will be a more theoretical and bibliographical subject (a large body of work already exists in the literature).

3. **Further developments of the bispectrum estimator.** Several further issues will need to be addressed, first theoretically and then implemented in the code. For example, how to combine data from different CMB experiments? This was not an issue for Planck, but will be for future experiments, as the satellite LiteBIRD has rather low resolution, while the ground-based CMB-S4 on the other hand is missing the largest scales. Combining data from the two would be optimal. As a second example, how to deal with incomplete sky coverage in large-scale structure data? For the CMB we found that masking and inpainting worked well, but is that still true for large-scale structure, or will a new method have to be developed?

4. **Determine the primordial trispectrum from the Planck data.** The trispectrum is the Fourier transform of the four-point correlator and is another observable that can help to constrain and distinguish inflation models. The trispectral analysis of the Planck data was very limited, and having a “binned trispectrum estimator” would be an important step forward. As the Planck data already exists, this project will not only involve development of the estimator, but also actual data analysis and drawing conclusions for inflation.

A good knowledge of cosmology as well as an interest and experience in programming (Python and/or C) is essential for the candidate, as a large part of the project will be developing computer code. The candidate should also have an interest in data analysis, because, while there is not much actual data analysis in the project, the theoretical and code development work is all aimed at future data analysis.

The student will have the opportunity to visit Japan in the context of the CMB work for the LiteBIRD collaboration (funding for travel has already been obtained). It should be noted that at the end of the PhD, the student should be in a good position to secure a postdoctoral position in one of the CMB or large-scale structure collaborations.