𝕆SMU23

Octonions, Standard Model, and Unification

February 24 – December 15, 2023

an online lecture series presented by

Archive Trust for Research in Mathematical Sciences and Philosophy

www.archmathsci.org (Oxford)

and

Inter-University Centre for Astronomy and Astrophysics

www.iucaa.in (Pune)

Motivation:

Several physicists believe that quantum theory, as presently understood, is likely to be approximate, not exact. In particular, our understanding of space-time structure in quantum field theory might be in for an overhaul. Twistor theory, trace dynamics, and the number system known as the octonions, will possibly play an important role in this improved understanding of space-time. Octonions have also emerged significantly in recent years in the investigation of elementary particles, the standard model, and its unification with gravitation. The present lecture series presents ongoing research from eminent physicists and mathematicians working in these fields. Each session will be two hours long, with one hour for the talk, followed by an hour long question-answer session.

Hosts: Tejinder P. Singh (IUCAA, Pune) and Michael Wright (ATRMSP, Oxford)

Advisors: Latham Boyle (Perimeter), Felix Finster (Regensburg), Cohl Furey (Berlin), Niels Gresnigt (Xi'an Jiaotong-Liverpool University), Basil Hiley (University College London), Roger Penrose (Oxford)

SPEAKERS

Roger Penrose (*Oxford*)
Basil Hiley (*University College London*)
Albert Schwarz (*UC Davis)*
Niels Gresnigt (*Xi'an Jiaotong-Liverpool University*)
Felix Finster (*University of Regensburg*)
Cohl Furey *(Humboldt University, Berlin)*
Stephen Adler (*IAS, Princeton)*
John Barrett (*University of Nottingham*)
Tejinder P. Singh (*IUCAA, Pune*)
Ashutosh Kotwal (*Duke University*)
Angelo Bassi (*University of Trieste*)
Hendrik Ulbricht (*University of Southampton*)
Tevian Dray (*Oregon State University*)
Niel Turok (*University of Edinburgh*)
Latham Boyle (*Perimeter Institute*)
David Chester (*Quantum Gravity Research*)
Corinne Manogue (*Oregon State University*)
Anthony Lasenby (*Cavendish Laboratory, Cambridge*)
Matej Pavsic (*J. Stefan Institute, Ljubljana*)
Robert Wilson (*Queen Mary University of London*)
Kyu-Hun Chae (*Sejong University*)
~~Kirill Krasnov (*University of Nottingham)*~~ CANCELLED
~~Ivan Todorov (*Bulgarian Academy of Sciences*)~~ CANCELLED

Indranil Banik (*University of St. Andrews*)

Peter Woit (*Columbia University, New York*)

SCHEDULE

All talks will be on Fridays, once every two weeks, at 4 pm London time

February 24, 2023	Roger Penrose *Basic twistor theory, bitwistors, and Split-octonions* (Abstract on page 6)	Video Recording
March 10, 2023	Basil Hiley *Dyson's three-fold way, quantum processes and the split-quaternions* (Abstract on page 7)	Video Recording
March 24, 2023	Albert Schwarz *Jordan algebras, quantum theory, and particle physics* (Abstract on page 8)	Video Recording
April 7, 2023	Niels Gresnigt *Cayley-Dickson algebras, braids, and the Standard Model* (Abstract on page 9)	Video Recording
April 21, 2023	Felix Finster *The theory of causal fermions* (Abstract on page 10)	Video Recording
Postponed from May 5 to: May 12, 2023	Cohl Furey *Bott periodic particle physics*	Video Recording

May 19, 2023	Stephen Adler *Trace dynamics and implications for my work of the last two decades* (Synopsis on page 12)	Video Recording
June 2, 2023	John Barrett *Non-commutative geometry and the standard model* (Abstract on p. 13)	Video Recording
June 16, 2023	Tejinder P. Singh *Trace dynamics, octonions, and unification* (Summary on page 14)	Video Recording

~~June 30, 2023~~ **POSTPONED to JULY 21, 2023**	Ashutosh Kotwal *Particle physics: what we know and what we do not know*	Video Recording
July 14, 2023	Angelo Bassi *Is quantum theory exact or approximate?*	Video Recording
July 28, 2023	Hendrik Ulbricht *Experimental tests of quantum mechanics for large systems*	Video Recording
September 1, 2023	Tevian Dray *A Division Algebra Description of the Magic Square, including E_8* (Abstract on p.16)	Video Recording
September 15, 2023 POSTPONED TO DEC. 8, 2023	Latham Boyle TBA	Confirmed
September 18, 2023 (Monday)	Neil Turok *The CP symmetric universe*	Video Recording

September 29, 2023	David Chester *Physically realistic minimal models from E8* (Abstract on p. 17)	Video Recording
October 13, 2023	Corinne Manogue *E_8 and the Standard Model* (Abstract on p.16)	Video Recording
October 27, 2023	Anthony Lasenby *Geometric algebra, octonions, and the standard model* (Abstract on p. 20)	Video Recording
November 3, 2023	Matej Pavsic *Extending physics to Clifford space: towards the unification of particles and forces, including gravity* (Abstract on p. 19)	Video Recording
November 10, 2023	Robert Wilson *Einstein's nightmare: is physics fundamentally discrete?* (Abstract on p.22)	Video Recording
November 24, 2023 CANCELLED	Kirill Krasnov TBA	~~Confirmed~~ CANCELLED
November 24, 2023 **2 pm London time** (please note unusual time)	Kyu-Hun Chae *Observational evidence for the breakdown of Newtonian gravitation in wide binaries* (Abstract on p.21)	Video Recording
December 1, 2023	Indranil Banik *Strong constraints on weak gravity from Gaia DR3 wide binaries* (Abstract on p.23)	Video Recording
December 8, 2023	Peter Woit *Space-time is right handed* (Abstract on p.25)	Video Recording

December 15, 2023	~~Ivan Todorov TBA~~ Latham Boyle *The Penrose tiling is a quantum error correcting code* (Abstract on p. 24)	Video Recording

ZOOM link

Topic: OSMU 23 (Octonions Standard Model + Unification Meeting)

Join Zoom Meeting
https://us06web.zoom.us/j/89956931861?pwd=YkN4bUg0NE1STFlRd0MwY0NUVjcwdz09

Meeting ID: 899 5693 1861
Passcode: 451794

The hosts request that questions from the audience may kindly be postponed to the discussion session. Questions can also be left in the chat box. Thank you. We look forward to having you with us in this lecture series.

Talks and discussion sessions will be recorded. We hope to make the recording available within two weeks after the lecture. URL www.archmathsci.org

Video recordings are available at

https://www.youtube.com/@archivetrustforresearch/featured

Communications Partner

Curt Jaimungal

Podcast Host
Theories of Everything https://www.youtube.com/TheoriesOfEverything

----

Abstracts of talks are on the following pages.

TITLE: Basic Twistor Theory, Bi-twistors, and Split-octonions.

Roger Penrose, 2023

Abstract:

Twistor theory was introduced in the mid 1960s as an approach to combining quantum theory with space-time structure. A driving force behind the introduction of Twistor Theory was to combine the quantum-field theoretic requirement of positive frequency with the structure of space-time. In order to achieve this, the notion of twistor space was introduced to codify the structure of space-time in a way which related it to the splitting of the twistor space into two halves, one representing positive frequency, and the other representing negative frequency. Standard twistor theory involves a complex projective 3-space PT which naturally divides into two halves PT^+ and PT^-, joined by their common 5-real-dimensional boundary PN. The points of the space PN represent light rays in Minkowski space-time. However, this splitting has two quite different basic physical interpretations, namely positive/negative helicity and positive/negative frequency, which ought not to be confused in the formalism, and the notion of "bi-twistors" is introduced to resolve this issue. It is found that quantized bi-twistors have a previously unnoticed G_2* structure, which enables the split-octonion algebra to be directly formulated in terms of quantized bi-twistors, once the appropriate complex structure is incorporated.

Dyson's three-fold way, quantum processes and the split-quaternions. B. J. Hiley.

My talk is based on a long neglected paper by Brice DeWitt in which he shows that in order to write the Kline-Gordon equation in a pseudo-Riemannian space in a fully relativistic covariant manner, the quantum Hamiltonian must contain an additional energy term, $\hbar 2Q$ which he calls the "quantum potential". This term is manifested as a scalar curvature term in the geodesic. As is well known, a similar potential appears in the real part of the Schrödinger equation under polar decomposition of the wave function in Bohm's approach. Indeed a relation between the two potentials has been established.

If we include the arguments that Dyson outlines in his 1962 paper "The three-fold way" we find that the imaginary units demanded by quantum mechanics arise, not through the complex field, but through the basis elements (*i*, *j* and *k)* of the real quaternions. This provide a rich structure allowing a purely algebraic approach to quantum phenomena rather than the usual Hilbert space formalism and no collapse of the wave function is necessary. The geometrical aspects of the dynamics emerge from the split quaternions, which combine the orthogonal and symplectic structure in a new way. This provides a link between the dynamical mass and the rest mass opening up the possibility of new ways of exploring the rest mass problem. If time allows I will show the relationship between the Dirac spinor and the semi-spinor of the conformal Clifford, the twistor.

1. DeWitt, B. S., Point Transformations in Quantum Mechanics, Phys. Rev. 85 (1952) 653-661.
2. Freeman J. Dyson, The Threefold Way. Algebraic Structure of Symmetry Groups and Ensembles in Quantum Mechanics, J. Math. Phys. **3**, (1962) 1199-1215
3. Bohm, D. and Hiley, B. J., The Undivided Universe: An Ontological Interpretation of Quantum Mechanics, Routledge, London, (1993).
4. Bohm D. J. and Hiley, B. J., Generalisation of the Twistor to Clifford Algebras as a Basis for Geometry, Revista Brasilera de Fisica, Vol. Especial Os 70 anos de Mario Schönberg, 1-26, (1984).

Albert Schwarz   March 24, 2023

Title: Jordan algebras, quantum theory, and particle physics

Abstract

In the geometric approach to quantum theory that was suggested recently in my papers we are taking as a starting point the set of states (a bounded convex set of normalized states or a convex cone of not necessarily normalized states). In this framework one can prove a generalization of decoherence and use this proof to derive probabilities from the first principles (from random interaction with the environment). Fixing an action of time and spatial translations on the cone of states one can define a notion of elementary excitation of translation invariant state and of scattering of elementary excitations. (Elementary excitations of ground state should be identified with particles, in general case elementary excitations should be regarded as quasiparticles.)

The geometric approach allows us to construct physical theories corresponding to Jordan algebras. This construction is based on the remark that one can define a cone of positive elements of a Jordan algebra. (In Jordan Banach algebras this is a homogeneous cone consisting of all squares.) In the talk I will analyze elementary excitations and scattering in physical theories based on Jordan algebras.

Cayley-Dickson algebras, braids, and the Standard Model

Niels Gresnigt April 7, 2023

The initial part of this talk will review the applications of the quaternions and octonions to describing the particle content and symmetries of the Standard Model. Most of this review will be based on the works of Dixon and Furey. In the second half of the talk I will discuss some of my own ideas relating to algebraic unification.

It is proposed that going beyond the division algebras, and considering the CayleyDickson algebra of sedenions provides a natural means of generalizing existing results from a single generation to exactly three. The additional S_3 automorphisms of the sedenions might then be interpreted as a flavor symmetry, incorporating neutrino oscillations and quark mixing.

I will finish by discussing a curious association between algebraic unification based on the division algebras, and a topological representation of fermions in terms of simple braids. The structure of the Clifford algebras generated from the quaternions and octonions in this case provides a justification for many of the ad hoc assumptions in the topological model.

Throughout the presentation, the focus will primarily be on the underlying ideas, recognizing that many of the ideas presented are still a work in progress. The intent is to generate stimulating discussion.

Title: Causal fermion systems and octonions

Felix Finster April 21, 2023

Abstract:

The theory of causal fermion systems is an approach to describe fundamental physics. It gives quantum mechanics, general relativity and quantum field theory as limiting cases and is therefore a candidate for a unified physical theory. Moreover, causal fermion systems provide a general framework for modelling and analyzing non-smooth spacetime structures. The dynamics of a causal fermion system is described by a nonlinear variational principle, the causal action principle.

The aim of the talk is to give a simple introduction, with an emphasis on the underlying concepts. At the end of the talk, I will explain how octonions arise naturally by acting on the vacuum measure.

Stephen L. Adler, May 19, 2023

Title: Trace dynamics and implications for my work of the last two decades

Synopsis: Trace dynamics is a Lagrangian theory of completely non-commuting variables q (generalized coordinate) and p (generalized momentum), which can be bosonic (Grassmann even) or fermionic (Grassmann odd). The Lagrangian is formed as a trace over polynomials in the q's and p's, and validity of cyclic permutation under the trace is assumed. From a trace action principle one directly finds the equations of motion, in Lagrangian form, and forming a trace Hamiltonian by a Legendre transform one finds the equations of motion in Hamiltonian form. When the trace Lagrangian is assumed invariant under global unitary transformation of the q's and p's, which requires that it contain no noncommuting coefficients, then there is a conserved Noether charge, given by the sum over bosonic variables of the commutators [q,p], minus the sum over fermionic variables of the anticommutators {q,p}. Forming a canonical ensemble, and taking averages over this ensemble, one finds that equipartition arguments give an emergent structure with the form of quantum field theory, provided the underlying theory develops a scale hierarchy in which variations of the trace Hamiltonian decouple, and provided that the numbers of bosonic and fermionic variables are essentially equal. In this theory the ensemble average of the conserved Noether charge plays the role of the complex unit i. The general framework is described in my 2004 Cambridge University Press book ``Quantum Theory as an Emergent Phenomenon''.

Much of my work since 2004 has been motivated by ideas coming from this book: (i) Thermodynamics has Brownian motion corrections, which suggests that these play a role in quantum measurements. This in turn suggests a connection at the phenomenological level with the Ghirardi-Rimini-Weber-Pearle model of objective reduction, with the aim of confronting experiment. (ii) The effective complex unit coming from trace dynamics is a 2X2 real matrix representation, which acts as i on one sector and -i on the other. Perhaps ``dark matter'' is a -i sector coupled to the standard model i sector only by gravitation. (iii) The equality of bosonic and fermionic variable numbers in trace dynamics suggests that extending the standard model with exact supersymmetry may be too strong a requirement. Perhaps one should only impose the weaker condition of boson-fermion balance, suggesting alternative unification models. (iv) The underlying trace dynamics theory naturally admits a Weyl scaling invariance of the metric, and this suggests that the non-derivative part of the induced gravitational action is also a Weyl scaling invariant, giving a novel model for "dark energy". In gravity including this action, black holes no longer have horizons; near and inside the nominal horizon, the time-time component of the metric becomes very small but remains positive, never changing sign. (v) This motivates exploring horizonless ``dynamical gravastar'' models in which radii where structural changes occur come just from the relativistic Tolman-Oppenheimer-Volkoff equations with an assumed jump in the equation of state at high pressure to one with pressure plus energy density approximately zero. Continuity properties of the TOV equations require the jump to be in the energy density, not in the pressure as assumed in prior work. This model may describe the structure of astrophysical ``black holes''. Since material getting in can also emerge, such objects could play a role in galaxy formation, leading to a simple formula for the disk galaxy scale radius, depending only on properties of atomic hydrogen.

John Barrett

Friday, June 2, 2023

Title: Non-commutative geometry and the standard model

Abstract: The talk will discuss the spectral triple approach to non-commutative geometry as applied to the standard model of particle physics. The aim is to explain two things: 1. the non-commutative algebraic structure of the standard model, and 2. the spectral action principle. Most of the talk is an introduction to well-established ideas from the 2000s and before, but there may be a few remarks on more recent developments.

Tejinder P. Singh June 16, 2023

Trace dynamics, octonions, and unification

There ought to exist a reformulation of quantum field theory in which evolution does not depend on classical time. This is because the principle of quantum linear superposition does not permit a point structure for spacetime, except in the approximation that the universe is dominated by macroscopic classical bodies. These remarks are true irrespective of the energy scale under consideration. The fact that the Dirac operator is also the gradient operator on quaternionic space is already an indicator that space-time noncommutativity plays a key role in fermion dynamics, at all energies.

We describe our group's ongoing research program to develop the aforesaid reformulation of quantum theory, which also opens the route to quantum gravity and its unification with the standard model of particle physics. Instead of real numbers, split biquaternions and split bioctonions are used to construct the space inhabited by fermions and bosons. These obey a matrix-valued Lagrangian dynamics (generalized trace dynamics). The role of time parameter is played by the Connes time, a feature of non-commutative geometries resulting from the Tomita-Takesaki theory. The Lagrangian of the theory is based on the Chamseddine-Connes spectral action principle and is essentially trace of the squared Dirac operator which also includes Yang-Mills fields. The use of split bioctonions permits chiral fermions to arise, including three sterile neutrinos. The associated quadratic form describes two copies of 4D spacetime overlaid by two vector bundles. The dynamics is deterministic and non-unitary, though norm preserving; quantum theory emerges from coarse-graining this underlying dynamics. The Lagrangian is assumed to obey an E_8 x E_8 symmetry and describes a left-right symmetric extension of the standard model. The assumed branching $E_8 \rightarrow SU(3)$ x E_6 for each of the E_8 leads to the emergence of the standard model, along with an $SU(2)_R$ pre-gravitation symmetry, and two new forces, SU(3)_grav and U(1)_grav.

The particle content of the theory can also be deduced from Clifford algebras possessing the associated dynamical symmetries. It is known from earlier research that Cl(6), associated with complex octonions, describes one generation of standard model fermions under the unbroken symmetry SU(3)_c x U(1)_em. We generalize this to show that Cl(7), associated with complex split bioctonions, and being a direct sum of two copies of Cl(6), describes one generation of chiral fermions under SU(3)_c X U(1)_em X SU(3)_grav X U(1)_grav. Whereas the quantum number associated with U(1)_em is electric charge, the quantum number associated with U(1)_grav is square root of mass (in Planck mass units). Each of the Cl(6) is extended by a Cl(2) to include the SU(2)_L and SU(2)_R symmetries, giving rise to two copies of Cl(8). Between them they account for three fermion generations, and the resulting Cl(9) algebra appears to be the algebra of unification. We predict twelve new gauge bosons associated with the dark (gravitational) sector SU(3)_grav X SU(2)_R X U(1)_grav, as also a BSM charged Higgs. This Higgs assigns electric charge to the right-handed fermions, whereas the standard model Higgs assigns mass to the left-handed fermions, upon electroweak symmetry breaking, which in this theory is also left-right symmetry breaking.

Our investigations suggest that the electroweak scale is also the scale for the unification of the standard model with gravitation. Prior to this scale the universe undergoes an inflationary phase which resets the Planck scale from 10^{19} GeV to the electroweak scale. Symmetry breaking gives rise to the emergence of U(1)_em as well as U(1)_grav, along with their associated quantum numbers – electric charge and square-root mass, respectively. The exceptional Jordan algebra (EJA) of 3x3 Hermitian matrices with octonionic entries describes a family of three generations of left-handed fermions (electric charge eigenstates) / right-handed fermions (square root mass eigenstates), once the value of the electric charge / square-root mass is specified. The characteristic equation of the EJA is a cubic, and its eigenvalues carry information about the values of fundamental constants of the standard model. In particular, by expressing square-root mass eigenstates as superpositions of electric charge eigenstates, we deduce the observed mass ratios of charged fermions, and the CKM matrix parameters, in addition to the low energy fine structure constant and the weak mixing angle. The Triality operator can permute vector spaces, it is a special feature of Cl(8) algebra. It allows us to mix the flavour and mass eigenstates; and obtain them from a single Cl(9) algebra. The CKM matrix is then interpreted as a transformation that rotates the normalised mass eigenstates of the gravi-charge vectors to the normalised flavour eigenstates.

Quantum systems do not live on spacetime, but on split bioctonionic space. We suggest that the Ghirardi-Rimini-Weber-Pearle (GRWP) process of spontaneous localization leads to the emergence of our 4D classical universe, and quantum theory on a classical spacetime background overlaid with a vector bundle describing the unbroken symmetries of strong force and electromagnetism. The weak force appears to be a spacetime symmetry associated with a second 4D spacetime which has microscopic dimensions but is also a part of our universe, and which might be acting as a (hitherto undetected) channel for EPR communication. Along this channel, communication obeys relativistic causality, but any two points of our universe are only a microscopic distance apart (of the order of the range of the weak force).

We end by outlining open questions, and the considerable work which remains to be done, to carry this program of unification to completion.

The research articles associated with this program are listed at https://www.tifr.res.in/~tpsingh

Tevian Dray
A Division Algebra Description of the Magic Square, including E8
(joint work with Robert Wilson and Corinne Manogue)

The Freudenthal--Tits magic square of Lie algebras provides an abstract parameterization of a family of Lie algebras in terms of two division algebras, with the exceptional cases all involving the octonions. In the non-octonionic cases, it is straightforward to provide a matrix interpretation of the magic square, which can be exponentiated to yield a parametrization of the corresponding Lie groups. I describe here joint work with Robert Wilson and Corinne Manogue that extends these constructions to E8, thus providing an explicit representation in terms of (two copies of) the octonions. This mathematical construction is at the heart of the octonionic description of the Standard Model that will be presented in the talk scheduled for 13 October.

October 13, 2023
Corinne Manogue
E8 and the Standard Model
(joint work with Tevian Dray and Robert Wilson)

Using the explicit parameterization in terms of octonions presented in the talk on 1 September, we interpret the elements of the Lie algebra e8 as objects in the Standard Model. We obtain lepton and quark spinors with the usual properties, the Standard Model Lie algebra su(3)+su(2)+u(1), and the Lorentz Lie algebra so(3,1).

Friday, September 29, 2023

Speaker: David Chester

Title: Physically realistic minimal models from E8

Abstract: This talk reviews the relationship of octonions to the most exceptional Lie group E8 and its applications to unified field theory. I will explain how the conformal group with many conventional GUT groups can fit inside the quaternionic noncompact real form E8(-24), which provides the representation theory for building a class of models. The Grassmann envelope allows for E8 to be turned into a super-Lie group to provide a rigorous formulation of a superconnection, giving the N=1 D=11+3 superconformal group. I will then demonstrate how a single 248 representation of E8 can encode three generations of standard model fermions, gravity, the spin-1 gauge bosons of SU(5), and a complete Higgs sector. To provide one explicit model, a theory inspired by MacDowell-Mansouri gravity will be demonstrated to contain a minimal gravitational sector with the Einstein-Hilbert action and a cosmological constant at low energies.

If time permits, I'll discuss recent work on uplifting the physics from Dixon-Furey C (x) H (x) O to new projective lines and projective planes, including discussion of Jordan algebras. Additionally, I'll outline recently published work discussing how to recover the

superalgebras of M-theory, F-theory, S-theory, and beyond from nested membranes found in superalgebras from D=25+1, D=26+1, D=27+3, and D=28+4. This includes rich mathematical connections to the Leech lattice, Monster group, and Griess algebra as well as a candidate warm dark matter spectrum stemming from a 2,048 spinor representation. Further insights on the D=11+3 superconformal group provides hints on how to make a supergravity or membrane theory for physically realistic physics without any unobserved superpartners such as selectrons or squarks.

Friday, November 3, 2023

Matej Pavsic

We assume that in 4D spacetime, $M_{1,3}$, there exist fundamental extended objects like strings and branes. These are described in terms of infinite-dimensional embedding functions. Alternatively, they can also be described in terms of the finite number of area/volume degrees of freedom, which constitute a 16-dimensional manifold, $M_{8,8}$, called "Clifford space" C, with $Cl(1,3)$ as a tangent space. We generalize the theory of relativity from $M_{1,3}$ to $M_{8,8}$. "Point particles" and "strings" in Clifford space appear from the perspective of $M_{1,3}$ as "thick particles" and "thick strings", because they are conglomerates of p-branes for various values of p (p = 0, 1, 2,3). String theory formulated in Clifford space is consistent, and no additional dimensions of the underlying spacetime $M_{1,3}$ are necessary.

Within the 16-dimensional manifold $M_{8,8}$, we have a platform for the SO(10) grand unification of particles and forces, including gravity. To achieve this, we replace the tangent space $Cl(1,3)$ with the vector space $V_{8,8}$. Because quantum states are represented by complex-valued wave functions, the signature is irrelevant in quantum setups and one can work with V_{16} as well. The basis vectors of V_{16} generate the Clifford algebra $Cl(16)$ in which is embedded the algebra e_8. We have thus obtained the possible unification group E8 by starting with extended objects in 4D spacetime.

Anthony Lasenby

Friday, October 27, 2023

Geometric algebra, octonions, and the standard model

Spacetime Algebra (STA) is the Geometric Algebra (GA) of real 4-dimensional spacetime. Its elements are the simple geometric objects of spacetime (points, planes, volumes, etc.) equipped with the algebra of the Clifford product. The aim of this talk is to see how much of modern physics we can do with just the STA as our mathematical toolbox, and in particular whether it can stretch all the way through from gravity in 4d spacetime to the possible unification groups and higher dimensional spaces that have been a focus of this talk series. In doing so, the minimal nature of the STA can act as a guide to the type of symmetries which may be important. GA provides a natural home for the normed division algebras of complex numbers and quaternions, with the latter being effectively Pauli spinors in a GA approach. We will show how Octonions can also be realised in the Spacetime Algebra, and thereby can make contact with the recent efforts where chains of Octonion multiplications lead through to larger Clifford algebras in which there is space to represent the standard model, but where, via the translation here, the groups involved can still be instantiated in terms of operations in the 4d STA. We also briefly consider the Sedenions, for which a similar translation is possible, again within the STA, and notions of triality, which find a natural expression in the STA approach.

Friday, November 24, 2023
2 pm London time

Kyu-Hyun Chae

Title: Observational evidence for the breakdown of standard gravity in favor of MOND-type modified gravity

Abstract: I present conclusive evidence from Gaia observations of wide binary stars that the Newton-Einstein standard gravity starts to break down at acceleration near 1 nm (nano-meter) per second squared. Gaia DR3 (data release 3) proper motions along with radial velocities were accurately and painstakingly modeled to obtain the evidence. Remarkably, the trend of the deviation agrees well with the prediction of MOND-type modified gravity theories such as AQUAL. At accelerations higher than about 10 nm per second squared, binary motions agree well with the Newtonian prediction. In contrast, at accelerations lower than about 0.1 nm per second squared, binary motions agree well with a quasi-Newtonian prediction with Newton's constant boosted by a factor of 1.4. This is exactly what AQUAL predicts under the strong external field effect from the Milky Way. The Newton-AQUAL transition occurs at near 1 nm per second squared which corresponds to a sky-projected separation of about 3,000 au for typical binaries with total masses in the range from 0.5 to 2 solar masses.

EINSTEIN'S NIGHTMARE: IS PHYSICS FUNDAMENTALLY DISCRETE?

ROBERT A. WILSON

ABSTRACT. I propose a discrete model of fundamental physics, based on the binary tetrahedral group of order 24. The real group algebra adds continuous symmetries to this, and provides the gauge groups and the Lorentz group required for the standard model, subject to some technical modifications which I will discuss. There are 12 bosonic dimensions, and 12 fermionic dimensions, each of which has three distinct interpretations, at the levels of (1) internal symmetries, (2) quantum field theory or measurement and (3) classical physics.

These three interpretations of the same mathematical model help to explain a number of the unexplained parameters of the standard model. The classical interpretation includes Newtonian gravity, and therefore the other interpretations allow us to construct a quantum theory of gravity. This quantum gravity is neither Newtonian nor Einsteinian, but somewhere in between, and is not an addition to the standard model, but a re-interpretation of it. It splits matter into baryonic and leptonic, not into baryonic and dark.

Friday, December 1, 2023
4 pm London time

Indranil Banik

Strong constraints on weak gravity from *Gaia* DR3 wide binaries

Abstract:

I will present a recently published detailed test of Milgromian dynamics (MOND) using wide binary stars (WBs) with separations of 2-30 kAU or about 0.01-0.15 pc (Arxiv:2311.03436). Locally, the WB orbital velocity in MOND should exceed the Newtonian prediction by about 20% at asymptotically large separations given the Galactic external field effect (EFE). I led an international team that investigated this with a detailed statistical analysis of *Gaia* DR3 data on 8611 WBs within 250 pc of the Sun. Orbits were integrated in a rigorously calculated gravitational field that directly includes the EFE (MNRAS, 480, 2660). We also allowed line of sight contamination and undetected close binary companions to the stars in each WB. We interpolated between the Newtonian and Milgromian predictions using the parameter alpha_grav, with 0 indicating Newtonian gravity and 1 indicating MOND. Directly comparing the best Newtonian and Milgromian models revealed that Newtonian dynamics is preferred at 19σ confidence. Using a complementary Markov Chain Monte Carlo (MCMC) analysis, we found that alpha_grav = -0.021+0.065-0.045, which is fully consistent with Newtonian gravity but excludes MOND at 16σ confidence. This is in line with a similar result using a somewhat different sample selection and less thoroughly explored population model (Arxiv:2205.02846). We showed that although our best-fitting model does not fully reproduce the observations, an overwhelmingly strong preference for Newtonian gravity remains in a considerable range of variations to our analysis targeting the main systematic uncertainties in the problem. Adapting the MOND interpolating function to explain this result would cause tension with rotation curve constraints. We discuss the broader implications of our results in light of other works, concluding that MOND must be substantially modified on small scales to account for local WBs. Our paper reveals catastrophic problems with the selection criteria applied in the paper discussed at the talk the week before this talk (ApJ, 952, 158), which I will briefly discuss. In addition, I will also mention severe difficulties faced by MOND with Solar System constraints from the Cassini mission to Saturn and from recent observations of galaxy cluster outskirts. Taken in combination, these results preclude MOND as a fundamental modification to gravity at low accelerations.

Friday December 15, 2023

Latham Boyle

Title: The Penrose tiling is a quantum error correcting code

Abstract: I will begin by introducing Penrose tilings ("PTs") and quantum error correcting codes ("QECCs"). A PT is a remarkable, intrinsically non-periodic way of tiling the plane whose many beautiful and unexpected properties have fascinated physicists, mathematicians, and geometry lovers of all sorts, ever since its discovery in the 1970s. A QECC is a fundamental way of protecting quantum information from noise, by encoding the information with a sophisticated type of redundancy. Such codes play an increasingly important role in physics: in quantum computing (where they protect the delicate quantum state of the computer); in condensed matter physics (where they underpin the notion of topologically-ordered phases); and even in quantum gravity (where the "holographic" or "gauge/gravity" duality may be understood as such a code).

Although PTs and QECCs might seem unrelated, I will explain how PTs gives rise to (or, in a sense, *are*) a new type of QECC in which any local errors or erasures in any finite region of the code space, no matter how large, may be diagnosed and corrected. Variants of this code (based on the cousins of the Penrose tiling, called the Ammann-Beenker and Fibonacci tilings) can live in a finite space, in discrete spin systems, and in an arbitrary number of spatial dimensions.

In keeping with the theme of this series, I will end by discussing possible connections to quantum gravity, the octonions and the standard model.

(Based on the recent paper https://arxiv.org/abs/2311.13040 by Zhi Li and myself.)

Peter Woit

Friday, December 8, 2023

Title: Spacetime is Right-handed

Abstract

Spinors in Minkowski and Euclidean spacetimes are usually related by considering them as real forms of spinors in complexified spacetime. The Lorentz $SL(2, C)$ is taken to be the (conjugate) diagonal of the complexified Lorentz group $SL(2, C)_L \times SL(2, C)_R$, the Euclidean $Spin(4)$ is $SU(2)_L \times SU(2_R)$. An alternative choice is proposed, taking the Lorentz group instead to be the chiral factor $SL(2, C)_R$. The relation between Minkowski and Euclidean spinors now no longer is via analytic continuation in $SL(2, C)_L \times SL(2, C)_R$. Instead, the Euclidean spacetime geometry has a distinguished imaginary time direction and spatial rotations are $SU(2)_R$, not the diagonal $SU(2)$.

It appears to be possible to formulate the standard model and gravity using fundamentally chiral spacetime variables that just transform under $SL(2, C)_R$, with the Euclidean $SU(2)_L$ behaving like an internal rather than spacetime symmetry.

Twistor geometry has a very similar inherently chiral nature consistent with this proposal, with points in complexified space time given by the right-handed spinor space, now thought of as a complex two-plane in twistor space.