

Formal Theory

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Southampton
Theory
Astrophysics
Gravity
Research Centre



QCD

Amplitudes

Superstrings

Quantum Gravity

Black holes

Gauge/gravity duality

Breaking News

The Nobel Prize in Physics 2016 was divided, one half awarded to David J. Thouless, the other half jointly to F. Duncan M. Haldane and J. Michael Kosterlitz *"for theoretical discoveries of topological phase transitions and topological phases of matter"*.



The Nobel Prize in Physics 2016

Nobelpriset i fysik 2016

KUNGL.
VETENSKAPS-
AKADEMIEN
THE ROYAL SWEDISH ACADEMY OF SCIENCES

Med ena hälften till
With one half to



Photo: American Physical Society

David J. Thouless
University of Washington
Seattle, WA, USA

och med andra hälften till
and the other half to



Photo: IOP Physics Portal

F. Duncan M. Haldane
Princeton University
NJ, USA



Photo: Brown University

J. Michael Kosterlitz
Brown University
Providence, RI, USA

" för teoretiska upptäckter av topologiska fasövergångar och topologiska materiefaser "

" for theoretical discoveries of topological phase transitions and topological phases of matter "



Nick Evans



Tim Morris



Kostas
Skenderis



Marika
Taylor



James Drummond



Andy O'Bannon



Oscar Dias

Andreas
Schmitt



Carlos Mafra

Experiment is still busy confirming the Standard Model – 1960s & 70s theory...

So what are formal theorists up to?

Answer: what they should be doing!

- * understanding field theory, the structure that underlies the SM**
 - * understanding strong coupling ala QCD**
 - * thinking about quantum gravity where we know we must go eventually**
- * pursuing anomalies from the SM from astronomy – dark energy**

Perturbative Approaches

Quantum Field Theory:
Scattering amplitudes, correlation functions,
...
Integrability, solvability, novel symmetries,...
Bootstrap techniques, analytic structure,
Loop integrals, differential equations,
Development of new techniques for QFT

Large N_c

Supersymmetry –
fermion/boson symmetry
that hugely constrains form
of solution.

James Drummond + Carlos Mafra

Postdocs:

Omer Gurdogan

Chrysostomos

Kalousios

Kasper Larsen

PhD students:

Stefan Druc

Jack Foster

Hynek Paul

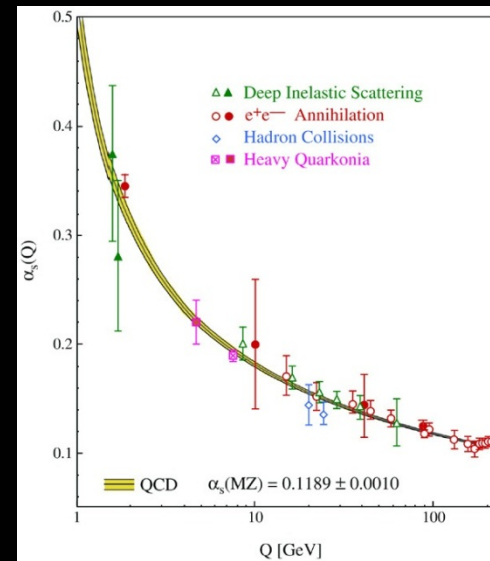
QCD

Quarks

Gluon mediated
interactions

SU(3) gauge invariance

Confinement due to
asymptotic freedom

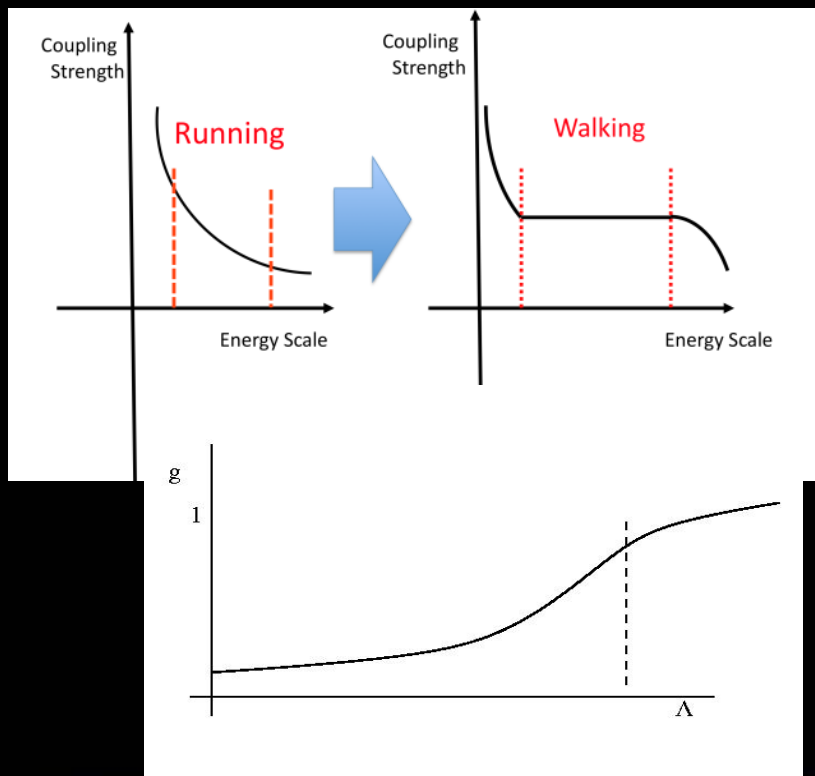


Dynamical mass
generation $m_p \neq 3 m_{u,d}$

Exact renormalization techniques: running without gauge fixing

Large N_c

Supersymmetry – fermion/boson symmetry that hugely constrains form of solution. Duality, monopoles,



Theories with novel running:

IR conformal

walking

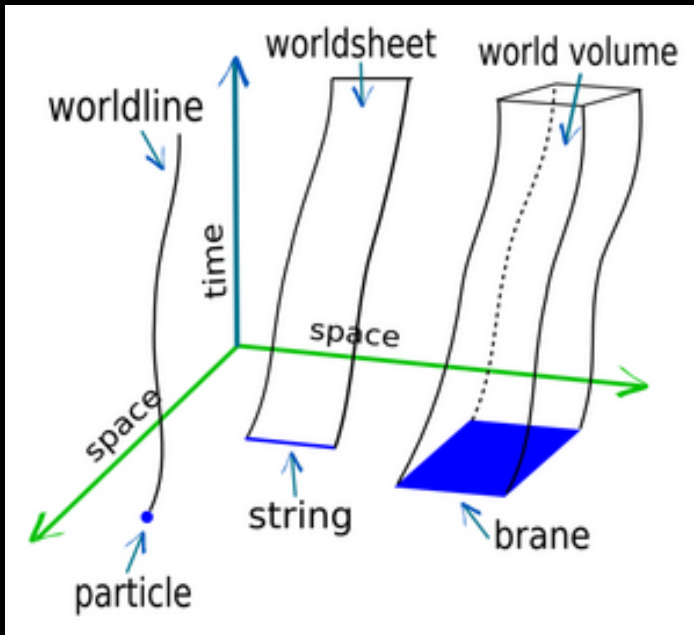
asymptotic safety

conformal – $N=4$ Super Yang Mills

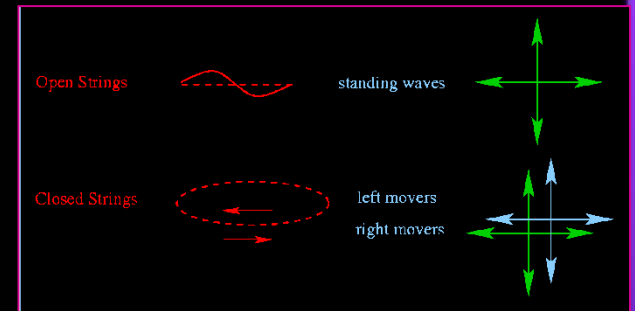
String Theory



suggests
string theory



We need:
supersymmetry
9+1 dimensions
membranes
graviton



A candidate for a TOE or at least
quantum gravity

Fundamental strings

Basic property is Tension

BUT.. Only understood
perturbatively... and not
directly linked to the SM...

Quantum Gravity

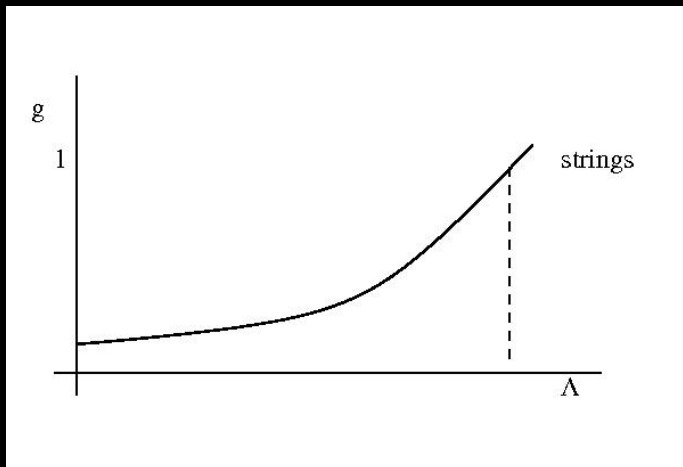
$$S \sim \int d^4x \sqrt{-g} R$$

R is a function of $g_{\mu\nu}$
and 2 derivatives

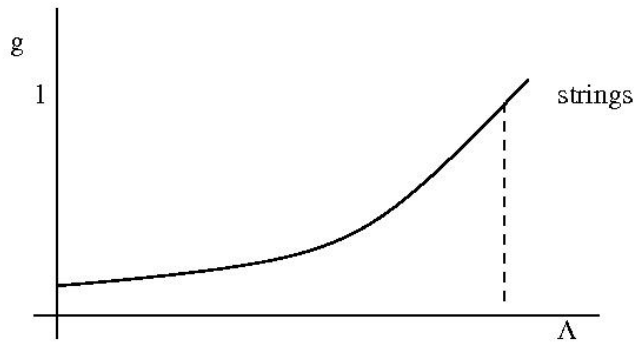
$$g_{\mu\nu} = \eta_{\mu\nu} + h_{\mu\nu}$$

$$S \sim \int d^4x \left(\frac{1}{2} (\partial h)^2 + \frac{g}{\Lambda^2} (\partial h)^2 h^2 + \dots \right)$$

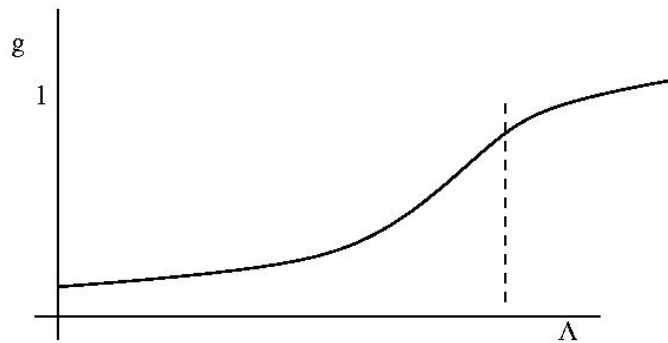
This is a non-renormalizable theory...



$$M_{Pl} = \sqrt{\frac{\hbar c}{G}} \simeq 10^{19} GeV$$



New physics such as the string length sets in at the Planck scale (or before)

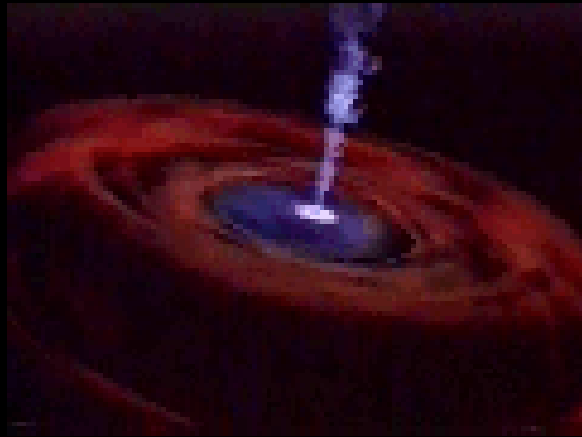


Asymptotic safety – a non-perturbative UV fixed point emerges?

Any such theory needs to address – dark energy (vacuum energy) problem $(10^{-11} \text{ GeV})^4 \dots$

Black Holes

General Relativity predicts black holes...



Pure states dropped into a black hole are re-emitted as thermal Hawking radiation...

'tHooft argued that any information dropped into a black hole must be

- lost (breaking QM)
- spread over the surface ($S \sim A$)

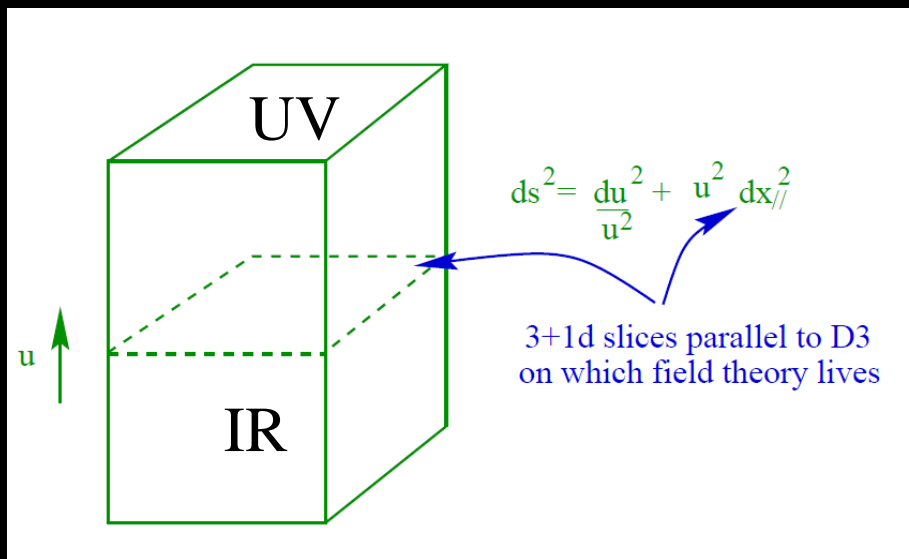
If the surface can contain all the information of the contents the real theory of the Universe must be $2 + 1$ dimensional!

HOLOGRAPHY

Gauge/Gravity Duality



N=4 SYM = IIB strings on AdS₅



String theory/quantum gravity are holographically emergent phenomena...

We now know this IS a string theory but in higher dimensions than QCD!

Couplings such as g or $\text{Tr } F^2$ are scalar fields in this bulk...

Remarkably those fields are weakly coupled in some cases when the gauge theory is strongly coupled...

Gauge/Gravity Duality Applications

- QCD confinement
- QCD mass generation
- Meson/glueball spectrum
- Deep inelastic scattering, hadronization...
- Quark gluon plasma – heavy ion collisions...
- BSM strong coupling – unparticles, composite higgs, SUSY breaking...
- Inflation
- Strongly coupled condensed matter – graphene, high T_c super conductors, Kondo effect..

- Non-perturbative definition of strings
- Black holes
- The Big Bang singularity



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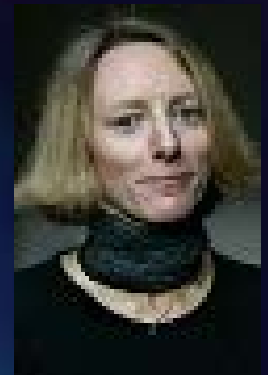
Holography
QCD, BSM



ERG
AS & QG



Fundamentals of
strings/holography



Black holes



Amplitudes



Holography & CM



Black holes

QCD &
neutron
stars



CFT & string
amplitudes



STAG Lunch Group: Tuesday 1pm

STAG Seminar: Wednesday 1pm

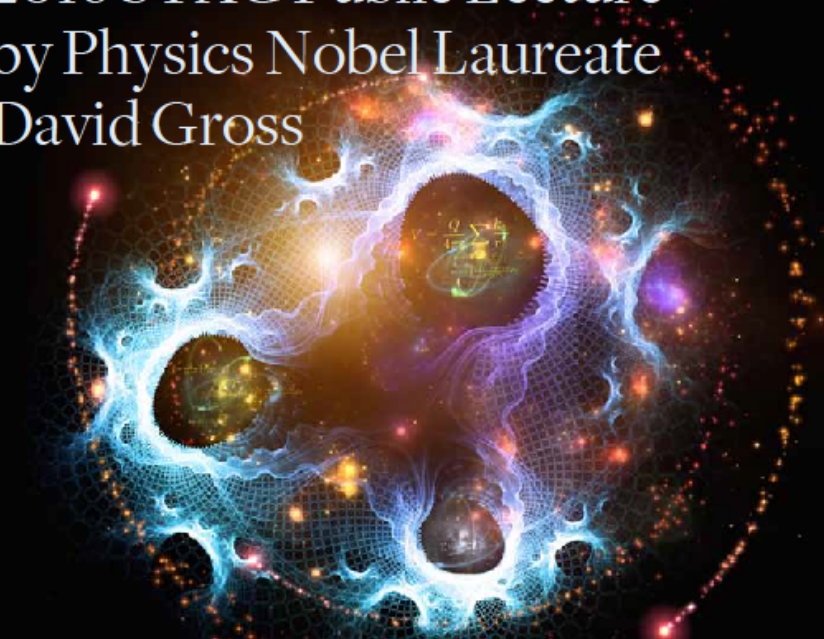
Gravity seminar: Thursday noon

STAG also includes the classical **GR group in Maths**: neutron star structure, compact object collisions and merger, numerical GR.

Astrophysics group: observation and modelling of compact objects and gas inflow

The Frontiers Of Fundamental Physics

2016 STAG Public Lecture
by Physics Nobel Laureate
David Gross



At the frontiers of physics we search for the principles that might unify all the forces of nature and we strive to understand the origin and history of the universe.

The 2004 Nobel Laureate for Physics, David Gross, shall describe some of the questions that we ask and some of the proposed answers. He will also discuss what it might mean to have a final theory of fundamental physics and whether we are capable of discovering it.

The STAG Research Centre brings together world-leading academics from three research groups – Particle Physics, Astrophysics and Gravitation – to explore issues of fundamental physics and astronomy.

To book your free tickets please go to www.turnersims.co.uk/events

Please contact Michelle Pemberton at M.Pemberton@soton.ac.uk for further information.

Wednesday 26 October 2016 2.30pm Turner Sims

To find out more about the STAG research centre visit www.southampton.ac.uk/stag