Spring workshop on gravity and cosmology

Monday, 25 May 2020 - Friday, 29 May 2020

Jagiellonian University

Book of Abstracts

Contents

1

Stochastic gravitational waves from inflaton decays

Author: Lu Yin[None]

Corresponding Author: yinlu@gapp.nthu.edu.tw

Because of the universality of gravitational interactions, it is generally expected that a stochastic gravitational wave (GW) background could form during the reheating period when the inflation perturbatively decays with the emission of gravitons. Previously, only models in which the inflation dominantly decays into a pair of light scalar and/or fermion particles were considered in the literature. We focus on the cases with a vector particle pair in the final decay product. The differential decay rates for the three-body gravitational inflaton decays are presented for two typical couplings between the inflaton and vector fields, from which we predict their respective GW frequency spectra. It turns out that, similar to the scalar and fermion cases, the obtained GW spectra is too high in frequency to be observed by the current and near-future GW detection experiments and calls for a new design of high-frequency GW detectors.

2

Approximate Killing symmetries in non-perturbative quantum gravity

Author: Marcus Reitz[1]

Co-authors: Renate Loll [1]; Joren Brunekreef [1]

[1] *Radboud University, IMAPP*

Corresponding Author: m.reitz@science.ru.nl

An open question in quantum gravity is if and how small scale quantum fluctuations and inhomogeneities behave in such a way that at some larger scale they can be well approximated by a classical geometry with some number of exact symmetries. Causal Dynamical Triangulation (CDT) is a non-perturbative approach to quantum gravity, based on a lattice regularisation of space-time, in which these kind of questions possibly can be addressed. After a short introduction of the framework, I will present a specific notion of approximate Killing vectors that can be generalised to simplicial manifolds using the framework of discrete exterior calculus. These discrete approximate Killing vectors show promise as an observable to study effective symmetries in quantum gravity. As a proof of concept, I will present a comparison between quantum ensembles of three different two-dimensional models, CDT, Dynamical Triangulations and small perturbations around flat space.

3

Disformal transformations in modified teleparallelism

Authors: Maria Jose Guzman[1]; Alexey Golovnev[None]

[1] *University of La Serena*

Corresponding Authors: agolovnev@yandex.ru, maria.j.guzman.m@gmail.com

We present recent work on disformal transformations in the context of modified gravity based on the teleparallel equivalent of general relativity, and applications to f(T) gravity. We show the implications a disformal transformed tetrad has in the main geometric quantities, and explore the relation

with the loss of local Lorentz invariance and the issue of the degrees of freedom in these theories. Finally, we discuss some applications to scalar-torsion gravity models.

4

Quantum fate of the BKL scenario

Author: Włodzimierz Piechocki[1]

[1] *National Centre for Nuclear Research*

Corresponding Author: wlodzimierz.piechocki@ncbj.gov.pl

We present the quantum model of the asymptotic dynamics underlying he Belinski-Khalatnikov-Lifshitz (BKL) scenario. The classical BKL scenario concerns generic singularity of general relativity. The quantum BKL scenario shows that gravitational singularity can be replaced by quantum bounce that presents a unitary evolution of considered gravitational system. Our results suggest that quantum general relativity has a good chance to be free from singularities.

7

Ongoing Efforts to Constrain Lorentz Symmetry Violation in Gravity

Author: Nils A. Nilsson[1]

[1] *National Centre for Nuclear Research, Warsaw, Poland*

Corresponding Author: albin.nilsson@ncbj.gov.pl

Searching for minuscule departures from exact Lorentz symmetry is an excellent probe of new physics; recently, there has been a large increase in gravity tests of Lorentz symmetry. In the context of the Standard-Model Extension effective field theory, we discuss and summarise recent developments in the search for Lorentz violation. We also present recent work done in Lorentz-violating models of gravity.

9

Proof of the quantum null energy condition for free fermionic field theories

Author: Taha Malik[None]

Co-author: Rafael Lopez-Mobilia

Corresponding Authors: rafael.lopezmobilia@utsa.edu, tahamalik@cantab.net

The quantum null energy condition (QNEC) is a quantum generalization of the null energy condition which gives a lower bound on the null energy in terms of the second derivative of the von Neumann entropy or entanglement entropy of some region with respect to a null direction. The QNEC states that $T_{kk}\ p\ lim_{A\to 0}(\frac{}{2A}S_{out})$ where S_{out} is the entanglement entropy restricted to one side of a codimension-2 surface which is deformed in the null direction about a neighborhood of point p with area A. A proof of QNEC has been given before, which applies to free and super-renormalizable bosonic field theories, and to any points that lie on a stationary null surface. Using similar assumptions and methods, we prove the QNEC for fermionic field theories.

10

Cosmic Fibers and the parametrization of time in CDT quantum gravity

Author: Dániel Németh[1]

[1] *Németh Dániel*

Corresponding Author: nemeth.daniel.1992@gmail.com

Causal Dynamical Triangulations is an attempt to quantize gravity via lattice regularization, where 4-dimensional simplices play the role of the building blocks of space-time. Numerical simulations show that CDT has a well defined semi-classical limit. One of the questions of this approach which needs clarification is: whether the space-time foliation introduces a preferred time coordinate? By incorporating scalar fields with non-trivial boundary conditions, we created a new space-time coordinate system, where the the field in the time direction admits to a time coordinate different from that of the original foliation. The distribution of the scalar field observed in various phases varies depending on the choice of the coupling constants. Furthermore coupling the scalar fields to the gravitational action results in nontrivial effects.

11

Stable Cosmology in Generalised Massive Gravity

Author: Michael Kenna-Allison[None]

Co-authors: Emir Gumrukcuoglu ; Kazuya Koyama [1]

[1] *University of Portsmouth*

Corresponding Authors: kazuya.koyama@port.ac.uk, emir.gumrukcuoglu@port.ac.uk, michael.kenna-allison@port.ac.uk

Generalised Massive Gravity is an extension of de Rham-Gabadadze-Tolley theory where the translation invariance in the Stuckelberg field space is broken. This allows the mass parameters to be promoted to functions of the Stuckelberg fields. We consider an exact cosmological background in this theory and study the stability of perturbations. We derive conditions to avoid ghost, gradient and tachyonic instability. The cosmology is an extension of the self-accelerating branch of the constant mass parameter theory, but now all five massive graviton polarisations propagate. For concreteness, we consider a minimal version of the theory where cosmology undergoes an accelerated expansion at late times and show that the perturbative stability is preserved for a range of parameters.

12

Constraining the inflationary field content

Author: Laura Iacconi[1]

[1] *Institute of Cosmology and Gravitation (University of Portsmouth)*

Corresponding Author: laura.iacconi@port.ac.uk

Understanding the laws of inflation can shed light on the processes that govern physics at very high energy scales, beyond current experimental limits. In particular, the characterisation and detection of primordial gravitational waves produced during inflation can be an excellent test for the particle content of the very early universe. We consider an inflationary realisation whose tensor spectrum is sourced already at linear order. We show how this set-up supports a sufficient production of primordial gravitational waves to make the signal detectable at interferometer scales. We complement theoretical consistency checks on the model with stringent observational bounds on its parameter space stemming from CMB measurements, LIGO and Big Bang Nucleosynthesis bounds, as well as constraints from Primordial Black Holes production and UltraCompact MiniHalos.

session I / 13

The (glorious) past, (exciting) present and (foreseeable) future of gravitational wave detectors.

The first trace left by a gravitational wave in a man-made detector in September 2015 marked the birth of gravitational wave astronomy. Less than four years from that first signal, gravitational wave detections have become routine, the LIGO and VIRGO instruments are standing up to their mission of being "observatories" and the trove of signals collected is enabling exciting new science and multi-messenger astronomy. And yet, the gravitational wave community has plans to expand the band, reach and sensitivity of detectors even further.
I will quickly review the experimental basis of gravitational wave detection, the status of the current detectors with highlight on the most significant detections performed so far, and try to shed some light on what's coming next.

session I / 14

reception

session IV / 15

Testing Inflation with Primordial Messengers

session IV / 16

Gravitational waves from inflation

session II / 17

CDT, a theory of quantum geometry.

Causal Dynamical Triangulations (CDT) is a lattice model which provides a non-perturbative, background independent formulation of four-dimensional quantum gravity. It provides an emergent background geometry and one can study the quantum fluctuations around this background geometry. The model has second order phase transition lines in the bare coupling constants. These transition lines may be used to test the asymptotic safety scenario of quantum gravity. A minisuperspace effective action can be reconstructed from the data obtained from computer simulations of the model. By studying geometries where the spatial topology is toroidal we can "reintroduce" coordinates and attempt to construct a complete effective action.

session II / 18

Cosmic Fibers and the parametrization of time in CDT quantum gravity

session II / 19

Loop-based observables in 4D CDT

session II / 20

Spectral Analysis of Causal Dynamical Triangulations via Finite Element Methods

I will describe the current state of research on the application of spectral methods to the
Quantum Gravity approach known as Causal Dynamical Triangulations (CDT).
Firstly, I will give an overview of the class of analysis methods based on graph theory
applied to the dual graphs of simplicial manifolds, arguing why they are inadequate, in some regimes, to capture distance information, therefore distorting some of the current results (e.g., the dimensional reduction plot).
Secondly, I will present a method based on finite elements as solution to this problem, showing
a toy model where the previous method blatantly fails and some preliminary results on its application
to
CDT configurations.

session II / 21

A consistent theory of D -> 4 Einstein-Gauss-Bonnet gravity

TBA

session II / 22

Quantum Ostrogradsky theorem

session III / 23

Big Bounce and inflation from spin and torsion

The conservation law for the total (orbital plus spin) angular momentum of a Dirac particle in the presence of gravity requires that spacetime is not only curved, but also has a nonzero torsion.
The coupling between the spin and torsion in the Einstein-Cartan theory of gravity generates gravitational repulsion at extremely high densities, which should prevent a singularity in a black hole and may create there a new, closed, baby universe.
We show that such a universe may form when a particular function of the scale factor and temperature is greater than some threshold, and that the universe can undergo one or more nonsingular bounces.
We also show that quantum particle production caused by an extremely high curvature near a bounce, and creating enormous amounts of matter, can generate a finite period of inflation.
This scenario has only one parameter, does not depend significantly on the initial conditions, does not involve hypothetical scalar fields, avoids eternal inflation, and predicts plateau-like inflation that is supported by the Planck observations of the cosmic microwave background.
This scenario also suggests that our Universe may have originated from a nonsingular Big Bounce in a black hole existing in another universe.

session II / 24

Ongoing Efforts to Constrain Lorentz Symmetry Violation in Gravity

session I / 25

Physical implications of a fundamental period of time

session I / 26

Quantum fluctuations of the compact phase space cosmology

In the recent article Phys. Rev. D 100, no. 4, 043533 (2019) a compact phase space generalization of the flat de Sitter cosmology has been proposed. The main advantages of the compactification is that physical quantities are bounded, and the quantum theory is characterized by finite dimensional Hilbert
space. The purpose of this presentation is to discuss the extraction of semiclassical effects from this model by way of canonical effective methods. First, a brief review of canonical effective methods is given. Afterwards, we discuss the character of the semiclassical solutions of the compact phase space cosmological model. Finally, a relation between the behavior of the quantum fluctuations of the cosmological sector and the holographic Bousso bound is discussed.

session I / 27

some new results on quasinormal modes of black holes

I will show how quasinormal modes of black holes can be used to investigate new physics and quantum gravity. Some results on isospectrality will also be underlined.

session I / 28

Theory confronts Observations: Cosmology in the era of the Swampland

It is well-known that accelerating spacetimes form the basis of our understanding of early and late-time cosmology. On the other hand, there has been a pile of mounting evidence, mainly based on numerous results from String Theory (but not limited to them), that de Sitter space is difficult to embed in a quantum theory of gravity. Thus, these theoretical constraints that any consistent effective field theory must satisfy in order to have a UV-completion – the so-called "Swampland conjectures" – form a new challenge for phenomenologically viable model-building in cosmology. In this talk, I shall discuss some aspects of these conjectures, evidence in support of them and how to reconcile them with astronomical observations with a special focus on inflation. The importance of non-perturbative quantum corrections in constructing quasi de-Sitter backgrounds shall also be demonstrated.

session III / 29

Looking for a healthy nonsingular bounce

In this talk I plan to review the cosmological paradigm of nonsingular bounces, which is often regarded as an alternative to inflation in describing the very early universe. Such a scenario, while can avoid the big bang spacetime singularity, often suffers from conceptual challenges, namely, the dangerous growth of anisotropic stress, the possibly existence of ghosts, gradient instabilities or even superluminal propagation of primordial perturbations. I will introduce how these issues can be addressed in turn, which push the study on nonsingular bounce towards a possibly healthy version. Recently, a novel nonsingular bounce model was proposed based on the most generic scalar tensor theory dubbed the DHOST theory, which can mostly resolve the aforementioned conceptual challenges within a covariant form. This new cosmology shall inspire a series of follow-up studies from theoretical, phenomenological and observational perspectives.

session III / 30

Stable Cosmology in Generalised Massive Gravity

session III / 31

Gravitational footprints of massive neutrinos and lepton number

breaking

We investigate the production of primordial Gravitational Waves (GWs) arising from First Order Phase Transitions (FOPTs) associated to neutrino mass generation in the context of type-I seesaw schemes. We examine both "high-scale"as well as "low-scale"variants, with either explicit or spontaneously broken lepton number symmetry. In the latter case, a pseudo-Goldstone boson, dubbed majoron, may provide a candidate for warm or cold cosmological dark matter. We find that schemes without majoron lead to either no FOPTs or too weak FOPTs, precluding the detectability of GWs in present or near future experiments. Nevertheless, we found that, in the presence of majorons, one can have strong FOPTs and non-trivial primordial GW spectra which can fall well within the frequency and amplitude sensitivity of upcoming experiments, including LISA, BBO and u-DECIGO. We further analyze the associated types of FOPTs and show that in certain cases, the resulting GW spectra entail, as characteristic features, double or multiple peaks, which can be resolved in forthcoming experiments. We also found that the majoron variant of the low-scale seesaw mechanism implies a different GW spectrum than the one expected in the high-scale majoron seesaw. This feature will be testable in future experiments. Our analysis shows that GWs can provide a new and complementary portal to test the neutrino mass sector.

session III / 32

Cosmology with unparticles: Bounces, inflation, cyclic Universe and dark energy

Our understanding of the Universe is based on general relativity and on the standard model of fundamental interactions. This picture suffers from several issues that cannot be explained by GR or SM, like primordial singularity, inflation, dark energy or dark matter. I will show how unparticles may solve at least some these problems and generate realistic cyclic Universe and dark energy

session III / 33

Some aspects of stochastic background of gravitational waves

Our universe is fulfilled by stochastic background of gravitational waves with a large range of frequencies, which may have various astrophysical/cosmological origins in the early universe. As our universe is transparent to gravitational wave, it is a fossil recording the information of its generation and how our universe evolves. In this talk I will briefly review the stochastic background of the gravitational waves, especially the secondary gravitational waves induced by scalar perturbations and their connection to the primordial black holes as dark matter. I will also introduce our recent work on the shapes of the spectrum: infrared scaling and the peak.

session III / 34

Induced gravitational waves in general cosmologies

Gravitational waves (GWs) are unavoidably induced at second order in cosmological perturbation theory. The so-called induced GWs are a crucial counterpart of the primordial black hole scenario and might be observable by future space based gravitational waves detectors. However, only the generation during radiation and matter domination eras has been analytically studied. In this talk, I will show new analytical results for the scalar induced GWs in decelerating cosmologies. I will argue that the induced GW spectrum can be a probe of the thermal history of the universe. Lastly, I will discuss possible degeneracies with known sources, such as first order phase transitions.

session II / 35

Gravitational Waves from Cosmological B-L Breaking

The type-I seesaw mechanism crucially depends on the presence of right-handed neutrinos (RHNs) with large Majorana masses. These heavy RHN neutrinos are, however, notoriously hard to produce in terrestrial experiments, which impedes their experimental discovery. In the present talk, I will therefore present a novel, cosmological window onto the seesaw mechanism: the gravitational-wave (GW) signal associated with the cosmological phase transition in the early Universe during which RHNs acquire their mass. I will discuss both first-order and second-order phase transitions as well as GW production from both bubble collisions and cosmic strings. As I will show, the expected GW signal is going to be within the reach of upcoming GW experiments in large parts of the seesaw parameter space, opening up the possibility to probe a variety of RHN and leptogenesis scenarios in the near future. This talk is based on work in collaboration with Simone Blasi, Vedran Brdar, Wilfried Buchmuller, Valerie Domcke, Kohei Kamada, and Hitoshi Murayama (see 1305.3392, 1912.03695, 2004.02889).

session III / 36

Proof of the quantum null energy condition for free fermionic field theories

session IV / 37

TBA

session IV / 38

TBA

session IV / 39

Searching for gravitational wave bursts from cosmic string cusps with the Parkes Pulsar Timing Array

Cosmic strings are one of the gravitational wave (GW) sources that can be probed by pulsar timing arrays (PTAs). In this work we develop a detection algorithm for the GW burst from a cusp on a cosmic string, and apply it to a Parkes PTA data release. We find four events with a false alarm probability less than 1\%. However further investigation shows that all of these are likely to be spurious. As there are no convincing detections we place upper limits on the GW amplitude for different event durations. From these bounds, we place limits on the cosmic string tension, that are independent from other bounding techniques. Finally, we discuss the physical implications of our results and the prospect of probing cosmic strings in the era of Square Kilometre Array.

session IV / 40

Gravitational Waves from a Rolling Axion Monodromy

In string theory inspired models of axion-like fields, sub-leading non-perturbative effects, if sufficiently large, can introduce steep cliffs and gentle plateaus onto the underlying scalar potential. During inflation, the motion of a spectator axion in this potential becomes temporarily fast, leading to exponential amplification of one helicity state of gauge fields. In this model, the axion- gauge field sector interacts gravitationally with the inflaton, therefore the resulting sourced scalar and tensor fluctuations are produced only through gravitational interactions. Due to the tem- porary speeding up of σ in the cliff-like regions, the tensor and scalar correlators sourced by the gauge fields exhibit a localized bump in momentum space corresponding to the modes that exit the horizon while the roll of σ is significant. Thanks to the gravitational coupling of gauge fields with the visible sector and the localized nature of particle production, this model can generate observable gravitational wave signal at CMB scales while satisfying the current limits on scalar perturbations. The resulting gravitational wave signal breaks parity and exhibit sizeable tensor non-Gaussianity that can be probed by future CMB B-mode missions. Depending on the initial conditions on σ and model parameters, the roll of the spectator axion can also generate an ob- servably large GW signature at interferometer scales while respecting the bounds on the scalar fluctuations from primordial black hole limits.

session IV / 41

Anisotropies and non-Gaussianity in Cosmic Microwave and Gravitational-Wave Backgrounds

session IV / 42

Constraining the inflationary field content

session IV / 43

Testing Cosmology with Gravitational Waves

As we enter the era of precision cosmology, the behavior of gravity on large scales and the nature of the main constituents of the universe still remain debatable. Future data from the Cosmic Microwave Background and galaxy surveys, along with the advent of gravitational waves (GW) will provide us precise constraints that will help uncover some cosmological puzzles.

In this talk, I will focus on testing the nature of dark energy with GW. I will show how we can generically study possible modifications to the concordance LCDM model in a unified manner, and discuss how GW are affected. Then, I will show how these modifications can be constrained with observations of binary neutron stars and discuss results for LIGO.

session IV / 44

Probing Gravitational Couplings in Dark Energy Theories

session V / 45

The universe as a quantum gravity condensate and effective cosmological dynamics

session V / 46

Approximate Killing symmetries in non-perturbative quantum gravity

session V / 47

Possible observational consequences of Planckian granularity

I will argue that discreteness at the Planck scale (naturally expected to arise from quantum gravity) might manifest in the form of minute violations of energy-momentum conservation of the matter degrees of freedom when described in terms of (idealized) smooth fields on a smooth spacetime. In the context of applications to cosmology, such "energy diffusion"from the low energy matter degrees of freedom to the discrete structures underlying spacetime would lead to the emergence of an effective dark energy term in Einstein's equations. We estimate this effect using a (relational) hypothesis about the materialization of discreteness in quantum gravity which is motivated by the strict observational constraints supporting the validity of Lorentz invariance at low energies. Arguments based on a simple dimensional analysis lead to an estimate of an effective cosmological constant agreeing in order of magnitude with its observed value. I will also mention possible implications in the more recent dynamics of the universe.

session V / 48

Disformal transformations in modified teleparallelism

session V / 49

Stochastic shear in bouncing cosmologies

Bouncing cosmologies is a popular alternative to (or an extension of) primordial inflation. However, the contracting phase preceding the bounce is known to be flawed with a shear instability with important consequences on the fate of the bouncing universe. Depending on the concrete model, this instability could either prevent the bounce to occur or drive the universe in an expanding phase radically different from the observed one. I will show that even in the absence of initial shear, quantum fluctuations of the matter content lead to a non-zero anisotropic stress. This unavoidable anisotropic stress is stochastic by nature and sources a non-zero shear. The amount of stochastic shear built up by quantum fluctuations is computed considering the simple situation of a massless scalar field and using the stochastic « inflation » formalism to describe its quantum fluctuations. I'll show that for a soft equation-of-state, i.e. w>-1/9, the shear contribution remains small enough up to the bounce and there is no additional source of shear instability. However, for w<-1/9, the shear backreaction becomes non-negligible because quantum fluctuations in that case have a spectrum which is too red.

session V / 50

TBA

session V / 51

Quantum fate of the BKL scenario

I will present the quantum model of the asymptotic dynamics underlying the Belinski-Khalatnikov-Lifshitz (BKL) scenario. The classical BKL scenario concerns generic singularity of general relativity. The quantum BKL scenario shows that gravitational singularity can be replaced by quantum bounce. I will suggest that quantum general relativity has a good chance to be free from singularities.

session I / 52

Probing the Physics of the Early Universe with Gravitational Wave Experiments

session I / 53

Gravitational-Wave Implications for the Parity Symmetry of Gravity at GeV Scale

session II / 54

4-D Gauss Bonnet from an Amplitudes Perspective