Particle Theory

We study the fundamental nature of matter and forces in the universe ... seeking to explain why the world is the way it is?

Academics Subir Sarkar, Jorge Casalderrey-Solana, Joseph Conlon, Lucian Harland-Lang, Andre Lukas, John March-Russell, Gavin Salam, Andrei Starinets, John Wheater

http://www2.physics.ox.ac.uk/research/particle-theory
Oxford Particle Theory Group

Founded in 1963 by Richard (Dick) Dalitz
Former members: Jack Paton, Ian Aitchison, John Taylor, Chris Llewellyn-Smith, Frank Close, Graham Ross*, Mike Teper*, Giulia Zanderighi, Uli Haisch

Conformal field theory & quantum gravity

Gauge-string duality, holography, AdS-CFT

+ presently 3 postdocs & ~18 DPhil students

+ Visitors: Christopher Herzog (KCL)
Stephen West (RHUL)
James Unwin (Illinois) - for MT18

+ Many associates in Astro, PP & Maths Inst

Supported by: UKRI, EU, Royal Society …


Particle astrophysics and cosmology

Physics beyond the Standard Model

Phenomenology of EW & strong interactions
Oxford alumnus shares Nobel Prize in Physics 2016

A DOUBLE REGGE MODEL OF PRODUCTION PROCESSES

J. M. KOSTERLITZ
Department of Theoretical Physics, Oxford University,
12 Parks Road, Oxford, England

Received 15 July 1968

Abstract: The Feynman diagram method is used to calculate the amplitude for a bi-
Regge pole exchange for multiparticle production processes at very high energies.
The two cases of normal and abnormal coupling of the Reggeon-Reggeon-particle
vertex are considered. Certain differential cross sections are evaluated and com-
pared to previous results.

The author would like to thank Dr. J. C. Taylor and Mr. G. Thomas, the
former for suggesting this problem, and both for many helpful conversa-
tions. He is indebted to the Science Research Council for a grant.
HOW PROFESSORS SPEND THEIR TIME

How they actually spend their time:
- Teaching: 59%
- Research: 18%
- Service: 23%

How departments expect them to spend their time:
- Teaching: 20%
- Research: 175%
- "Service": 20%

How Professors would like to spend their time:
- Don’t tell me what to do

Source: Higher Education Research Institute Survey (1999)
Fabrizio Caola

Higher order QCD calculations and precision collider phenomenology

**Theoretical aspects:**
- soft/collinear structure of QCD, NNLO and higher order subtractions
- new ideas for amplitude computations

\[
\begin{align*}
\partial_x \bar{f} &= \epsilon \bar{A}_x(x, y, z, \ldots) \bar{f} \\
G(a_n, a_{n-1}, \ldots, a_1, t) &= \int_0^t \frac{dt}{t_n - a_n} G(a_{n-1}, \ldots, a_1, t_n)
\end{align*}
\]

**Phenomenological implications:**
- Higgs studies (off-shell, VH, bbH, H+j...)
- Single-top@NNLO
- Vector bosons (gg → VV& off-shell H...)

I will move to Oxford in January. I should be visiting for a couple of days in November.
Heavy Ion Collisions & Holography

- Extremely high temperatures
  \[ T > 2 \times 10^{12} \text{ K} = 170 \text{ MeV} \]
- A new state of matter
  Quark Gluon Plasma
- A strongly coupled fluid

- LHC: Pb-Pb @ \( \sqrt{s} = 2.76 \text{ TeV} \)

Main tool that I use: Holography
- Strong coupling field theory solved by classical gravity

Topics I will address this year
- Phase transitions and holography
- Onset of hydro behaviour
- Inhomogeneous horizons in 5D
- Gravitational waves at strong coupling

*FIG. 1.* Energy density versus temperature for the gauge theory dual to (1). At high and low \( T \) there is only one phase shown in dashed-dotted blue. The preferred phase in the multivalued region is shown in solid purple. The dotted green curve is metastable. The dashed red curve is locally unstable. The black vertical line indicates \( T_c = 0 \). The top (bottom) dashed, grey horizontal line indicates the highest (lowest) average energy density that we have considered. The top (bottom) dotted, grey horizontal line indicates the maximum (minimum) value of the energy in the corresponding final states. The solid, black horizontal line is the state for which we show specific results.

*FIG. 2.* Energy density for the initial state indicated by the solid, black horizontal line in Fig. 1, perturbed by the third Fourier mode. The color coding on the final-time slice is the same as in Fig. 1.
JOSEPH CONLON

String theory and compactifications
String phenomenology
Also interest in astroparticle physics, cosmology and BSM

Students: Nick Jennings (just defended PhD viva)
I am a QCD phenomenologist. Two main topics of research:

- **Parton Distribution Functions:**
  - Precise extraction of proton structure. Essential to all LHC physics - member of MMHT collaboration.
  - Ongoing/recent work: new ‘MMHT18’ release, including theoretical uncertainties, looking to the HL-LHC (w. Shaun Bailey).

- **Central Exclusive Production:**
  \[ pp \rightarrow p + X + p \]
  - Unique ‘elastic’ class of event. Different avenue of exploration vs. standard ‘inclusive’ channels.
  - Ongoing/recent work: updating SuperChic MC to include heavy ions, glueballs at the LHC.
John March-Russell

- BHs
  - Classical/Quantum
- DM
- Stringy phenom
- E>1 TeV
- BSM physics
- V. low E
- Fundamental physics are novel tests

16/17th QSFP
Andre Lukas

Main interest: string theory, with emphasis on compactifications, model building and phenomenology.

More specifically:

- Calabi-Yau manifolds, vector bundles and heterotic model building
- Flux compactifications and non-CY manifolds
- (Computational) algebraic geometry and string theory
- M-theory compactifications and F-theory
- String cosmology

Major theme: “Getting the standard model from string theory”

For example arXiv:1810.00444:

Counting String Theory Standard Models

Andrei Constantin
Department of Physics and Astronomy, Uppsala University, SE-751 20, Uppsala, Sweden

Yi-Hui He
Department of Mathematics, City University of London, E15 4UL, UK,
Merton College, University of Oxford, OX1 4JD, UK, and
School of Physics, Nankai University, Tianjin, 300071, China

Andreas Klauser
Rudolph Peierls Centre for Theoretical Physics, Oxford University, 1 Keble Road, Oxford, OX1 3NP, UK

(Dated: October 2, 2018)

We derive an approximate analytic relation between the number of consistent heterotic Calabi-Yau compactifications of string theory with the exact charged matter content of the standard model of particle physics and the topological data of the internal manifold: the former scaling exponentially with the number of Kähler parameters. This is done by an estimate of the number of solutions to a set of Diophantine equations representing constraints satisfied by any consistent heterotic string vacuum with three chiral massless families, and has been computationally checked to hold for complete intersection Calabi-Yau threefolds (CICYs) with up to seven Kähler parameters. When extrapolated to the entire CICY list, the relation gives \( \log(N(h)) \approx -5.0 + 1.5h \) for the class of Calabi-Yau hypersurfaces in toric varieties, \( N(h) \) gives \( \sim 10^{25} \) standard models.

Current students: Stefan Blasneag, Callum Brodie
Gavin P. Salam
Just joined Dept. + All Souls
funded by ERC & Royal Society Research Professorship
[on leave from CERN & CNRS]

Main interest: LHC physics
mostly from a QCD point of view

- Jet-physics
  *(anti-kt algorithm, FastJet)*
- Higgs studies
  *(e.g. VBF @ NNLO, jet vetoes)*
- Parton Distribution Functions
  *(e.g. hoppet, LUXqed photons)*
- BSM searches
  *(jet substructure, ColliderReach)*
- heavy-ion collisions
- future colliders

Current main project:
Attempting to reformulate the foundations of “parton showers”,
which are used in almost every measurement at the LHC

![Graph showing ratio of dipole-shower double-soft ME to correct result](image)

**Graph Details:**
- **r** = \( \frac{p_{T,2}/p_{T,1}}{1} \)
- **IM^2 shower** and **IM^2 correct**
- Applies to "diamond" rapidity region

**References:**
arXiv:1805.09327
Dasgupta, Dreyer, Hamilton, Monni & GPS
**Late universe:** Our local ‘bulk flow’ extends out *much* further than is expected in a (statistically) homogeneous universe ... biases determination of cosmological parameters using Type Ia Supernovae - evidence for acceleration only 2σ and it has a comparable dipole along the bulk flow direction!

**Early universe:** Tikhonov reconstruction of a quadrupolar modulation in the spectrum of primordial scalar fluctuations from Planck data ➔ spectral features may be evidence for multiple episodes of inflation (with associated non-Gaussianity)

**High energy neutrinos:** I participate in the IceCube expt. which discovered cosmic high energy neutrinos ... predicted deep inelastic scattering cross-section using HERAPDF ➔ now confirmed upto ~1000 TeV (measured absorption in the Earth)

**Dark matter:** Particularly interested in asymmetric relic particles and their phenomenology – and attempts at detection by both terrestrial and cosmic experiments ...
**Closed strings picture:** dynamics of strings & branes at low energy is described by string theory in curved space in higher dim.

**Open strings picture:** dynamics of strings & branes at low energy is described by a quantum field theory without gravity

**STRENGTH COUPLING**

Allows study of correlation functions, Wilson loops, thermodynamics, transport, non-equilibrium behavior, turbulence, quantum quenches etc in STRONGLY interacting systems (of some class) by using their DUAL weak gravity description

Oxford Holography Group: B.Meiring, C.Herzog (long-term visitor), A.Starinets (on sabbatical)
John Wheater

Discretized models of Quantum Gravity & Quantum Geometry

Manifolds ↔ Graphs

Quantum Field Theory ↔ Statistical Mechanics

Matrix Models ↔ Rigorous Combinatorics

Numerical Simulation

JW, Aravinth Kulanthaivelu, Dennis Xavier, collaborators in Copenhagen & Reykjavik
Emeriti & Visitors
Graham Ross - Physics Beyond the Standard Model?

- B physics FCNC anomalies
  \[ m_L \sim 70 \text{GeV} \]
  \[ R_{K,K^*} \checkmark \]
  \[ g_\mu - 2 \checkmark \]
  \[ \text{DM} \checkmark \]
  \[ R_D \times \]

- Scale invariant theories (including gravity)
  Classical + quantum
  ...inflation
  ...the hierarchy problem \[ m_h \ll M_{\text{Planck}}? \]

- SUSY GUT:
  Gauge coupling unification
  Threshold effects: \[ M_{\text{SUSY},i} = F(M_{\text{KK},i}) \]
Mike Teper – Lattice Field Theory

physics of strongly-coupled field theories e.g. gauge theories

recent and current:

• Spinorial flux tubes in SO(N) gauge theories in 2+1 dimensions
  Michael Teper: arXiv:1712.01185
• SO(4), SO(3) and SU(2) gauge theories in 2+1 dimensions: comparing glueball spectra and string tensions
  Michael Teper: arXiv:1801.05693
• On the spectrum and string tension of U(1) lattice gauge theory in 2+1 dimensions
  Andreas Athenodorou, Michael Teper: being written
• Pfaffian particles and strings in SO(2N) gauge theories
  Michael Teper: being written
Dark Matter and Hidden sectors

- Beyond WIMP DM - freeze-in, Nuclear Dark matter…
- Link to matter-antimatter asymmetry - asymmetric dark matter
- Dark matter consequences for stars
- Dark matter direct and indirect detection
- How do we probe more complicated hidden sectors?

BSM physics at the Colliders

- Long lived states
- Anything BSM including SUSY

Black Holes

- Colliding particles in the fields of…

Electroweak Symmetry breaking

- Extended Higgs sectors

Early Universe Cosmology

- Phase Transitions
- Topological Defects

Neutrino Physics
Postdocs

Actually, being a postdoc isn't so bad.

You don't have to write grants.

You don't have to worry about graduating.

You don't even have to teach!

You finally get to spend all your time doing the thing all your training has prepared you to do.

Research?

Applying for faculty jobs.
Rehan Deen

Bio:
Henry Skynner Research Fellow in Astrophysics at Balliol
Ph.D. at University of Pennsylvania under direction of Burt Ovrut

Thesis: “Aspects of Phenomenology and Cosmology in Heterotic M-theory”

Previous work:
- **SUSY phenomenology**: $R$-parity violating $B - L$ MSSM - arXiv:1604.08588

Interests:
- **String model building**: Constructing standard models from smooth heterotic compactifications – Moduli stabilization
- **Cosmology from string theory**: Dynamics of moduli in quintessence and inflation – Bouncing cosmologies – Hidden sector dynamics + dark matter in het. M-theory
Frédéric Dreyer

- Jet substructure and boosted object tagging at the LHC.
- Applications of machine learning in jet physics.
- Accuracy of parton showers and connection with resummation.
- Higgs physics and fixed order QCD corrections.
Beyond the Standard Model / Dark Matter phenomenology

> Gauge extensions of the SM
  Violation of $B$ and $L$
  Model building: $G_{SM} \otimes U(1)_B \otimes U(1)_L$
  Low-scale breaking of $U(1)_B$: testable

> Consistent simple DM models
  Add the minimal amount of structure to the SM that is necessary to explain DM
  How simple can these setups be?

> Current projects
  Inelastic DM searches at Belle II
  Signatures of/constraints on anomaly-free DM models

Interested in many other things: axions, neutrinos, self-interacting DM, ... → happy to discuss and start new projects!
**Particle physics**

**Research themes**

**High-energy frontier physics**
Exploring fundamental physics with high-energy colliders

*ATLAS Oxford Group*
LHCb Neville Harnwe, Guy Wilkinson, Malcolm John

**Neutrinos**
The group studies the properties of neutrinos, one of the most abundant particles in the Universe.

*Group Leaders* Giles Barr, Steve Biller, Alfons Weber

*Liquid Argon Neutrino Experiments*
MINOS / MINOS+ Alfons Weber

*SNO* Steve Biller

*Sol* Antonin Vacherel

*T2K* Giles Barr, Alfons Weber

**Dark matter and Precision measurements**
Particle physics is not just huge detectors and collaborations. We study fundamental particles from a different perspective, with small high precision experiments.

*Group Leaders* Samuel Henry, Hans Kraus

**Cosmology**
We lead observational and theoretical work to determine what the dark matter is, what is the dark energy, why they behave the way they do and how did the Universe start off this way.

*C-Band All Sky Survey*
Cosmic Microwave Background
Cosmological Gravity
Dark Matter & Dark Energy
Euclid Lance Miller, Matt Jarvis
Large-Scale Structure
Supernova Cosmology
Weak Lensing

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**Mathematical Physics Group**

Welcome to the web pages of the Mathematical Physics Group. We are part of the Mathematical Institute at the University of Oxford, and are located on the first floor of the north wing of the Andrew Wiles Building on Woodstock Road; click here for a map.

The group's research is centred around gauge and gravity theories with an emphasis on their quantum field theories. There is also a subgroup working on quantum computation and cryptography. Much of our research is connected in one way or another with string theory; see the string theory pages for a unified view of this group, which includes people in the Theoretical Physics Group in the Department of Physics in addition to the Mathematical Institute. This includes Calabi-Yau manifolds and related heterotic geometry, AdS/CFT and twistor theory & scattering amplitudes. Much of the work of the group impacts on mathematics as well as physics, and we enjoy close relations with the Geometry Group in the Mathematical Institute. More detailed descriptions of our Research Areas may be found by exploring the panel on the left. The specific research interests of individual members are contained in their department profiles, which can be accessed from our Members page.
Astrophysics

- Circa 29 faculty, HoSD: Prof Steve Balbus
- Areas:
  - Instrumentation (ELT, SKA, CBASS, WEAVE, ...)
  - Observations (CMB, Optical, Radio, IR, Xray)
  - Theory (compact objects, galaxies, large scale structure, early universe)
- Oxford Astro is involved most big surveys (Simons Observatory, CBASS, LOFAR, MeerKat, SKA, Weave, Euclid, LSST but also KIDS, RCS lens)

Cosmology

- David Alonso (Cosmology) - Large scale structure, CMB, statistical methods
- Julien Devriendt (Galaxy evolution and formation) - computational and analytical techniques
- Pedro G Ferreira (Cosmology theory) - Early universe, general relativity, large scale structure, CMB
- Lance Miller (Weak Lensing) - CFHTLenS, Euclid, KIDS
- Joe Silk (Astroparticle and Galaxies) - dark matter, large scale structure, CMB
- Adrienne Slyz (Galaxy evolution and formation) -

Beecroft Institute (BIPAC)

- Max Abitbol (CMB)
- Emilio Bellini (GR, Early Universe)
- Tessa Baker (GR, LSS)
- Katy Clough (GR)
- Elisa Chisari (WL)
- Giulia Cusin (Early Universe, Gravity)
- Harry Desmond (LSS, Galaxies)
- Chris Duncan (WL)
- Harley Katz (Galaxies)
- Shahab Joudaki (LSS, WL)
- Clotilde Laigle (LSS, Galaxies)
- Eva-Maria Mueller (LSS)
- Julian Mertens (WL)

Weekly Events

- Cosmology seminar (Tuesdays, 11:30)
- Journal Club and group meeting (Fridays, 11:00 - 12:30, BIPAC)
String Theory Group (Maths Branch)

James Sparks  
AdS/CFT

Chris Beem  
N=4 SYM, conformal field theories

Fernando Alday  
Integrability, strong coupling limit SYM

Lionel Mason  
Scattering amplitudes of N=4 SYM, gravity

Sakura Schafer-Nameki  
F-theory, heterotic string theory

Xenia de la Ossa and PC  
Heterotic string theory, CY manifolds
Oxford Experimental Particle Physics

Chris Hays for Experimental PP

Theory PP introductions, 11 October 2018

Oxford ATLAS

- Standard Model
  - PDF-sensitive measurements (W & Z production)
  - EW measurements (W mass, VBF W production)

- Higgs
  - Many production/decay channels & searches
    - $H\rightarrow WW^*$, $H\rightarrow ZZ^*$, $VH\rightarrow bb$, $H\rightarrow \mu\mu$
    - HH($\rightarrow bb\bar{b}\bar{b}$), HH($\rightarrow WW^{*}bb$)
  - Combinations & interpretations using EFT

- Supersymmetry
  - Strong production: multijets and boosted objects
  - Electroweak production: soft leptons

- Exotics
  - Strong production (dijets, ISR+dijets, multijets)

Amanda Cooper-Sarkar
Claire Gwenlan
Chris Hays
+ postdocs + students

Daniela Bortolotto
Chris Hays
Cigdem Issever
Ian Shipsey

Alan Barr
Claire Gwenlan

James Frost (Royal Society)
Todd Huffman
Cigdem Issever
Tony Weidberg

Oxford ATLAS & phenomenology

- Leading ATLAS PDF fits
  - Cooper-Sarkar & Gwenlan have been ATLAS PDF forum conveners
  - Cooper-Sarkar on PDF4LHC steering committee, Gwenlan has IPPP fellowship
  - Have had joint students with theory

- Many Higgs phenomenology grants & paper
  - Barr, Issever: IPPP fellowships on di-Higgs production
  - Issever: ERC on di-Higgs
    - Joint paper with Bortolotto & Rojo on HH to 4b prospects
  - CH: IPPP on Higgs & EFT (also ATLAS LHC Higgs WG2 convener)

- Supersymmetry studies
  - Multiple joint students with theory
  - Papers on SUSY phenomenology and search interpretations

ATLAS SM group @ Oxford

- W boson measurements
  - Mass
  - Vector-boson fusion production

- Parton distribution functions
  - PDF fits adding V, tbar, jets, V+jets, ...
  - Strangeness suppression?
  - Low x and BFKL resummation

Academics:
Amanda Cooper-Sarkar
Claire Gwenlan
Chris Hays

Students:
Francesco Giulia
Gavin Pownall
ATLAS Exotics group @ Oxford

- High-mass probes
  - Multi-jets
  - Di-jets
  - ISR+di-jets

- Boosted Higgs (Runs 2 & 3)
  - Added b-tagging and Higgs tagging
  - ISR+X/H(→bb) searches
  - Di-Higgs to bbb (→WWbb) searches
  - H(→bb) + MET searches

  Academics & senior fellow:
  - James Frost (Royal Society)
  - Todd Huffman
  - Cigdem Issever (with ERC)
  - Tony Weidberg

  Junior fellow:
  - Lydia Beresford

  PDRA:
  - Bill Balunas

  Students:
  - Nurfiqri Bin Norjoharuddeen
  - Santiago Paredes Saenz
  - Beojan Stanislaus
  - Migle Stankaityte

Oxford flavour

- LHCb
  - Precise determination of the angle γ
    - Led by John & Malcom
  - Rare heavy-flavour decays
  - Electroweak physics (W mass)
  - Diffractive physics
  - Flavour anomalies (B→D(∗)τν)
  - Wilkinson recent spokesperson, Harnew RICH leader

- CLEO-c & BESIII
  - Strong phase difference between D & D

- TauFV
  - Proposal for best sensitivity in τ→3l decays
  - Other experimental sensitivity studied by CH through IPPP

Neville Harnew
Sneha Malde (Royal Society)
John Malcolm
Guy Wilkinson

Sneha Malde (Royal Society)
Guy Wilkinson

Guy Wilkinson

Oxford neutrinos

- SNO+
  - New approach to Neutrinoless double beta decay
    - 32S-Te-loaded scintillator proposed by Biller
  - Responsible for software (Tseng) & laser system (Reichold)
  - Path to mass measurement with normal hierarchy (Biller)

  Steve Biller
  - Armin Reichold
  - Jeff Tseng

T2K/HyperK/SuperK/DUNE

- Organizing data acquisition (Barr) & near detector (Weber)
- Past T2K international co-spokesperson (Wark)
- DUNE UK PI (Weber)

  Giles Barr
  - Dave Wark
  - Altons Weber

Oxford dark sector

- LZ
  - Kraus chief editor of technical design report
  - Designing and commissioning front-end electronics

  Hans Kraus

- LSST
  - Shipsey on executive board
  - Work on camera control systems (Azfar) and database (Tseng)

  Farrukh Azfar
  - Ian Shipsey
  - Jeff Tseng

+ postdocs
+ students
+ postdocs
+ students