Scientific Report

Proposal 299969

Quantum Cosmology

FP7-PEOPLE-2011-IIF

15th February 2014

Major accomplishments

Publications:

"The pre-inflationary dynamics of loop quantum cosmology: Confronting quantum gravity with observations", I. Agullo, A. Ashtekar, W. Nelson Class. Quant. Grav. 30, 085014 (2013)

"Local and global definitions of time: Cosmology and quantum theory", W. Nelson, to appear in a Special edition of Studies in History and Philosophy of Modern Physics.

Presentations & Conferences:

Attended: "The search for quantum gravity, CDR and Friends", Radboud University, November 2012

Presented: "Workshop on Cosmology and Time", Penn State University, April 2013

Outreach:

Article in the popular science magazine 'New Scientist'

"Galaxies could give glimpse of the instant time began" by Stephan Battersby October 2012.

Summary

Scientific:

The major goals of this project were:

1. Develop and extend the Loop Quantisation approach to cosmological systems with perturbative inhomogeneities.
2. Derive the expected cosmological power spectra for such systems and hence confront these Loop Quantum Gravity cosmological models with precision observational data.
3. Use these inhomogeneous cosmological models to shed light on the challenges facing the development of the full, non-linear theory, in particular use the Hamiltonian and dynamics of the inhomogeneous cosmological models as a guide to understanding the dynamical sector of the full theory.
4. Begin a program of 'Loop Quantising' cosmological models of higher derivative gravity in order to go beyond the phase space of general relativity.

Despite the fact that this project was terminated after seven months, due to a change in personal circumstances, the first two of these goals was achieved and the results published (see the Major Accomplishments section above). Together with two other publications in the same series, this work has been extremely well received by the quantum gravity community and has already been cited more the fifty times. The specific goals and milestones reached are detailed in the following 'Goals and Milestones' section.

At the end of the seven month period, the project was approximately four months ahead of schedule.

Outreach:

Several outreach goals were specified in the original proposal, the first two to be completed at four and eight months into the project (see 'Goals and Milestones' section below). The first of these was to give a series of talks to Philosophy and other non-physics undergraduates, and was partially completed.

As an invited speaker at a philosophy and physics workshop at Penn State (see Major Accomplishments section above), I had an opportunity to present this work to philosophy students, in addition to other workshop attendees. This was very successful, however it was not the initially envisioned series of talks and hence can only be considered to have been partially successful.

The second outreach goal, 'Give a series of talks/ presentations to local secondary schools' was to be completed at month eight, however the project was suspended prior to this stage.

In addition to the outreach activities outlined in the original proposal, the work completed in this project was documented by the international popular science magazine 'New Scientist' (see Major Accomplishments section above).

Impact:

EU – Third country collaboration:

- As part of this project I visited Professor Frans Pretorius, creating links between the high energy theory group at Nijmengen University and the numerical relativity group at Princeton University, in the USA.
- As part of this project I attended a physics and philosophy workshop at Pennsylvania University, which further strengthened the already strong connection between Nijmegen University and Penn State.

Goals and Milestones

Goal	Timeline	Status
• Complete the move to, and be fully settled in, Nijmegen. • Have become familiar with day-to-day life at the institute and the university. • Present a seminar to the group outlining the project, its aims and approach as well as the current challenges and open questions within the Loop Quantum Cosmology. • Being regular, informal meetings with graduate students and post-docs to discuss various aspects of Loop Quantum Cosmology.	Month 1	• Completed • Completed • Completed • Competed
• Derive the Hamiltonian formulation of classical gauge invariant cosmological perturbations, in both metric and connection variables. • Identify terms that cannot be directly promoted to quantum operators such as inverse volume terms etc. • Develop strategies to handle such terms, for example by looking for canonical transformations that eliminate them, or extending the standard 'Thiemann's trick' used in homogeneous Loop Quantum Cosmology.	Month 3	• Completed • Completed • Completed
Give a series of talks/ presentations to undergraduate students of Philosophy and other non-physicists as a 'Marie Curie Ambassador'.	Month 4	Partially complete
• Use this Hamiltonian and the derivation of quantum fields on a classical background from quantum fields on quantum space-times, to produce the effective equations of motion for the inhomogeneous cosmological perturbations. • Understand the conditions under which these effective equations are valid and compare them to previous attempts to include inhomogeneous modes into Loop Quantum Cosmology. • Describe a natural vacuum state for such perturbations, based on these equations using the methods that produced the standard Bunch-Davis vacuum. • Investigate and understand the different possibilities and motivation for such a vacuum state and its physical consequences.	Month 6	• Completed • Completed • Completed • Completed
Give a series of talks/ presentations to local secondary schools as a 'Marie Curie Ambassador'.	Month 8	Not complete (Project suspended)
• Numerically solve these evolution equations to produce the evolution of the number operator acting on a vacuum state, as a function of time. • Deduce the state of the perturbations at the onset of standard slow-roll inflation, given the initial vacuum state. • Compare this state to the standard Bunch-Davis vacuum and the observational constraints that exist on the form of this state.	Month 9	• Completed • Completed • Completed
• Produce the scalar and tensor power spectra for primordial perturbations arising from the derived effective evolution equations and motivated vacuum state. • Hence derive the predicted temperature and polarisation correlation function and bi-spectrum for the CMB. • Compare these with the most up-to-date observational data.	Month 12	• Partially completed • Partially completed • Completed