

# Fundamental Theory and Cosmology

**Daniel F Litim**

**US**

University of Sussex

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# standard model

local QFT for fundamental interactions

**strong** nuclear force

**weak** force

**electromagnetic** force

degrees of freedom

spin 0 (the **Higgs** has finally arrived)

spin 1/2 (quite a few)

spin 1

perturbatively renormalisable & **predictive**

# fundamental theory

how does **quantum gravity** fit into the SM?

**Higgs, QED**: maximal UV extension?

**hierarchy** problem

**unification** of couplings

what is the origin of **mass**?

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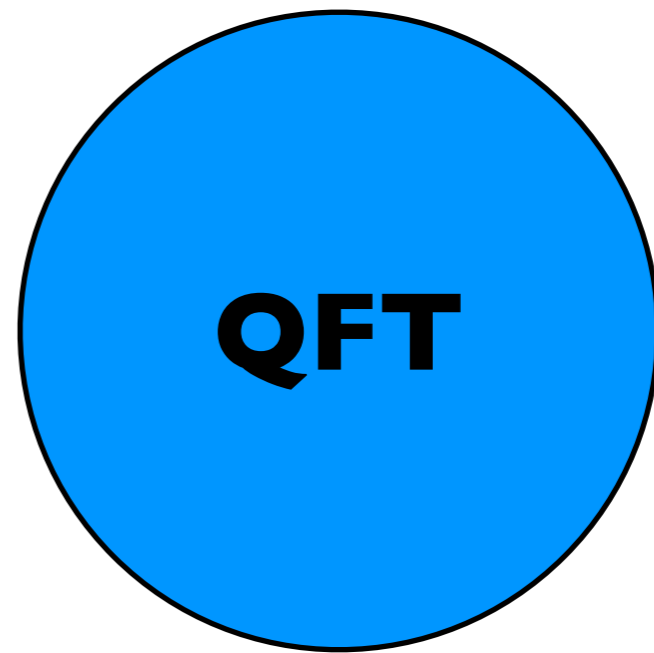
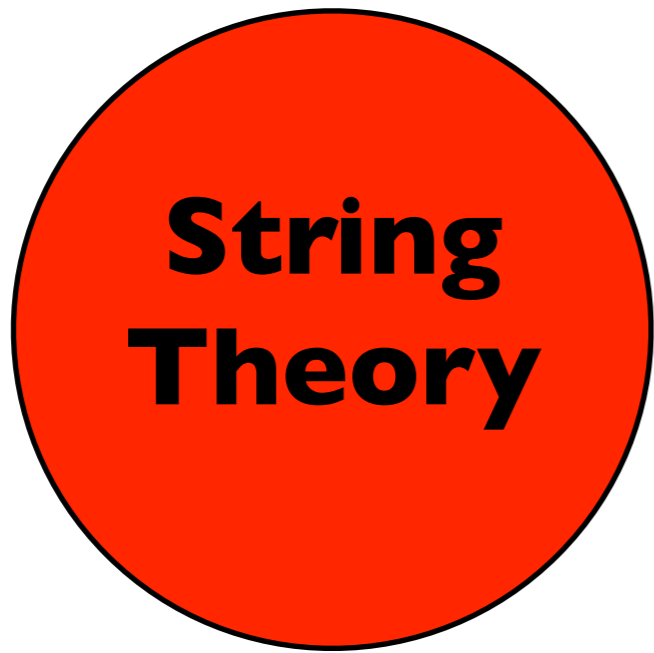
**we also need to understand:**

**strong coupling** (confinement, bound states)

**finite temperature** (QCD transition, early universe)

**finite density** (dense nuclear matter, stars interior)

**time evolution of QFT** (inflation, early universe)



# string theory (incorporates quantum gravity)

## **gauge-gravity correspondence**

applications to systems at finite  $T$  and density with possible applications to QCD cold dense matter, condensed matter, hydrodynamics, and beyond standard model physics

## **holography and renormalisation**

applications to various fields theories, establish 'dictionary'  
**holography for higher spin theories of gravity and CFTs with extended symmetries**

## **amplitudes**

powerful alternative tool to access QFTs  
**twistors, high order amplitudes in QCD**

# string theory (incorporates quantum gravity)

## integrability

important progress which could lead to complete understanding of certain quantum field theories such as N=4 SYM for all couplings  
quantum integrability of certain world-sheet theories

## further developments

progress in understanding **new geometrical structures** in string theory, especially using exceptional groups

developing new **solution generating techniques** using the (novel) notion of non-Abelian T-duality in string theory

New classes of **black holes** in string theory

# quantum field theory

## functional methods [eg. functional renormalisation]

... for **strongly coupled** theories including gauge theories, models with or without Susy, and quantum gravity

... for **time evolution** of quantum field theory (eg. early universe, heavy ions)

## interacting UV fixed points [asymptotic safety]

increasing evidence for **asymptotic safety of gravity** in 4D

promising high-order results

**prospect: incorporate gravity into the SM as an asymptotically safe QFT**

**novel exact results** for interacting UV fixed points in certain 4D gauge-Yukawa theory (without gravitation)

**prospect: elementary scalars can exist fundamentally**

## exact results in SUSY theories and beyond

progress with quiver gauge theories

exploring Seiberg duality for non-SUSY theories



# quantum field theory

## phenomenology of quantum gravity

signatures of low-scale **quantum gravity at colliders**

signatures of quantum gravity in inflation & cosmology

## quantum corrections to black holes

quantum **black holes** signatures at colliders

quantum corrections to **black hole thermodynamics**

## holographic vs functional renormalisation

progress with understanding links, could lead to new applications for holography

# (particle) cosmology

standard model: inflation with **dark matter** / **dark energy**  
**alternatives** to inflation and DM, eg. **modified** gravity

## **BICEP2**

ratio of tensor to scalar perturbations  
hints towards **quantum gravity**

**extract phenomenology** of quantum gravity  
(asymptotic safety and other) and test against data

gravitational waves

topological defects, cosmic strings  
matter anti-matter asymmetry

equilibrium and non-equilibrium QFT  
in the early universe

# UK activities

- regular UK-wide **workshops** & **meetings**:
  - **UK-Cosmo**  
[since '90, STFC-sponsored]
  - **UK-QFT**  
[Kings '12, Sussex '13, Soton '14]

# esteem factors

- **Nobel prize 2013** [P Higgs]
- **Knighthood 2014** [TWB Kibble]
- **ERC grants** [3+ adv, 7+ start & consol'd]
- many **plenary talks** at major conferences
- many **major conferences** within UK
  - **growing UK community**  
[pre-CG13 & pre-REF14]

# community concerns

- continuously **decreasing** funding envelope

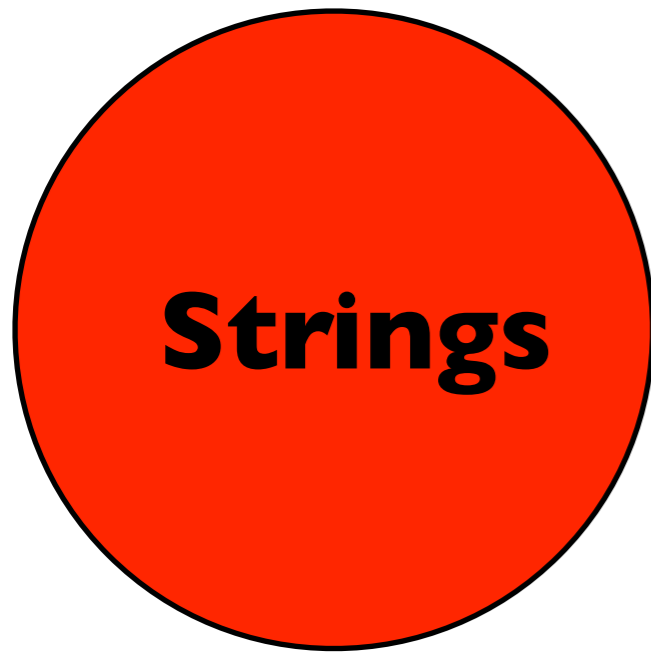
"The Theory community expresses its deep concern at the damage caused by funding cuts and considers that at this level it cannot sustain a balanced programme of internationally important research." (post-CG13)

- good groups **w/out** CG13 PDRA support

- **max FEC low** [-er than in other areas]

- **no** STFC postdoctoral fellowships  
`**continuity**` under threat

- perspectives for **mathematical physics**, formerly @ epsrc ?



**incorporates quantum gravity**

**gauge-gravity correspondence  
dualities**

**Gauge-gravity correspondence:  
applications to systems at finite T and density with possible applications to QCD  
and/or condensed matter.**

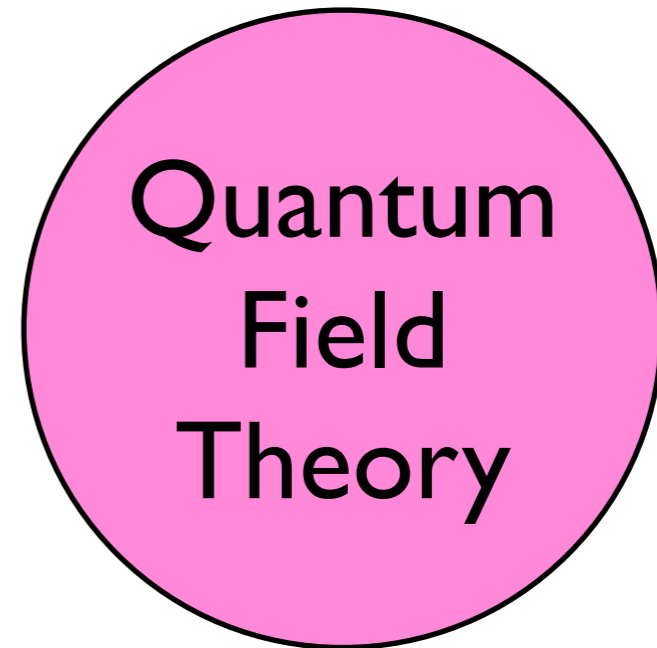
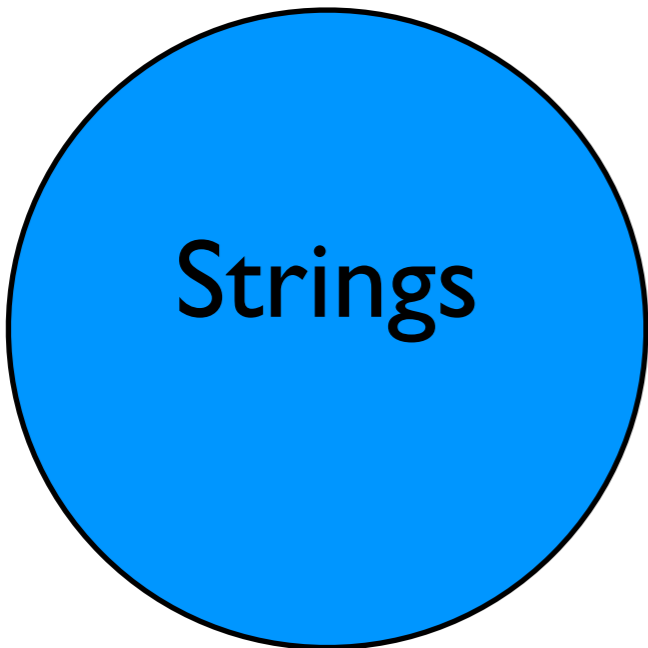
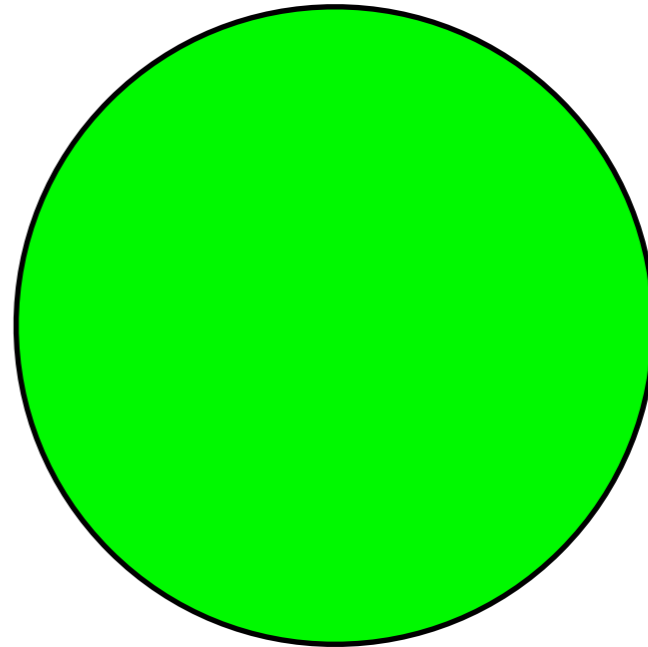
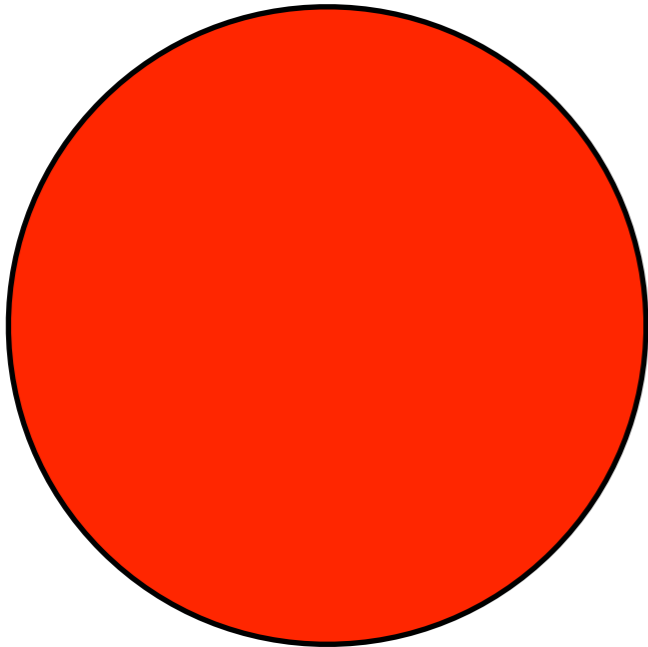
**New classes of black holes in string theory**

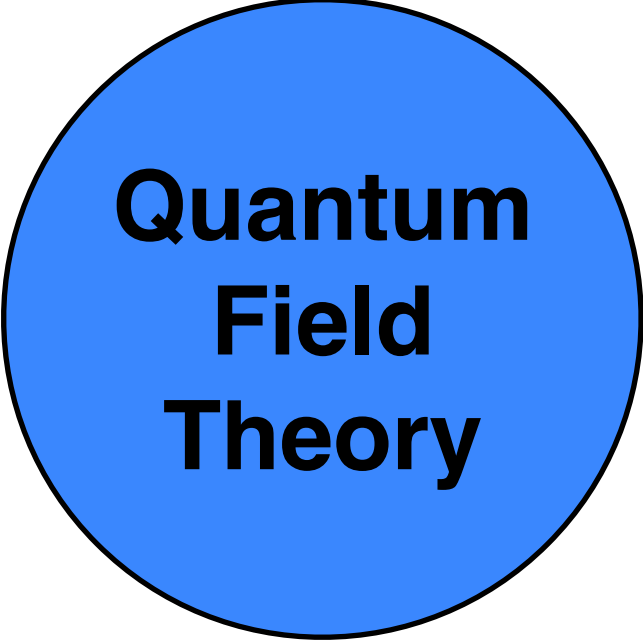
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understanding of certain quantum field theories such as N=4 SYM for all  
couplings**

**Progress in understanding new geometrical structures in string theory,  
especially using exceptional groups**

**Developing new solution generating techniques using the (novel) notion of non-  
Abelian T-duality in string theory**

**b) Novel aspects of Quantum Integrability of the world-sheet theory of the AdS<sub>5</sub>  
x S<sup>1</sup> superstring (Tim Hollowood)**





**Quantum  
Field  
Theory**

**at weak coupling:**

**high-order perturbation theory**

**at strong coupling:**

**confinement, bound states, masses**

**at finite temperature:**

**QCD phase transition, early universe**

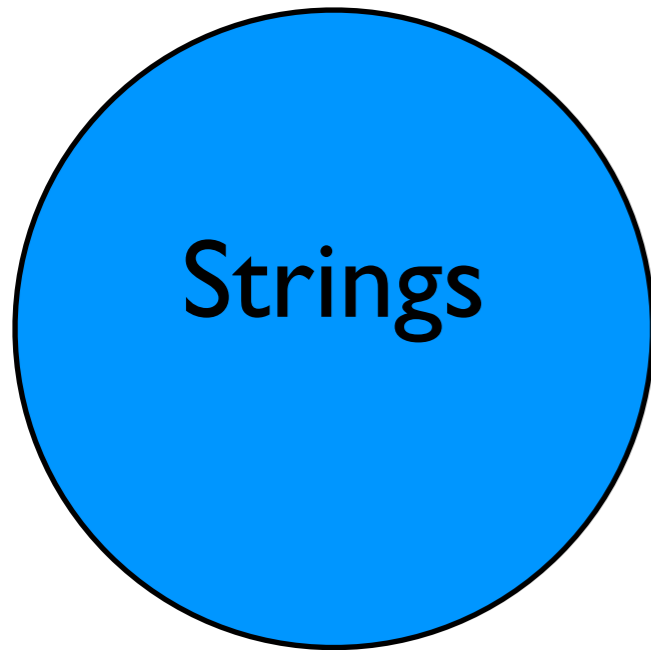
**at finite density:**

**dense nuclear matter**

**time evolution:**

**inflation, early universe**





quantum gravity

at strong coupling:

confinement, bound states, masses

at finite temperature:

QCD phase transition, early universe

at finite density:

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# Strings

Correspondence:

strings at finite  $T$  and density with possible applications to QCD and/or

discovered new classes of black holes in string theory

Integrability structures: important progress which could lead to complete understanding of certain quantum field theories such as  $N=4$  SYM for all couplings

Progress in understanding new geometrical structures in string theory, especially using exceptional groups

**Developing new solution generating techniques using the (novel) notion of non-Abelian T-duality in string theory (Carlos Nunez)**

**b) Novel aspects of Quantum Integrability of the world-sheet theory of the  $AdS_5 \times S^5$  superstring (Tim Hollowood)**

**c) Applying novel SUGRA solutions and exploiting gauge/gravity duality to beyond the standard model physics (Nunez and Piai)**

**d) Exploring Seiberg duality for non-SUSY theories (Adi Armoni).**

**e) Developing new top-down string duals for cold dense quark matter at strong coupling (Prem Kumar)**

**f) Study of holography for higher spin theories of gravity and CFT's with extended symmetries .**

# particle physics & cosmology

- How can we explore and understand the extremes of the universe?
- Are the particles described by the Standard Model fundamental, and how do they interact?
- What is mass - how do particles get heavy?
- Where does gravity fit in to the Standard Model?
- What are the properties of neutrinos and what is their role in cosmic evolution?
- What is the origin of cosmic rays?
- Why is there an imbalance between the existence of antimatter and matter?
- How can high energy particles and gravitational waves tell us about the extreme universe

# **Quantum Field Theory**

**quantum gravity**

**increasing evidence for interacting UV fixed point in 4d**

**prospect: incorporate gravity into the SM as an asymptotically safe QFT**

**fingerprints of low-scale quantum gravity at colliders**

**signatures of quantum gravity from cosmology / early universe**

**implications for quantum black holes & black hole thermodynamics**

**new exact results for asymptotically safe (non-gravitational)**

**extensions of the SM**

**Particle Cosmology**

**BICEP2**

**ratio of tensor to scalar perturbations**

**gravitational waves**

**matter anti-matter asymmetry**

**topological defects, cosmic strings**

1. The breadth and quality of the science (some of it world leading).

One measure is the number of ERC grants:

Advanced: Ellis, Gauntlet, Tseytlin,...

Starting/Consolidated: Martelli, Starinets, Rangamani, Conlon, Tong, Reall, Alday,...

2. The size of the community -- its very large and the office at STFC should be able to provide figures from

recent Consolidated Grant applications

3. The funding crisis: a maximum of 20% FEC means that

Departments/Faculties at Universities can interpret it as being an area less worthwhile than others.

The paucity of PDRA support (you could highlight that there are some good groups with no or v little

PDRA support) means that the UK is not getting the benefit of the considerable investment that UK universities have put into the area.

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**UV fixed points**