What is gravity?

Pierre Vanhove

&

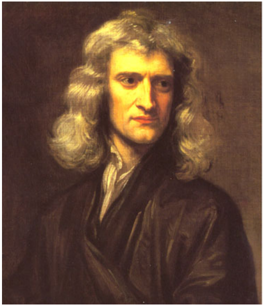
Département de Physique ENS, Paris

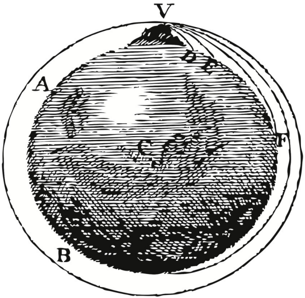
Decembre, the 6th, 2017

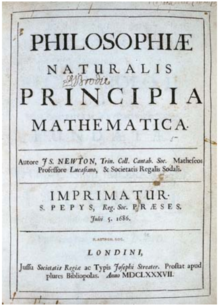
Part I

Gravity

Gravity is a force






PHILOSOPHIÆ

NATURALIS

PRINCIPIA

MATHEMATICA.

Autore J S. NEWTON, Trin. Coll. Cantab. Soc. Matheseos Professore Lucasiano, & Societatis Regalis Sodali.

IMPRIMATUR.

S. PEPYS, Reg. Soc. PRÆSES.

Julii 5. 1686.

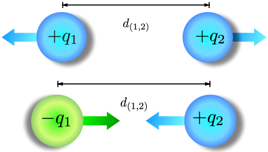
LONDINI,

Jussu Societatis Regiæ ac Typis Josephi Streater. Prostat apud plures Bibliopolas. Anno MDCLXXXVII.

With the same supposition I state that a force set outside a spherical surface is attracted towards the centre of the sphere by a force reciprocally proportional to the square of its distance from the centre. Principia Proposition XL. theorem XXII

$$F_{1-2} = -\frac{G_N m_1 m_2}{d^2_{(1,2)}}$$

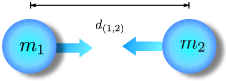
Gravity is a force



Same charges repel each other

Opposite charges attract each other

$$F_{\text{electric}} = \pm \frac{1}{4\pi\epsilon_0} \frac{q_1 q_2}{d^2_{(1,2)}}$$

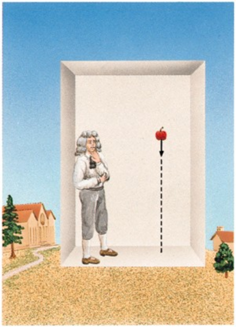


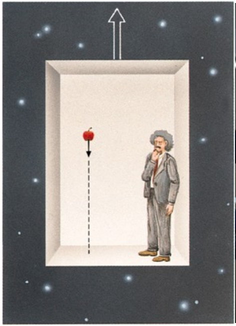
Masses always attract

There is no negative mass

$$F_{\text{gravity}} = -G_N \frac{m_1 m_2}{d^2_{(1,2)}}$$

The Equivalence Principle



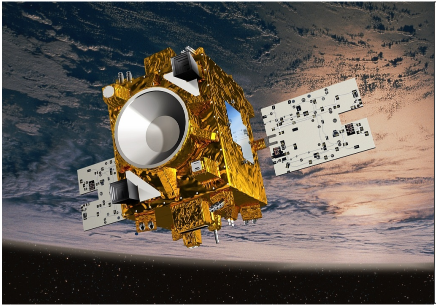


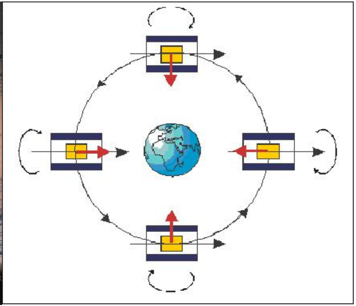
J'étais assis sur ma chaise au Bureau Fédéral de Berne... Je compris que si une personne est en chute libre, elle ne sentira pas son propre poids. J'en ai été saisi. Cette pensée me fit une grande impression. Elle me poussa vers une nouvelle théorie de la gravitation. (Einstein 1907)

Play/Pause

Confirmation on the Moon of the free fall law formulated by Galileo in 1638
Apollo 15 mission

Tests expérimentaux dans l'espace





Experiments show the equality between gravitational mass and inertial mass to the precision

$$\frac{m_{\text{inerte}} - m_{\text{grave}}}{m_{\text{grave}}} \simeq 10^{-13}$$

The French collaboration MICROSCOPE launched on the 25 of april 2016 a satellite for bringing this precision to 10^{-15}

MICROSCOPE Mission: First Results of a Space Test of the Equivalence Principle

According to the weak equivalence principle, all bodies should fall at the same rate in a gravitational field. The *MICROSCOPE* satellite, launched in April 2016, aims to test its validity at the 10^{-15} precision level, by measuring the force required to maintain two test masses (of titanium and platinum alloys) exactly in the same orbit. A nonvanishing result would correspond to a violation of the equivalence principle, or to the discovery of a new long-range force. Analysis of the first data gives $\delta(\mathrm{Ti},\mathrm{Pt}) = [-1 \pm 9(\mathrm{stat}) \pm 9(\mathrm{syst})] \times 10^{-15}$ (1σ statistical uncertainty) for the titanium-platinum Eötvös parameter characterizing the relative difference in their free-fall accelerations.

DOI: 10.1103/PhysRevLett.119.231101

Introduction.—Gravity seems to enjoy a remarkable universality property: bodies of different compositions fall at the same rate in an external gravitational field [1–3]. Einstein interpreted this as an equivalence between gravitation and inertia [4], and used this (weak) equivalence principle (WEP) as the starting point for the theory of general relativity [5]. In terms of the Eötvös parameter $\delta(A,B) = 2(a_A - a_B)/(a_A + a_B)$ (a_A and a_B being the free-fall accelerations of the two bodies A and B), the best laboratory (1σ) upper limits on $\delta(A,B)$ are $\delta(\mathrm{Be},\mathrm{Ti}) = (0.3 \pm 1.8) \times 10^{-13}$ and $\delta(\mathrm{Be},\mathrm{Al}) = (-0.7 \pm 1.3) \times 10^{-13}$ [2], with similar limits on the differential acceleration between Earth and the Moon toward the Sun [3].

General relativity (GR) has passed all historical and current experimental tests [6], including, most recently, the direct observation of the gravitational waves emitted by two coalescing black holes [7]. However, it does not provide a consistent quantum gravity landscape and leaves many questions unanswered, in particular about dark energy and the unification of all fundamental interactions. Possible avenues to close those problems may involve very weakly coupled new particles, such as the string-theory spin-0 dilaton [8,9], a chameleon [10], or a spin-1 boson U from an extended gauge group [11,12], generally leading to an apparent WEP violation.

The *MICROSCOPE* space mission implements a new approach to test the WEP by taking advantage of the very quiet space environment. Nongravitational forces acting on the satellite are counteracted by cold gas thrusters making it possible to compare the accelerations of two test masses of different compositions "freely falling" in the same orbit around Earth for a long period of time [13,14]. This is done by accurately measuring the force required to keep the two test masses in relative equilibrium. Present data allow us to improve the 1σ upper limit on the validity of the WEP by an order of magnitude.

The MICROSCOPE space mission.—MICROSCOPE aims to test the equivalence principle with an unprecedented

Does antimatter falls like matter?

Volume 88B, number 3,4 PHYSICS LETTERS 17 December 1979

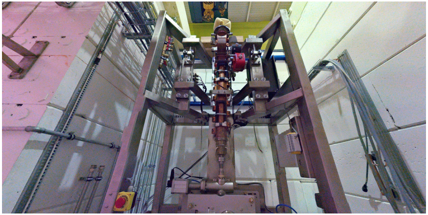
ANTIGRAVITY: A CRAZY IDEA? ☆

J. SCHERK
Laboratoire de Physique Théorique de l'Ecole Normale Supérieure [1], *Paris Cédex 05, France*

Received 11 September 1979

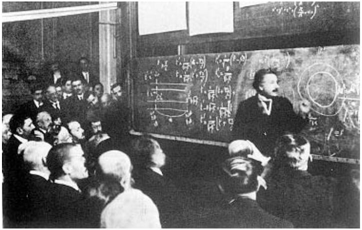
The theoretical aspect of antigravity is briefly discussed. It is shown that supergravity with $N = 2, 3, \ldots, 8$ fermionic generators leads naturally to antigravity.

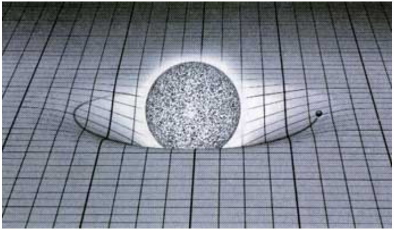
Experiments are being conducted at CERN



Gravitation as a curvature of space-time

Novembre, the 25th 1915, Einstein publishes general relativity



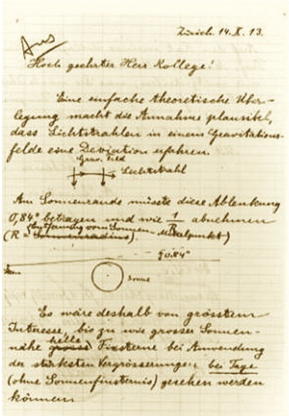


All Space and Time are affected by gravity:

Gravity is the consequence of the curvature of space-time

A mass is not attracted by another one but runs along freely along geodesics

Einstein predicted the bending of star lights by the Sun


Zürich 14.X.13.

Hoch geehrter Herr Kollege!

Eine einfache theoretische Überlegung macht die Annahme plausibel, dass Lichtstrahlen in einem Gravitationsfelde eine Deviation erfahren.

Grav. feld

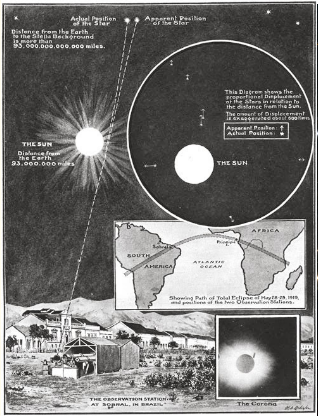
Lichtstrahl

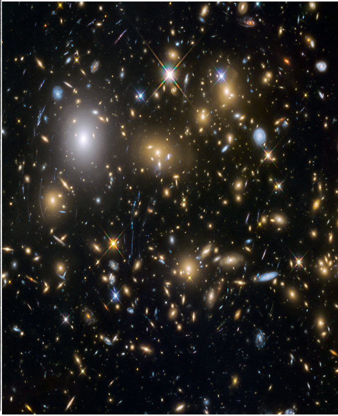
Am Sonnenrande müsste diese Ablenkung 0,84" betragen und wie $\frac{1}{R}$ abnehmen (R = ~~Sonnenradius~~ Abstand vom Sonnen-Mittelpunkt).

0,84"

Sonne

Es wäre deshalb von grösstem Interesse, bis zu wie grosser Sonnennähe ~~grosse~~ helle Fixsterne bei Anwendung der stärksten Vergrösserungen bei Tage (ohne Sonnenfinsternis) gesehen werden können.

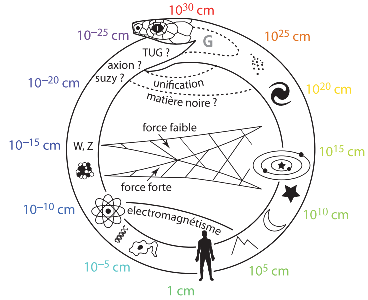




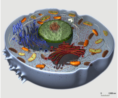
Confirmed by the observation of the 1919 eclipse by Eddington et Dyson

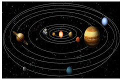
Seen as well by Hubble telescope in gravitational lensing induced by the cluster of galaxies MACSJ0717.5+3745

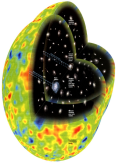
Gravity is a universal force



Gravity affects all masses and energy at all scales from microscopic to macroscopic



$10^{-35}m$ $10^{-6}m$ $1m$ $10^{9}m$ $10^{19}m$ $10^{21}m$ $10^{27}m$

???

poorly tested

very good knowledge

pretty good knowledge

no precise datas

poorly tested

Adapted from the ESA Fundamental Physics Roadmap (2010)

lab experiments

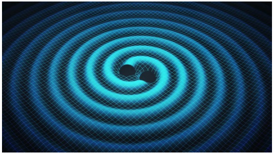

spatial probes

astronomy

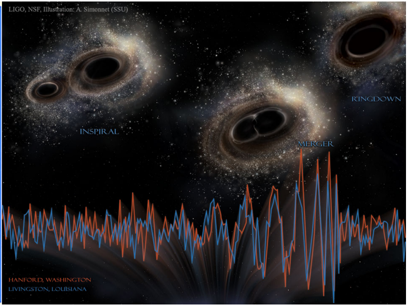
astrophysics

cosmology

Gravitational waves



Septembre, the 14th 2015 LIGO detected gravitational waves from a black hole binary system

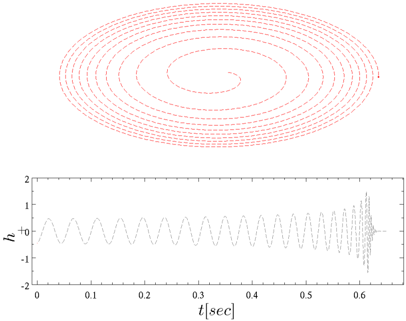


Dancing black holes

The gravitational waves are radiated energy by the black hole binary system as they attract each other until they merge into a final black hole

Theoretical prediction

This observation has been possible thanks to the incredible theoretical work in predicting the wave form



Why is this important?

ON A STATIONARY SYSTEM WITH SPHERICAL SYMMETRY CONSISTING OF MANY GRAVITATING MASSES

BY ALBERT EINSTEIN

(Received May 10, 1939)

If one considers Schwarzschild's solution of the static gravitational field of spherical symmetry

$$ds^2 = -\left(1 + \frac{\mu}{2r}\right)^4 (dx_1^2 + dx_2^2 + dx_3^2) + \left(\frac{1 - \frac{\mu}{2r}}{1 + \frac{\mu}{2r}}\right)^2 dt^2 \tag{1}$$

sents the gravitating mass.)

There arises the question whether it is possible to build up a field containing such singularities with the help of actual gravitating masses, or whether such regions with vanishing g_{44} do not exist in cases which have physical reality. Schwarzschild himself investigated the gravitational field which is produced by an incompressible liquid. He found that in this case, too, there appears a region with vanishing g_{44} if only, with given density of the liquid, the radius of the field-producing sphere is chosen large enough.

This argument, however, is not convincing; the concept of an incompressible liquid is not compatible with relativity theory as elastic waves would have to travel with infinite velocity. It would be necessary, therefore, to introduce a compressible liquid whose equation of state excludes the possibility of sound

ON GRAVITATIONAL WAVES.

BY

A. EINSTEIN and N. ROSEN.

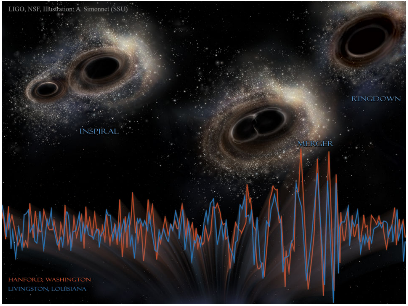
ABSTRACT.

The rigorous solution for cylindrical gravitational waves is given. For the convenience of the reader the theory of gravitational waves and their production, already known in principle, is given in the first part of this paper. After encountering relationships which cast doubt on the existence of *rigorous* solutions for undulatory gravitational fields, we investigate rigorously the case of cylindrical gravitational waves. It turns out that rigorous solutions exist and that the problem reduces to the usual cylindrical waves in euclidean space.

Einstein questioned the physical reality of black hole and gravitational waves

He wondered if they could not just be only mathematical solution

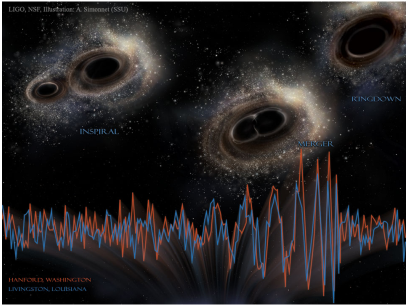
A new window on gravitation



The detection of GW150914 by LIGO has open a new window on the gravitational physics of our universe

- For the first time detection and test of GR in the strong gravity coupling regime
- For the first time dynamics of Black hole (not just static object curving space-time)

A new window on gravitation

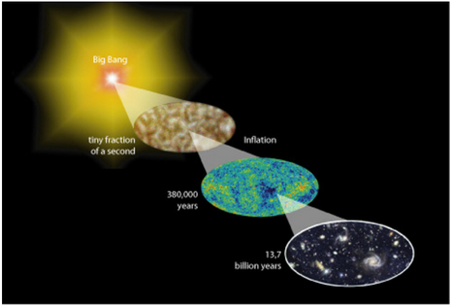


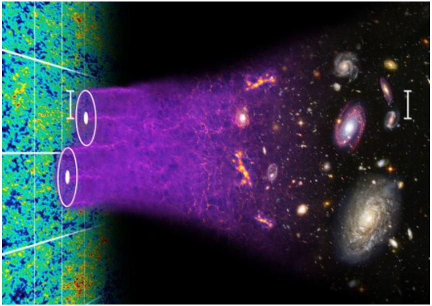
[Yunes, Yagi, Pretorius] have listed theoretical implications of GW150914 in particular

GW150914 constrains a number of theoretical mechanisms that modify GW propagation

Primordial Gravitational waves

Quantum gravity effects at the early stage of the Universe should be detectable by looking at the cosmic microwave background





Primordial Gravitational waves

Libération

{SCIENCES²}

Par Sylvestre Huet
Journaliste à Libération

rechercher

À LIRE AUSSI

SUR LE BLOG SCIENCES

- L'essai nucléaire nord-coréen
- Novembre: la Terre au plus chaud
- Arianespace en plein boum
- Darwin l'original à la Cité des sciences
- Ravines de Mars : le CO2, pas l'eau

ONDES GRAVITATIONNELLES: PLANCK DÉMOLIT BICEP-2

La vision de Planck de la zone étudiée par Bicep-2

Les ondes g… toujours pas… sujet de l'équ… Bicep-2, installé en Antarctique, à la station Amundsen-Scott, était donc plus que prématurée. Elle est aujourd'hui réfutée et *«la recherche continue»*, explique François Bouchet, de l'Institut d'Astrophysique de Paris.

C'est ce qu'affirment ce matin les deux équipes

LE FIGARO·fr

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FLASH ACTU | 11h14 FMI : les migrants «grave problème» pour l'UE | Tout le flash ▸

« Nous ne pensions pas trouver les ondes gravitationnelles du big bang aussi vite »

ACTUALITE > SCIENCES & ENVIRONNEMENT Par Tristan Vey, Cyrille Vanlerberghe | Publié le 18/04/2014 à 18:30

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RÉAGIR (271)
PARTAGER
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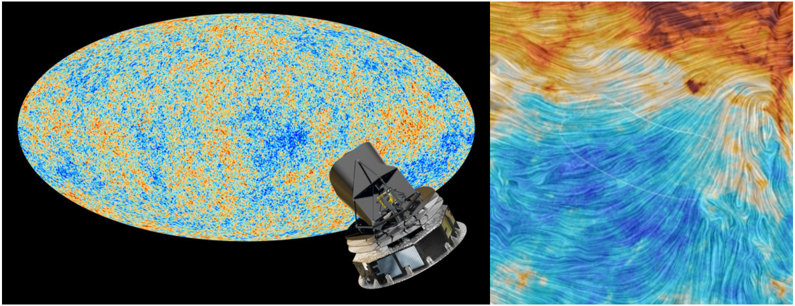
Primordial Gravitational waves

Despite numerous efforts not observation yet

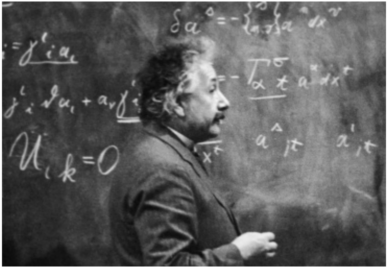


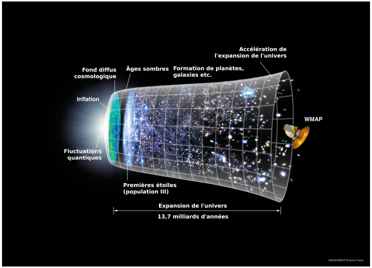
Planck Collaboration 2015

Part II

Why quantize gravity ?

Stabilty of the atoms





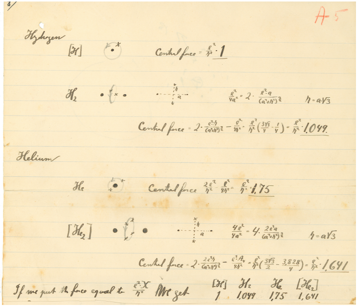
He computes that an atom would collapse under gravity in 10^{30} year

He tough that the Universe had and will exists for ever

Today we estimate that the Universe is 13.8 milliard year old

But Einstein worries is still valid

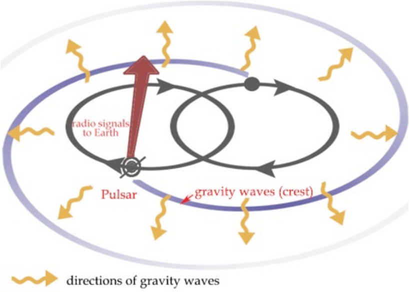
Stabilty of the atoms

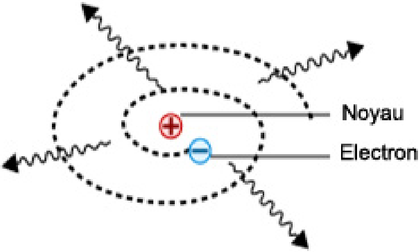


In classical theory the atom collapses in 10^{-11} secondes under because of the electric force between the electron and the nucleus

Quantum mechanics has been introduced to resolve this issue

Stabilty of the atoms

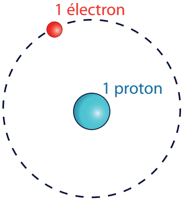




In 1916 Einstein writes

> *À cause des mouvements intra-atomiques, l'atome doit rayonner (...) de l'énergie gravitationnelle, même en très faibles quantités.*
>
> *Comme cela ne peut être le cas dans la nature, il apparaît alors que la théorie quantique doit modifier (...) la nouvelle théorie de la gravitation.*

Gravity is a very weak force



Electric force $F_{\text{electric}} = \pm \frac{1}{4\pi\epsilon_0} \frac{q_1 q_2}{d^2_{(1,2)}}$

Gravitational force $F_{\text{gravity}} = -G_N \frac{m_1 m_2}{d^2_{(1,2)}}$

For an elementary particle

$$\left| \frac{F_{\text{gravity}}}{F_{\text{electric}}} \right| \simeq 2 \times 10^{-43}$$

This explain the huge difference between the typical collapse time for the atom

Quantum scale

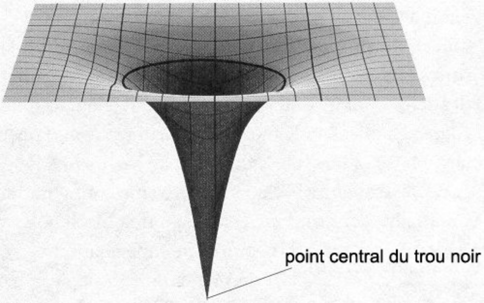
The Compton wavelength $\lambdabar = \frac{\hbar}{mc}$ is the quantum limit for determining the position in space of a massive object

Body	Mass (Kg)	$\lambdabar$ (m)	Size (m)
electron	3.1×10^{-31}	4×10^{-13}	10^{-15}
Sun	2×10^{30}	1.6×10^{-73}	10^{-15}

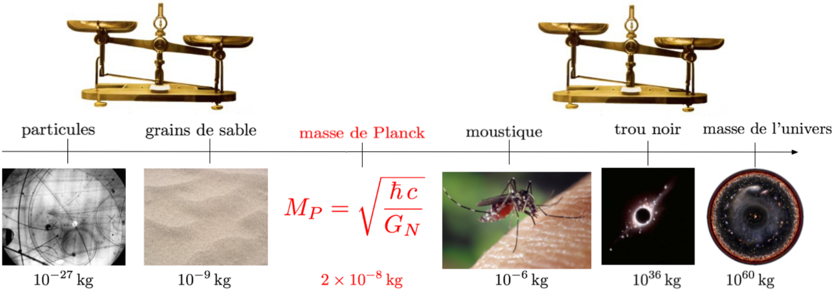
size of an atom 10^{-10} m.

Classical gravitational radius

Schwarzschild radius $r_S = 2G_N M/c^2$



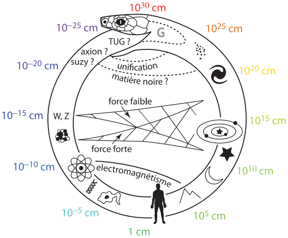
Body	Mass (Kg)	r_S (m)	Radius (m)
electron	3.1×10^{-31}	1.3×10^{-57}	10^{-15}
Sun	2×10^{30}	3000	7×10^{8}

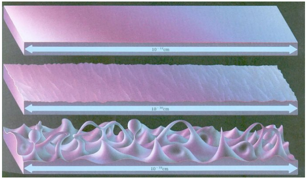


The elementary particle are too light comparing to the Planck mass

The macroscopic object are too heavy compared to the Planck mass

Scales of gravity



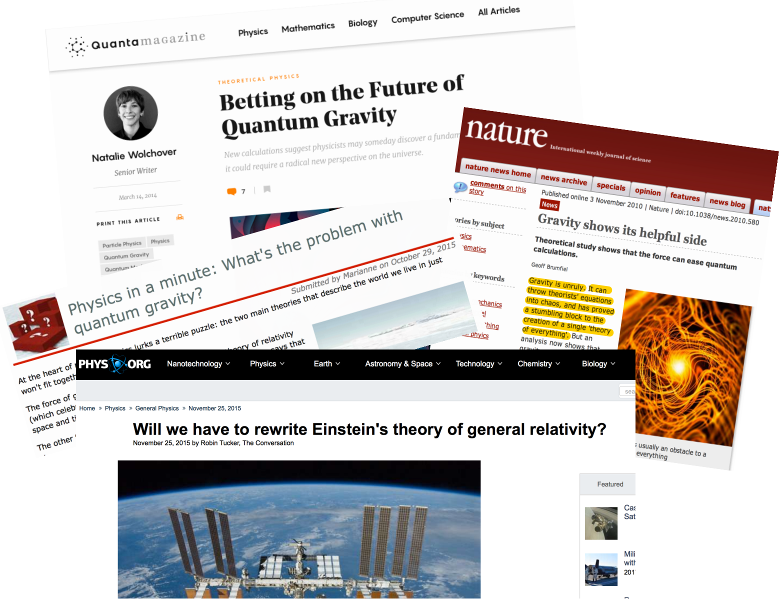


- Classical Schwarzschild radius: $r_S = \frac{2G_N M}{c^2}$
- Quantum Compton wavelength $\lambdabar = \frac{\hbar}{Mc}$
- Quanym gravity : Planck length

$$r_S \times \lambdabar = 2\ell_P^2 = 2\frac{G_N \hbar}{c^3} \leftrightarrow r_S = \frac{\sqrt{2}\ell_P}{\lambdabar}$$

Part III

Gravity and quantum mechanics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Senior Writer
March 14, 2014
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Quantum Gravity
THEORETICAL PHYSICS
Betting on the Future of Quantum Gravity
New calculations suggest physicists may someday discover a fundam
it could require a radical new perspective on the universe.
Physics in a minute: What's the problem with quantum gravity?
Submitted by Marianne on October 29, 2015
the two main theories that describe the world we live in just
lurks a terrible puzzle:
theory of relativity
says that
At the heart of
won't fit togeth
The force of g
(which celeb
space and t
The other
nature
International weekly journal of science
nature news home
news archive
specials
opinion
features
news blog
comments on this story
Published online 3 November 2010 | Nature | doi:10.1038/news.2010.580
News
Gravity shows its helpful side
Theoretical study shows that the force can ease quantum calculations.
Geoff Brumfiel
Gravity is unruly. It can throw theorists' equations into chaos, and has proved a stumbling block to the creation of a single 'theory of everything'. But an analysis now shows that
usually an obstacle to a
everything
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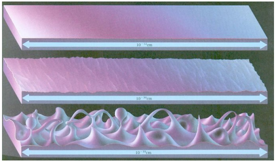
Home » Physics » General Physics » November 25, 2015
Will we have to rewrite Einstein's theory of general relativity?
November 25, 2015 by Robin Tucker, The Conversation
Featured

Quantum of space time

In quantum mechanics the very notion of geometrical point does not exist any more

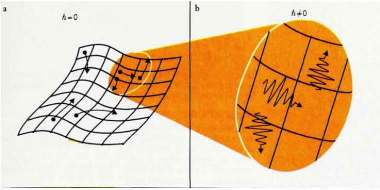
$\hbar = 0$

$\hbar \gg 1$



classique

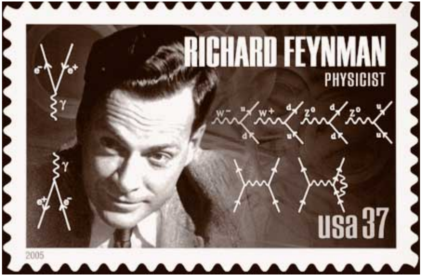
quantique

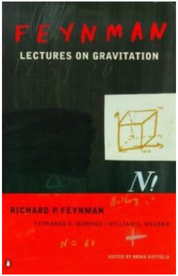


The beauty of Einstein theory of gravity lies in its geometric formulation

What happens to his theory if we quantize it?

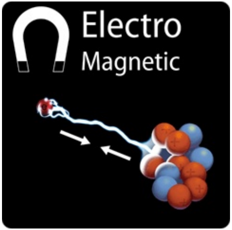
Quantizing gravity

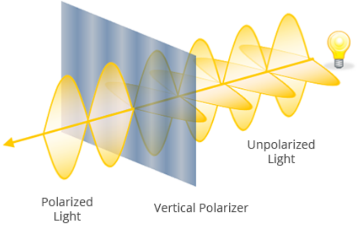




My subject is the quantum theory of gravity. My interest in it is primarily in the relation of one part of nature to another. There's a certain irrationality to any work in gravitation, so it's hard to explain why you do any of it; ...(Feynman Jablonna, 1962)

Quantum of light : the photon





the photon is massless particule of spin 1, quantum of electromagnetic waves

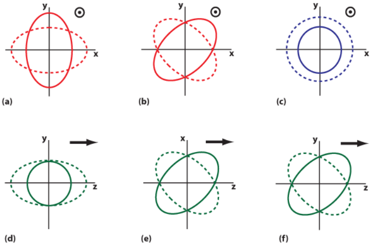
$$\gamma : \qquad \epsilon^{+}_{\mu}, \qquad \epsilon^{-}_{\mu}, \qquad \text{mass} = 0$$

Das Lichtquant

Skepticism of Max Planck in his support letter for Eintein application to the Prussian academy of science (1913)

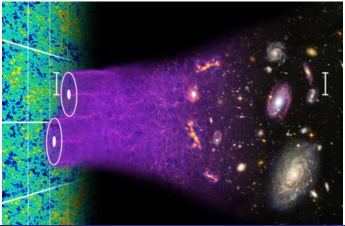
Il ne faut pas trop lui tenir rigueur de ce que, dans ses spéculations, il ait occasionnellement pu dépasser sa cible, comme par exemple avec son hypothèse des quanta de lumière. (Max Planck)

Quantum of space-time : the graviton

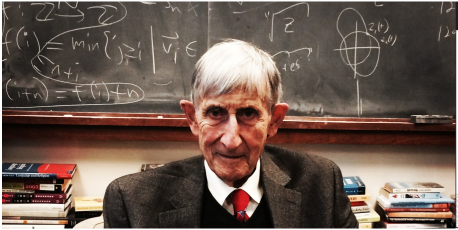


The graviton (massless, spin 2) is that quantum of gravitational waves

$$h: \qquad \epsilon^{++}_{\mu\nu}, \qquad \epsilon^{--}_{\mu\nu}, \qquad \text{mass} = 0$$



Can we detect a graviton?

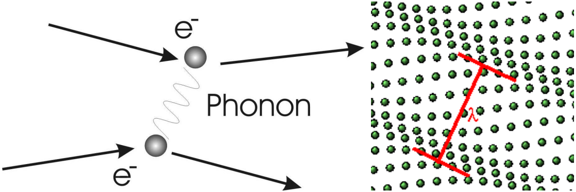


In his Poincaré Prize lecture Freeman Dyson gives various argument against the detection of single graviton

is it possible that the graviton does not exist?

Can we conceive experiments that could test the quantum nature of space-time?

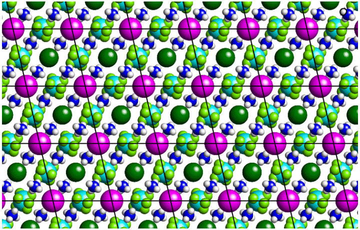
Acoustic waves : the phonon

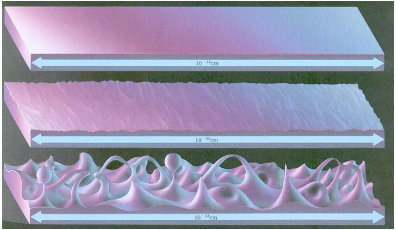


Phonons describe very well the acoustic waves but are not elementary particles

We can quantize quasi-particles even if there are not fundamental particle existing at all energy scales

Fundamental symmetries of emergent symmetries?





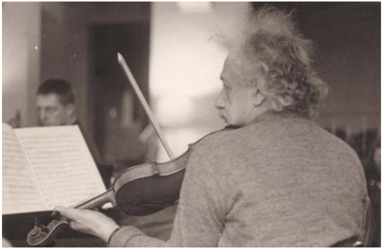
The observation of gravitational wave confirm the validity of Einstein's gravity till a scale of 10% of the size of our observable Universe

But is this still true of the microscopic length? at the cosmological scales?

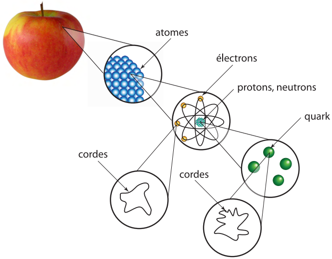
Part IV

String theory

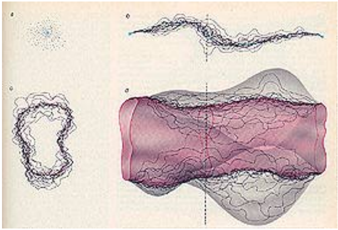
There is no intellectual exercise that is not ultimately $\underbrace{\text{\sout{pointless}}}_{\text{stringy}}$

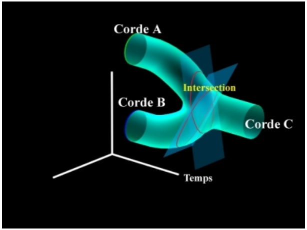


(J.-L. Borges, in “Pierre Ménard, Author of the Quixote”)

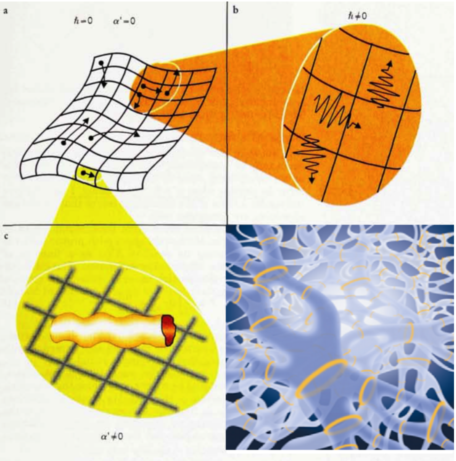


the string may be invisible we hear its music in the form of elementary particles

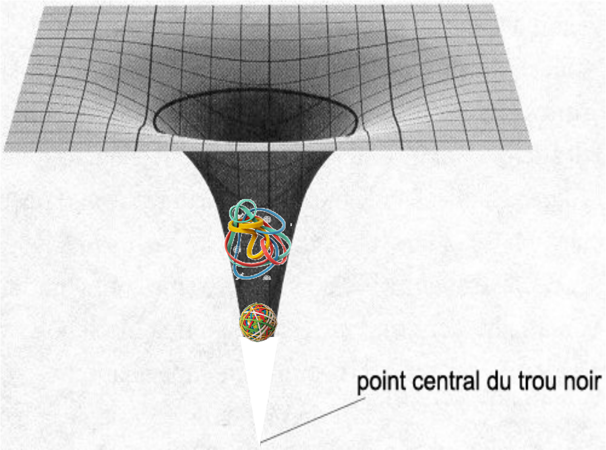




Space-time has seen by string theory

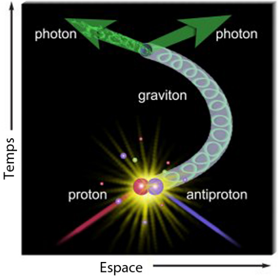


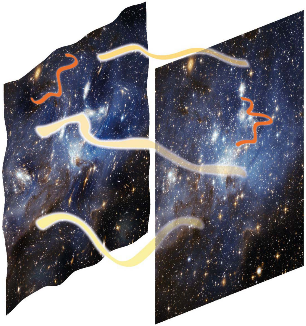
Black holes as seen by string theory



String theory can screen the black hole singularity

Extra dimensions



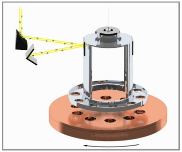


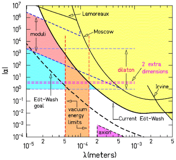
The weakness of gravity could be explained with extra dimensions

The force of gravity is diluted in the extra dimensions only seen by her

$$\left|\frac{F_{\text{gravity}}}{F_{\text{electric}}}\right| = \frac{1}{\text{Volume}}$$

Extra dimensions are actively looked after



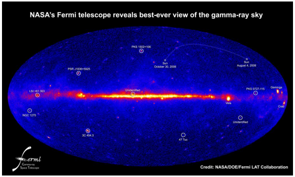


Journal of Cosmology and Astroparticle Physics
An IOP and SISSA journal

Limits on large extra dimensions based on observations of neutron stars with the Fermi-LAT

JCAP

Fermi-LAT collaboration



Physics Letters B 697 (2011) 434–453

Contents lists available at ScienceDirect

Physics Letters B

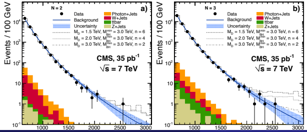
www.elsevier.com/locate/physletb

ELSEVIER

Search for microscopic black hole signatures at the Large Hadron Collider ☆

CMS Collaboration *

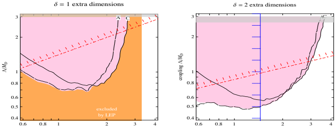
CERN, Switzerland



LHC bounds on large extra dimensions

JHEP

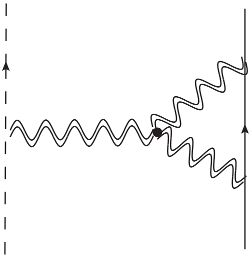
Roberto Franceschini[a], Pier Paolo Giardino[b]
Gian F. Giudice[c], Paolo Lodone[d], Alessandro Strumia[b,e]

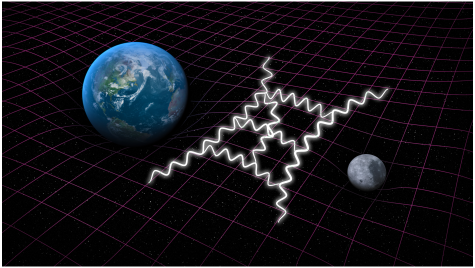


Part V

Work done in the Paris area

Quantum gravity : Pierre Vanhove [IPhT]



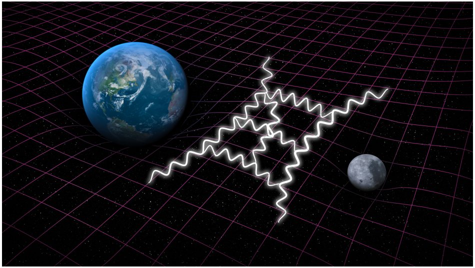


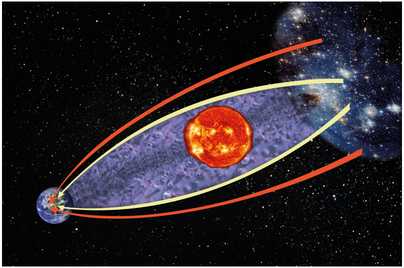
We can compute

- Classical gravity contributions for gravitational waves
- Quantum corrections to Einstein's theory

This approch is universal because any theory of quantum gravity that has the symmetries of general relativity must give the same answer

Quantum gravity : Pierre Vanhove [IPhT]





Quantum gravity correction to Einstein's theory

$$\theta_\gamma - \theta_\varphi = \frac{8(bu^\gamma - bu^\varphi)}{\pi} \frac{r_S \ell_P^2}{b^3}.$$

Very effects but at least shows that one can compute interesting effects : violation of the equivalence principle

Geometry of string theory : Ruben Minasian [IPhT]

IPhT Saclay

Higher-derivative couplings in string theory: dualities and the B-field

James T. Liu, Ruben Minasian

(Submitted on 10 Apr 2013)

The first quantum correction to the IIA string effective action arises at the eight-derivative level and takes the schematic form (t_8 t_8 - 1/8 \epsilon\epsilon)R^4 + B_2 \wedge X_8. This correction, however, cannot be complete by itself, as it is neither supersymmetric nor T-duality covariant. We reexamine these eight-derivative couplings and conjecture that the simple replacement R -> R(\Omega_+), where \Omega_+ = \Omega + 1/2 H is the connection with torsion, nearly completely captures their dependence on the B-field. The exception is in the odd-odd spin structure sector, where additional terms are needed. We present here a complete result at the level of the five-point function and a partial one for the six-point function. Further evidence for this conjecture comes from considering T-duality as well as heterotic/IIA duality beyond leading order. Finally, we discuss the eleven-dimensional lift of the modified one-loop type IIA couplings.

M-theoretic Lichnerowicz formula and supersymmetry

André Coimbra, Ruben Minasian

(Submitted on 11 May 2017)

A suitable generalisation of the Lichnerowicz formula can relate the squares of supersymmetric operators to the effective action, the Bianchi identities for fluxes, and some equations of motion. Recently, such formulae have also been shown to underlie the (generalised) geometry of supersymmetric theories. Ir this paper, we derive an M-theoretic Lichnerowicz formula that describes eleven-dimensional supergravity together with its higher-derivative couplings. The first corrections to the action appear at eight-derivative level, and the construction yields two different supersymmetric invariants, each with a free coefficient. We discuss the restriction of our construction to seven-dimensional internal spaces, and implications for compactifications on manifolds of G_2 holonomy. Inclusion of fluxes and computation of contributions with higher than eight derivatives are also discussed.

Bulk fields from the boundary OPE

Monica Guica (IPhT, Saclay & Uppsala U. & Nordita & Royal Inst. Tech., Stockholm)

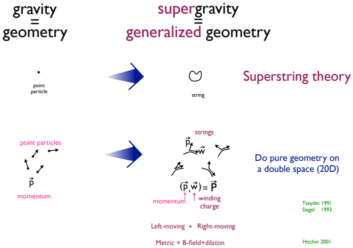
Oct 27, 2016 - 5 pages

NORDITA-2016-144
e-Print: arXiv:1610.08952 [hep-th] | PDF

Abstract (arXiv)
Previous work has established an equality between the geodesic integral of a free bulk field in AdS and the contribution of the conformal descendants of its dual CFT primary operator to the OPE of two other operators inserted at the endpoints of the geodesic. Working in the context of the AdS_3/CFT_2 correspondence, we extend this relation to include the $1/N$ corrections to the bulk field obtained by dressing it with i) a $U(1)$ current and ii) the CFT stress tensor. In the former case, we argue that the contribution of the Ka\v{c}-Moody descendants to the respective boundary OPE equals the geodesic integral of a particular $U(1)$-dressed bulk field, which is framed to the boundary via a split Wilson line. In the latter case, we compute the gravitational $1/N$ corrections to the bulk field in various gauges, and then write a CFT expression for a putative bulk field whose geodesic integral captures the contribution of Virasoro descendants to the OPE of interest. We comment on the bulk interpretation of this expression.

Generalized Geometry in string theory : Mariana Graña [IPhT]

IPhT Saclay



Amplitudes in supergravity and QFT: John-Joseph Carrasco [IPhT]

The Five-Loop Four-Point Integrand of N=8 Supergravity as a Generalized Double Copy

Zvi Bern (UCLA) , John Joseph M. Carrasco (IPhT, Saclay) , Wei-Ming Chen (UCLA) , Henrik Johansson (Uppsala U. & Nordita & Stockholm U. & Royal Inst. Tech., Stockholm) , Radu Roiban (Penn State U.) , Mao Zeng (UCLA)

Aug 22, 2017 - 78 pages

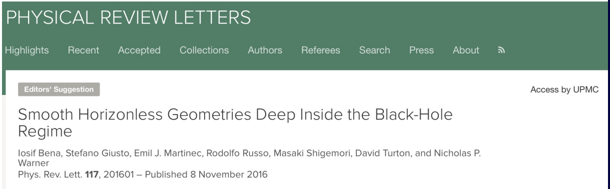
UCLA-17-TEP-105, NORDITA-2017-071, UUITP-29-17
e-Print: arXiv:1708.06807 [hep-th] | PDF

Abstract (arXiv)
We use the recently developed generalized double-copy procedure to construct an integrand for the five-loop four-point amplitude of N=8 supergravity. This construction starts from a naive double copy of the previously computed corresponding amplitude of N=4 super-Yang-Mills theory. This is then systematically modified by adding contact terms generated in the context of the method of maximal unitarity cuts. For the simpler generalized cuts, whose corresponding contact terms tend to be the most complicated, we derive a set of formulas relating the contact contributions to the violations of the dual Jacobi identities in the relevant gauge-theory amplitudes. For more complex generalized unitarity cuts, which tend to have simpler contact terms associated with them, we use the method of maximal cuts more directly. The five-loop four-point integrand is a crucial ingredient towards future studies of ultraviolet properties of N=8 supergravity at five loops and beyond. We also present a nontrivial check of the consistency of the integrand, based on modern approaches for integrating over the loop momenta in the ultraviolet region.

Show more plots

Black holes in string theory : Iosif Bena [IPhT]

IPhT Saclay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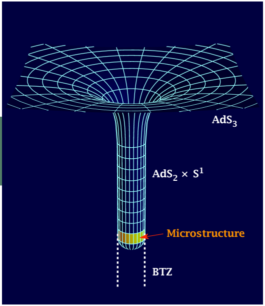
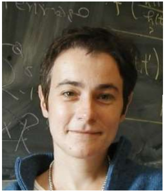
Smooth Horizonless Geometries Deep Inside the Black-Hole Regime

Iosif Bena, Stefano Giusto, Emil J. Martinec, Rodolfo Russo, Masaki Shigemori, David Turton, and Nicholas P. Warner

Phys. Rev. Lett. **117**, 201601 – Published 8 November 2016



Generalized geometry in string theory : Michela Petrini [LPTHE]



LPTHE
LABORATOIRE DE PHYSIQUE
THEORIQUE ET HAUTES ENERGIES

Exactly marginal deformations from exceptional generalised geometry

Anthony Ashmore (Merton Coll., Oxford & Oxford U., Inst. Math.) , Maxime Gabella (Princeton, Inst. Advanced Study) , Mariana Graña (IPhT, Saclay) , Michela Petrini (UPMC, Paris (main) & Paris, LPTHE) , Daniel Waldram (Imperial Coll., London)

May 18, 2016 - 52 pages

JHEP 1701 (2017) 124
(2017-01-27)
DOI: 10.1007/JHEP01(2017)124
IMPERIAL-TP-16-DW-03, IPHT-T16-035
e-Print: arXiv:1605.05730 [hep-th] | PDF

Abstract (Springer)
We apply exceptional generalised geometry to the study of exactly marginal deformations of $\mathcal{N}$ = 1 SCFTs that are dual to generic AdS_5 flux backgrounds in type IIB or eleven-dimensional supergravity. In the gauge theory, marginal deformations are parametrised by the space of chiral primary operators of conformal dimension three, while exactly marginal deformations correspond to quotienting this space by the complexified global symmetry group. We show how the supergravity analysis gives a geometric interpretation of the gauge theory results. The marginal deformations arise from deformations of generalised structures that solve moment maps for the generalised diffeomorphism group and have the correct charge under the generalised Reeb vector, generating the R-symmetry. If this is the only symmetry of the background, all marginal deformations are exactly marginal. If the background possesses extra isometries, there are obstructions that come from fixed points of the moment maps. The exactly marginal deformations are then given by a further quotient by these extra isometries.
Abstract (arXiv)

String theory, Black hole entropy : Boris Pioline [LPTHE]

LPTHE
LABORATOIRE DE PHYSIQUE THEORIQUE ET HAUTES ENERGIES

Indefinite theta series and generalized error functions

Sergei Alexandrov, Sibasish Banerjee, Jan Manschot, Boris Pioline

(Submitted on 17 Jun 2016 (v1), last revised 12 Jul 2016 (this version, v2))

Theta series for lattices with indefinite signature (n_+, n_-) arise in many areas of mathematics including representation theory and enumerative algebraic geometry. Their modular properties are well understood in the Lorentzian case ($n_+ = 1$), but have remained obscure when $n_+ \geq 2$. Using a higher-dimensional generalization of the usual (complementary) error function, discovered in an independent physics project, we construct the modular completion of a class of `conformal' holomorphic theta series ($n_+ = 2$). As an application, we determine the modular properties of a generalized Appell-Lerch sum attached to the lattice A_2, which arose in the study of rank 3 vector bundles on $\mathbb{P}^2$. The extension of our method to $n_+ > 2$ is outlined.

Wall-Crossing from Boltzmann Black Hole Halos

Jan Manschot, Boris Pioline, Ashoke Sen

(Submitted on 4 Nov 2010 (v1), last revised 11 Mar 2011 (this version, v3))

A key question in the study of N=2 supersymmetric string or field theories is to understand the decay of BPS bound states across walls of marginal stability in the space of parameters or vacua. By representing the potentially unstable bound states as multi-centered black hole solutions in N=2 supergravity, we provide two fully general and explicit formulae for the change in the (refined) index across the wall. The first, "Higgs branch" formula relies on Reineke's results for invariants of quivers without oriented loops, specialized to the Abelian case. The second, "Coulomb branch" formula results from evaluating the symplectic volume of the classical phase space of multi-centered solutions by localization. We provide extensive evidence that these new formulae agree with each other and with the mathematical results of Kontsevich and Soibelman (KS) and Joyce and Song (JS). The main physical insight behind our results is that the Bose-Fermi statistics of individual black holes participating in the bound state can be traded for Maxwell-Boltzmann statistics, provided the (integer) index \Omega(\gamma) of the internal degrees of freedom carried by each black hole is replaced by an effective (rational) index \bar\Omega(\gamma)= \sum_{m|\gamma} \Omega(\gamma/m)/m^2. A similar map also exists for the refined index. This observation provides a physical rationale for the appearance of the rational Donaldson-Thomas invariant \bar\Omega(\gamma) in the works of KS and JS. The simplicity of the wall crossing formula for rational invariants allows us to generalize the "semi-primitive wall-crossing formula" to arbitrary decays of the type \gamma\to M\gamma_1+N\gamma_2 with M=2,3.

Modified gravity : Cédric Deffayet [IAP]

Recovering General Relativity from massive gravity

E. Babichev, C. Deffayet, R. Ziour (APC, Paris)

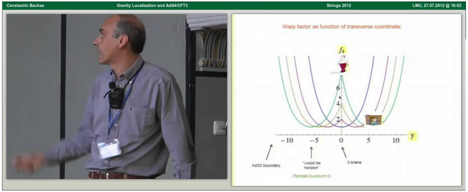
Jul 2009 - 4 pages

Phys.Rev.Lett. 103 (2009) 201102
DOI: 10.1103/PhysRevLett.103.201102
e-Print: arXiv:0907.4103 [gr-qc] | PDF

Abstract (arXiv)
We obtain static, spherically symmetric, and asymptotically flat numerical solutions of massive gravity with a source. Those solutions show, for the first time explicitly, a recovery of the Schwarzschild solution of General Relativity via the so-called Vainshtein mechanism.

Keyword(s): INSPIRE: gravitation: massive | space-time: Schwarzschild | general relativity | tensor: energy-momentum | field equations: solution | field equations: nonlinear | boundary condition | Dvali-Gabadadze-Porrati model | numerical calculations

String theory theory and phenomenology : Costas Bachas [LPT-ENS]



LPTENS

Quantum Gates to other Universes

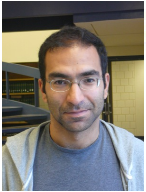
Constantin Bachas, Ioannis Lavdas

Nov 30, 2017 - 17 pages

e-Print: arXiv:1711.11372 [hep-th] | PDF

Abstract (arXiv)
We present a microscopic model of a bridge connecting two large Anti-de-Sitter Universes. The Universes admit a holographic description as three-dimensional $\mathcal{N}=4$ supersymmetric gauge theories based on large linear quivers, and the bridge is a small rank-n gauge group that acts as a messenger. On the gravity side, the bridge is a piece of a highly-curved $AdS_5 \times S_5$ throat carrying n units of five-form flux. We derive a universal expression for the mixing of the two massless gravitons: $M^2 \simeq 3n^2(\kappa_4^2 + \kappa_4'^2)/16\pi^2$, where M is the mass splitting of the gravitons, $\kappa_4^2, \kappa_4'^2$ are the effective gravitational couplings of the AdS_4 Universes, and n is the quantized charge of the gate. This agrees with earlier results based on double-trace deformations, with the important difference that the effective coupling is here quantized. We argue that the apparent non-localities of holographic double-trace models are resolved by integrating-in the (scarce) degrees of freedom of the gate.

Topological Strings : Amir Kashani-Poor [LPT-ENS]



LPTENS

Refined BPS invariants of 6d SCFTs from anomalies and modularity

Jie Gu (Ecole Normale Superieure & UPMC, Paris (main)) , Min-xin Huang (Hefei, CUST) , Amir-Kian Kashani-Poor (Ecole Normale Superieure & UPMC, Paris (main)) , Albrecht Klemm (U. Bonn, Phys. Inst., BCTP)

Jan 3, 2017 - 64 pages

JHEP 1705 (2017) 130
(2017-05-23)
DOI: 10.1007/JHEP05(2017)130
e-Print: arXiv:1701.00764 [hep-th] | PDF

Abstract (Springer)
F-theory compactifications on appropriate local elliptic Calabi-Yau manifolds engineer six dimensional superconformal field theories and their mass deformations. The partition function Z_{top} of the refined topological string on these geometries captures the particle BPS spectrum of this class of theories compactified on a circle. Organizing Z_{top} in terms of contributions Z_β at base degree β of the elliptic fibration, we find that these, up to a multiplier system, are meromorphic Jacobi forms of weight zero with modular parameter the Kähler class of the elliptic fiber and elliptic parameters the couplings and mass parameters. The indices with regard to the multiple elliptic parameters are fixed by the refined holomorphic anomaly equations, which we show to be completely determined from knowledge of the chiral anomaly of the corresponding