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Abstracts of Award Winning and Honorable Mention Essays for 2021

Award Essays

First Award – **The Elastic Vacuum** by Samir D. Mathur; Department of Physics, The Ohio State University, Columbus, OH 43210; e-mail: mathur.16@osu.edu

Abstract – The quantum gravity vacuum must contain virtual fluctuations of black hole microstates. These extended-size fluctuations get 'crushed' when a closed trapped surface forms, and turn into on-shell 'fuzzball' states that resolve the information puzzle. We argue that these same fluctuations can get 'stretched' by the antitrapped surfaces in an expanding cosmology, and that this stretching generates vacuum energy. The stretching happen when the Hubble deceleration reduces quickly, which happens whenever the pressure drops quickly. We thus get an inflation-scale vacuum energy when the heavy GUTS particles become nonrelativistic, and again a small vacuum energy when the radiation phase turns to dust. The expansion law in the radiation phase does not allow stretching, in agreement with the observed irrelevance of vacuum energy in that phase.

Second Award – **Quantum Gravity Phenomenology in the Infrared** by Laurent Freidel[1], Jerzy Kowalski-Glikman[2][3], Robert G. Leigh[4], and Djordje Minic[5]; [1]Perimeter Institute for Theoretical Physics, 31 Caroline St. N., Waterloo ON, Canada, [2]Institute for Theoretical Physics, University of Wroclaw, Pl. Maksa Borna 9, 50-204 Wroclaw, Poland, [3]National Centre for Nuclear Research, Pasteura 7, 02-093 Warsaw, Poland, [4]Illinois Center for Advanced Studies of the Universe & Department of Physics, University of Illinois, 1110 West Green St., Urbana IL 61801, [5]Department of Physics, Virginia Tech, Blacksburg, VA 24061; e-mail: lfreidel@perimeterinstitute.ca, jerzy.kowalski-glikman@uwr.edu.pl, rgleigh@illinois.edu, dminic@vt.edu

Abstract – Quantum gravity effects are traditionally tied to short distances and high energies. In this essay we argue that, perhaps surprisingly, quantum gravity may have important consequences for the phenomenology of the infrared. We center our discussion around a conception of quantum gravity involving a notion of quantum spacetime that arises in metastring theory. This theory allows for an evolution of a cosmological Universe in which string-dual degrees of freedom decouple as the Universe ages. Importantly such an implementation of quantum gravity allows for the inclusion of a fundamental length scale without introducing the fundamental breaking of Lorentz symmetry. The mechanism seems to have potential for an entirely novel source for dark matter/energy. The simplest observational consequences of this scenario may very well be residual infrared modifications that emerge through the evolution of the Universe.

Third Award – **The Quantum Emission of an Alive Black Hole** by J. A. Rueda[1][2][3][4][5] and R. Ruffini[1][2][6]; [1]ICRANet, Piazza della Repubblica 10, I-65122 Pescara, Italy, [2]ICRA, Dipartimento di Fisica, Sapienza Università di Roma, P.le Aldo Moro 5, I-00185 Rome, Italy, [3]ICRANet-Ferrara, Dipartimento di Fisica e Scienze della Terra, Università degli Studi di Ferrara, Via Saragat 1, I-44122 Ferrara, Italy, [4]Dipartimento di Fisica e Scienze della Terra, Università degli Studi di Ferrara, Via Saragat 1, I-44122 Ferrara, Italy, [5]INAF, Istituto de Astrofisica e Planetologia Spaziali, Via Fosso del Cavaliere 100, 00133 Rome, Italy, [6]INAF, Viale del Parco Mellini 84, 00136 Rome Italy; e-mail: jorge.rueda@icra.it, ruffini@icra.it

Abstract – A long fifty-years march of successive theoretical progress and new physics discovered using observations of gamma-ray bursts, has finally led to the formulation of an efficient mechanism able to extract the rotational energy of a Kerr black hole to power these most energetic astrophysical sources and active galactic nuclei. We here present the salient features of this long-sought mechanism, based on gravito-electrodynamics, and which represents an authentic shift of paradigm of black holes as forever "*alive*" astrophysical objects.

Fourth Award – **Einstein-Hilbert Action, with quantum Corrections, from the Planck Scale Coarse-Graining of the Spacetime Microstructure** by T. Padmanabhan; IUCAA, Post Bag 4, Ganeshkhinde, Pune – 411 007, India; e-mail: paddy@iucaa.in

Abstract – The gravitational dynamics of the coarse-grained spacetime geometry should emerge from extremizing the number of microscopic configurations, Ω, of the pre-geometric variables corresponding to a given geometry. This Ω will be the product over all events $\mathcal{P}$ of the density, $\rho(\mathcal{P})$, of microscopic configurations associated with each event $\mathcal{P}$. I show how ρ can be computed, in terms of the Van-Vleck determinant, and thus obtain directly the gravitational effective action $\mathcal{L}_E$ at mesoscopic scales. The leading term of this, non-perturbative, effective action gives the Einstein-Hilbert action, thereby providing its microscopic derivation. The higher order corrections are finite without any need for regularisation and I demonstrate how they can be computed in a systematic manner.

Fifth Award – **Euclidean Gravity and Holography** by Daniel Harlow[1] and Edgar Shaghoulian[2]; [1]Center for Theoretical Physics, Massachusetts Institute of Technology, Cambridge, MA 02139, [2]David Rittenhouse Laboratory, University of Pennsylvania, 209 S. 33rd Street, Philadelphia PA, 19104; e-mail: harlow@mit.edu, eshag@sas.upenn.edu

Abstract – We discuss a recent proposal that the Euclidean gravity approach to quantum gravity is correct if and only if the theory is holographic, providing several examples and general arguments to support the conjecture. This provides a natural mechanism for the low-energy gravitational effective field theory to access a host of deep ultraviolet properties, like the Bekenstein-Hawking entropy of black holes, the unitarity of black hole evaporation, and the lack of exact global symmetries.

Honorable Mention Awards **(Alphabetical Order)**

1. **Covariance Group for Null Geodesic Expansion Calculations, and its Application to the Apparent Horizon** by Stephen L. Adler; Institute for Advanced Study, 1 Einstein Drive, Princeton, NJ 08540; e-mail: adler@ias.edu

Abstract - We show that the recipe for computing the expansions θ_ℓ and θ_n of outgoing and ingoing null geodesics normal to a surface admits a covariance group with nonconstant scalar $\kappa(x)$ corresponding to the mapping $\theta_\ell \rightarrow \kappa\theta_\ell$, $\theta_n \rightarrow \kappa^{-1}\theta_n$. Under this mapping, the product $\theta_\ell\theta_n$ is invariant, and thus the marginal surface computed from the vanishing of θ_ℓ, which is used to define the apparent horizon, is invariant. This covariance group naturally appears in comparing the expansions computed with different choices of coordinate system.

2. **Absorption Spectroscopy of Quantum Black Holes with Gravitational Waves** by Ivan Agullo[1], Vitor Cardoso[2], Adrián del Rio[3], Michele Maggiore[4], and Jorge Pullin[5]; [1]Department of Physics and Astronomy, Louisiana State University, Baton Rouge, LA 70803-4001, [2]CENTRA, Departamento de Física, Instituto Superior Técnico – IST, Universidade de Lisboa – UL, Avenida Rovisco Pais 1, 1049 Lisboa, Portugal, [3]Institute for Gravitation and the Cosmos, Physics Department, Penn State, University Park, PA 16802-6300, [4]Departement de Physique Theorique and Center for Astroparticle Physics, Universite de Geneve, 24 quai Ansermet, CH-1211 Geneve 4, Switzerland, [5]Department of Physics and Astronomy, Louisiana State University, Baton Rouge, LA 70803-4001; e-mail: agullo@lsu.edu, vitor.cardoso@ist.utl.pt, adriandelrio@tecnico.ulisboa.pt, Michele.Maggiore@unige.ch, pullin@lsu.edu

Abstract - The observation of electromagnetic radiation emitted or absorbed by matter was instrumental in revealing the quantum properties of atoms and molecules in the early XX century, and constituted a turning-point in the development of the quantum theory. Quantum mechanics changes dramatically the way radiation and matter interact, making the probability of emission and absorption of light strongly frequency dependent, as clearly manifested in atomic spectra. In this essay, we advocate that gravitational radiation can play, for the quantum aspects of black holes, a similar role as electromagnetic radiation did for atoms, and that the advent of gravitational-wave astronomy can bring this fascinating possibility to the realm of observations.

3. **New Species of Fermions and Bosons with no Cosmological Constant Problem** by Dharam Vir Ahluwalia; Mountain Physics Camp, Bir, Himachal Pradesh, 176077, India; e-mail: dharam.v.ahluwalia@gmail.com

Abstract – If dark matter exists in the form of *ultra light fermionic and bosonic species* then, (a) it can accelerate evaporation of astrophysical black holes to the extent that their lifetimes can be reduced to astronomical time scales, and (b) if there are *extremely large number of such species* it has the potential to solve the hierarchy problem. Here we put forward a proposal that darkness of many of these new particles is natural, and in addition the net zero point energy of the fermions exactly cancels that coming from the new bosons. The needed fermion-boson equality, and matching the fermion-boson degrees of freedom, comes about naturally.

4. **Cosmic Cloaking of Rich Extra Dimensions** by Aghil Alaee[1][2], Marcus Khuri[3], and Hari Kunduri[4]; [1]Department of Mathematics and Computer Science, Clark University, Worcester, MA 01610, [2]Center of Mathematical Sciences and Applications, Harvard University, Cambridge, MA 02138, [3]Department of Mathematics, Stony Brook University, Stony Brook, NY 11794, [4]Department of Mathematics and Statistics, Memorial University of Newfoundland, St John's NL A1C 5S7, Canada; e-mail: aalaeekhangha@clarku.edu, khuri@math.sunysb.edu, hkkunduri@mun.ca

Abstract – We present arguments that show why it is difficult to see rich extra dimensions in the Universe. Conditions are found where significant size and variation of the extra dimensions in a Kaluza-Klein compactification leads to a black hole in the lower dimensional theory. The idea is based on the hoop conjecture concerning black hole existence, as well as on the observation that dimensional reduction on macroscopically large, twisted, or highly dynamical extra dimensions contributes positively to the energy density in the lower dimensional theory and can induce gravitational collapse. A threshold for the size is postulated on the order of $10^{-19}m$, whereby extra dimensions of length above this level must lie inside black holes, thus cloaking them from the view of outside observers. The threshold depends on the size of the Universe, leading to speculation that in the early stages of evolution truly macroscopic and large extra dimensions would have been visible.

5. **A Poynting Theorem Formulation for the Gravitational Wave Stress Pseudo Tensor** by Steven A. Balbus; Department of Physics, Astrophysics, University of Oxford, Denys Wilkinson Building, Keble Road, Oxford OX1 3RH, United Kingdom; e-mail: steven.balbus@physics.ox.ac.uk

Abstract – A very simple and physical derivation of the conservation equation for the propagation of gravitational radiation is presented. The formulation is exact. The result takes the readily recognizable and intuitive form of a Poynting-style equation, in which the outward propagation of stress-energy is directly related to the volumetric equivalent of a radiation reaction force acting back upon the sources, including the purely gravitational contribution to the sources. Upon averaging, the emergent pseudo tensor for the gravitational radiation is in exact agreement with that found by much more labor-intensive methods.

6. **Curing with Hemlock: Escaping the Swampland Using Instabilities from String Theory** by Souvik Banerjee[1], Ulf Danielsson[2], and Suvendu Giri[3][4]; [1]Institut für Theoretische Physik und Astrophysik, Julius-Maximilians-Universität Würzburg, Am Hubland, D-97074 Würzburg, Germany, [2]Institutionen för fysik och astronomi, Uppsala Universitet, Box 803, SE-75108 Uppsala, [3]Dipartimento di Fisica, Universit'a di Milano-Bicocca, I-20126 Milano, [4]INFN, sezione di Milano-Bicocca, I-20126 Milano, Italy; e-mail: souvik.banerjee@physik.uni-wuerzburg.de, ulf.danielsson@physics.uu.se, suvendu.giri@unimib.it

Abstract – In this essay we will take a wonderful ride on a dark bubble with strings attached, which carries our universe out of the swampland and makes it realizable in the landscape of string theory. To find the way to the landscape, we make use of apparently hostile corners of the swampland and their instabilities.

7. **Black Hole Cannibalism** by Ning Bao[1] and Elizabeth Wildenhain[2]; [1]Computational Science Initiative, Brookhaven National Laboratory, Upton, New York, 11973, [2]Center for Theoretical Physics and Department of Physics, University of California, Berkeley, CA 94720; e-mail: ningbao75@gmail.com, Elizabeth_wildenhain@berkeley.edu

Abstract – We consider a version of the Hayden-Preskill thought experiment in which the message thrown into the black hole is itself a smaller black hole. We then discuss the implications of the existence of a recovery channel for this black hole message at asymptotic infinity, resulting in a sharpening of the black hole information paradox for observers who never need to approach a horizon. We suggest decoherence mechanisms as a way of resolving this sharpened paradox.

8. **Were Strong Inflaton Field Fluctuations the Cause of the Big Bang?** by Mauricio Bellini[1][2]; [1]Departamento de Física, Facultad de Ciencias Exactas y Naturales, Universidad Nacional de Mar del Plata, Funes 3350, C.P. 7600, Mar del Plata, Argentina, [2]Instituto de Investigaciones Físicas de Mar del Plata (IFIMAR), Consejo Nacional de Investigaciones Científicas y Técnicas (CONICET), Mar del Plata, Argentina ; e-mail: mbellini@mdp.edu.ar

Abstract – In this essay I propose a model to describe the birth of the universe taking into account back reaction effects produced by the inflaton field fluctuations, with self-interactions included. These fluctuations $\delta\varphi = \varphi(x) - \langle\varphi\rangle$ would have been very important at the Planck scales and their self-interactions could have been the fuel to the primordial expansion of the universe.

9. **Through a Black Hole into a New Universe** by Robert Brandenberger[1], Lavinia Heisenberg[2], and Jakob Robnik[2]; [1]Department of Physics, McGill University, Montréal, QC, H3A 2T8, Canada, [2]Institute for Theoretical Physics, ETH Zürich, Wolfgang-Pauli-Strasse 27, 8093, Zürich, Switzerland; e-mail: rhb@physics.mcgill.ca, lavinia.heisenberg@phys.ethz.ch, jakob.robnik@gmail.com

Abstract – We show that an S-Brane which arises in the inside of the black hole horizon when the Weyl curvature reaches the string scale induces a continuous transition between the inside of the black hole and the beginning of a new universe. This provides a simultaneous resolution of both the black hole and Big Bang singularities. In this context, the black hole information loss problem is also naturally resolved.

10. **Quantum Love** by Ram Brustein and Yotam Sherf; Department of Physics, Ben-Gurion University, Beer-Sheva 84105, Israel; e-mail: ramyb@bgu.ac.il, sherfyo@post.bgu.ac.il

Abstract – The response of a gravitating object to an external tidal field is encoded in its Love numbers, which identically vanish for classical blackholes (BHs). Here we show, using standard time-independent quantum perturbation theory, that for a quantum BH, generically, the Love numbers are nonvanishing and negative. We calculate the quadrupolar electric quantum Love number of slowly rotating BHs and show that it depends most strongly on the first excited level of the quantum BH. Finally, we discuss the detectability of the quadrupolar quantum Love number in future precision gravitational-wave observations and show that, under favourable circumstances, its magnitude is large enough to imprint an observable signature on the gravitational waves emitted during the inspiral phase of two moderately spinning BHs.

11. **Maximal Acceleration, Reciprocity & Nonlocality** by Luca Buoninfante; Department of Physics, Tokyo Institute of Technology, Tokyo 152-8551, Japan; e-mail: buoninfante.l.aa@m.titech.ac.jp

Abstract – The existence of a fundamental scale is expected to be a key feature of quantum gravity. Many approaches assume this property as a starting assumption. Here, instead, we take a less conventional viewpoint based on a critical inspection of both fundamental principles and kinematic laws. We point out that rigorous arguments suggest a more urgent need to revise known theories to incorporate a fundamental force (or acceleration) scale already in flat space. The reciprocity principle can naturally do so. In addition to noticing links with string theory, we argue that the reciprocity principle implies an infinite-derivative generalization of the Einstein-Hilbert action that makes the gravitational interaction fundamentally nonlocal, thus providing a guiding principle that could lead us towards a consistent theory of quantum gravity.

12. **Implications of Quantum Gravity for Dark Matter** by Xavier Calmet and Folkert Kuipers; Department of Physics and Astronomy, University of Sussex, Brighton, BN1 9QH, United Kingdom; e-mail: X.Calmet@sussex.ac.uk, F.Kuipers@sussex.ac.uk

Abstract – In this essay we show that quantum gravity and the spin-statistic theorem have very interesting consequences for dark matter candidates. Quantum gravity can lead to fifth force type interactions which lead to a lower bound on bosonic candidates masses. In the case of fermions, the spin-statistic theorem leads to a lower bound on fermion masses. For both bosonic and fermionic dark matter candidates, quantum gravity leads to a decay of dark matter particles. A comparison of their lifetime with the age of the universe leads to an upper bound on their masses. For singlet scalar dark matter fields, we find $10^{-3}eV \lesssim m \lesssim 10^{7}eV$.

13. **Hearts of Darkness: the Inside Out Probing of Black Holes** by Raúl Carballo-Rubio[1], Francesco Di Filippo[2], and Stefano Liberati[3][4][5]; [1]Florida Space Institute, University of Central Florida, 12354 Research Parkway, Partnership 1, 32826 Orlando, FL.,[2]Center for Gravitational Physics, Yukawa Institute for Theoretical Physics, Kyoto University, Kyoto 606-8502, Japan, [3}SISSA - International School for Advanced Studies, Via Bonomea 265, 34136 Trieste, Italy, [4]IFPU - Institute for Fundamental Physics of the Universe, Via Beirut 2, 34014 Trieste, Italy, [5]INFN Sezione di Trieste, Via Valerio 2, 34127 Trieste, Italy; e-mail: raul.carballorubio@ucf.edu, francesco.difilippo@yukawa.kyoto-u.ac.jp, liberati@sissa.it

Abstract – Classical black holes shield us from the singularities that inevitably appear in general relativity. Being singularity regularization one of the main landmarks for a successful theory of quantum gravity, quantum black holes are not obliged to hide their inner core from the outside world. Notwithstanding the aforesaid, it is often implicitly assumed that quantum gravity effects must remain confined to black hole interiors. In this essay we argue in the opposite direction, discussing theoretical evidence for the existence of strong correlations between the physics inside and outside non-singular black holes. We conclude that astronomical tests of the surroundings of black holes can provide invaluable information about their so-far unexplored interiors.

14. **Dual Fields of Massive/Massless Gravitons in IR/UV Completions** by Ashkbiz Danehkar[1], Hassan Alshal[2][3] and Thomas L. Curtright[4]; [1]Department of Astronomy, University of Michigan, Ann Arbor, MI 48109, [2]Department of Chemistry and Physics, Lincoln University, PA 19352, [3]Department of Physics, Cairo University, Giza 12613, Egypt, [4]Department of Physics, University of Miami, Coral Gables, FL 33146; e-mail: danehkar@umich.edu, halshal@sci.cu.edu.eg, curtright@miami.edu

Abstract – In the holographic picture, the BEH mechanism in d-dimensional Yang-Mills theories is conjectured to provide a Higgs-like mechanism for gravity in $d + 1$ dimensions, resulting in massive (or massless) gravitons in IR (or UV) completions. Accordingly, one could imagine dual (magnetic-type) fields of massive gravitons in the IR (low-energy) limit that are coupled to the curl of their own energy-momentum, as well as to the rotation of matter fields on large scales. This hypothesis, which might solve cosmological issues currently ascribed to dark matter and dark energy, needs to be examined by the future LISA mission using observations of gravitational waves emitted from extragalactic sources.

15. **Emergent Gravity and the Quantum** by Saurya Das[1] and Sourav Sur[2]; [1]Theoretical Physics Group, Department of Physics and Astronomy, University of Lethbridge, 4401 University Drive, Lethbridge, Alberta T1K 3M4, Canada, [2]Department of Physics and Astrophysics, University of Delhi, New Delhi 110007, India; e-mail: saurya.das@uleth.ca, sourav.sur@gmail.com

Abstract – We show that if one starts with a Universe with some matter and a cosmological constant, then quantum mechanics naturally induces an attractive gravitational potential and an effective Newton's coupling. Thus gravity is an emergent phenomenon and what should be quantized are the fundamental degrees of freedom from which it emerges.

16. **Emergent Gravity from Stochastic Fluctuations** by Joshua Erlich; High Energy Theory Group, Department of Physics, William & Mary, PO Box 8795, Williamsburg, VA 23187-8795; e-mail: erlich@physics.wm.edu

Abstract – It is possible that both the classical description of spacetime and the rules of quantum field theory emerge from a more-fundamental structure of physical law. Pregeometric frameworks transfer some of the puzzles of quantum gravity to a semiclassical arena where those puzzles pose less of a challenge. However, in order to provide a satisfactory description of quantum gravity, a semiclassical description must emerge and contain in its description a macroscopic spacetime geometry, dynamical matter, and a gravitational interaction consistent with general relativity at long distances. In this essay we argue that a framework that includes a stochastic origin for quantum field theory can provide both the emergence of classical spacetime and a quantized gravitational interaction.

17. **The Friedmann-Planck-Schrödinger Equation and the Quantization of the Universe** by Arthur E. Fischer; Department of Mathematics, University of California, Santa Cruz, California 95064; e-mail: aef@ucsc.edu

Abstract – We combine the Schrödinger equation with the Friedmann equation to introduce the **Friedmann-Planck-Schrödinger equation**

$$\frac{d^2\psi(a)}{da^2} + \left(\frac{\Omega_{m,0}}{a} + \frac{\Omega_{r,0}}{a^2} + \Omega_{\Lambda,0}a^2 + \Omega_{K,0} + \frac{2E}{E_P}\right)\psi(a) = 0$$

which we apply to the **mixed matter-radiation universe**. Except for the all-matter subcase, for **every** $E < 0$, we find the global wave function of the universe to be the normalized wave function

$$\psi_E(a) = \frac{W_{\mu,\nu}(2\kappa a)}{\left\|W_{\mu,\nu}(2\kappa a)\right\|_{L^2}}$$

where $W_{\mu,\nu}$ is the Whittaker function that vanishes at infinity. Consequently, the energy spectrum of the quantized Friedmann equation is the continuum $(-\infty, 0)$ and the **energy levels of the mixed matter-radiation universe are not quantizable.** Using these results and by examining $\psi_E(a)$ in the big-bang-near-zone $(0 \leq a \ll 1)$, we give a quantum mechanical explanation of the big bang and inflation.

18. **The Equivalence Principle and the Cosmological Constant Problem** by Yonadav Barry Ginat; Faculty of Physics, Technion – Israel Institute of Technology, Haifa, 3200003, Israel; e-mail: ginat@campus.technion.ac.il

Abstract – In this essay I point out that, in the context of semi-classical gravity, the equivalence principle can mitigate the cosmological constant problem. On a Minkowski space-time background with the usual $\mathbb{R}^4$ topology, the vacuum self-energy is removed by normal ordering; this is allowed because it is not observable; I argue that, in a freely-falling frame of reference, the same must hold true, up to contributions from modes whose wavelength is of the order of the background radius of curvature. Thus, the equivalence principle implies that ultra-violet modes do not contribute to the effective energy-momentum tensor.

19. **Implications of the Spectrum of Dynamically Generated String Tension Theories** by E.I. Guendelman; Department of Physics, Ben-Gurion University of the Negev, Beer-Sheva, Israel, Frankfurt Institute for Advanced Studies, Giersch Science Center, Campus Riedberg, Frankfurt am Main, Germany, Bahamas Advanced Studies Institute and Conferences, 4A Ocean Heights, Hill View Circle, Stella Maris, Long Island, The Bahamas; e-mail: guendel@bgu.ac.il

Abstract – The string tension does not have to be put in by hand, it can be dynamically generated, as in the case when we formulate string theory in the modified measure formalism, and other formulations as well. Then string tension appears, but as an additional dynamical degree of freedom. It can be seen however that this string tension is not universal, but rather each string generates its own string tension, which can have a different value for each string. The consequences of this for the spectrum of these string theories is profound both in the ultraviolet behavior as in the low energy physics. There should be also a considerable effect for the effective gravity theories derived from these string theories.

20. **The Hawking Black-Hole Radiation Spectrum Has a Short Tail** by Shahar Hod; The Ruppin Academic Center, Emeq Hefer 40250, Israel, and The Hadassah Institute, Jerusalem 91010, Israel; e-mail: shaharhod@gmail.com

Abstract – It is proved that the Hawking emission spectrum of a semi-classical Schwarzschild black hole of mass *M* has a sharp cut at the frequency scale $\omega_{max} = (\hbar M)^{-\frac{1}{3}}$. In particular, taking into account the non-linear gravitational coupling between the tunneled Hawking quanta and the emitting black hole, it is explicitly shown that the upper bound $\omega < \omega_{max}$ on the energies of the emitted Hawking quanta is a direct consequence of the famous Thorne hoop relation.

21. **Reconsidering Maximum Luminosity** by Aden Jowsey and Matt Visser; School of Mathematics and Statistics, Victoria University of Wellington, PO Box 600, Wellington 6140, New Zealand; e-mail: aden.jowsey@sms.vuw.ac.nz matt.visser@sms.vuw.ac.nz

Abstract – The suggestion that there is a maximum luminosity (maximum power) in nature has a long and somewhat convoluted history. Though this idea is commonly attributed to Freeman Dyson, he was actually much more circumspect in his views. What is certainly true is that dimensional analysis shows that the speed of light and Newton's constant of gravitation can be combined to define a quantity $P_* = \frac{c^5}{G_N}$ with the dimensions of luminosity (equivalently, power). Then in *any* physical situation we *must* have $P_{physical} = \wp P_*$ where the quantity $\wp$ is some dimensionless function of dimensionless parameters. This has led some authors to suggest a maximum luminosity/maximum power conjecture. Working within the framework of standard general relativity, we will re-assess this conjecture, paying particular attention to the extent to which various examples and counter-examples are physically reasonable. We focus specifically on Vaidya spacetimes, and on an evaporating version of Schwarzschild's constant density star. For both of these spacetimes luminosity can be arbitrarily large. We argue that any luminosity bound must depend on delicate internal features of the radiating object.

22. **The Unification of Classical and Quantum Gravity** by John R. Klauder; Department of Physics and Department of Mathematics, University of Florida, Gainesville, FL 32611-8440; e-mail: john.klauder@gmail.com

Abstract – This short analysis exhibits how classical and quantum stories can be unified by a suitable 'bridge' expression that is just created for that purpose. Our initial example features a simple model which illustrates our procedures. Afterwards, we show how to unify the classical and quantum stories for gravity.

23. **Noncanonical Scalar Fields and the Primeval Thermal Bath** by José Ademir Sales Lima and Pedro Eleutério Mendonça Almeida; Departamento de Astronomia, Universidade de São Paulo, Rua do Matão 1226, 05508-900, São Paulo, SP, Brazil; e-mail: jas.lima@iag.usp.br, pedro.emalmeida@usp.br

Abstract – In this *Essay* we show that a smooth dynamic evolution from an initial unstable de Sitter stage to the standard radiation phase can analytically be described by a dominant noncanonical scalar field. At the end of this vacuum decaying process, the remaining potential energy density is almost completely stored in the kinetic part of the field satisfying the radiation equation of state. In this model, the early Universe is nonsingular, free of horizon and different from many inflationary variants none post-inflationary reheating is required since the formation of the thermal bath is concomitant with inflation. The thermodynamic behaviour of the thermal bath is determined. Finally, it is also found that the resulting primeval cosmology may also be interpreted as a time-varying $\Lambda(H)$ model (vacuum fluid) interacting with a radiation component forming the thermal bath.

24. **External Field Effect in Gravity** by Philip D. Mannheim[1] and John W. Moffat[2]; [1]Department of Physics, University of Connecticut, Storrs, CT 06269, [2]Perimeter Institute for Theoretical Physics, Waterloo, Ontario N2L 2Y5, Canada; e-mail: philip.mannheim@uconn.edu, jmoffat@perimeterinstitute.ca

Abstract – In both Newtonian gravity and Einstein gravity there is no force on a test particle located inside a spherical cavity cut out of a static, spherically symmetric mass distribution. Inside the cavity exterior matter is decoupled and there is no external field effect that could act on the test particle. However, for potentials other than the Newtonian potential or for geometries other than Ricci flat ones this is no longer the case, and there then is an external field effect. We explore this possibility in various alternate gravity scenarios, and suggest that such (Machian) external field effects can serve as a diagnostic for gravitational theory.

25. **The Page Curve and Baby Universes** by Donald Marolf and Henry Maxfield; Department of Physics, University of California, Santa Barbara, CA 93106; e-mail: marolf@ucsb.edu hmaxfield@physics.ucsb.edu

Abstract – Black hole thermodynamics suggests that, in order to describe the physics of distant observers, one may model a black hole as a standard quantum system with density of states set by the Bekenstein-Hawking entropy SBH. This idea has long been considered to be in strong tension with Hawking's prediction that radiation from black holes is nearly thermal, and with low-energy gravity more generally. But the past two years have shown that low-energy gravity does offer a self-consistent description of black hole evaporation consistent with the above idea, and which in particular reproduces the famous Page curve. We provide a brief overview of this new paradigm, focusing on Lorentz-signature asymptotically flat spacetimes, and emphasizing operationally-defined observables that probe the entropy of Hawking radiation.

26. **Asymptotically Flat Black Hole Solutions in Quadratic Gravity** by Frank Saueressig, Mina Galis, Jesse Daas, and Amir Khosravi; Institute for Mathematics, Astrophysics and Particle Physics (IMAPP), Radboud University Nijmegen, P.O. Box 9010, 6500 GL Nijmegen, The Netherlands; e-mail: f.saueressig@science.ru.nl, m.galis@student.science.ru.nl j.daas@science.ru.nl ap.khosravi@science.ru.nl

Abstract – Black holes constitute some of the most fascinating objects in our universe. According to Einstein's theory of general relativity they are also deceivingly simple: Schwarzschild black holes are completely determined by their mass. Moreover, the singularity theorems by Penrose and Hawking indicate that they host a curvature singularity within their event horizon. The presence of the latter invites the question whether these dead-end points of spacetime can be made regular by considering (quantum) corrections to the classical field equations. In this light we use the Frobenius method to investigate the phase space of asymptotically flat, static, and spherically symmetric black hole solutions in quadratic gravity. We argue that the only asymptotically flat black hole solution visible in this approach is the Schwarzschild solution.

27. **What Actually Happens when You Approach a Gravitational Singularity?** by Susan M Scott and Ben W Whale; Centre for Gravitational Astrophysics, Research School of Physics, College of Science, The Australian National University, Building 38A, Science Road, Acton ACT 2601, Australia; e-mail: susan.scott@anu.edu.au ben@benwhale.com

Abstract – Roger Penrose's 2020 Nobel Prize in Physics recognises that his identification of the concepts of "gravitational singularity" and an "incomplete, inextendible, null geodesic" is physically very important. The existence of an incomplete, inextendible, null geodesic doesn't say much, however, if anything, about curvature divergence, nor is it a helpful definition for performing actual calculations. Physicists have long sought for a coordinate independent method of defining where a singularity is located, given an incomplete, inextendible, null geodesic, that also allows for standard analytic techniques to be implemented. In this essay we present a solution to this issue. It is now possible to give a concrete relationship between an incomplete, inextendible, null geodesic and a gravitational singularity, and to study any possible curvature divergence using standard techniques.

28. Quantum Theory without Classical Time: Octonions, and a Theoretical Derivation of the Fine Structure Constant 1/137 by Tejinder P. Singh; Tata Institute of Fundamental Research, Homi Bhabha Road, Mumbai 400005, India; e-mail: tpsingh@tifr.res.in

Abstract – There must exist a reformulation of quantum field theory which does not refer to classical time. We propose a pre-quantum, pre-spacetime theory, which is a matrix-valued Lagrangian dynamics for gravity, Yang-Mills fields, and fermions. The definition of spin in this theory leads us to an eight dimensional octonionic space-time. The algebra of the octonions reveals the standard model; model parameters are determined by roots of the cubic characteristic equation of the exceptional Jordan algebra. We derive the asymptotic low energy value 1/137 of the fine structure constant, and predict the existence of universally interacting spin one Lorentz bosons, which replace the hypothesised graviton. Gravity is not to be quantized, but is an emergent four-dimensional classical phenomenon, precipitated by the spontaneous localisation of highly entangled fermions.

29. "Mysteries" of Modern Physics and the Fundamental Constants *c, h,* and *G* by W.M. Stuckey[1], Timothy McDevitt[2], and Michael Silberstein[3][4]; [1]Department of Physics, Elizabethtown College, Elizabethtown, PA 17022, [2]Department of Mathematical Sciences, Elizabethtown College, Elizabethtown, PA 17022, [3]Department of Philosophy, Elizabethtown College Elizabethtown, PA 17022, [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 msilbers@umd.edu

Abstract – We review how the kinematic structures of special relativity and quantum mechanics both stem from the relativity principle, i.e., "no preferred reference frame" (NPRF). Essentially, NPRF applied to the measurement of the speed of light *c* gives the light postulate and leads to the geometry of Minkowski spacetime, while NPRF applied to the measurement of Planck's constant h gives "average-only" projection and leads to the qubit Hilbert space of quantum mechanics. These kinematic structures contain the counterintuitive aspects ("mysteries") of time dilation, length contraction, and quantum entanglement. In this essay, we extend the application of NPRF to the gravitational constant *G* and show that it leads to the "mystery" of the contextuality of mass in general relativity. Thus, we see an underlying coherence and integrity in modern physics via its "mysteries" and the fundamental constants *c*, *h*, and *G*.

30. Twisted Light, a New Tool for General Relativity and Beyond - Revealing the properties of rotating black holes with the vorticity of light – by F. Tamburini[1], F. Feleppa[2], and B. Thidé[3]; [1]ZKM – Zentrum für Kunst und Medien, Lorenzstraβe 19, D-76135 Karlsruhe, Germany, [2]Institute for Theoretical Physics, Utrecht University, Princetonplein 5, 3584 CC Utrecht, The Netherlands, [3]Swedish Institute of Space Physics, Ångström Laboratory, Box 537, SE-751 21 Uppsala, Sweden; e-mail: fabrizio.tamburini@gmail.com f.feleppa@uu.nl bothide@gmail.com

Abstract – We describe and present the first observational evidence that light propagating near a rotating black hole is twisted in phase and carries orbital angular momentum. The novel use of this physical observable as an additional tool for the previously known techniques of gravitational lensing allows us to directly measure, for the first time, the spin parameter of a black hole. With the additional information encoded in the orbital angular momentum, not only can we reveal the actual rotation of the compact object, but we can also use rotating black holes as probes to test General Relativity.

31. **Truly Two-Dimensional Black Holes under Dimensional Transitions of Spacetime** by Wanpeng Tan; Department of Physics, Institute for Structure and Nuclear Astrophysics (ISNAP), University of Notre Dame, Notre Dame, Indiana 46556; e-mail: wtan@nd.edu

Abstract – A sufficiently massive star in the end of its life will inevitably collapse into a black hole as more deconfined degrees of freedom make the core ever softer. One possible way to avoid the singularity in the end is by dimensional phase transition of spacetime. Indeed, the black hole interior, two-dimensional in nature, can be described well as a perfect fluid of free massless Majorana fermions and gauge bosons under a 2-d supersymmetric mirror model with new understanding of emergent gravity from dimensional evolution of spacetime. In particular, the 2-d conformal invariance of the black hole gives rise to desired consistent results for the interior microphysics and structures including its temperature, density, and entropy.

32. **Gravity Cannot Cure Quantum Mechanics of its Malady of the Collapse of the Wavefunction** 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 – The speculation that gravity is the key to solving the quantum measurement problem has been alive for decades, without any convincing demonstration of a solution. One necessary factor in the relevant proposals is that the gravitational energy of mutual interaction, which scales quadratically with the mass, facilitates the spontaneous collapse of the wavefunctions in spatially separated superpositions. Relying on a simple physical input from electrodynamics, supported by robust first principle calculations, we show that the speculations connecting gravity and the hypothetical spontaneous collapse of the wavefunction are inconsistent and not tenable. The result suggests that the gravitational solution to the problem of the collapse of the wavefunction be put to rest.

33. **Nonlocality in Quantum Gravity and the Breakdown of Effective Field Theory** by Nicolás Valdés-Meller; Perimeter Institute for Theoretical Physics, 31 Caroline St N, Waterloo, ON N2L 2Y5, Canada and University of Waterloo, 200 University Ave W, Waterloo, ON N2L 3G1, Canada; e-mail; nvaldes@mit.edu

Abstract – We argue that quantum gravity is nonlocal, first by recalling well-known arguments that support this idea and then by focusing on a point not usually emphasized: that making a conventional effective field theory (EFT) for quantum gravity is particularly difficult, and perhaps impossible in principle. This inability to realize an EFT comes down to the fact that gravity itself sets length scales for a problem: when integrating out degrees of freedom above some cutoff, the effective metric one uses will be different, which will itself re-define the cutoff. We also point out that even if the previous problem is fixed, naïvely applying EFT in gravity can lead to problems – we give a particular example in the case of black holes.

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34. **A Tensorial Analogue of Newtonian Force and Galactic Rotation Curves in General Relativity** by Ram Gopal Vishwakarma; Unidad Académica de Matemáticas, Universidad Autónoma de Zacatecas, C.P. 98068, Zacatecas, ZAC, Mexico ; e-mail: vishwa@uaz.edu.mx

Abstract – The dark matter problem is one of the most pressing problems in modern physics. As currently there is no well-established claim from a direct detection experiment supporting the existence of the illusive dark matter that has been postulated to explain the flat rotation curves of galaxies, and since the whole issue of an alternative theory of gravity remains controversial, it may be worth to reconsider the familiar ground of general relativity (GR) itself for a possible way out. It has recently been discovered that a skew-symmetric rank-three tensor field - the Lanczos tensor field - that generates the Weyl tensor differentially, provides a proper relativistic analogue of the Newtonian gravitational force. By taking account of the conformal invariance of the Weyl tensor, the Lanczos tensor leads to a modified acceleration law which can explain, within the framework of GR itself, the flat rotation curves of galaxies without the need for any dark matter whatsoever.

35. **Violation of Unitarity in Gravitational Subregions** by Aron C. Wall; Department of Applied Mathematics and Theoretical Physics, University of Cambridge; e-mail: aroncwall@gmail.com

Abstract – This essay contends that in quantum gravity, some spatial regions do not admit a unitary Hilbert space. Because the gravitational path integral spontaneously breaks CPT symmetry, “states” with negative probability can be identified on either side of trapped surfaces. I argue that these negative norm states are tolerable, by analogy to quantum mechanics. This viewpoint suggests a resolution of the firewall paradox, similar to black hole complementarity. Implications for cosmology are briefly discussed.

36. **Tully - Fisher Relations and Retardation Theory for Galaxies** by Asher Yahalom; Ariel University, Ariel 40700, Israel and Princeton University, Princeton, New Jersey 08543; e-mail: asya@ariel.ac.il

Abstract – Galaxies are huge physical systems having dimensions of many tens of thousands of light years. Thus any change at the galactic center will be noticed at the rim only tens of thousands of years later. Those retardation effects seem to be neglected in present day galactic modelling used to calculate rotational velocities of matter in the rims of the galaxy. The significant differences between the predictions of Newtonian theory and observed velocities are usually explained by either assuming dark matter or by modifying the laws of gravity (MOND). In this essay we will show that taking retardation effects into account one can explain the radial velocities of galactic matter and the well known Tully-Fisher relations of galaxies.