

Quantum Sensors
Fundamental Physics

Consortium

T. Bowcock



Ian will talk (tomorrow)
about

status
next steps
Milestones
Governance
Review Board

....





Glasgow, Strathclyde

Aberdeen

St Andrews

Edinburgh, Heriot Watt

Newcastle

Lancaster

Durham

Belfast

Leeds

Liverpool

Sheffield

Manchester

Birmingham

Nottingham

Warwick

Cambridge

Swansea

Oxford

Cardiff

ICTS, King's, UCL, NPL, RH

RAL

Brighton, Sussex

Plymouth

Southampton



UK

- 31 institutes
- Multiple companies
- Scientists....





Quantum Sensors for Hidden Sector Physics



WP1



Macroscopic quantum superpositions for physics beyond the standard model



WP2

AION



WP3



Quantum Sensors for Neutrino Mass



WP4



WP5

Quantum Simulators of Fundamental Physics



Networked Sensors



WP6



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



WP7



Fundamental Physics with exotic atoms



WP8



WP9

Lorentz Invariance Space Test

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





Workpage 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

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

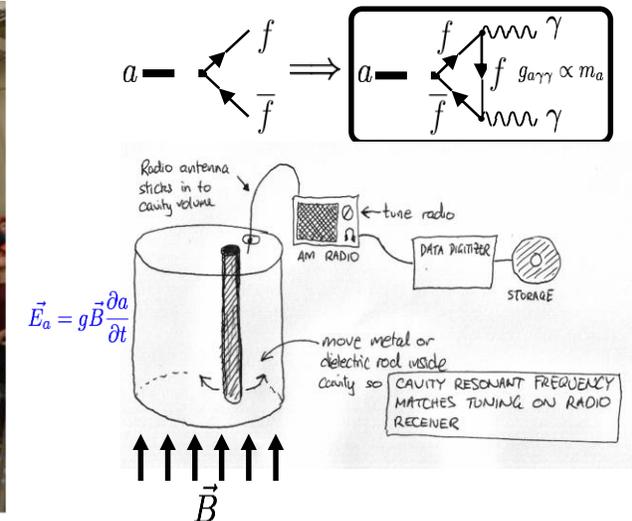
Yr 2-3: Component technology development -
superconducting electronics, etc.

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.

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:

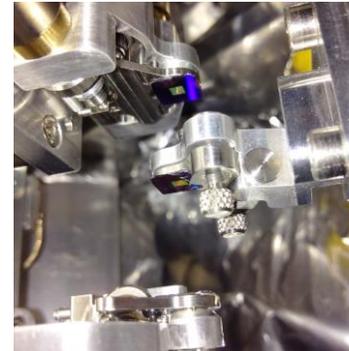
Results come with/without spontaneous collapse

Leverages investment in three QT Hubs

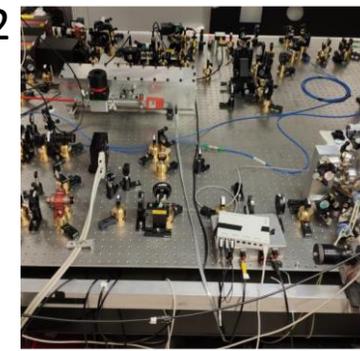
Many years of work by us to propose this work

Community already working together

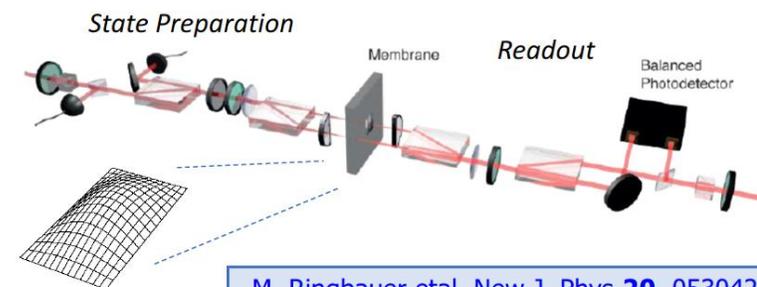
sp1



sp2



sp3

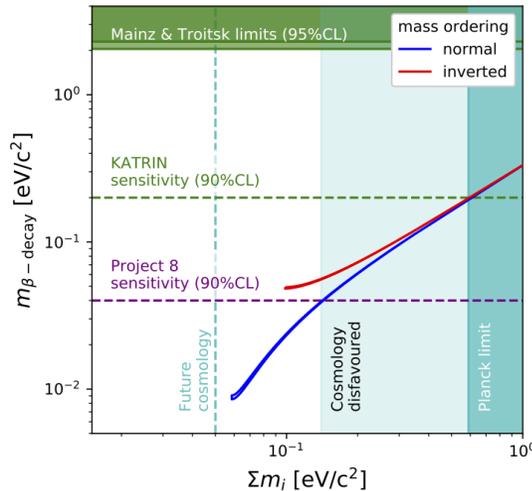


M. Ringbauer et al, New J. Phys **20**, 053042 (2018)

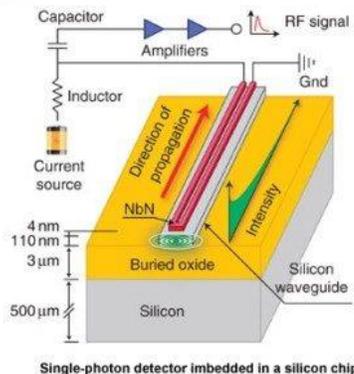
Neutrino Mass



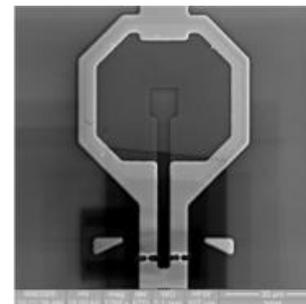
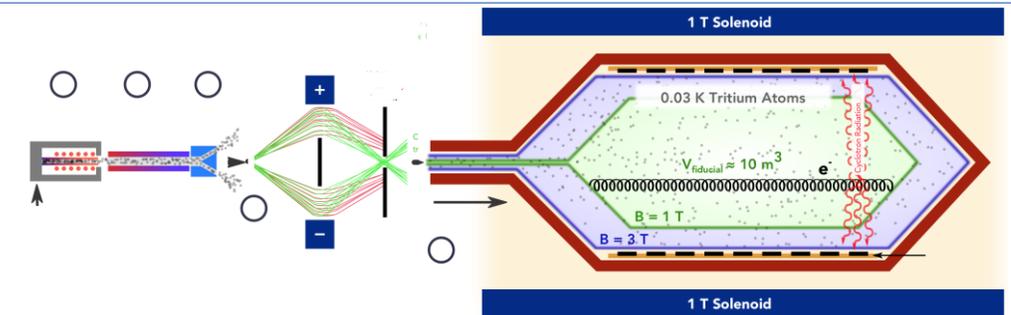
Guaranteed observation
Deliverable: trapping 10^{20} D/T atoms
Cyclotron Radiation Emission Spectroscopy
Beyond Bolometers (det. dev.)



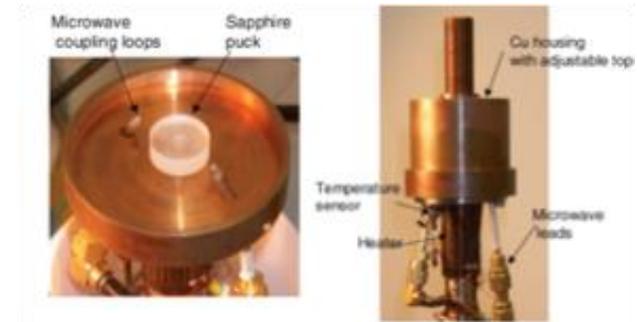
Sensitivity to 9mev



Nanowire



bolometers



Simulators



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

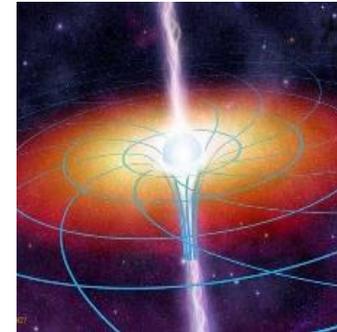
Bose-Einstein Condensates, superfluid Helium and optical systems.



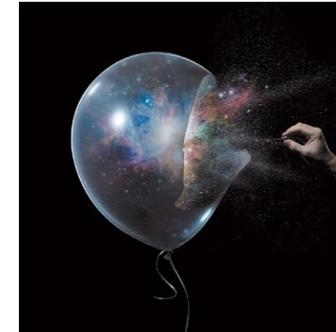
2-component Bose-Einstein cond. in 2D box trap: under development (Cambridge)



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

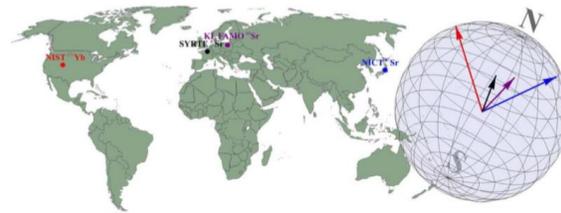
Networked Sensors



“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

Deliverables	Year 1	Year 2	Year 3	Year 4	Year 5	Year 6
Measure frequency ratios between existing Yb ⁺ , Sr and Cs clocks						
Build a cold HCI setup						
Sm ¹⁴⁺ spectroscopy						
Cold HCI clock						
Build a molecular ion clock						
Measurement of the vibrational spectrum of molecular nitrogen ion						
Frequency comparison with the molecular ion clock and calcium ion clock						
Build a continuously running optical lattice clock						
Launch ultracold molecules into a fountain and demonstrate 100ms coherence time						
Drive vibrational transition in ultracold molecules						
Frequency comparison campaigns with EU partners						
National and international fibre link comparison						
Build a (K,Rb) ⁺ (Xe,Ne) co-magnetometer						
Build a (Cs,Rb) ⁺ (He,Xe) co-magnetometer						
Build an unscreened magnetometer						
Installation and integration with UK and GNOME networks						
Magnetometer measurement campaigns (National and international)						
Build a clock-interferometer						
Build an atom interferometer with test mass						
Develop advanced interferometric schemes						
Interferometer measurement campaigns						
Build a light-through-the-wall experiment						
Set up the control system and automatic alignment system						
CFP local network measurement campaigns						
Correlated national networks measurement campaigns						
Preparation of the fibre link, acquisition of satellite kits						
Implementation of national networks and link to global networks						
Implementation of correlated networks						

5th force + ...

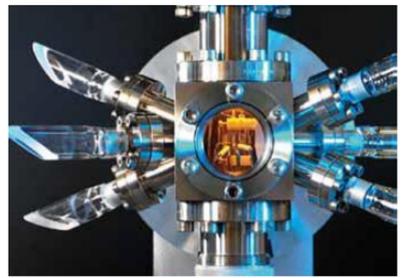


$$Z \frac{\alpha}{r} \rightarrow Z \frac{\alpha}{r} + \frac{y_i y_j e^{-m_\phi r}}{4\pi r} \quad \text{Yukawa potential}$$

WP7: Programme of Work (Years 1 – 3)

Experiments

Sussex (Keller)

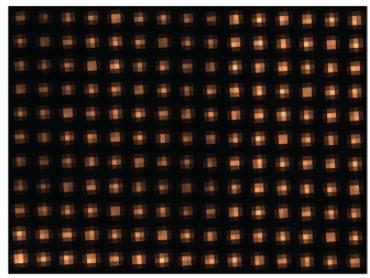


Two Ca⁺ ion clocks. Compare for isotope shifts

Deliverables

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

Durham (Jones/Adams)



Rydberg spectroscopy on Sr atom tweezer array

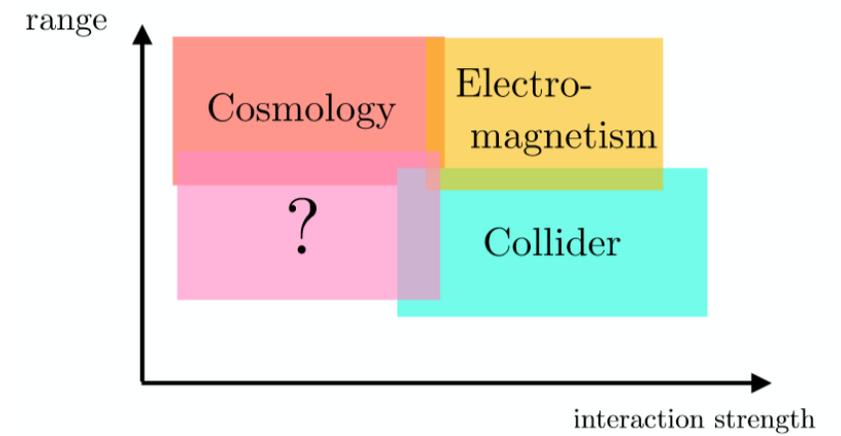
- Absolute frequencies of Sr Rydberg states, $n = 35-100$ with <1 kHz accuracy ($>10^3$ increase over state of art).
- Testbed for methods to control statistical and systematic errors for other experiments.
- **Constraints within**

Durham (Carty/Jones/Adams)



Rydberg spectroscopy on ultracold H/D-atom fountain

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



Exotic Atoms



Antihydrogen

trapping efficiency will go up by an order of magnitude,

never been a better time to support this field

Positronium...

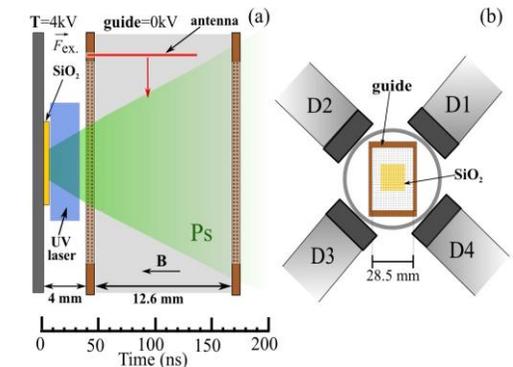
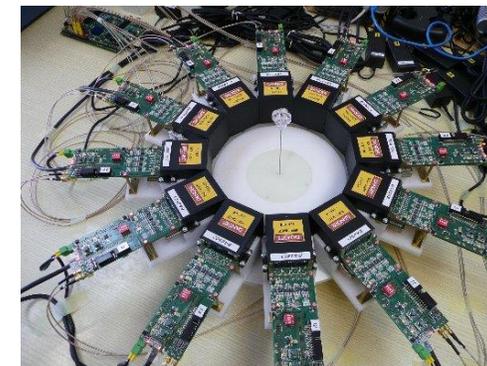
Production of slower focused beams [via Rydberg Stark deceleration/manipulation methods]

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 in Space

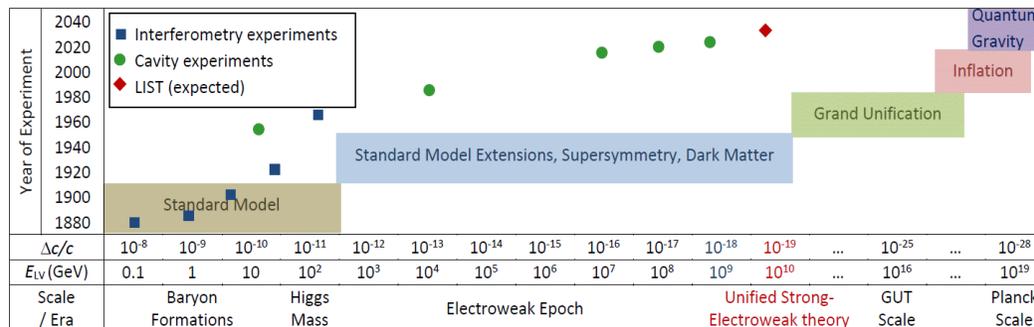
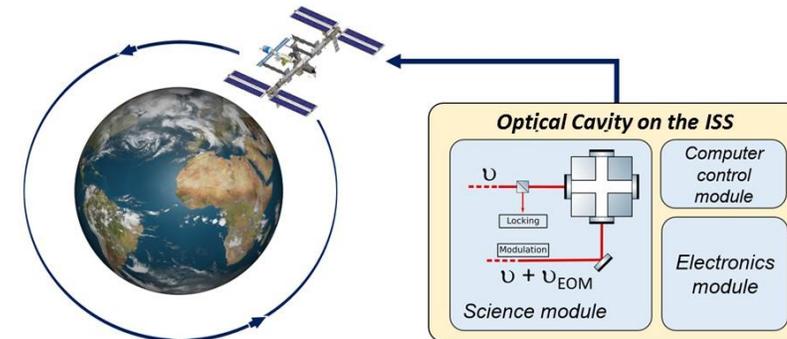


A Michelson-Morley-type of experiment in microgravity

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

Wide range of thoughts and deliverables



AION (next 2 days!)

Physics Goals

Detector development

Deliverables

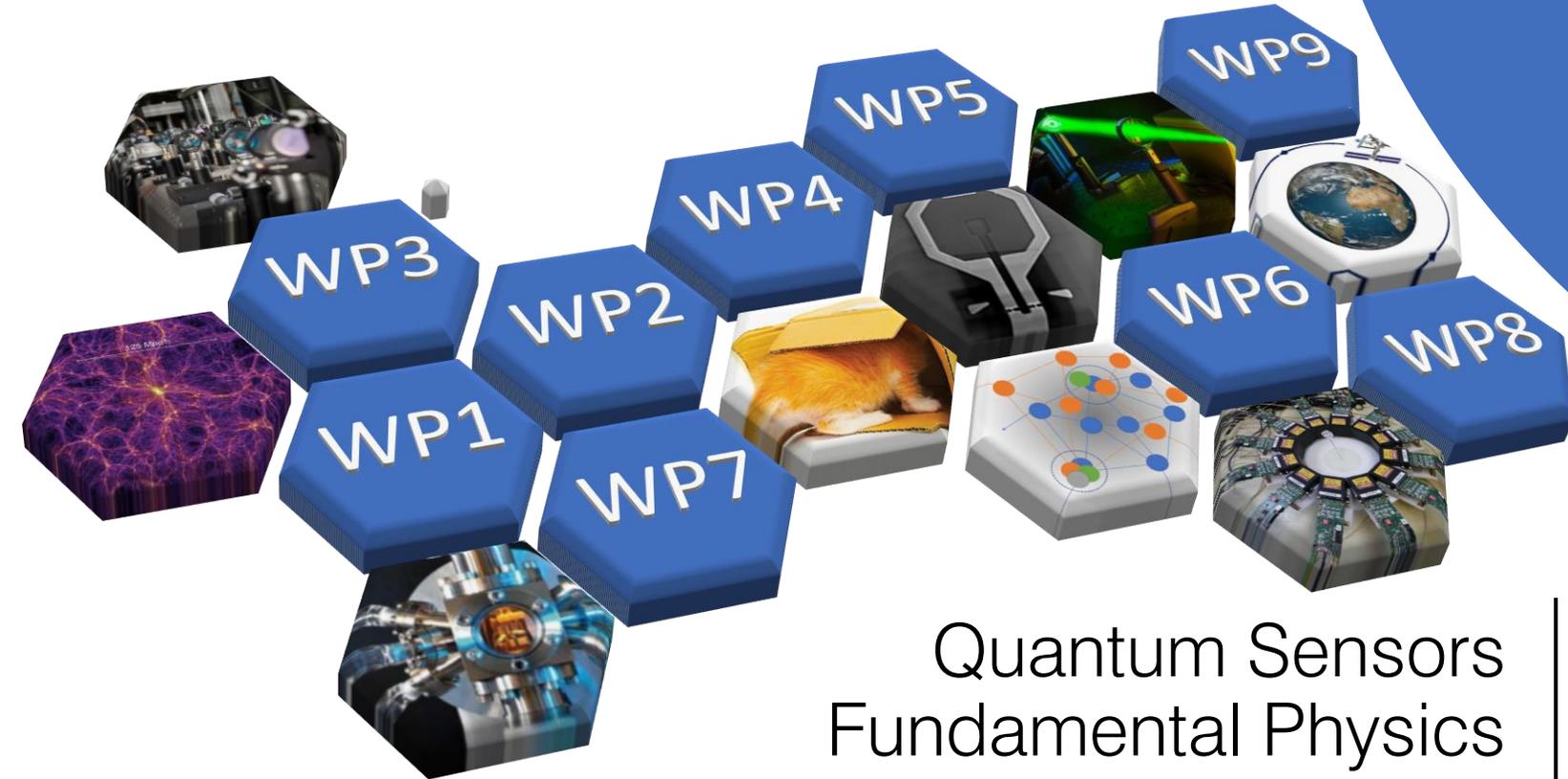
Theory

Plan

Competitiveness

Staff internal WP work allocation

Benefit to UK and UK Industry



Quantum Sensors
Fundamental Physics

Consortium

T. Bowcock