AUSTRALIAN SOCIETY FOR GENERAL RELATIVITY AND GRAVITATION

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Listening to the Thunder of Gravity in the Cosmos

Rana Adhikari
Caltech

In 1916, Albert Einstein predicted the existence of gravitational waves: vibrations of spacetime that travel throughout the universe at the speed of light. These vibrations are produced by the most cataclysmic events in the universe; exploding stars, the mergers of black holes, and the big bang itself. The waves travel unimpeded throughout the universe and offer a unique picture of these wonderful astrophysical laboratories. For several decades, it was imagined that these waves either did not exist or were too weak to ever detect. For the last 45 years, teams of scientists have been developing a series of ever more sensitive detectors to be able measure these spacetime distortions from as far away as hundreds of millions of light years. A pair of 4 km long laser interferometers is now poised to open this new window on the universe. Adhikari will describe how our understanding of the quantum physics of the very, very small has allowed us to explore gravitational physics of the very, very large.

On burning a lump of coal

Ana Alonso-Serrano
School of Mathematics and Statistics VUW

Matt Visser
School of Mathematics and Statistics VUW

Burning something in a blackbody furnace leads to an approximately Planck emission spectrum with an average entropy/information transfer of approximately 3.9 bits per emitted photon. This result depends only on the underlying unitarity of quantum physics of burning, combined with the statistical mechanics of blackbody radiation. The fact that the utterly standard and unitarity preserving process of burning something nevertheless has an associated entropy/information budget, is a severely under-appreciated feature of standard quantum statistical physics.

Crucially, once one develops a deeper understanding of the entropy/information flows prevalent in quite standard quantum statistical physics, the entropy/information "puzzle" that is commonly attributed to the Hawking evaporation process looks a lot less mysterious.

Self-gravitating spherical shells with a stiff elastic equation of state

Malcolm Anderson
Universiti Brunei Darussalam

Elastic equations of state were first developed to model the crusts of neutron stars, but can also be used to construct realistic examples of relativistic anisotropic fluids. In this talk I will describe a natural class of elastic equations of state, in which the underlying lattice is effectively cubic, and is taken to be as stiff as possible given the constraints of microcausality and the strong and dominant energy conditions.

This equation of state is then applied to the particular problem of self-gravitating spherical shells. If a sufficiently advanced civilisation could construct an ultra-stiff spherical shell, how massive and thick could the shell be before it collapsed? And what would physical conditions be like inside such a shell?

The Particle Physics of Dark Matter, and Beyond

Nicole Bell
University of Melbourne

Focusing on Weakly Interacting Massive Particles (WIMPs), we review theoretical ideas about dark matter candidates. We outline strategies to search for dark matter at the Large Hadron Collider, and describe recent developments in dark matter indirect detection searches. We also describe a scenario known as “Asymmetric Dark Matter” in which the abundances of both ordinary and dark matter are determined by particle-antiparticle asymmetries. We present possible models for generating such asymetries, and discuss interesting features of this scenario.

Observing the dark: cosmological constraints on gravity theory

Tamara Davis
University of Queensland

In this talk I review the many varied ways we have tested the laws of gravity using cosmological observations. From supernovae, cosmic microwave background, growth of structure, galaxy clustering, gravitational lensing, and more, we now have very strong constraints on the properties of our theory of gravity and any quantum (or other) improvements we may want to make to it. I’ll review the latest results of a wide range of cosmological probes, and show what we expect to be able to do with the next generation of surveys including our own Australian Dark Energy Survey, OzDES.

The Planck-Hubble conspiracy: coincidence or physics of dark energy?

Allan D Ernest
Charles Sturt University

Attempts to understand dark energy typically modify the equations of general relativity, for example adding a cosmological constant to the Friedmann equation. Other approaches are possible however and here we use the concept of "the wavefunction of the universe" adapted from [1], and ask the question: "What are the evolutionary consequences for a universe which is described by a quantum wavepacket?"

In quantum theory the rate of expansion of a free particle wavefunction depends on the initial mass and size. We construct an expansion parameter for such a wavefunction, analogous to the Hubble parameter, and find a remarkable coincidence: a Gaussian wavepacket that is initially Planck sized, and whose initial mass corresponds to that of the present-day observable universe, expands at a rate today equal to the Hubble constant. The coincidence suggests examining how the universe would evolve if a relevant quantum wavepacket expansion term was included in general relativity.

In this talk we outline how quantum wavepacket expansion might be incorporated into general relativity, and discuss some of the potential limitations and difficulties involved with trying to explain dark energy in this way. We also present, as an example, the results of incorporating wavepacket expansion into Einstein-de Sitter cosmology. It will be shown that when these quantum effects are included in this cosmology, cosmic acceleration arises naturally during cosmic history, and the resulting theoretical temporal evolution is well fit with observational results [2] with the switchover time from deceleration to acceleration occurring at about 7 Gyr before the present epoch.

[1] Hawking, S W, and Hartle, J B., (1983) *Phys Rev D (28) 2960-2975.*

[2] Blake, C., et al., (2012) *Mon.Not.Roy.Astron.Soc. (425) 405-414.*

A quantum of darkness: gravitational scale and dark matter

Allan D Ernest
Charles Sturt University

The experimental validation of the existence of gravitational quantum states is well recognized, the most recent results now demonstrating "Balmer-type" resonances for gravitationally bound neutrons in the Earth's gravitational field [1]. Work by Ernest [2,3] has shown that in the weak gravity regions of deep gravity wells such as the halos of galaxies and clusters of galaxies, there exist many stable gravitational quantum states whose interaction with electromagnetic radiation is negligible. Ordinary particles such as electrons and protons whose eigenspectral composition includes significant quantities of these "dark quantum states" will have reduced electromagnetic cross sections compared to what would be expected from measurements made in Earth based laboratories. Effectively, particles with such eigenspectral mixes can function as the weakly interacting massive particles (WIMPS) of the lambda cold dark matter (LCDM) paradigm. Furthermore, reduced electromagnetic interaction cross sections allow the gravitational coalescing of baryons much earlier in cosmic history than is predicted by acoustic oscillation theory used in cosmic microwave background (CMB) anisotropy analysis.

In this talk we present the latest work which shows that scale-invariant inverse square radial density profiles are formed in the outer halo regions of deep gravity well halos as quasi-equilibrium is approached, provided there is a small amount of collisional coupling between particles. Furthermore dark states are energetically favoured in inverse square density profiles so that the proximity to equilibrium is accompanied by an increase in the electromagnetic "darkness" of a particle, and indeed an increase in the fractional darkness of the structure itself, along with increased darkness due to the relative "size" of the well.

[1] Abele, H and Leeb, H, (2012) *New Journal of Physics (14) 055010*

[2] Ernest A D, (2009) *J. Phys. A: Math. Theor. 42:115207 and 115208*

[3] Ernest A D, (2012) *in Advances in Quantum Theory, I I Cotaescu, Ed., InTech, Rijeka, pp.221-248*

Three easy(?) pieces in Computational Gravity

Jörg Frauendiener
University of Otago

Even though the binary black hole problem can be considered as solved there are still many open problems in GR which can probably only be tackled with significant input from computer simulations. In this presentation I will talk about recent developments that are currently underway at Otago. Specifically, these are the implementation of the Newman-Penrose "eth" operator, an implementation of Corvino's method for glueing initial data sets and symplectic integrators.

Mukhanov-Sasaki equations in Hybrid Loop Quantum Cosmology

Laura Castello Gomar
Instituto de Estructura de la Materia - CSIC

Javier Olmedo
Louisiana State University

Guillermo Antonio Mena Marugan
Instituto de Estructura de la Materia - CSIC

Scalar cosmological perturbations are analyzed in the framework of Loop Quantum Cosmology, using a hybrid quantization approach and Mukhanov-Sasaki variables. A kind of Born-Oppenheimer ansatz is employed to extract the dynamics of the inhomogeneous perturbations, separating them from the homogeneous sector of the geometry. With this ansatz, we derive an approximate Schr"odinger equation for the cosmological perturbations and study its range of validity. We obtain the effective equations that are naturally associated with the Mukhanov-Sasaki variables. They provide the master equation to extract predictions about the power spectrum of primordial scalar perturbations.

Detecting gravitational waves from mountains on neutron stars

Brynmor Haskell
The University of Melbourne

Mountains on neutron stars are one of the main targets for continuous gravitational wave searches. I will focus on theoretical estimates of mountain sizes in known neutron stars in Low Mass X-ray Binaries, and on two of the main mechanisms: crustal mountains and magnetic mountains. I will show that persistent X-ray sources are the best candidates for detection, and discuss particular signatures of signals from magnetic mountains.

Thermality of observer-dependent causal horizons

E M Howard
Macquarie University

Are causal horizons thermal? For a causal Rindler horizon, an observer inside the horizon will see a thermal spectrum carrying observer-dependent entropy. We show that the entropy of a local physical event described by different Rindler observers is also different. The entropy associated with a causal horizon is not an invariant quantity defined by the spacetime alone, but rather depends on the observer that measures it. We discuss the relation between the entropy of local horizons and the thermality observed by a local Rindler observer, suggesting a deeper connection between gravity and horizon thermodynamics. We shall discuss several implications and open issues in the thermodynamics of spacetime that concern observer-dependent thermality of causal horizons.

Investigations of the shear-free conjecture for a perfect fluid

Peter A Huf
Deakin University

John Carminati
Deakin University

In this paper we continue our investigation of the shear-free conjecture ($\sigma = 0 \Rightarrow \omega\theta = 0$) for a perfect fluid using TensorPack (a recently released, Maple-based software package for the algebraic manipulation of tensors). The kinematic and field equations used in our study are based on the work of Senovilla et al [1]. We have explicitly demonstrated full proofs of the authors for dust, and propose a further proof that is considerably shorter than the original paper. We continue the investigations where acceleration is either parallel or orthogonal to the vorticity. The application of the software to the equations enhances the solving of the proofs.

[1] Senovilla et al., (1998) *Gen.Rel.Grav. (30) pp.389-411.*

Gravitational-wave cosmology across 29 decades in frequency

Paul Lasky
Monash Centre for Astrophysics - Monash University

Quantum fluctuations of the gravitational field in the early Universe, amplified by inflation, produce a primordial gravitational-wave background across a broad frequency band. I will show how constraints on the spectrum of this gravitational radiation, and hence on theories of the early Universe, can be generated by combining experiments that cover 29 orders of magnitude in frequency. These include Planck observations of cosmic microwave background temperature and polarization power spectra and lensing, together with baryon acoustic oscillations and big bang nucleosynthesis measurements, as well as new pulsar timing array and ground-based interferometer limits. I will also show how these constraints will be modified with future experiments, and emphasise the power of this method once a primordial gravitational-wave signal is found in any of the given frequency bands.

Non-orthogonally transitive G_2 spike solution

Woei Chet Lim
University of Waikato

We generalize the orthogonally transitive (OT) G_2 spike solution to the non-OT G_2 case. This is achieved by applying Geroch's transformation on a Kasner seed. The new solution contains two more parameters than the OT G_2 spike solution. Unlike the OT G_2 spike solution, the new solution always resolves its spike.

Intergalactic cable in an expanding universe

Colin MacLaurin
University of Queensland

The scenario of a cosmic-length cable reaching through a Friedmann-Lemaitre-Robertson-Walker (FLRW) universe helps to understand the expansion of space. It has been proposed that tension on such a cable could be used to mine energy from the expansion, or even spare us from the eventual heat death of the universe, and certain situations parallel the mining of energy from black holes. Past treatments in the literature have been flawed by incorrect consideration of lengths/distances in relativity. In particular, the usual "proper distance" is overused, whereas it only corresponds to proper length for frames comoving with the Hubble flow, and not other radial motions. I will show how a correct understanding of the cable's behaviour illustrates lengths and distances in relativity and within FLRW spacetime in particular. Furthermore, the dynamics of such a cable have relevance for whether the "stretching of space" is a useful interpretation of the metric expansion of the universe.

Formation of linear structures in our universe: A full general relativistic treatment

Hayley Macpherson
Monash University

The underlying assumptions of modern cosmology are homogeneity and isotropy of the universe. Under these assumptions we require the existence of dark energy, a mysterious negative pressure forcing the expansion of the universe to accelerate at late times. While these assumptions are valid on large scales, small scale inhomogeneities and anisotropies can have significant general relativistic effects on observations. In order to quantify these effects, we perform fully general relativistic cosmological simulations with the open source code Cactus. We test the code by reproducing general relativistic perturbation theory, and compare this with the growth of structures in the Universe. The full development of this code will enable us to perform full general relativistic cosmological simulations that include full non-linear effects.

Gauge invariant formalism for perturbations in quantum cosmology

Guillermo A Mena Marugan
Instituto de Estructura de la Materia-CSIC

Laura Castello Gomar
Instituto de Estructura de la Materia-CSIC

Mercedes Martin Benito
Radboud University Nijmegen

We consider cosmological perturbations around FLRW spacetimes minimally coupled to a scalar field and present a formulation designed to preserve covariance. The perturbations are described in terms of Mukhanov-Sasaki gauge invariants, linear perturbative constraints, and variables canonically conjugate to them. This set is completed into a canonical one for the entire system, including the homogeneous degrees of freedom. We then explain how to quantize the system respecting covariance and how to extract the evolution of the primordial scalar perturbations.

Persistent gravitational waves from "glitchy" millisecond pulsars

Andrew Melatos
University of Melbourne

Millisecond pulsars (MSPs) are not popularly associated with glitch activity; after over 40 years of radio timing experiments, only one impulsive spin-up event has been discovered in an MSP. Nevertheless it is possible that many MSPs do experience glitches, whose waiting times exceed 40 years. If these events are triggered by vortex avalanches in the pinned superfluid inside the star, as suggested by recent quantum mechanical simulations, it can be shown that historical glitch activity imprints long-lived nonaxisymmetries on the velocity field of the pinned superfluid, generating quasi-monochromatic current quadrupole gravitational radiation. The amplitude of the signal is estimated under various conditions, subject to caveats regarding the avalanche physics.

tpTensor: index-free tensor algebra in Mathematica

Andrew Norton
unaffiliated

I shall demonstrate a Mathematica package that I have developed over the last few years for use in my research. The package, tpTensor, allows tensor computer algebra to be done using an elegant index-free formalism. Its strengths are: ease of use, flexibility, and conceptual clarity. As such, it could be an ideal teaching tool for an introduction to differential geometry. It is also well suited for certain research problems. For example, it has been used to derive (for the first time) the electromagnetic radiation reaction force on a radiating charged point-dipole in arbitrary motion.

tpTensor is now at a stage that others might also find it useful, or at least see its potential and be inspired to participate in its further development and general release as free software.

Interpreting the Mathisson-Papapetrou equations

Andrew Norton
unaffiliated

The equations of motion for a spinning test mass in a curved background spacetime are the Mathisson-Papapetrou (MP) equations, together with a spin supplementary condition. The supplementary condition is needed in order to close the otherwise underdetermined system of MP equations. The two supplementary conditions that feature most prominently in the literature are the Tulczyjew (T-) condition and the Frenkel-Pirani (FP-) condition.

The supplementary T-condition was proposed so as to ensure that the resulting solutions of the MP equations behave "as they should" based on our classical intuition. On the other hand, the FP-condition arises naturally in at least two different derivations of the MP equations.

The solutions of the MP equations, when solved with the "more natural" FP-condition, are spacetime helices that describe a free particle that executes a circular motion at the frequency $\omega = mc^2/|S|$. For a particle with $|S| = \hbar/2$, this mass-frequency relationship is the same as that for the quantum mechanical Zitterbewegung (ZBW), $\hbar\omega = 2mc^2$, and the diameter of the circular motion approximates the reduced Compton wavelength, $\hbar/(mc)$.

The generalization of the MP system to include electromagnetic interactions is known as the Dixon-Souriau (DS) system of equations. I shall describe some of my ongoing efforts to reinterpret quantum mechanics as a relativistic pilot-wave theory based on a model of the electron that follows from the DS equations when radiation reaction effects are included.

A stochastic background of gravitational waves from binary black hole mergers

Letizia Sammut
Monash University

Eric Thrane
Monash University

Ripples in spacetime known as gravitational waves are predicted by Einstein's theory of general relativity. Second-generation ground-based gravitational wave interferometers are expected to achieve the sensitivity required for the first direct detection. The newly upgraded Laser Interferometer Gravitational-wave Observatory (LIGO) recently began its first observing run. Coalescing compact binary systems involving black holes and neutron stars are among the most promising candidate sources for the first detection of gravitational waves. At design sensitivity, Advanced LIGO is likely to detect dozens of compact binary coalescence sources per year. A stochastic gravitational wave background resulting from a superposition of many independent and unresolved signals, such as from binary black hole mergers, could also be detectable in the next few years with advanced LIGO. We investigate how the merger rates and black hole mass distributions affect the stochastic background, and whether observations of the stochastic background can distinguish between different formation models.

On the sparsity of the Hawking flux

Sebastian Schuster
School of Mathematics and Statistics VUW

Finnian Gray
School of Mathematics and Statistics VUW

Matt Visser
School of Mathematics and Statistics VUW

Although known since the 1970s, the sparsity of the Hawking flux remains under-appreciated. To draw more attention to this issue, we provide several ways of illustrating and quantifying this sparsity. This is done by comparing the average time between emission of successive particles with the natural timescale set by their energies. These quantities will be calculated both for particles obeying different statistics, and for different black hole scenarios. For the most general cases, we carefully try to separate super-radiance and the actual Hawking radiation. Finally, we will discuss the consequences of taking this sparsity into account seriously in discussions of the Hawking process.

LIGO data analysis methods for continuous gravitational waves

Ling Sun
University of Melbourne

The Laser Interferometer Gravitational Wave Observatory (LIGO) achieved its design sensitivity over a wide band during its fifth science run and exceeded it during the sixth science run. Ten times improvement in sensitivity is expected in Advanced LIGO, which makes direct detection of gravitational waves promising in near future. LIGO data analysis is of great importance at this stage. We work on the data analysis methods searching for continuous gravitational waves from isolated young spinning neutron star or binary source like Sco X-1. The methods have been developed and verified with synthetic data, applied to searches with initial LIGO S5 data, and will be extended to the coming new science runs of Advanced LIGO. The sources, methods and searches will be introduced in the presentation.

Multipole moments in non-Einstein gravities and tests of the no-hair relations

Arthur Suvorov
University of Melbourne

Andrew Melatos
University of Melbourne

We construct multipole moments for stationary, asymptotically flat, spacetime solutions to higher- order curvature theories of gravity. The moments are defined using 3+1 techniques involving timelike Killing vector constructions as in the classic papers by Geroch and Hansen. Using the fact that the Kerr-Newman metric is a vacuum solution to a particular class of $f(R)$ theories of gravity, we compute all its moments, and find that they admit recurrence relations similar to those for the Kerr solution in general relativity. It has been proposed previously that modelling the measured frequencies of quasi-periodic oscillations from galactic microquasars enables experimental tests of the no-hair theorem. We explore the possibility that, even if the no-hair relation is found to break down in the context of general relativity, there may be an $f(R)$ counterpart that is preserved. We apply the results to the microquasars GRS 1915+105 and GRO J1655-40 using the diskoseismology and kinematic resonance models, and constrain the spins and "charges" (which are not really electric charges in the $f(R)$ context) of their black holes.

Hunting for gravitational waves with complicated signals

Eric Thrane
Monash University

Advances in numerical relativity have allowed us to precisely predict the gravitational waveforms for a large class of compact binary coalescences. The gravitational-wave signature from known pulsars can be similarly predicted with great accuracy. In both cases, precise a priori knowledge of the signal allows observers to design optimal search algorithms. However, there are compelling astrophysical targets for which precise predictions are not possible. I consider two such sourcesnewborn neutron stars and electromagnetically quiet neutron stars in binary systemsand describe recent work developing tools for the detection of such systems. I discuss the prospects for detection with advanced detectors.

Solving Quantum Gravity and the Nature of Dark Matter Through Low-Energy Precision Measurement

Michael Tobar
University of Western Australia

Some major unsolved problems in fundamental physics include the discovery of the correct theory of Quantum Gravity and the determination of Dark Matter. In this seminar I will present the latest projects and results at UWA that implement ultra-precise measurement techniques to test fundamental physics, with the goal of solving or at least shedding light on these two problems.

These experiments include:

1. Extremely new sensitive tests of General Relativity capable of probing suppressed effects emanating from the Planck scale. Such tests include new experiments of Lorentz invariance violations of photons and phonons and tests fundamental constant invariance through the implementation of sapphire and quartz bulk acoustic wave resonator and related technology at low temperature.

2. Dark matter is a fundamental component of the universe yet the nature of its composition is still unknown. There is growing evidence that it could be comprised of axions; a low energy, weakly interacting particle species. Through the development of remarkable precision electromagnetic measurement tools and techniques we aim to perform a comprehensive laboratory search for dark matter axions at UWA in a mass range that is currently untested.

3. Precision measurement of opto-mechanical systems at the milligram and kilogram scale using quartz bulk acoustic wave and sapphire technology. The goal is to cool such systems to the ground state and read them out with quantum-limited precision. Such massive systems can be used to search for gravitational effects on the uncertainty relations, which could give insights to the correct theory of quantum gravity.

4. Related experiments are also planned through the European Space Agency's Atomic Clock Ensemble in Space mission. If time permits Australian involvement will be presented.

Influence of plasma on gravitational lensing effects

Oleg Tsupko
Space Research Institute of Russian Academy of Sciences

Gennady Bisnovatyi-Kogan
Space Research Institute of Russian Academy of Sciences

Volker Perlick
ZARM of University of Bremen

We consider an influence of plasma on gravitational lensing. In presence of both gravity and plasma the deflection angle is physically defined by mutual combination of different phenomena: gravity, dispersion, refraction. While effects of deflection by gravity in vacuum and the refractive deflection in non-homogeneous medium are well known, the new effect is that in case of homogeneous plasma, in absence of refractive deflection, the gravitational deflection differs from vacuum deflection and depends on the photon frequency. In presence of non-homogeneity in plasma the chromatic refractive deflection also occurs, so the presence of plasma always makes gravitational lensing chromatic. For strong lens systems with multiple images, the presence of plasma leads to difference in angular positions of the same image if observed at different wavelengths. Shift of angular position can be significant for observation in radio band. Gravitational lensing in plasma beyond weak deflection approximation and influence of plasma on the shadow of spherically symmetric black hole are also considered.

Black holes from domain walls and vacuum bubbles

Alex Vilenkin
Tufts University

Many particle physics models predict the existence of a number of vacuum states with different energy densities. Bubbles of different vacua could then be formed during inflation in the early universe. A positive energy bubble will expand with acceleration, as long as its energy density is lower than that in the inflating background. But when inflation ends, the bubble will decelerate and will eventually form a black hole. The resulting population of black holes can have significant astrophysical effects, and for some parameter values could even provide seeds for the observed supermassive black holes. Each black hole produced in this way will have an inflating universe inside, connected by a wormhole to the space outside.

Dynamic and Thermodynamic Stability of Black Holes and Black Branes

Bob Wald
University of Chicago

I describe work with Stefan Hollands that establishes a general criterion for the dynamical stability of black holes and black branes in arbitrary spacetime dimensions with respect to axisymmetric perturbations. We show that the positivity of the canonical energy on a subspace of linearized solutions that have vanishing linearized ADM mass and angular momentum implies mode stability. Conversely, failure of positivity of canonical energy on this subspace implies instability in the sense that there exist perturbations that cannot asymptotically approach a stationary perturbation; furthermore, failure of positivity on a solution that can be written as the time derivative of another solution implies exponential growth. We further show that positivity of canonical energy is necessary and sufficient for thermodynamic stability (maximum of area at fixed mass and angular momentum) and is also equivalent to the satisfaction of a local Penrose inequality. For black branes, we show that a sufficient condition for instability is the failure of the Hessian of area with respect to mass and angular momentum to be negative, thus proving a conjecture of Gubser and Mitra. Our methods can be applied quite generally to diffeomorphism covariant theories derived from a Lagrangian.

The Search for Continuous Gravitational Waves with LIGO and Virgo

Karl Wette
Max Planck Institute for Gravitational Physics

The Advanced LIGO gravitational-wave detectors will begin their first observations this year. In the next 5 years, along with the Advanced Virgo detector and potentially the KAGRA detector, they are widely anticipated to make the first direct detections of gravitational waves in ground-based detectors, and open up exciting new possibilities for observing the Universe. One class of sources which may be detected are continuous gravitational waves emitted by rapidly-spinning nonaxially-deformed neutron stars. I will present an overview of past and present efforts to search for continuous gravitational waves, and the data analysis challenges such searches entail.

Cosmic microwave background anisotropies in the timescape cosmology

David L Wiltshire
University of Canterbury

M Ahsan Nazer
University of Canterbury

We analyse cosmic microwave background (CMB) anisotropies in the timescape cosmology: a potentially viable alternative to homogeneous isotropic cosmologies without dark energy. Fits to the Planck satellite data are performed and best fit values of cosmological parameters determined, including the Hubble constant and the present epoch void fraction. While the likelihood is comparable to that of the standard homogeneous isotropic Lambda Cold Dark Matter cosmology, large systematic uncertainties of 8-13% remain, as we are currently limited to using a projection technique, which exploits the fact that the universe was very close to a standard cosmology at early epochs. We draw the lesson that future progress requires fully considering backreaction of inhomogeneities in the primordial plasma also.

[1] Nazer, M.A., and Wiltshire, D.L., (2015) *Phys. Rev. D91, 063519*

Observational tests of differential expansion of space

David L Wiltshire
University of Canterbury

Krzysztof Bolejko
University of Sydney

M Ahsan Nazer
University of Canterbury

Recently it has been observed that the expansion of the universe on scales ¡ 100/h Mpc is significantly more uniform in the rest frame of the Local Group of galaxies than in the standard rest frame of the Cosmic Microwave Background (CMB) Radiation [1,2]. This suggests that a significant fraction of the CMB dipole may be nonkinematic, with an impact on observed large angle anomalies in CMB anisotropies. In new work [3] we have constructed exact solutions of Einstein's equations which match the standard Lambda Cold Dark Matter cosmology on ¿ 100/h Mpc scales but with an inhomogeneous Szekeres model on smaller scales. Using numerical ray tracing simulations we constrain models by requiring they match CMB anisotropies with a nonkinematic contribution. Such models are found to also match features of the observed anisotropies in the local expansion of the universe, as seen in the COMPOSITE sample of 4534 galaxies, better than the standard cosmology.

[1] Wiltshire, D.L., Smale, P.R., Mattsson, T., and Watkins, R., (2013) *Phys. Rev. D88, 083529*

[2] McKay, J.H., and Wiltshire, D.L., (2015) *arXiv:1503.04192*

[3] Bolejko, K., Nazer, M.A., and Wiltshire, D.L., (2015) *in preparation*

Optomechanics in gravitational wave detectors: instabilities and applications

Chunnong Zhao
University of Western Australia

The laser interferometer gravitational wave (GW) detectors use extremely high optical power and ultra-low optical and mechanical loss test masses to enhance the coupling of the test mass motion induced by passing GWs to the optical field for improving the sensitivity. The strong coupling between the test mass motion and the optical field creates strong optomechanical interactions.

The optomechanical interaction can transfer optical power into mechanical power. If the mechanical power injected by this mechanism exceeds the mechanical losses of the test mass, the test mass mechanical mode amplitude will grow exponentially until very large amplitude causes saturation of control electronics and failure operation of the instrument. This instability generally involving 2 optical modes and one mechanical mode is called 3-mode parametric instability. The self-sustained instability was observed on the high optical power facility at Gingin, Western Australia and on the first operation of advanced LIGO detectors at 25% of the full power. The instability was controlled by thermally tuned the frequency of the cavity high order mode involved. It is predicted that 40 unstable modes will appear when advanced LIGO detectors operate at the full power. Then the thermal tuning would not be so effective in controlling the instability because tuning away from one unstable mode will approach another one. Multiple control schemes might be required to work simultaneously to control all unstable modes.

The optomechanical interaction could introduce instability if not controlled as mentioned above, but it can also be useful in improving the quantum noise limited sensitivity of gravitational wave detectors. The signal recycling cavity is used in the advanced GW detectors, initially will be in the signal extraction mode in advanced LIGO. It can be tuned to resonance at a specific signal frequency to amplify the signal for improving the sensitivity, but with a narrowing detection bandwidth. It would be ideal if the signal recycling cavity could be resonance in broadband frequencies, which was called white-light cavity. In that case, the signal recycling would increase the broadband sensitivity. The white-light cavity can be achieved by place negative dispersion medium inside an empty optical cavity. We experimentally demonstrated that the tabletop optomechanical cavity can create negative dispersion required for a white-light cavity. If the optomechanical cavity with negative dispersion is place inside the signal recycling cavity, the quantum shot noise limited sensitivity of GW detectors will be improved in broadband frequencies subject to the thermal noise of the mechanical resonator.

In this talk, I will review the research in 3-mode parametric instabilities and their control, as well as the white-light signal recycling cavity using negative dispersion optomechanical cavity.

Programme

Tuesday, 1 December		
6.00-7.30pm		Reception and registration at the Monash University Club

Wednesday, 2 December		
8.00-8.45am		Registration at the Conference Centre
8.45-9.00am		Welcome address, President of the ASGRG Leo Brewin
Session 1		**Chair : Paul Lssky**
9.00-10.00am	Tamara Davis	*Observing the dark: cosmological constraints on gravity theory*
10.00-11.00am	Rana Adhikari	*Listening to the Thunder of Gravity in the Cosmos*
Morning tea		
Session 2		**Chair : Paul Lasky**
11.30-11.50am	Woei Chet Lim	*Non-orthogonally transitive G_2 spike solution*
11.50-12.10pm	Andrew Melatos	*Persistent gravitational waves from "glitchy" millisecond pulsars*
12.10-12.30pm	Arthur Suvorov	*Multipole moments in non-Einstein gravities and tests of the no-hair relations*
Lunch		
Session 3		**Chair : Bram Slagmolen**
1.30-2.30pm	Alex Vilenkin	*Black holes from domain walls and vacuum bubbles*
2.30-2.50pm	Karl Wette	*The Search for Continuous Gravitational Waves with LIGO and Virgo*
2.50-3.10pm	Colin MacLaurin	*Intergalactic cable in an expanding universe*
3.10-3.30pm	Oleg Tsupko	*Influence of plasma on gravitational lensing effects*
Afternoon tea		
Session 4		**Chair : Letizia Sammut**
4.00-4.20pm	Guillermo A Mena Marugan	*Gauge invariant formalism for perturbations in quantum cosmology*
4.20-4.40pm	Laura Castello Gomar	*Mukhanov-Sasaki equations in Hybrid Loop Quantum Cosmology*
4.40-5.00pm	Paul Lasky	*Gravitational-wave cosmology across 29 decades in frequency*

Thursday, 3 December		
Session 5	**Chair : Karl Wette**	
9.00-10.00am	Bob Wald	*Dynamic and Thermodynamic Stability of Black Holes and Black Branes*
10.00-11.00am	Nicole Bell	*The Particle Physics of Dark Matter, and Beyond*
Morning tea		
Session 6	**Chair : Karl Wette**	
11.30-11.50am	David L Wiltshire	*Observational tests of differential expansion of space*
11.50-12.10pm	Allan D Ernest	*A quantum of darkness: gravitational scale and dark matter*
12.10-12.30pm	Eric Thrane	*Hunting for gravitational waves with complicated signals*
12.30-12.50pm	Hayley Macpherson	*Formation of linear structures in our universe: A full general relativistic treatment*
Lunch		
Session 7	**Chair : Eric Thrane**	
1.50-2.10pm	Ana Alonso-Serrano	*On burning a lump of coal*
2.10-2.30pm	Sebastian Schuster	*On the sparsity of the Hawking flux*
2.30-2.50pm	E M Howard	*Thermality of observer-dependent causal horizons*
2.50-3.10pm	Andrew Norton	*Interpreting the Mathisson-Papapetrou equations*
3.10-3.30pm	Malcolm Anderson	*Self-gravitating spherical shells with a stiff elastic equation of state*
Afternoon tea		
4.00-6.00pm	**Bienniel General Meeting**	
7.00-9.30pm	**Banquet at the Monash University Club**	

Friday, 4 December		
Session 8	**Chair : Brynmor Haskell**	
9.00-10.00am	Michael Tobar	*Solving Quantum Gravity and the Nature of Dark Matter Through Low-Energy Precision Measurement*
10.00-11.00am	Jörg Frauendiener	*Three easy(?) pieces in Computational Gravity*
Morning tea		
Session 9	**Chair : Todd Oliynyk**	
11.30-11.50am	Ling Sun	*LIGO data analysis methods for continuous gravitational waves*
11.50-12.10pm	Letizia Sammut	*A stochastic background of gravitational waves from binary black hole mergers*
12.10-12.30pm	Peter A Huf	*Investigations of the shear-free conjecture for a perfect fluid*
12.30-12.50pm	Brynmor Haskell	*Detecting gravitational waves from mountains on neutron stars*
12.50-1.10pm	Chunnong Zhao	*Optomechanics in gravitational wave detectors: instabilities and applications*
Lunch		
Session 10	**Chair : Todd Oliynyk**	
2.10-2.30pm	David L Wiltshire	*Cosmic microwave background anisotropies in the timescape cosmology*
2.30-2.50pm	Allan D Ernest	*The Planck-Hubble conspiracy: coincidence or physics of dark energy?*
2.50-3.10pm	Andrew Norton	*tpTensor: index-free tensor algebra in Mathematica*
3.10-3.20pm	**Closing remarks**	