GRAVITY RESEARCH FOUNDATION

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Abstracts of Award Winning and Honorable Mention Essays for 2018

Award Essays

First Award – **Gravity's Universality: The Physics Underlying Tolman Temperature Gradients** by Jessica Santiago and Matt Visser; School of Mathematics and Statistics, Victoria University of Wellington, PO Box 600, Wellington 6140, New Zealand; e-mail: jessica.santiago@sms.vuw.ac.nz, matt.visser@sms.vuw.ac.nz

Abstract – We provide a simple and clear verification of the physical need for temperature gradients in equilibrium states when gravitational fields are present. Our argument will be built in a completely *kinematic* manner, in terms of the *gravitational red-shift/blue-shift* of light, together with a relativistic extension of Maxwell's two column argument. We conclude by showing that it is the *universality* of the gravitational interaction (the uniqueness of free-fall) that ultimately permits Tolman's equilibrium temperature gradients without any violation of the laws of thermodynamics.

Second Award – **A Microscopic Model for an Emergent Cosmological Constant** by Alejandro Perez[1], Daniel Sudarsky[2], and James D. Bjorken[3]; [1]Aix Marseille Univ, Université de Toulon, CNRS, CPT, Marseille, France, [2]Instituto de Ciencias Nucleares, Universidad Nacional, Autónoma de México, México, D.F. 04510, México, [3]SLAC National Accelerator Laboratory, Stanford University, Stanford, CA 94309; e-mail: perez@cpt.univ-mrs.fr, sudarsky@nucleares.unam.mx, bjbjorken@gmail.com

Abstract – The value of the cosmological constant is explained in terms of a noisy diffusion of energy from the low energy particle physics degrees of freedom to the fundamental Planckian granularity which is expected from general arguments in quantum gravity. The quantitative success of our phenomenological model is encouraging and provides possibly useful insights about physics at the scale of quantum gravity.

Third Award – **GR and Classical Mechanics: Magic?** by Ezra Newman; Department of Physics and Astronomy, University of Pittsburgh, Pittsburgh, PA 15213; e-mail: newman@pitt.edu

Abstract – A new *fundamental* ingredient is introduced in the study of Asymptotically Flat Einstein-Maxwell Space-Times, namely the change of coordinate systems from the standard ones constructed from the infinite number of possible Bondi null-surfaces to those based on the four complex-parameter set; z^a, of Asymptotically Shear-Free (ASF) null surfaces. ASF coordinate systems are determined by "world-lines" in the parameter space, $z^a = \xi^a(\tau)$. Setting a Weyl tensor component, **defined** as the *complex-mass-dipole*, to zero, a *unique complex center of mass/charge 'world-line'* is obtained. From this line and Bianchi identities, much of classical mechanics is directly obtained: spin, orbital angular momentum, kinematic momentum, angular-momentum conservation, energy-momentum conservation, Newton's 2nd law with Abraham-Lorentz-Dirac radiation reaction, Rocket force and Dirac g-factor.

Fourth Award – **The Kinetic Theory of the Mesoscopic Spacetime** by T. Padmanabhan; IUCAA, Pune University Campus, Ganeshkhind, Pune - 411 007, India; e-mail: paddy@iucaa.in

Abstract – At the mesoscopic scales — which interpolate between the macroscopic, classical, geometry and the microscopic, quantum, structure of spacetime — one can identify the density of states of the geometry which arises from the existence of a zero-point length in the spacetime. This spacetime discreteness also associates an internal degree of freedom with each event, in the form of a fluctuating vector of constant norm. The equilibrium state, corresponding to the extremum of the total density of states of geometry plus matter, leads precisely to Einstein's equations. In fact, the field equation can now be reinterpreted as a zero-heat dissipation principle. The analysis of fluctuations around the equilibrium state (described by Einstein's equations), will provide new insights about quantum gravity.

Fifth Award – **The Holographic Space-Time Model of Cosmology** by Tom Banks[1] and W. Fischler[2]; [1]NHETC and Department of Physics, Rutgers University, Piscataway, NJ 08854-8019, [2]Department of Physics and Texas Cosmology Center, University of Texas, Austin, TX 78712; e-mail: tibanks@ucsc.edu, fischler@physics.utexas.edu

Abstract – This essay outlines the Holographic Space-time (HST) theory of cosmology and its relation to conventional theories of inflation. The predictions of the theory are compatible with observations, and one must hope for data on primordial gravitational waves or non-Gaussian fluctuations to distinguish it from conventional models. The model predicts an early era of structure formation, prior to the Big Bang. Understanding the fate of those structures requires complicated simulations that have not yet been done. The result of those calculations might falsify the model, or might provide a very economical framework for explaining dark matter and the generation of the baryon asymmetry.

Honorable Mention Awards **(Alphabetical Order)**

1. **Minimal Length and the Flow of Entropy from Black Holes** by Ana Alonso-Serrano[1], Mariusz P. Dąbrowski[2], and Hussain Gohar[3]; [1]Max Planck Institute for Gravitational Physics, Albert Einstein Institute, Am Mühlenberg 1, D-14476 Golm, Germany, [2]Institute of Physics, University of Szczecin, Wielkopolska 15, 70-451 Szczecin, Poland, National Centre for Nuclear Research, Andrzeja Soltana 7, 05-400 Otwock, Poland, and Copernicus Center for Interdisciplinary Studies, Slawkowska 17, 31-016 Kraków, Poland, [3]Institute of Physics, University of Szczecin, Wielkopolska 15, 70-451 Szczecin, Poland; e-mail: ana.alonso.serrano@aei.mpg.de, mariusz.dabrowski@usz.edu.pl, hussain.gohar@usz.edu.pl

Abstract – The existence of a minimal length, predicted by different theories of quantum gravity, can be phenomenologically described in terms of a generalized uncertainty principle. We consider the impact of this quantum gravity motivated effect onto the information budget of a black hole and the sparsity of Hawking radiation during the black hole evaporation process. We show that the information is not transmitted at the same rate during the final stages of the evaporation, and that the Hawking radiation is not sparse anymore when the black hole approaches the Planck mass.

2. **Maximal Supergravity and the Quest for Finiteness** by Sudarshan Ananth[1], Lars Brink[2], and Sucheta Majumdar[1]; [1]Indian Institute of Science Education and Research, Pune 411008, India, [2]Department of Physics, Chalmers University of Technology, S-41296 Göteborg, Sweden and Division of Physics and Applied Physics, School of Physical and Mathematical Sciences, Nanyang Technological University, Singapore 637371; e-mail: ananth@iiserpune.ac.in, lars.brink@chalmers.se, sucheta.majumdar@students.iiserpune.ac.in

Abstract – We show that $N = 8$ supergravity may possess an even larger symmetry than previously believed. Such an enhanced symmetry is needed to explain why this theory of gravity exhibits ultraviolet behavior reminiscent of the finite $N = 4$ Yang-Mills theory. We describe a series of three steps that leads us to this result.

3. **Is There an Upper Bound on the Size of a Black Hole?** by Swastik Bhattacharya[1] and S. Shankaranarayanan[2]; [1]Department of Physics, BITS Pilani Hyderabad, Hyderabad 500078, Telangana State, India, [2]Department of Physics, Indian Institute of Technology Bombay, Mumbai 400076, India; e-mail: swastik@hyderabad.bits-pilani.ac.in, shanki@phy.iitb.ac.in

Abstract – According to the third law of Thermodynamics, it takes an infinite number of steps for any object, including black-holes, to reach zero temperature. For any physical system, the process of cooling to absolute zero corresponds to erasing information or generating pure states. In contrast with the ordinary matter, the black-hole temperature can be lowered only by adding matter-energy into it. However, it is impossible to remove the statistical fluctuations of the infalling matter-energy. The fluctuations lead to the fact that black-holes have a finite lower temperature and, hence, an upper bound on the horizon radius. We make an estimate of the upper bound for the horizon radius which is curiously comparable to Hubble horizon. We compare this bound with known results and discuss its implications.

4. **Gravitational Friedel Oscillations in Higher-Derivative and Infinite-Derivative Gravity?** by Jens Boos; Theoretical Physics Institute, University of Alberta, Edmonton, AB T6G 2E1, Canada; e-mail: boos@ualberta.ca

Abstract – When a positively charged impurity is placed inside a cold metal, the resulting charge density around that object exhibits characteristic ripples to negative values, known as *Friedel oscillations*. In this essay, we describe a somewhat analogous effect in (i) linearized higher-derivative gravity and (ii) linearized infinite-derivative "ghost-free" gravity: when a gravitational impurity (point particle) is placed in Minkowski vacuum, the local energy density $\rho \equiv G_{\mu\nu}u^\mu u^\nu$ exhibits oscillations to negative values. The wavelength of these oscillations is roughly given by (i) the Pauli-Villars regularization scale and (ii) the scale of non-locality. We hence dub this phenomenon *gravitational Friedel oscillations*.

5. **Cosmic Evolution with a General Gaussian Type Scale Factor** by Subenoy Chakraborty[1] and Subhra Bhattacharya[2]; [1]Department of Mathematics, Jadavpur University, Kolkata 700 032, India, [2]Department of Mathematics, Presidency University, Kolkata 700 073, India; e-mail: schakraborty@math.jdvu.ac.in, subhra.maths@presiuniv.ac.in

Abstract – Here we present a simple model of cosmic evolution in Einstein gravity, with the cosmic substratum being composed of an inhomogeneous and anisotropic fluid. The scale factor is supposed to be of Gaussian type. In this framework we show the existence of a continuously evolving eternal universe with no singularity, beginning or end.

6. **Gravitational Energy Is Well Defined** by Chiang-Mei Chen[1][2], Jian-Liang Liu[3]. and James M. Nester[1][4][5]; [1]Department of Physics, National Central University, Chungli 32001, Taiwan, [2]Center for High Energy and High Field Physics (CHiP), National Central University, Chungli 32001, Taiwan, [3]Department of Mathematics and Data Science, Dongguan University of Technology, Dongguan, China, [4]Graduate Institute of Astronomy, National Central University, Chungli 32001, Taiwan, [5]Leung Center for Cosmology and Particle Astrophysics, National Taiwan University, Taipei 10617, Taiwan; e-mail: cmchen@phy.ncu.edu.tw, 2018013@dgut.edu.cn, nester@phy.ncu.edu.tw

Abstract – The energy of gravitating systems has been an issue since Einstein proposed general relativity: considered to be ill defined, having no proper local density. Energy-momentum is now regarded as *quasi-local* (associated with a closed 2-surface). We consider the pseudotensor and quasi-local proposals in the Lagrangian-Noether-Hamiltonian formulations. There are two ambiguities: (i) many expressions, (ii) each depends on some non-dynamical structure, e.g., a reference frame. The Hamiltonian approach gives a handle on both problems. Our remarkable discovery is that with a 4D isometric Minkowski reference a large class of expressions – those that agree with the Einstein pseudotensor's Freud superpotential to linear order – give a common quasi-local energy value. With a best-matched reference on the boundary this value is the non-negative Wang-Yau mass.

7. **New Proof of General Relativity through the Correct Physical Interpretation of the Mössbauer Rotor Experiment** by Christian Corda; Research Institute for Astronomy and Astrophysics of Maragha (RIAAM), P.O. Box 55134-441, Maragha, Iran and International Institute for Applicable Mathematics & Information Sciences (IIAMIS), B. M. Birla Science Centre, Adarsh Nagar, Hyderabad - 500 463, India; e-mail: cordac.galilei@gmail.com

Abstract – In this Essay, we give a correct interpretation of a historical experiment by Kündig on the transverse Doppler shift in a rotating system (Mössbauer rotor experiment). This experiment has been recently first reanalyzed, and then replied by an experimental research group. The results of reanalyzing the experiment have shown that a correct re-processing of Kündig's experimental data gives an interesting deviation of a relative redshift between emission and absorption resonant lines from the standard prediction based on the relativistic dilatation of time. Subsequent new experimental results by the reply of Kündig experiment have shown a deviation from the standard prediction even higher. By using the Equivalence Principle (EP), which states the equivalence between the gravitational "force" and the *pseudo-force* experienced by an observer in a non-inertial frame of reference (included a rotating frame of reference), here the theoretical framework of the Mössbauer rotor experiment is reanalyzed directly in the rotating frame of reference through a general relativistic treatment. It will be shown that previous analyses missed an important effect of clock synchronization. By adding this new effect, the correct general relativistic prevision is in perfect agreement with the new experimental results. Such an effect of clock synchronization has been missed in various papers in the literature, with some subsequent claim of invalidity of the relativity theory and/or some attempts to explain the experimental results through "exotic" effects. The general relativistic interpretation in this Essay shows, instead, that the new experimental results of the Mössbauer rotor experiment are a new, strong and independent, proof of general relativity.

8. **Renormalizing Gravity: A New Insight into an Old Problem** by Saurya Das[1], Mir Faizal[2][1], and Elias C. Vagenas[3]; [1]Theoretical Physics Group and Quantum Alberta, Department of Physics and Astronomy, University of Lethbridge, 4401 University Drive, Lethbridge, Alberta T1K 3M4, Canada, [2]Irving K. Barber School of Arts and Sciences, University of British Columbia – Okanagan, 3333 University Way, Kelowna, British Columbia V1V 1V7, Canada, [3]Theoretical Physics Group, Department of Physics, Kuwait University, P.O. Box 5969, Safat 13060, Kuwait; e-mail: saurya.das@uleth.ca, mir.faizal@uleth.ca, elias.vagenas@ku.edu.kw

Abstract – It is well-known that perturbative quantum gravity is non-renormalizable. The metric or vierbein has generally been used as the variable to quantize in perturbative quantum gravity. In this essay, we show that one can use the spin connection instead, in which case it is possible to obtain a ghost-free renormalizable theory of quantum gravity. Furthermore in this approach, gravitational analogs of particle physics phenomena can be studied. In particular, we study the gravitational Higgs mechanism using spin connection as a gauge field, and show that this provides a mechanism for the effective reduction in the dimensionality of spacetime.

9. **New Sources of Gravitational Wave Signals: The Black Hole Graviton Laser** by Éric Dupuis and M. B. Paranjape; Groupe de physique des particules, Département de physique, Université de Montréal, C.P. 6128, succ. centre-ville, Montréal, Québec, Canada, H3C 3J7; e-mail: eric.dupuis.1@umontreal.ca, paranj@lps.umontreal.ca

Abstract – A graviton laser works, in principle, by the stimulated emission of coherent gravitons from a lasing medium. For significant amplification, we must have a very long path length and/or very high densities. Black holes and the existence of weakly interacting sub-eV dark matter particles (WISPs) solve both of these obstacles. Orbiting trajectories for massless particles around black holes are well understood and allow for arbitrarily long graviton path lengths. Superradiance from Kerr black holes of WISPs can provide the sufficiently high density. This suggests that black holes can act as efficient graviton lasers. Thus directed graviton laser beams have been emitted since the beginning of the universe and give rise to new sources of gravitational wave signals. To be in the path of particularly harmfully amplified graviton death rays will not be pleasant.

10. **Jittery Clocks and Folded Rulers: A Reason for Quantization and Gravitation** by Joshua Erlich; Department of Physics, William & Mary, P.O. Box 8795, Williamsburg, VA 23187-8795; e-mail: erlich@physics.wm.edu

Abstract – We propose a common origin for quantum mechanics and gravitation. We explain how diffeomorphism-invariant theories with scalar clock and ruler fields can include a stochasticity resembling standard quantum theory. The microscopic description of the stochastic process provides a physical covariant regulator for the quantum field theory conjectured to describe the stochastic system. A gravitational interaction then emerges at long distances by analogy with Sakharov's induced gravity. This framework predicts a breakdown of both quantum theory and general relativity at sufficiently short distances, and provides a description of spacetime and its causal structure at those scales.

11. **Boundary Conservation from Bulk Symmetry** by C. Fairoos, Avirup Ghosh, and Sudipta Sarkar; Indian Institute of Technology, Gandhinagar, 382355, Gujarat, India; e-mail: fairoos.c@iitgn.ac.in, avirup.ghosh@iitgn.ac.in, sudiptas@iitgn.ac.in

Abstract – The evolution of the black hole horizon can be effectively captured by a fictitious membrane fluid living on the stretched horizon. We show that the dynamics of this boundary matter arises from the invariance of the bulk action under local symmetries in the presence of the inner boundary. If general covariance is broken in a semi-classical treatment of a quantum field near a black hole horizon, we argue that it can be restored by the inclusion of a quantum flux into the membrane conservation equation which is exactly equal to the Hawking flux.

12. **Friedmann's Equation and the Creation of the Universe** by Arthur E. Fischer; Department of Mathematics, University of California, Santa Cruz, Santa Cruz, CA 95064; e-mail: aef@ucsc.edu

Abstract – In this essay we present *mathematical evidence* that the beginning of the universe did not occur at the big bang at $t = 0$ with the universe in a state of infinite density, but occurred at $t = -4$ with the universe in a state of infinite dilution. We show the essential importance played by the quadratic structure of Friedmann's equation in the time derivative $\dot{a}$ and how this quadratic structure has profound physical consequences in building Friedmann models of the universe, one of which is that the universe did not begin at the big bang. Thus we conclude that embedded in Friedmann's equation is previously undiscovered information about how the universe began.

13. **Quantum Gravity: A Quantum-First Approach** by Steven B. Giddings; Department of Physics, University of California, Santa Barbara, CA 93106; e-mail: giddings@ucsb.edu

Abstract – A "quantum-first" approach to gravity is described, where rather than quantizing general relativity, one seeks to formulate the physics of gravity within a quantum-mechanical framework with suitably general postulates. Important guides are the need for appropriate mathematical structure on Hilbert space, and correspondence with general relativity and quantum field theory in weak-gravity situations. A basic physical question is that of "Einstein separability:" how to define mutually independent subsystems, *e.g.* through localization. Standard answers via tensor products or operator algebras conflict with properties of gravity, as is seen in the correspondence limit; this connects with discussions of "soft hair." Instead, gravitational behavior suggests a networked Hilbert space structure. This structure plus unitarity provide important clues towards a quantum formulation of gravity.

14. **Gravity's Light in the Shadow of the Moon** by Andri Gretarsson[1], Preston Jones[1], and Douglas Singleton[2]; [1]Embry Riddle Aeronautical University, Prescott, AZ 86301, [2]California State University Fresno, Fresno, CA 93740; e-mail: Andri.Gretarsson@erau.edu, Preston.Jones1@erau.edu, dougs@mail.fresnostate.edu

Abstract – In this essay we look at the possibility of vacuum production of very low frequency electromagnetic radiation from a gravitational wave background (*i.e.* gravity's light). We also propose that this counterpart electromagnetic radiation should be detectable by a lunar orbiting satellite which is periodically occulted by the Moon (*i.e.* in the shadow of the Moon). For concreteness we consider the possibility of detection of both the gravitational wave and hypothesized electromagnetic radiation counterpart from the supernova core collapse of Betelgeuse.

15. **Membrane Paradigm from Near Horizon Soft Hair** by D. Grumiller[1] and M. M. Sheikh-Jabbari[2]; [1]Institute for Theoretical Physics, TU Wien, Wiedner Hauptstr. 8, A-1040 Vienna, Austria, [2]School of Physics, Institute for Research in Fundamental Sciences (IPM), P.O. Box 19395-5531, Tehran, Iran; e-mail: grumil@hep.itp.tuwien.ac.at, jabbari@theory.ipm.ac.ir

Abstract – The membrane paradigm posits that black hole microstates are dynamical degrees of freedom associated with a physical membrane vanishingly close to the black hole's event horizon. The soft hair paradigm postulates that black holes can be equipped with zero-energy charges associated with residual diffeomorphisms that label near horizon degrees of freedom. In this essay we argue that the latter paradigm implies the former. More specifically, we exploit suitable near horizon boundary conditions that lead to an algebra of "soft hair charges" containing infinite copies of the Heisenberg algebra, associated with area-preserving shear deformations of black hole horizons. We employ the near horizon soft hair and its Heisenberg algebra to provide a formulation of the membrane paradigm and show how it accounts for black hole entropy.

16. **Electromagnetic Spin Creates Torsion** by Richard T. Hammond; Department of Physics, University of North Carolina at Chapel Hill and Army Research Office, Research Triangle Park, NC; e-mail: rhammond@email.unc.edu

Abstract – It is shown the intrinsic spin, and only the spin, of the electromagnetic field creates torsion. The struggle raged for decades: How to reconcile the facts that photons have spin, but minimal coupling breaks gauge invariance and therefore must be abandoned, leaving us with the unphysical situation in which spin does not create torsion. By generalizing the gauge freedom of the torsion field, a covariant, gauge invariant description is found whereby the electromagnetic spin creates a torsion field. In fact, it is shown if electromagnetic gauge invariance holds, torsion must be present.

17. **Fermat's Principle in Black-Hole Spacetimes** by Shahar Hod; The Ruppin Academic Center, Emeq Hefer 40250, Israel and The Hadassah Institute, Jerusalem 91010, Israel; e-mail: shaharhod@gmail.com

Abstract – Black-hole spacetimes are known to possess closed light rings. We here present a remarkably compact theorem which reveals the physically intriguing fact that these unique null circular geodesics provide the *fastest* way, as measured by asymptotic observers, to circle around spinning Kerr black holes.

18. **On Background Independence in String Theory** by Olaf Hohm; Simons Center for Geometry and Physics, Stony Brook University, Stony Brook, NY 11794-3636; e-mail: ohohm@scgp.stonybrook.edu

Abstract – I discuss various aspects of background independence in the context of string theory, for which so far we have no manifestly background independent formulation. After reviewing the role of background independence in classical Einstein gravity, I discuss recent results implying that there is a conflict in string theory between manifest background independence and manifest duality invariance when higher-derivative corrections are included. The resolution of this conflict requires the introduction of new gauge degrees of freedom together with an enlarged gauge symmetry. This suggests more generally that a manifestly background independent and duality invariant formulation of string theory requires significantly enhanced gauge symmetries.

19. **The Redshift Dependence of Radial Acceleration: Modified Gravity versus Particle Dark Matter** by Sabine Hossenfelder and Tobias Mistele; Frankfurt Institute for Advanced Studies, Ruth-Moufang-Str. 1, D-60438 Frankfurt am Main, Germany; e-mail: hossi@fias.uni-frankfurt.de, tobias.mistele@gmail.com

Abstract – Modified Newtonian Dynamics has one free parameter and requires an interpolation function to recover the normal Newtonian limit. We show here that this interpolation function is unnecessary in a recently proposed covariant completion of Erik Verlinde's emergent gravity, and that Verlinde's approach moreover fixes the function's one free parameter. The so-derived correlation between the observed acceleration (inferred from rotation curves) and the gravitational acceleration due to merely the baryonic matter fits well with data. We then argue that the redshift dependence of galactic rotation curves could offer a way to tell apart different versions of modified gravity from particle dark matter.

20. **Quantum Gravity and BH-NS Binaries** by Michael J. Kavic[1], Djordje Minic[2], and John Simonetti[2]; [1]Department of Physics, Long Island University, Brooklyn, New York 11201, [2]Department of Physics, Virginia Tech, Blacksburg, VA 24061; e-mail: michael.kavic@liu.edu, dminic@vt.edu, jhs@vt.edu

Abstract – We argue that the Black Hole-Neutron Star (BH-NS) binaries are the natural astrophysical probes of quantum gravity in the context of the new era of multi-messenger astronomy. In particular, we discuss the observable effect of enhanced black-hole mass loss in a BH-NS binary, due to the presence of an additional length scale tied to the intrinsic non-commutativity of quantum spacetime in quantum gravity.

21. **A Duality between Curvature and Torsion** by Swanand Khanapurkar[1][2] and Tejinder P. Singh[2]; [1]Indian Institute of Science Education and Research, Pune 411008, India, [2]Tata Institute of Fundamental Research, Homi Bhabha Road, Mumbai 400005, India; e-mail: swanand.khanapurkar@students.iiserpune.ac.in, tpsingh@tifr.res.in

Abstract – Compton wavelength and Schwarzschild radius are considered here as limiting cases of a unified length scale. Using this length, it is shown that the Dirac equation and the Einstein equations for a point mass are limiting cases of an underlying theory which includes torsion. We show that in this underlying theory the gravitational interaction between small masses is weaker than in Newtonian gravity. We explain as to why the Kerr-Newman black hole and the electron both have the same non-classical gyromagnetic ratio. We propose a duality between curvature and torsion and show that general relativity and teleparallel gravity are respectively the large mass and small mass limit of the ECSK theory. We demonstrate that small scale effects of torsion can be tested with current technology.

22. **Conformal Symmetry and the Cosmological Constant Problem** by Stefano Lucat, Tomislav Prokopec, and Bogumila Świeżewska; Institute for Theoretical Physics, Spinoza Institute and EMMEΦ, Faculty of Science, Utrecht University, Postbus 80.195, 3508 TD Utrecht, The Netherlands; e-mail: S.Lucat@uu.nl, T.Prokopec@uu.nl, B.Swiezewska@uu.nl

Abstract – We argue that, when a theory of gravity and matter is endowed with (classical) conformal symmetry, the fine tuning required to obtain the cosmological constant at its observed value can be significantly reduced. Once tuned, the cosmological constant is stable under a change of the scale at which it is measured.

23. **Particle Creation, Emergent Gravity, and the Nature of the Vacuum** by Emil J. Martinec; Enrico Fermi Inst. and Dept. of Physics, University of Chicago, 5640 S. Ellis Ave., Chicago, IL 60637-1433; e-mail: e-martinec@uchicago.edu

Abstract – At the horizon of a black hole or inflating universe, field modes are pulled from the ultraviolet vacuum and stretched exponentially; virtual fluctuations become real in the process. The origin of these modes is reconsidered in the light of gauge/gravity duality.

24. **Can the Universe Be Described by a Wavefunction?** by Samir D. Mathur; Department of Physics The Ohio State University, Columbus, OH 43210; e-mail: mathur.16@osu.edu

Abstract – Suppose we assume that in gently curved spacetime (a) causality is not violated to leading order (b) the Birkoff theorem holds to leading order and (c) CPT invariance holds. Then we argue that the 'mostly empty' universe we observe around us cannot be described by an exact wavefunction Ψ. Rather, the weakly coupled particles we see are approximate quasiparticles arising as excitations of a 'fuzz'. The 'fuzz' *does* have an exact wavefunction Ψ_{fuzz}, but this exact wavefunction does not directly describe local particles. The argument proceeds by relating the cosmological setting to the black hole information paradox, and then using the small corrections theorem to show the impossibility of an exact wavefunction describing the visible universe.

25. **Perturbatively Renormalizable Quantum Gravity** by Tim R. Morris; STAG Research Centre and Department of Physics and Astronomy, University of Southampton, Highfield, Southampton, SO17 1BJ, U.K.; e-mail: T.R.Morris@soton.ac.uk

Abstract – The Wilsonian renormalization group (RG) requires Euclidean signature. The conformal factor of the metric then has a wrong-sign kinetic term, which has a profound effect on its RG properties. In particular around the Gaussian fixed point, it supports a Hilbert space of renormalizable interactions involving arbitrarily high powers of the gravitational fluctuations. These interactions are characterised by being exponentially suppressed for large field amplitude, perturbative in Newton's constant but non-perturbative in Planck's constant. By taking a limit to the boundary of the Hilbert space, diffeomorphism invariance is recovered whilst retaining renormalizability. Thus the so-called conformal factor instability points the way to constructing a perturbatively renormalizable theory of quantum gravity.

26. **Brans-Dicke Gravity: from Higgs Physics to (Dynamical) Dark Energy** by Joan Solà Peracaula; Departament de Física Quàntica i Astrofísica, and Institute of Cosmos Sciences, Universitat de Barcelona, Av. Diagonal 647 E-08028 Barcelona, Catalonia, Spain; e-mail: sola@fqa.ub.edu

Abstract – The Higgs mechanism is one of the central pieces of the Standard Model of electroweak interactions and thanks to it we can generate the masses of the elementary particles. Its fundamental origin is nonetheless unknown. Furthermore, in order to preserve renormalizability we have to break the gauge symmetry spontaneously, what leads to a huge induced cosmological constant incompatible with observations. It turns out that in the context of generalized Brans-Dicke theories of gravity the Higgs potential structure can be motivated from solutions of the field equations which carry harmless cosmological vacuum energy. In addition, the late time cosmic evolution effectively appears like a universe filled with mildly evolving dynamical dark energy mimicking quintessence or phantom dark energy.

27. **Efimov Physics in Curved Spacetime: Field Fluctuations and Exotic Matter** by Fabrizio Pinto; Izmir University of Economics, Department of Aerospace Engineering, Faculty of Engineering, Teleferik Mahallesi, Sakarya Cd. No:156, 35330 Balçova İzmir, Republic of Turkey; e-mail: fabrizio.pinto@ieu.edu.tr

Abstract – Several experimental detections have demonstrated the existence of Borromean states predicted by Vitaly Efimov within a nuclear physics context, that is, trimers bound despite the absence of bound states of any of the two-body subsystems. I show that novel Efimov physics is expected in gravitationally polarizable non-baryonic dark matter beyond the Standard Model with van der Waals-like forces driven by quantum gravitational fluctuations. I also discuss ground- and space- based tests of spacetime curvature effects on weakly bound, highly diffuse quantum three-body systems with standard electrodynamical van der Waals forces. Finally, I consider exotic gravitational quantum matter from higher-order Brunnian structures and analogies with classical systems, already proven in three-stranded DNA, driven by the stochastic gravitational wave background.

28. **The Simplest Origin of the Big Bounce and Inflation** by Nikodem Poplawski; Department of Mathematics and Physics, University of New Haven, 300 Boston Post Road, West Haven, CT 06516; e-mail: NPoplawski@newhaven.edu

Abstract – Torsion is a geometrical object, required by quantum mechanics in curved spacetime, which may naturally solve fundamental problems of general theory of relativity and cosmology. The black-hole cosmology, resulting from torsion, could be a scenario uniting the ideas of the big bounce and inflation, which were the subject of a recent debate of renowned cosmologists.

29. **Does GW170817 Falsify MOND?** by R. H. Sanders; Kapteyn Astronomical Institute, P.O. Box 800, 9700 AV Groningen, The Netherlands; e-mail: sanders@astro.rug.nl

Abstract – The gravitational-wave event GW170817 and the near-simultaneous corresponding gamma-ray burst (GRB 170817 A) falsify modified gravity theories in which the gravitational geometry differs non-conformally from physical geometry. Thus, the observations of this event definitively rule out theories, such as TeVeS, a suggested relativistic extension of Milgrom's modified Newtonian dynamics (MOND) that predict a significantly different Shapiro delay for electromagnetic and gravitational radiation. While not falsifying MOND per se, GW170817 severely constrains relativistic extensions of MOND to theories that do not rely on additional matter-coupling fields but rather upon modified field equations for one universal gravitational and physical metric. Here I mention a simple preferred-frame theory as an example.

30. **Could GR Contextuality Resolve the Missing Mass Problem?** by W. M. Stuckey[1], Timothy McDevitt[2], A. K. Sten[3] and Michael Silberstein[4]; [1]Department of Physics, Elizabethtown College, Elizabethtown, PA 17022, [2]Department of Mathematical Sciences, Elizabethtown College, Elizabethtown, PA 17022, [3]Department of Physics, University of North Texas, Denton, TX 76201, [4]Department of Philosophy and Foundations of Physics, Committee for Philosophy and the Sciences, University of Maryland, College Park, MD 20742; e-mail: stuckeym@etown.edu, mcdevittt@etown.edu, AlexanderSten@my.unt.edu, msilbers@umd.edu

Abstract – In Newtonian gravity, mass is an intrinsic property of matter while in general relativity (GR), mass is a contextual property of matter, e.g., when two different GR spacetimes are adjoined. Herein, we explore the possibility that the astrophysical missing mass attributed to non-baryonic dark matter (DM) actually obtains because we have been assuming the Newtonian intrinsic view of mass rather than the GR contextual view. Perhaps, we should model astrophysical phenomena via combined GR spacetimes to better account for their complexity. Accordingly, we consider a GR ansatz in fitting galactic rotation curve data (THINGS), X-ray cluster mass profile data (ROSAT/ASCA), and CMB angular power spectrum data (Planck 2015) without DM. We find that our fits compare well with both modified gravity programs and DM programs.

31. **Dark Angular Momentum of the Galaxy** by Angelo Tartaglia; DISAT, Politecnico, Corso Duca degli Abruzzi 24, 10129 Torino, Italy; e-mail: angelo.tartaglia@polito.it

Abstract – This paper proposes a strategy for detecting the presence of a gravito-magnetic field due to the rotation of the galactic dark halo. Visible matter in galaxies rotates and dark matter, supposed to form a halo incorporating baryonic matter, rotates also, since it interacts gravitationally with the rest. Pursuing the same line of reasoning, dark matter should produce all gravitational effects predicted by general relativity, including a gravito-magnetic field. I discuss a possible strategy for measuring that field. The idea recovers the old Sagnac effect and proposes to use a triangle having three Lagrange points of the Sun-Earth pair at its vertices. The asymmetry in the times of flight along the loop in opposite directions is proportional to the gravito-magnetic galactic field.

32. **Gravitational Waves on their Own Gravitational Speed** by C. S. Unnikrishnan[1] and George T. Gillies[2]; [1]Gravitation Group, Tata Institute of Fundamental Research, Homi Bhabha Road, Mumbai - 400 005, India, [2]School of Engineering and Applied Science, University of Virginia, Charlottesville, VA 22904-4746; e-mail: unni@tifr.res.in, gtg@virginia.edu

Abstract – Gravitational waves propagate at the speed of light in general relativity, because of its special relativistic basis. However, light propagation is linked to the electromagnetic phenomena, with the permittivity and permeability constants as the determining factors. Is there a deeper reason why waves in a geometric theory of gravity propagate at a speed determined by electromagnetic constants? What is the relation between gravity's constants and the speed of gravitational waves? Our attempt to answer these fundamental questions takes us far into the universe.

33. **Classical Hawking Radiation** by Tanmay Vachaspati[1] and George Zahariade[2]; [1]Physics Department, Arizona State University, Tempe, AZ 85287, [2]Beyond Center for Fundamental Concepts in Science and Physics Department, Arizona State University, Tempe, AZ 85287; e-mail: tvachasp@asu.edu, zahariad@asu.edu

Abstract – We show that a gravitationally collapsing object will emit classical radiation at a rate equal to the quantum Hawking radiation rate for one scalar field if suitable initial conditions are chosen for *two* classical fields. We then solve for the coupled dynamics of gravitational collapse and radiation in a toy model, illustrating how the classical system may be used to gain insight into Hawking evaporation.

34. **Constructing a Theory with Holographic Degrees of Freedom** by Yong Xiao; College of Physical Science and Technology, Hebei University, Baoding 071002, China; e-mail: xiaoyong@hbu.edu.cn

Abstract – In this essay, we construct a simple bulk theory with holographic degrees of freedom that is proportional to the boundary area of the system. Using the theory, we show that the black hole thermodynamics can be derived consistently. The theory has a deep implication for the microscopic structure of black holes and it strongly suggests that a holographic stage exists in the early universe.