CASPEN visit report

DATES: 8-12 September 2025

HOST: Andrew Pontzen

In the search for a quantum theory of gravity, an often overlooked alternative is a consistent framework in which classical spacetime interacts with quantum fields. In recent work with Professor Jonathan Oppenheim (UCL), Professor Pontzen and I have shown that such hybrid classical-quantum (CQ) theories have the potential to explain cold dark matter phenomenology without invoking a hidden matter fluid.

The objective of my CASPEN visit to Durham University was to explore whether this proposal could be strengthened by moving beyond a homogeneous and isotropic cosmological model—where the mechanism for generating this "phantom" cold dark matter was initially proposed—towards an inhomogeneous setting. The long-term goal is to bridge our theoretical predictions with observations of the Cosmic Microwave Background (CMB). Discussions with Professor Pontzen were particularly fruitful in this regard.

Together, we developed an inhomogeneous cosmological model that is both suitable and tractable for addressing these questions. After addressing issues of gauge dependence, we derived the evolution equations for linearised classical scalar perturbations in a de Sitter universe from the CQ gravitational framework. Notably, we found that even in CQ gravity, the dynamics of scalar perturbations can be captured by a single field whose equations of motion take the form of an Ornstein-Uhlenbeck process. This allowed us to integrate the equations exactly, obtaining the evolution of the average field and, crucially, an analytically exact expression for the two-point function of the scalar field in Fourier space.

These initial results are promising: the problem appears to be under analytical control, and we have access to closed-form solutions. The next step is to extend these results from a de Sitter background to a radiation-dominated era, enabling comparison with cosmological data. After discussing this in detail with Professor Pontzen, we are confident the project is viable and will continue to pursue it in the coming weeks.

During my time in Durham, I also had valuable discussions with researchers in both the mathematics and physics departments. In particular, I had a productive exchange with Dr Robie Hennigar, an assistant lecturer in mathematics. We discussed recent developments in regular black holes—those without interior singularities—which emerge naturally in theories including higher-curvature corrections to the Einstein-Hilbert action. While current results are limited to higher-dimensional gravity, we considered the potential (and challenges) of extending these to the physically relevant

3+1-dimensional case. We plan to continue these discussions with the aim of tackling the problem further.

Overall, my stay in Durham was extremely productive. I am grateful to the CASPEN collaboration for this opportunity and look forward to building on the collaborative momentum it has generated.