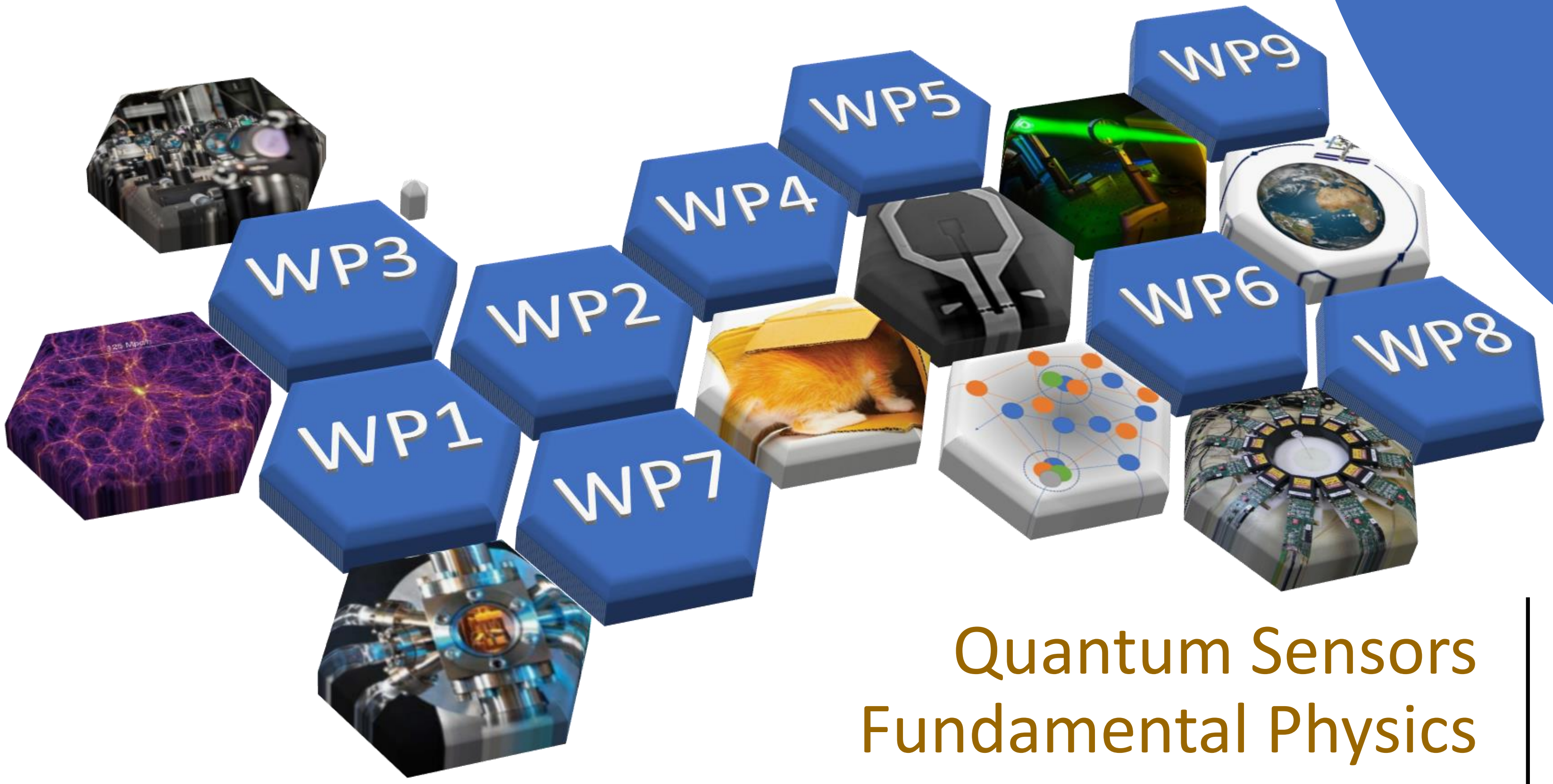
UK Research and Innovation

QSFP



Quantum Sensors Fundamental Physics

J. Coleman on behalf of the QSFP Consortium

UNIVERSITY OF LIVERPOOL

THE ROYAL SOCIETY

status
next steps
Milestones
Governance
Review Board
….

Quantum Sensors for Fundamental Physics

- Why is this good for all the partners?
- The exciting science will benefit all the partners involved: universities, labs & hubs
- Leverage the current Hubs to bring state of the art sensors to this new application.

  There will likely be a tension between performance and "manufacturability" but the Phase II Hubs should be able to deliver research to push performance, and additional support for user communities from STFC that could feed into and benefit from the Hubs activity
- **Why is this good match to the SPF?**
- This is a genuinely new *interdisciplinary* partnership between STFC, EPSRC and other partners
- - so plays well to the UKRI era.

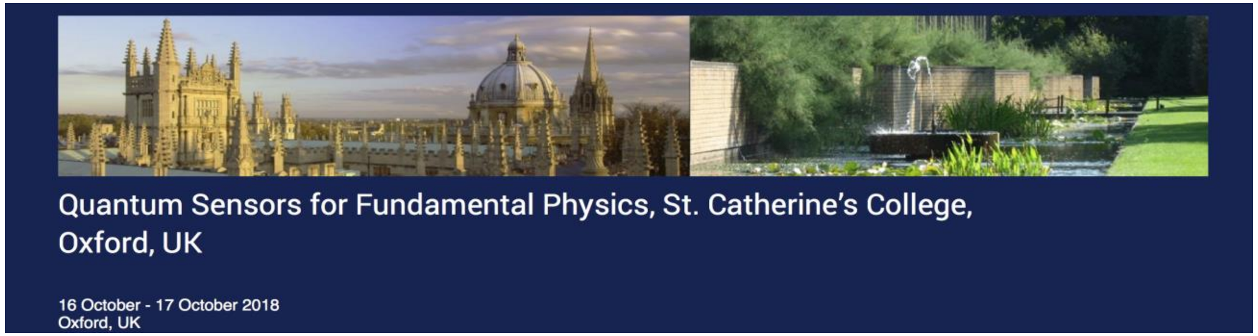
Wide range of thoughts and deliverables

Physics Goals
Detector development
Deliverables
Theory
Plan
Competitiveness
Staff internal WP work allocation
Benefit to UK and UK Industry

Status, next steps, Milestones
Governance
Review Board
….

QSFP - Workshop #1

The workshop had four goals



#1 To survey the extraordinary science opportunities and UK capabilities to exploit this science in a world-class programme

#2 To demonstrate to STFC, EPSRC and UKRI the immense interest in the UK in QSFP

#3 To begin to form teams around key experiments that would be funded by QSFP

#4 To work with STFC and EPSRC on the QSFP bid..

QSFP: Next Steps +1

Dec. 2018 Groups self organised and produced outline papers

There are currently 9 work packages circulated to all in December

Quantum Sensors for Fundamental Physics

https://indico.cern.ch/event/760005/

16 Oct 2018, 09:00 → 17 Oct 2018, 19:15 Europe/London

Bernard Sunley Room (St. Catherine's College, Oxford)

Ed Daw, Ian Shipsey (University of Oxford (GB)), Stig Topp-Jorgenson (Oxford)

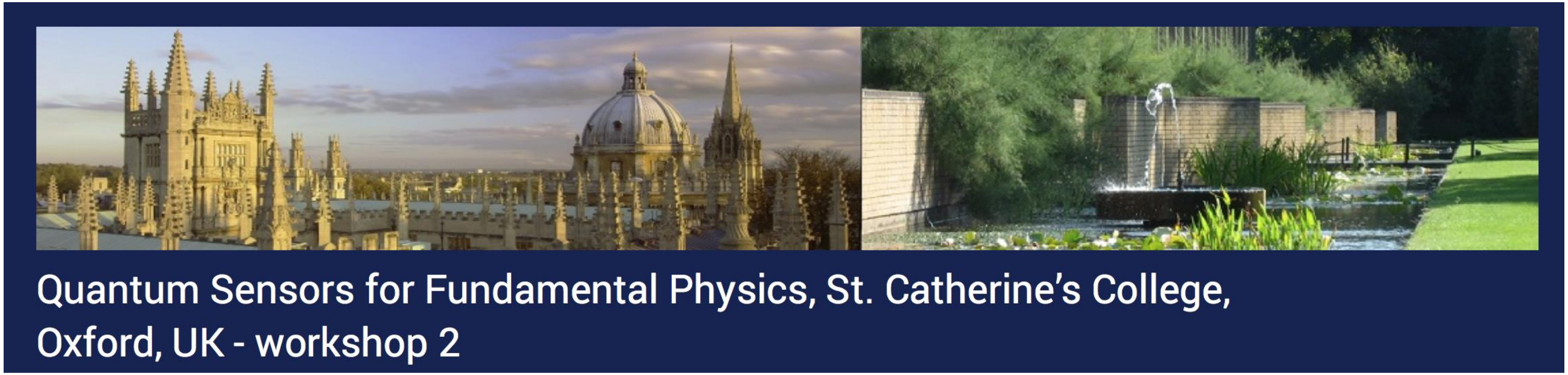
- WP1-qsfp-darkmatt...
- WP2-qsfp-MaQS pr...
- WP3_qsfp_AION-fi...
- WP4_qsfp-neutrino...
- WP5_qsfp-Quantu...
- WP6-Quantum-Net...
- WP7-5Force-DM-pr...
- WP8_precision-stu...
- WP9-LorentzInvari...

QSFP - Next Steps +2

- The submission into SPF wave 2 was made by STFC/EPSRC December 20. This requests the funding to create the QSFP programme (£40M/ 3 years)
- Feedback: The QSFP consortium has been essential to demonstrating the interdisciplinary interest & formation of a community . Without it there would have been no bid to SPF
- If SPF bid is successful (panel has met) will be informed (month, 2019) an open call will be made to the community ~ month+1, 2019 with a deadline of ~Month +(3 or 4) 2019
- QSFP Opportunities Funding from STFC was awarded to build a community and consortium to prepare for the call. Supporting workshops that facilitate formation of teams and proposals around key experiments that would be funded by QSFP.
- We will also appoint a International Review Board of world-leading experts from outside the UK that will review the proposals providing crucial feedback to strengthen them

QSFP - Next Steps +3

17 January 2019 consortium meeting to hear presentations from each workpackage, cross-fertilise, give feedback, merge if required, last chance of any late-breaking new ideas



Workpackage Summary

1. Hidden Sector Facility
2. Macroscopic Superposition
3. AION
4. Neutrino Mass
5. Simulators
6. Networked Sensors
7. 5th Force & Dark Matter
8. Exotic Atoms
9. Lorentz Invariance
10. Collective quantum excitations - new

		WP1	WP2	WP3	WP4	WP5	WP6	WP7	WP8	WP9
Aberdeen	1									
Belfast	1									
Birmingham	3									
Brighton	1									
Cambridge	5									
Cardiff	1									
Durham	2									
Edinburgh	1									
Glasgow	2									
Heriot Watt	1									
Imperial	3									
Kings	2									
Lancaster	1									
Leeds	1									
Liverpool	3									
Manchester	1									
Newcastle	1									
Nottingham	3									
NPL	4									
Oxford	4									
Plymouth	1									
RAL	1									
RH	2									
Sheffield	1									
Southampton	1									
St Andrews	1									
Strathclyde	2									
Sussex	4									
Swansea	2									
UCL	6									
Warwick	2									
		11	15	7	5	7	8	3	4	3

QSFP

UK

- 31 institutes
- Multiple companies
- Scientists….

QSFP

WP1

Quantum Sensors for Hidden Sector Physics

Quantum Sensors for Hidden Sector Physics

Decided not to focus on building a specific instrument during the first phase of the project

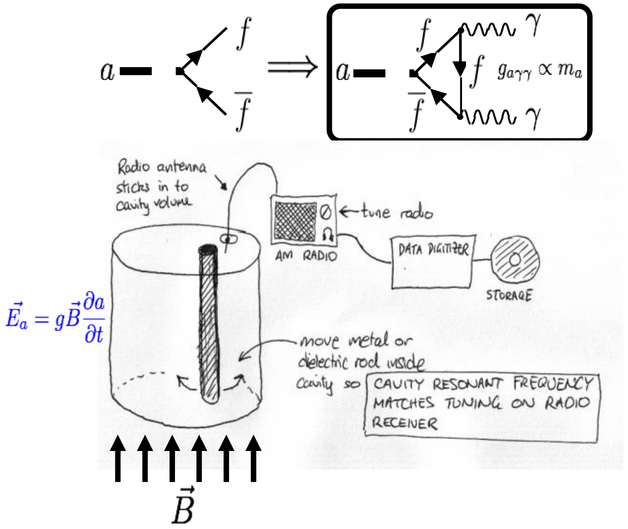
Yr 1-2: Build the team and institutional interfaces. Develop an optimised science case

Yr 2-3: Component technology development - superconducting electronics, etc.

Yr 3: Complete end-to-end signal-chain demonstrations through pathfinder – early science

Conceptual design study of national facility. Submit a comprehensive proposal.

Axions



UK Idea Improve hidden sector searches with feedback resonators arXiv:1805.11523.

QSFP

WP2

Macroscopic quantum superpositions for physics beyond the standard model

Macroscopic Superposition

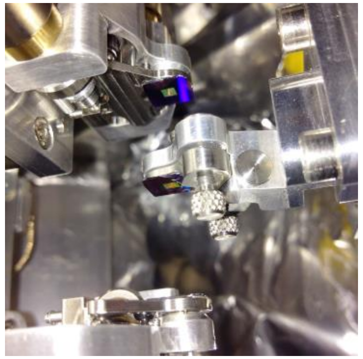
Subpackage 1: Silica spheres
Subpackage 2: Diamonds NV$^-$ centres
Subpackage 3: Clamped oscillators
Subpackage 4: Theory

Simulate the proposed experiments
Dark matter and neutrino detection
Short-range force tests
Relativistic effects
Non-equilibrium mesoscopic quantum mechanics
Gravitational wave detection

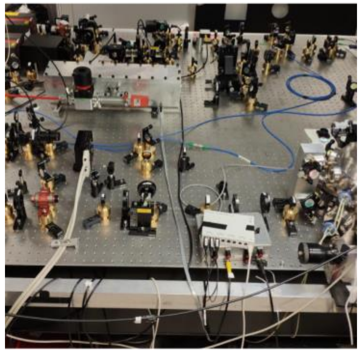
Strengths:

Results come with/without spontaneous collapse
Leverages investment in three QT Hubs
Many years of work by us to propose this work
Community already working together

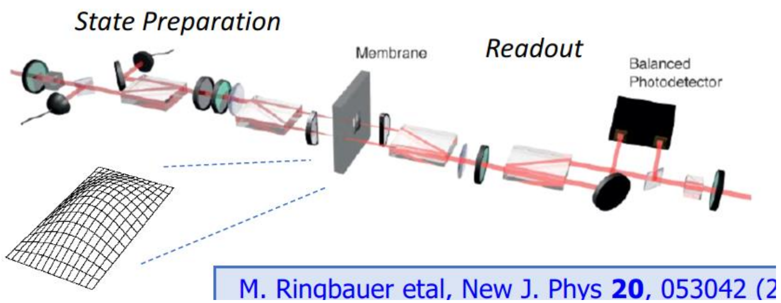
sp1



sp2



sp3



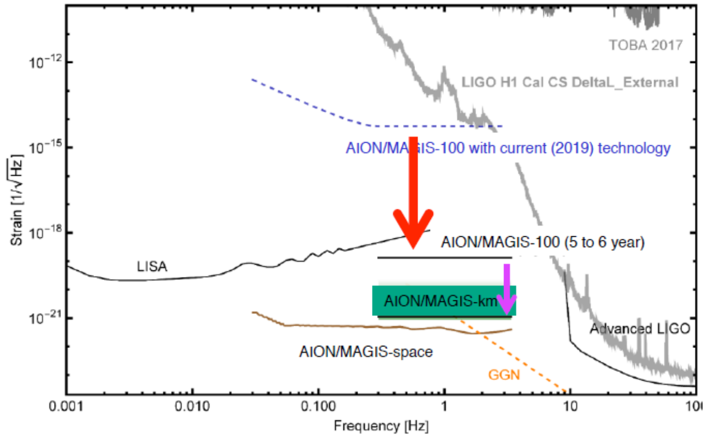
QSFP

WP3

AION

AION

- Atomic Interferometric Observatory Network (AION) in the UK
  - Ultralight (<1 eV) dark matter searches
  - gravitational waves in the mid-frequency band
- Networked with MAGIS
  - a'la LIGO and VIRGO



WG-Physics: Theory and Analysis
WG-AION-10: 10 m interferometer
WG-MAGIS: Collaboration with the Fermilab program
WG-AION-100: Site Planning & Preparation
WG-AION-Upgrades: reaching the ultimate sensitivity

Quantum Sensors for Neutrino Mass

QSFP
WP4

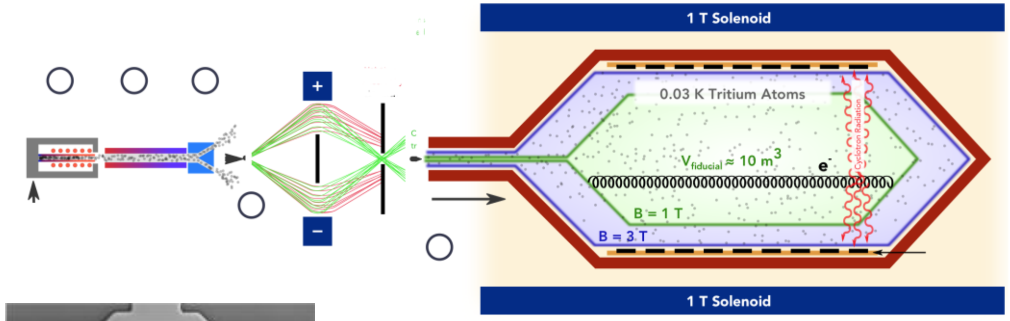
Neutrino Mass

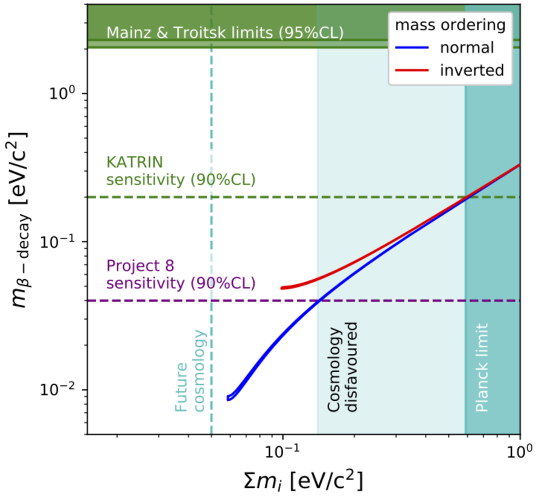
Guaranteed observation

Deliverable: trapping 10^{20} D/T atoms

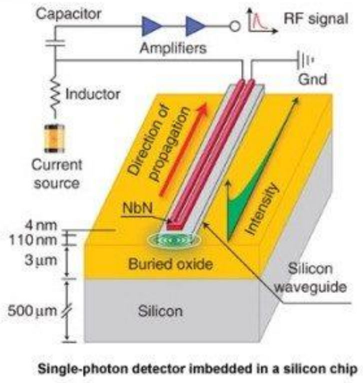
Cyclotron Radiation Emission Spectroscopy

Beyond Bolometers (det. dev.)



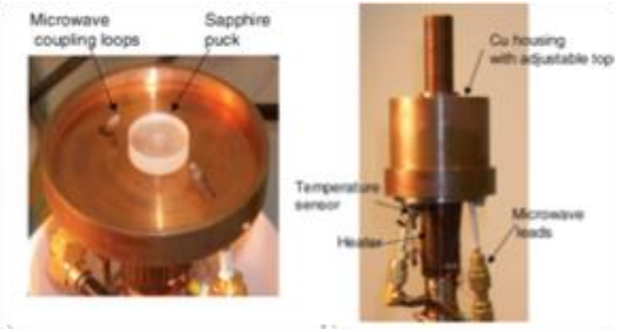


Sensitivity to 9mev



Nanowire

bolometers



Quantum Simulators of Fundamental Physics

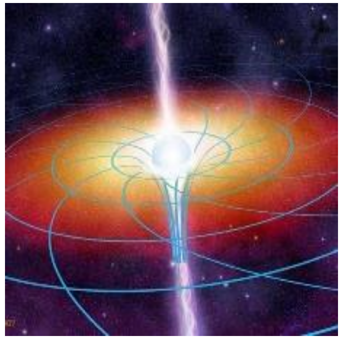
Simulators

Deeping our understanding of dynamics of the early universe and black holes

Bose-Einstein Condensates, superfluid Helium and optical systems.

2-component Bose-Einstein cond. in 2D box trap: under development (Cambridge)

Superfluid Helium 4 bathtub vortex flow (Nottingham, UK). Proof of principle under construction.



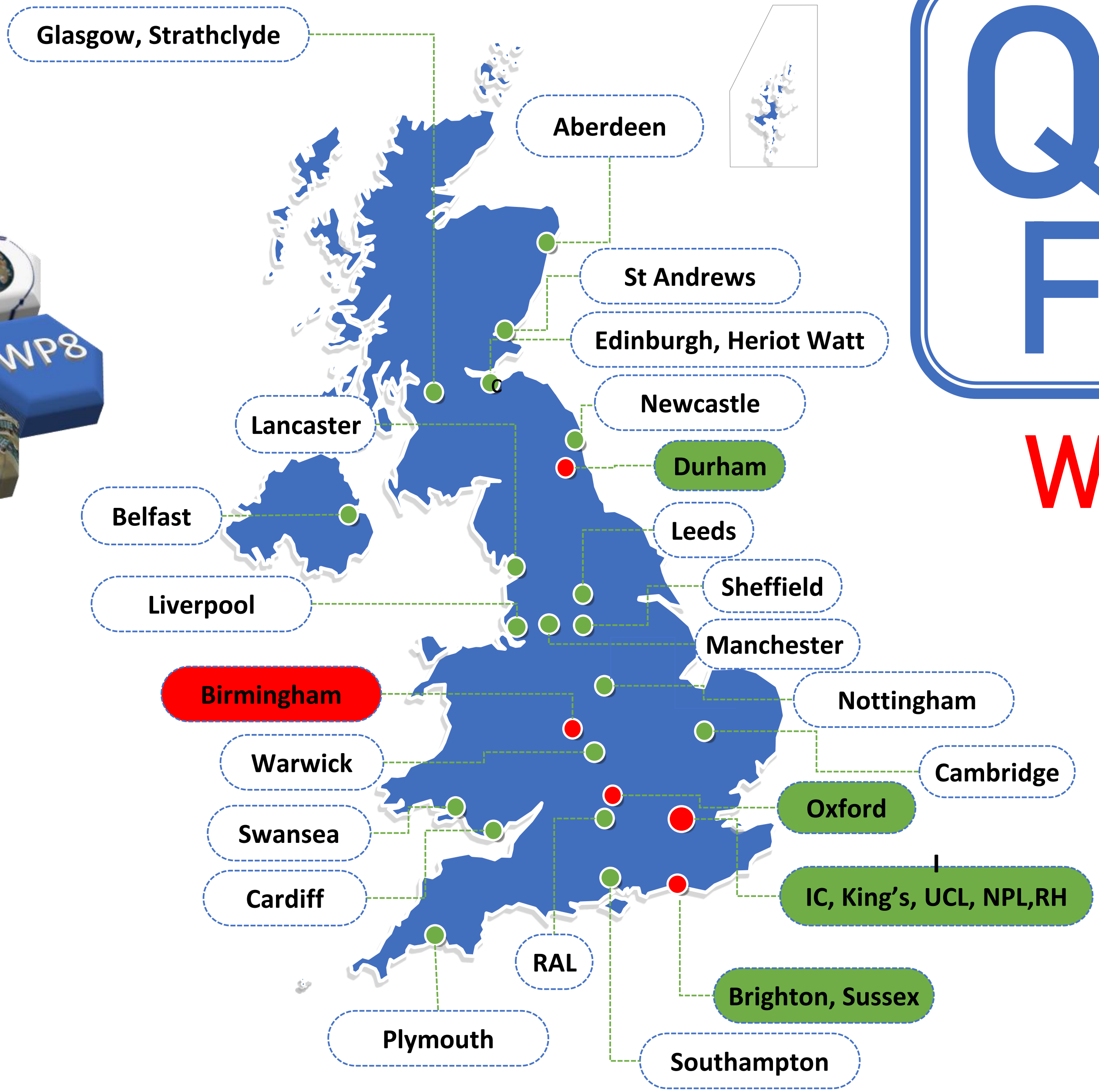
Black holes

Space-time

Vacuum

Our approach: to study these processes in theory & experiment in analogue quantum simulators

Networked Sensors



QS FP

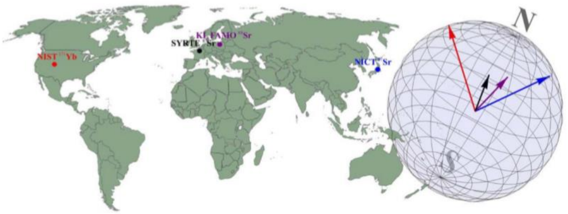
WP6

Networked Sensors

"Each node/element will deliver disruptive results in the search for variations in fundamental constants, Lorentz symmetry breaking, new forces, tests of the equivalence principle"

Magnetometers (GNOME)

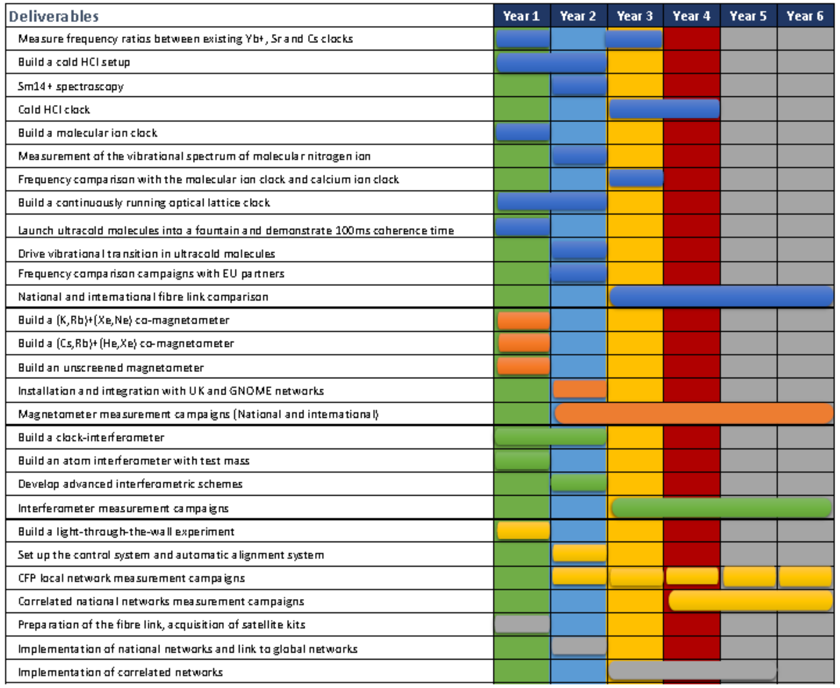
[https://budker.uni-mainz.de/gnome/]

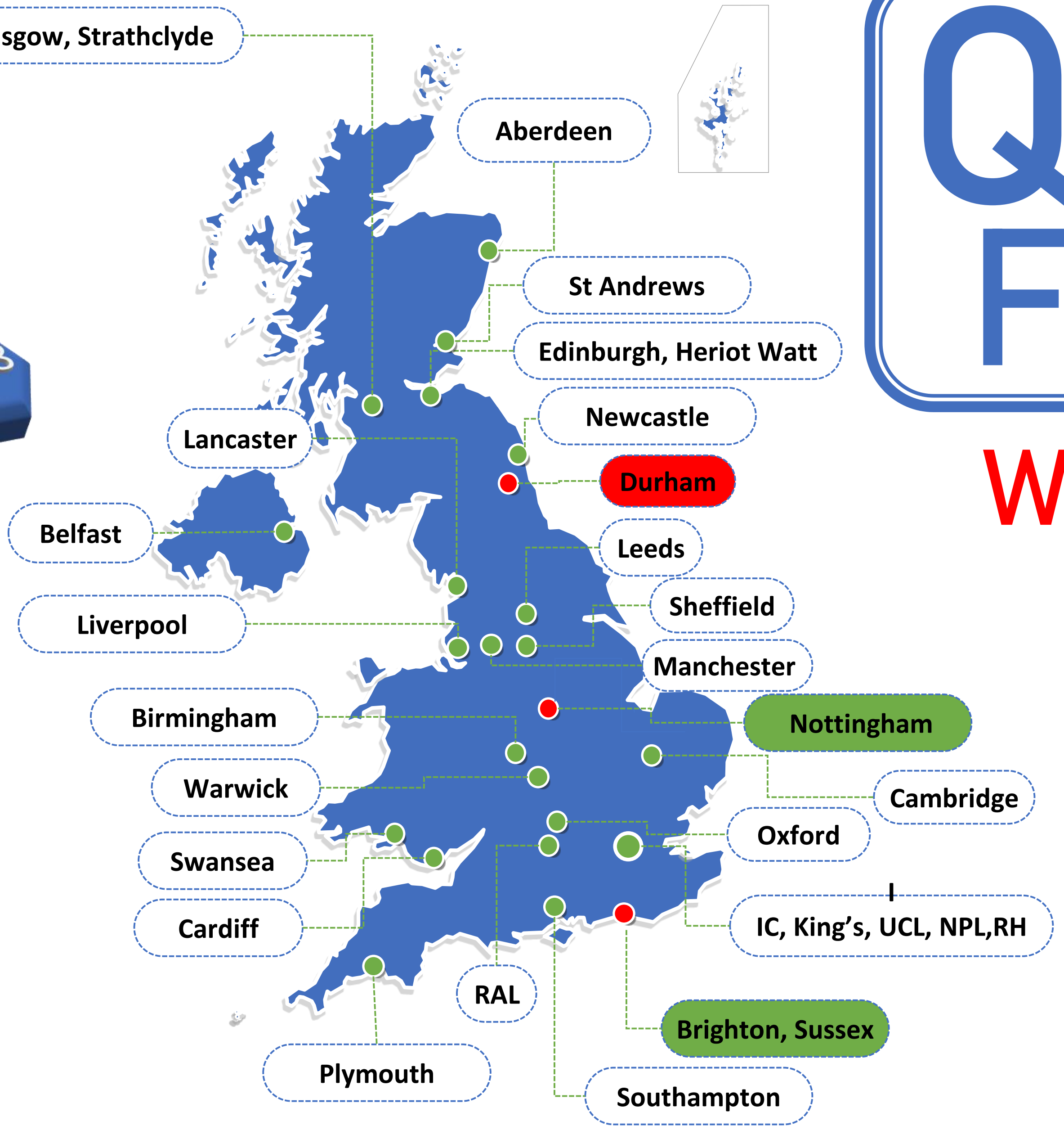


Optical atomic clocks

[Science Advances 4, eaau4869 (2018)]

"assemble a new tool" to enable completely new capabilities





QSFP

WP7

Searches for a Fifth Force and Dark Matter Using Precision Atomic Spectroscopy

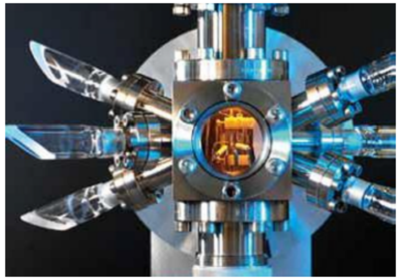
5^{th} force + …

$$Z\frac{\alpha}{r} \to Z\frac{\alpha}{r} + \frac{y_i y_j}{4\pi}\frac{e^{-m_\phi r}}{r}$$ **Yukawa potential**

WP7: Programme of Work (Years 1 – 3)

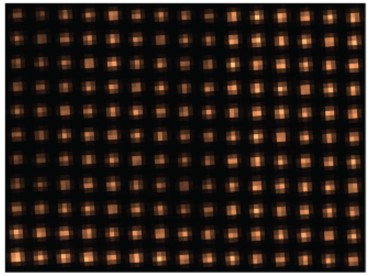
Experiments

Sussex (Keller)



Two Ca^{+} ion clocks. Compare for isotope shifts

Durham (Jones/Adams)



Rydberg spectroscopy on Sr atom tweezer array

Durham (Carty/Jones/Adams)

Rydberg spectroscopy on ultracold H/D-atom fountain

Deliverabes

Sussex (Keller):

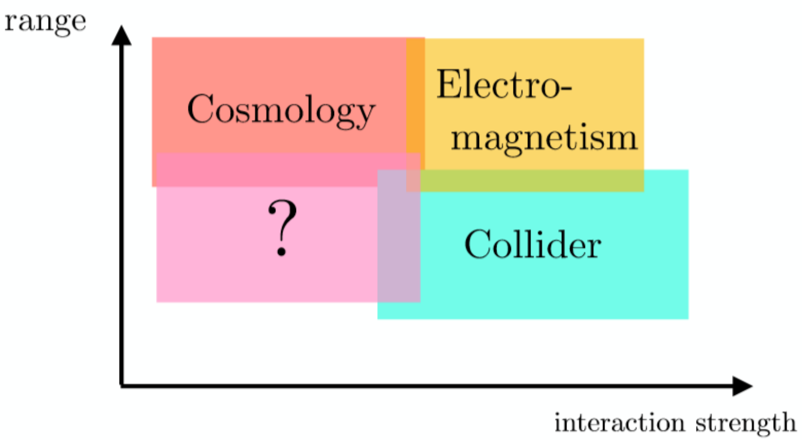
- A second Ca^{+} ion clock.
- Measure relative isotope shift of the $^2S_{1/2} \to {}^2D_{5/2}$ transition between $^{40}Ca^{+}$, $^{42}Ca^{+}$, $^{44}Ca^{+}$ and $^{48}Ca^{+}$ at Hz level.
- **Constraints within 3 years.**

Durham (Jones/Adams):

- Absolute frequencies of Sr Rydberg states, n = 35-100 with <1 kHz accuracy (>10^3 increase over state of art).
- Testbed for methods to control statistical and systematic errors for other experiments.
- **Constraints within**

Durham (Carty/Jones/Adams):

- Investigate H/D + Li collisions for sympathetic cooling H/D to μK.
- Develop set up for precision Rydberg spectroscopy of H/D atoms



QSFP

WP8

Fundamental Physics with exotic atoms

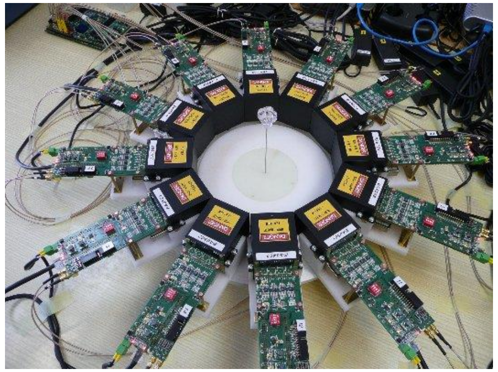
Exotic Atoms

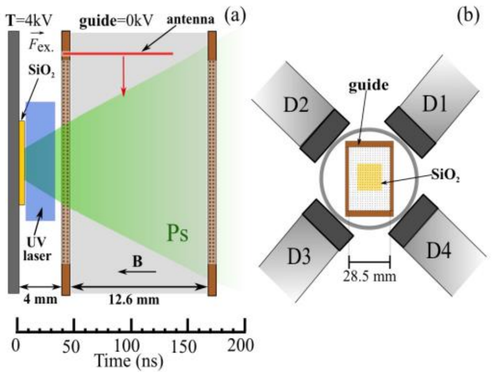
Antihydrogen

trapping efficiency will go up by an order of magnitude,
never been a better time to support this field

Positronium…

Production of slower focused beams [via Rydberg Stark deceleration/manipulation methods]
Construction of new detector(s)
Integration of Rydberg He spectroscopy into Ps experiments for high precision field characterization
Spectroscopic measurements of energy intervals and Rydberg constant
Demonstration of Rydberg Ps interference effects
"up or down" measurement of Ps gravity





New detector system for positronium

Lorentz Invariance Space Test

QSFP

WP9

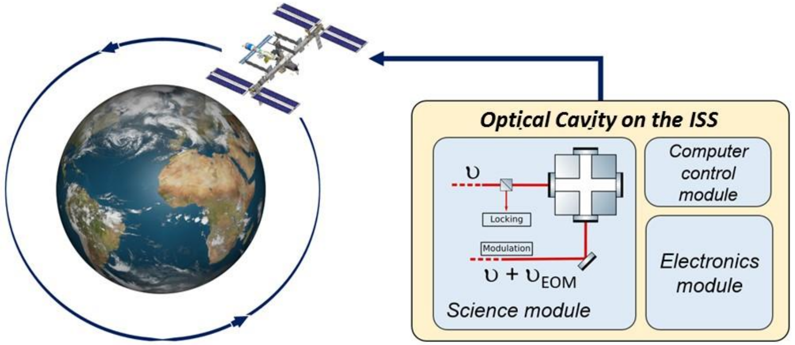
Lorentz invariance in Space

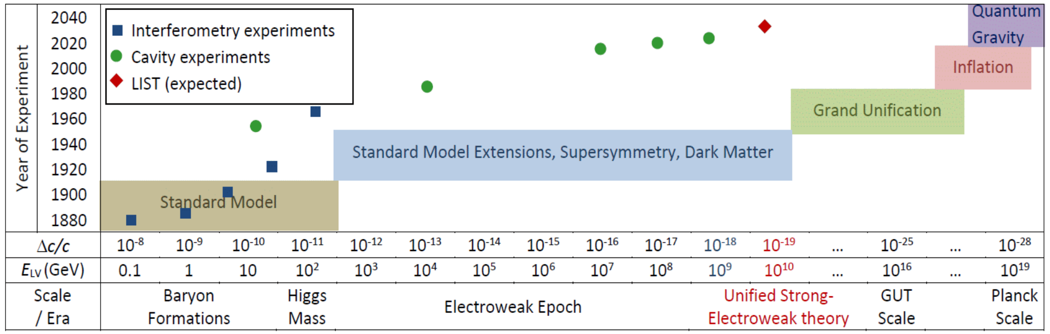
A Michelson-Morley-type of experiment in microgravity

LIST: 1st of kind

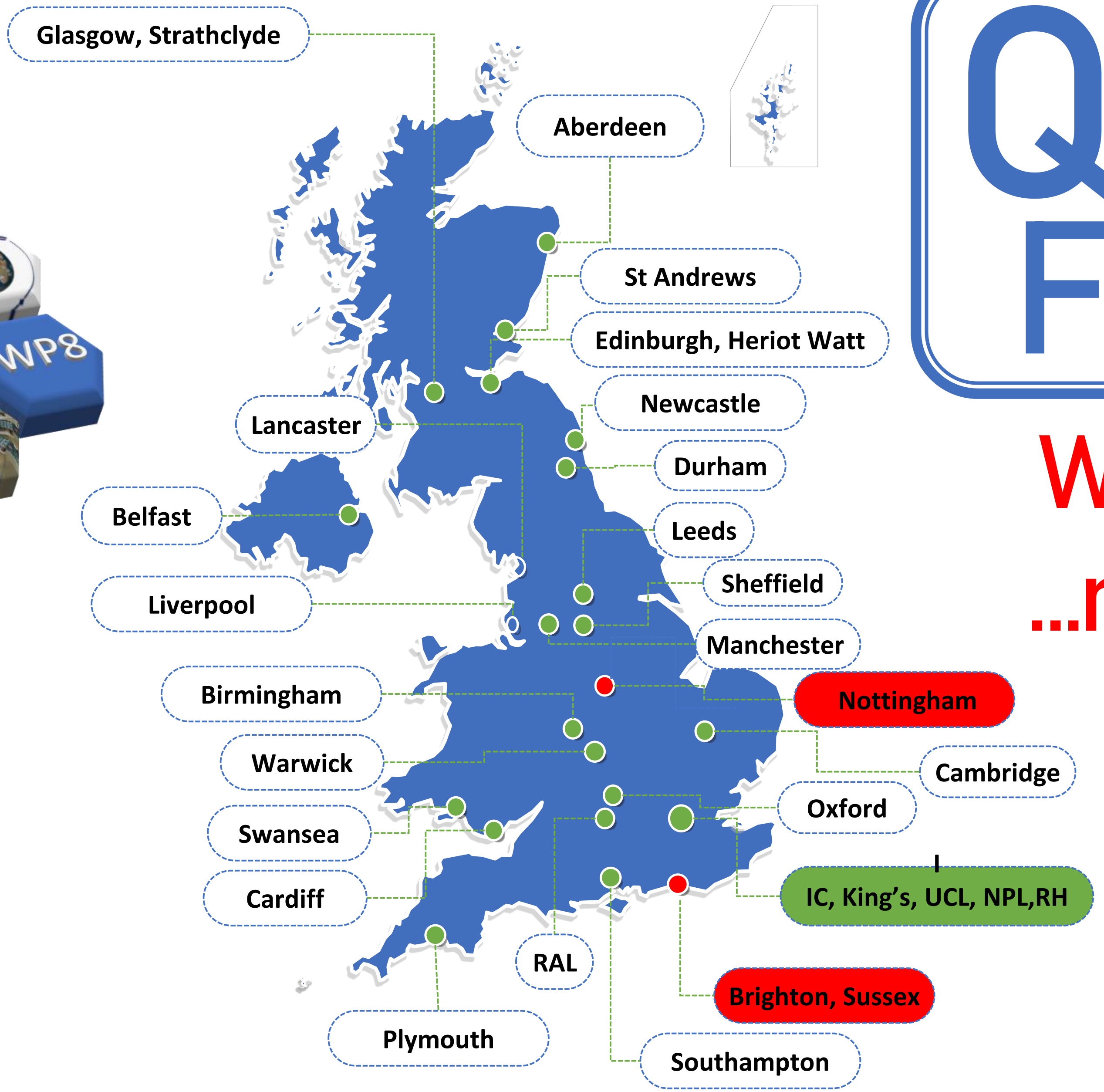
Earth-bound experiments limited

LIST aim is to **improve precision by an order of magnitude**





[k£]	Y1	Y2	Y3	Y4	Y5	Y6	SUM
Design & Build phase	1,403	1,939					3,341
Qualification & pre-Launch			926				926
Launch & Data analysis				296	216	206	718
TOTAL							4,985



QSFP

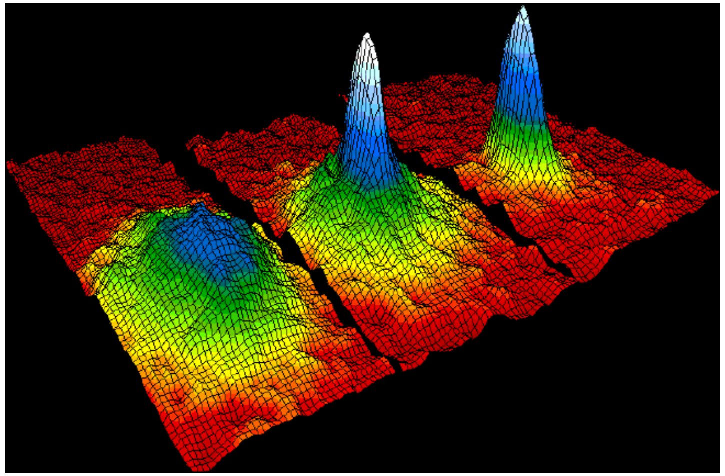
WP10 ...new

Collective quantum excitations as quantum sensors

Collective quantum excitations as quantum sensors

- screened scalar fields
- high-frequency gravitational waves
- gravimetery and gradiometery

1. Phonic field measurement to provide info on the temp of system
2. quantum dots as temp sensors
3. Build a BEC with quantum dots inside



Next Steps ++

- End April 2018 - Draft workpackages due for review by IRB
- End May 2018 - Final workpackages due for review by IRB, formal costings initiated
- don't yet know terms of funding call, possible the value of individual proposals may be capped. In that event, WPs would go into the bid as standalone proposals
  - If there is no cap, we have the option to submit as a consortium.
  - In which case a group of volunteers will be charged with developing wider aspects of proposal including metadata & coordinating with STFC/EPSRC towards submission
- Either way in May consortium meeting to review/sign off the proposal(s)
- Mid- June proposal(s) submission
  - of course no requirement to work within the QSFP framework but benefits are clear
- It is an open call (that is appropriate!), will be bids from outside the consortium

Update on Funding

As of Feb 26 the situation as described by Mark Thomson (Executive Chair STFC) is:

"In the event that QSFP were recommended for funding, there are other steps, potentially including BEIS clearance of the recommended SPF programme. This means that the timeline for announcement of the outcomes of the SPF bids is not completely clear."

Updates since have been unchanged, then on March 18:

"You should hear something shortly. Either way, we are likely to have to wait for ministerial clearance before any announcement."

Note added by us as a guide: if the announcement came at the end of March, the open call may be made in April and the deadline to submit proposals would be 2 -3 months later so June or July. Clearly this is only speculation on our part at this stage.

Review Board

- International Review Board (IRB): WP leaders identified world-leading experts from outside the UK that to review the proposals providing crucial feedback to strengthen them.
- IRB being set up now.
- Webpage - http://qsfp-uk.org/ ready by Monday 15th April
- QSFP School – aiming for a week in late September to cover all aspects of experimental & theoretical QSFP work from International experts

Summary

- In the US the QSFP interface area acts as a major attractor for creative, original young experimentalists and theorists. We believe this will be true in the UK as well. The programme will be world-leading, and highly complementary to the US programme and those of other nations
- In this competitive area it is important to quickly develop the community that can launch the proposed programme. To do this expeditiously it will build on expertise, selected existing activities within the UK and exploitation of existing resources.
- As the EPSRC, STFC and Space communities come together, and working with the quantum hubs, and NPL and US partners we anticipate entirely new and exciting science will emerge.