CASPEN Report

Dates of visit: 3rd to the 12th of November
Host Institution: Kavli Institute for Particle Astrophysics and Cosmology, Stanford University
Host Name: Professor Tom Abel

Primordial non-Gaussianity is an interesting probe of the early Universe with the potential to reveal the physics of the first moments of the Universe. In the coming years a range of high precision large scale structure (LSS) surveys will commence, however, with current analysis tools and these data, it will be very challenging to constrain primordial non-Gaussianity (PNG) to the theoretically interesting levels. The goal of my visit was to explore whether k-Nearest Neighbor (kNN) estimators, which Professor Abell and his group have developed, can be used to enhance what we learn from these surveys about primordial non-Gaussianity.

The work initially focused on applying these statistical methods to the Quijote-PNG simulations, a large suite of large scale structure (LSS) simulations that we recently ran at the CCA. These simulations contain three different types of primordial non-Gaussianity and are designed to be contrasted with the existing Quijote simulations, which contain no PNG but vary a range of other cosmological parameters. We used these simulations as a test bed to see whether kNN measurements of the simulated dark matter halo catalogs can differentiate signatures of primordial non-Gaussianity from the other cosmological parameters.

In highly preliminary results, we seemed to find evidence that the kNNs respond strongly to PNG! Interesting the way that PNG impacts the kNN signals seems to be distinct from variations in other cosmological parameters. These two effects combine to mean that a kNN analysis yields constraints on PNG that are significantly better than those obtained from existing methods (in this case we compared to bispectrum measurements on halos from the same simulations, as reported in Coulton et al 2022). Given the short nature of this visit, there are many aspects of this analysis that still need to be carefully checked.

Observations of the LSS do not directly observe dark matter halos – instead we observe the signals emitted by baryons within galaxies. To test whether other results may transfer to observations of galaxies, we generated a set of synthetic galaxy catalogs from our dark matter only simulations with Halo Occupation Distribution (HOD) – in this approach we probabilistically assign galaxies to dark matter halos based on the halo's mass. We then investigated if the kNN methods can still probe PNG in galaxy catalogs; of particular interest is whether the PNG signals resemble changes in the parameters characterizing the HOD. Our very preliminary findings are that these effects are also distinct. The mock galaxy catalogs will be of great use for other uses of the Quijote-PNG simulations, and we plan to make these available on the Quijote website for the community to use. The production of the galaxy catalogs was one of the stated aims of this visit.

The final task we began during this visit was to try to understand the physical origin of the observed signals. To do this we made use of a series of results obtained in Uhlemann et al (2018,2020 and Friedrich et al (2018, 2020), whose work builds on that of many others. These authors have been studying the matter probability distribution function as at a given smoothing scale and the counts of galaxies within a sphere of a given radius. These statistics are intimately related to the kNN statistics – if we consider all the orders of the kNN (1NN, 2NN etc) evaluated at a single scale, then we have precisely the counts in cell. Thus, the primary difference of these two statistics is that the CiC is typically interested in the distribution of counts at fixed scale, whereas the kNNs are used to probe the scale dependence at a fixed count. Using these theoretical tools we find qualitatively similar behavior to our simulation-based results. This is an exciting check of our results.

During my visit, I also spent some time chatting with various members of the CMB community at Stanford, including Kimmy Wu, Emmanuel Schaan and Abhishek Maniyar. As part of the ACT collaboration, I have been working on a direct measurement of galaxy clusters' temperatures via thermal Sunyaev Zel'dovich measurements and I received some valuable input on this work during my visit, as well as interesting future extensions. Whilst Abhishek was in New York, we had started working on a project together and this visit allowed us to discuss this project further and make a few steps towards wrapping it up.

In summary, this exchange provided valuable time for me to learn more about kNNs from Prof. Abel and his group, and during which we found some exciting, and highly preliminary, results. We plan to continue working on this topic in the coming weeks and are grateful to the Cosmology and Astroparticle Student and Postdoc Exchange Network (CASPEN), which supported this visit.