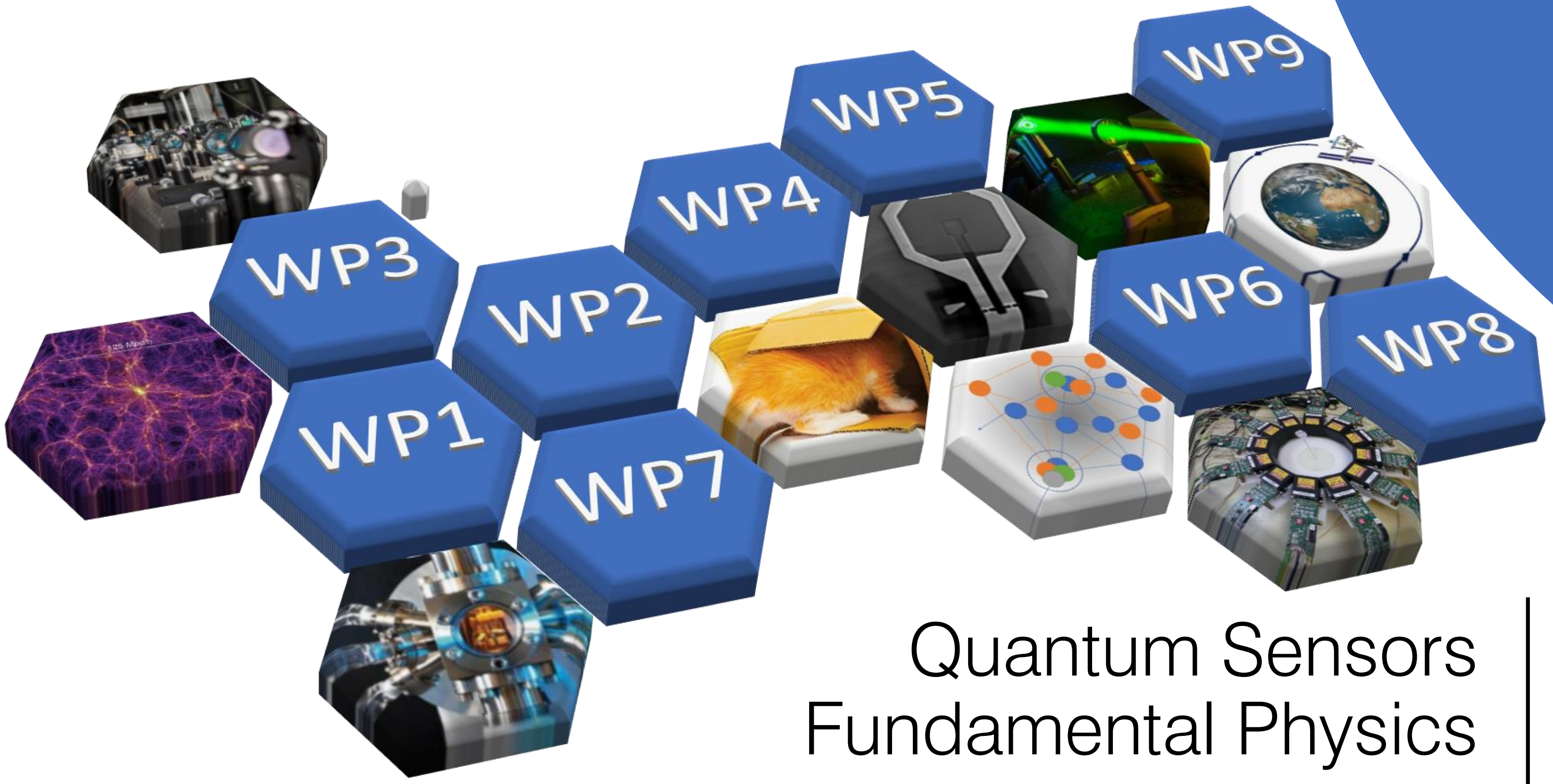
UK Research
and Innovation

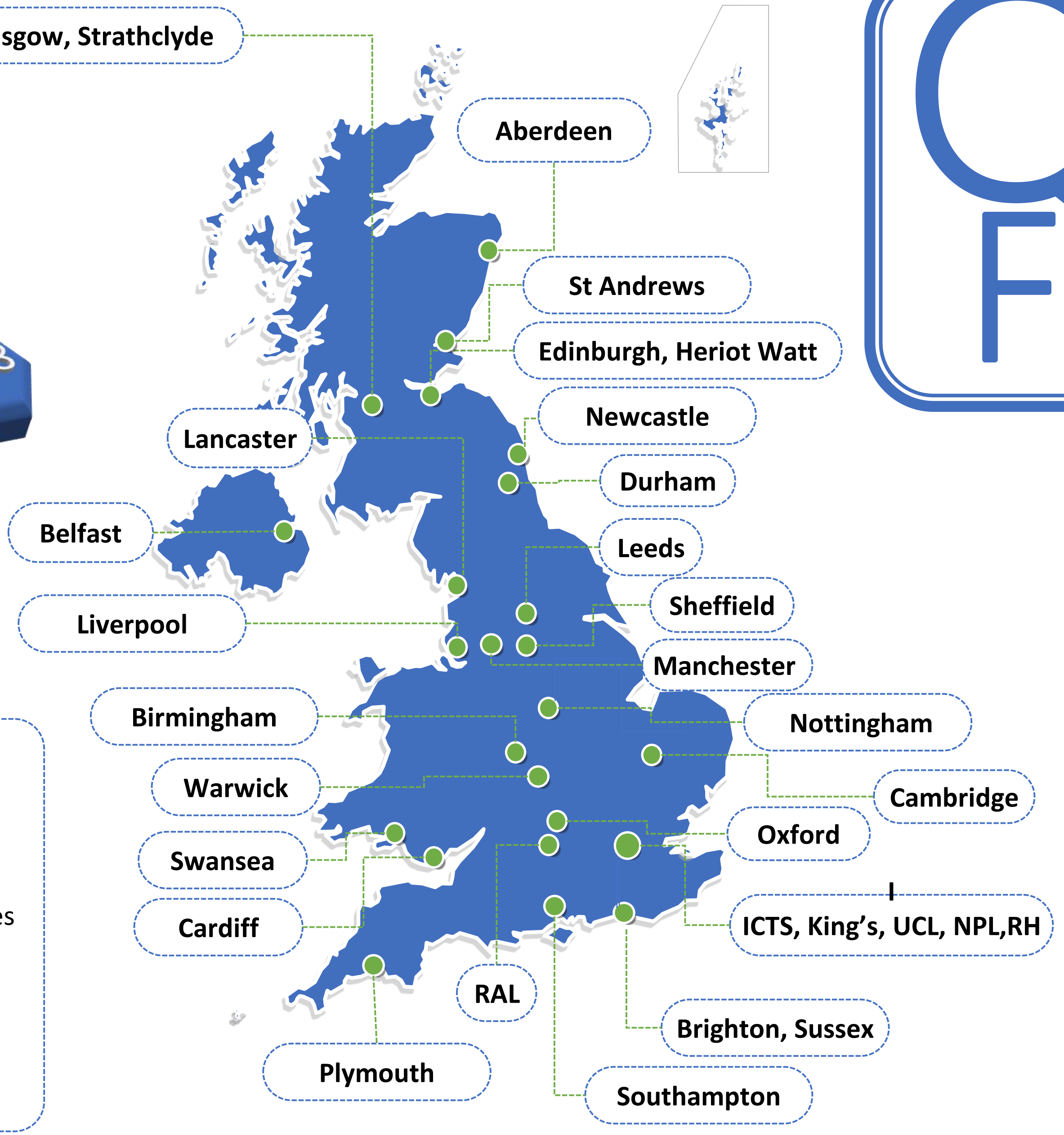


Quantum Sensors Fundamental Physics Consortium

T. Bowcock

Ian will talk (tomorrow)
about

status
next steps
Milestones
Governance
Review Board
....



UK

- 31 institutes
- Multiple companies
- Scientists….

WP1

Quantum Sensors for Hidden Sector Physics

WP2

Macroscopic quantum superpositions for physics beyond the standard model

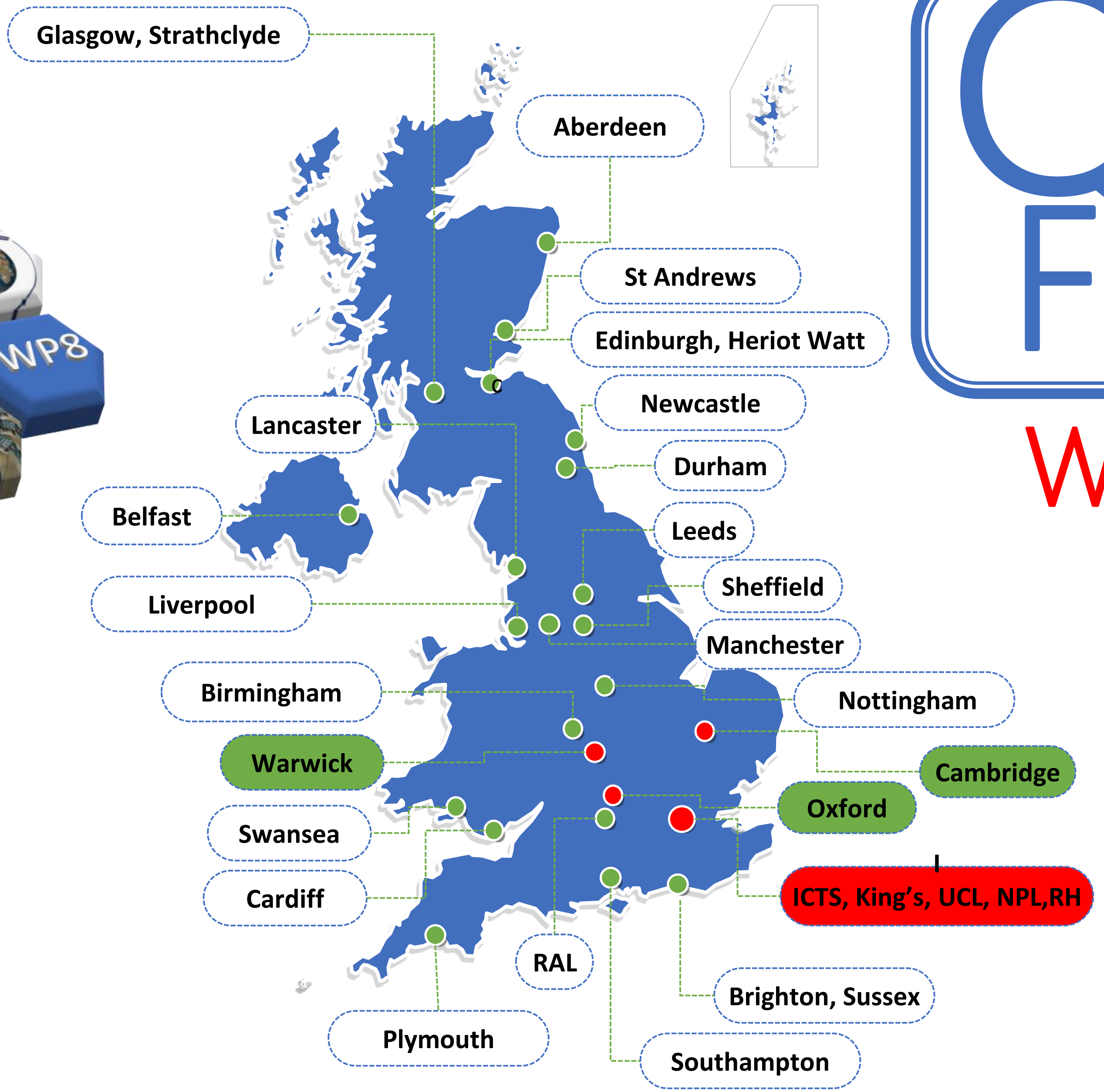

WP5
WP9
WP4
WP3
WP2
WP6
WP8
WP1
WP7

AION


Glasgow, Strathclyde
Aberdeen
St Andrews
Edinburgh, Heriot Watt
Newcastle
Lancaster
Durham
Belfast
Leeds
Sheffield
Liverpool
Manchester
Birmingham
Nottingham
Warwick
Cambridge
Oxford
Swansea
Cardiff
ICTS, King's, UCL, NPL,RH
RAL
Brighton, Sussex
Plymouth
Southampton

WP3

Quantum Sensors for Neutrino Mass



WP4

WP5

Quantum Simulators of Fundamental Physics

Networked Sensors

WP6

WP7

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

WP8

Fundamental Physics with exotic atoms

Lorentz Invariance Space Test

WP9

		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

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

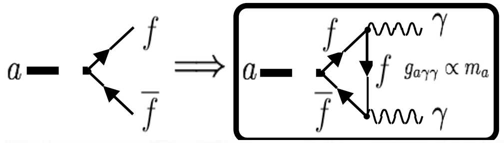
Yr 1-2: Build the team and institutional interfaces. Develop an optimised science case

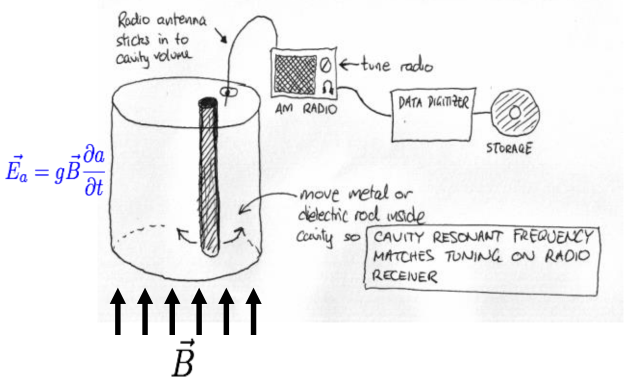
Yr 2-3: Component technology development - superconducting electronics, etc.

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

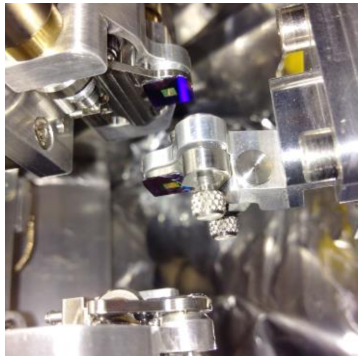
Subpackage 1: Silica spheres
Subpackage 2: Diamonds NV^- centres
Subpackage 3: Clamped oscillators
Subpackage 4: Theory

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

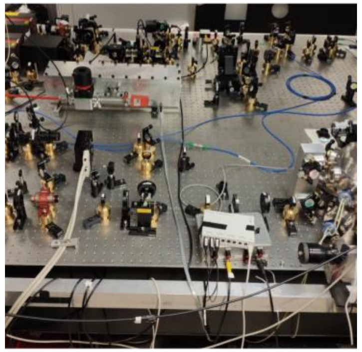
Strengths:

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

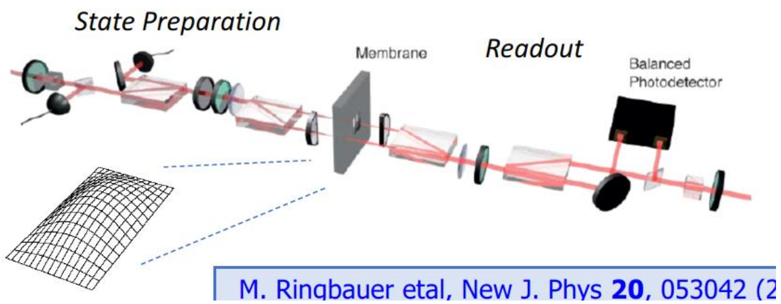
sp1



sp2

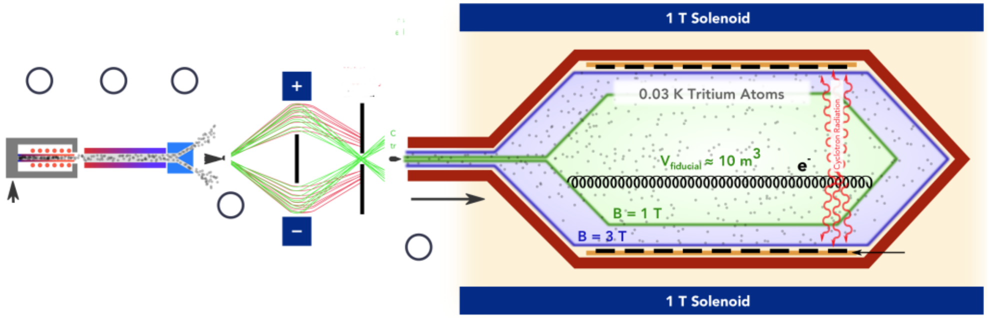


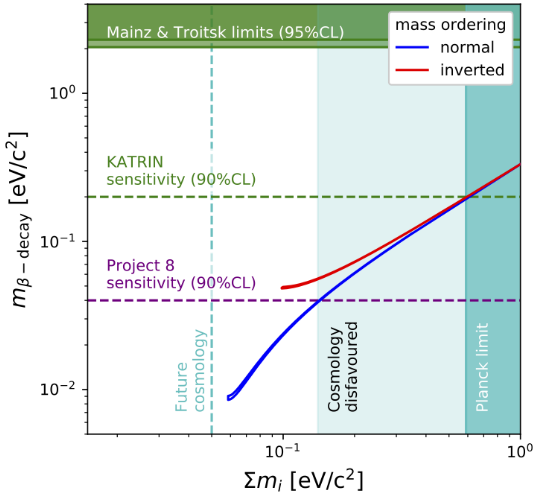
sp3



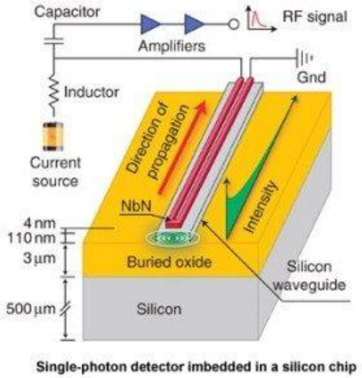
Neutrino Mass

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

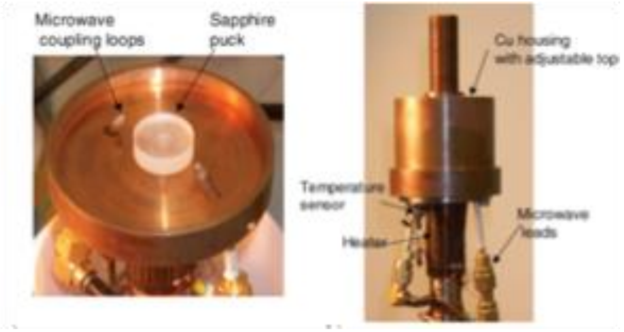




Sensitivity to 9mev



Nanowire



bolometers

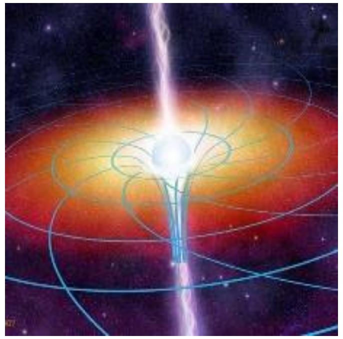
Simulators

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

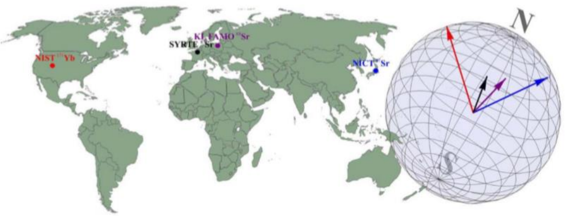
Our approach: to study these processes in theory & experiment in analogue quantum simulators

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)

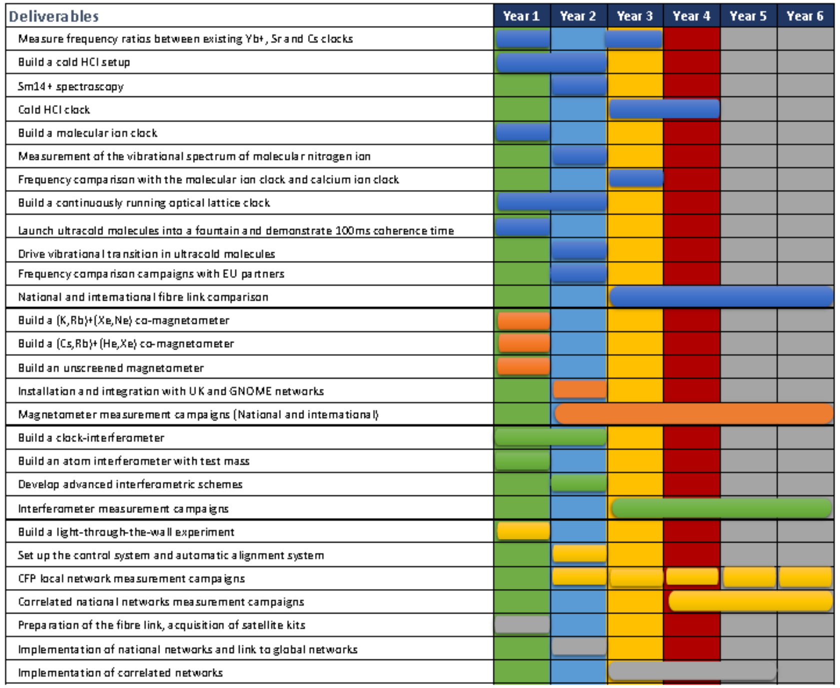
[https://budker.uni-mainz.de/gnome/]



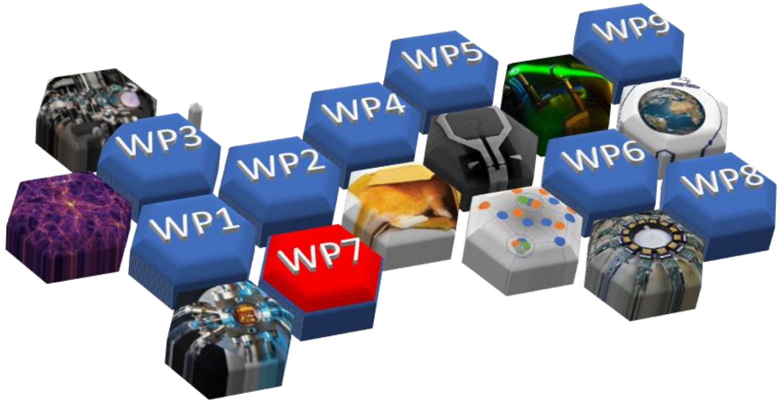
Optical atomic clocks

[Science Advances 4, eaau4869 (2018)]

"assemble a new tool" to enable completely new capabilities



5^{th} force + …



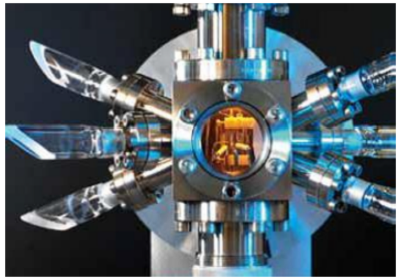
$$Z\frac{\alpha}{r} \to Z\frac{\alpha}{r} + \frac{y_i y_j}{4\pi}\frac{e^{-m_\phi r}}{r}$$

Yukawa potential

WP7: Programme of Work (Years 1 – 3)

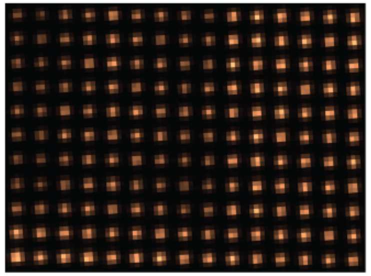
Experiments

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):

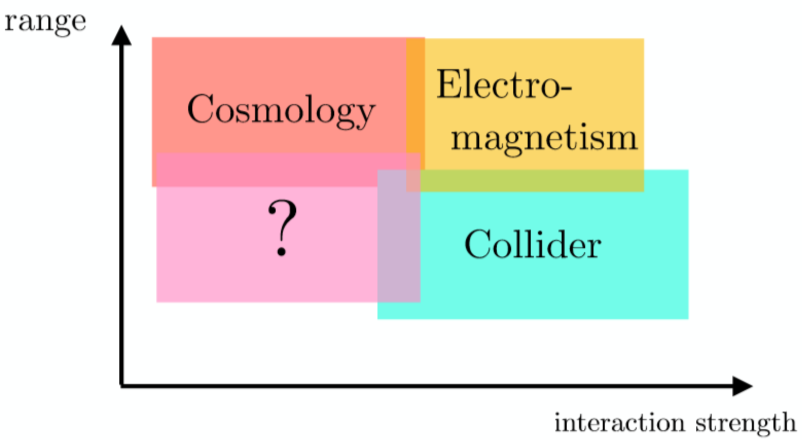
- A second Ca^{+} ion clock.
- Measure relative isotope shift of the $^2S_{1/2} \to {}^2D_{5/2}$ transition between $^{40}Ca^{+}$, $^{42}Ca^{+}$, $^{44}Ca^{+}$ and $^{48}Ca^{+}$ at Hz level.
- **Constraints within 3 years.**

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



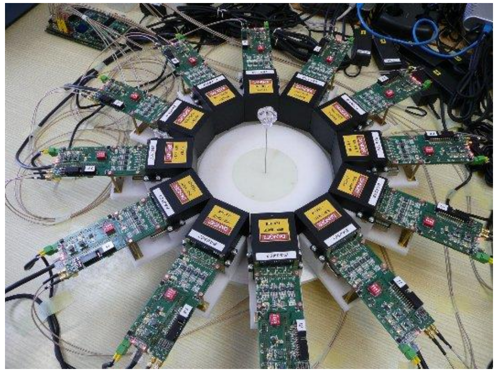
Exotic Atoms

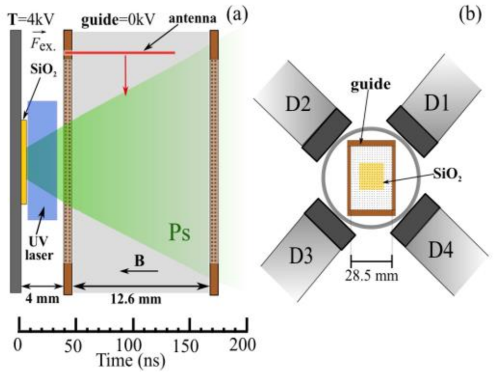
Antihydrogen

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

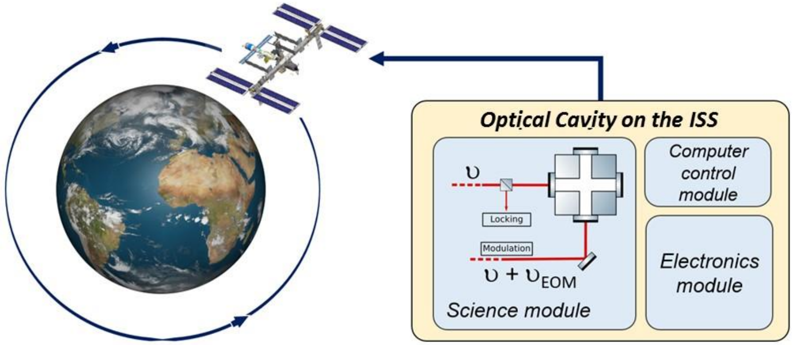
Lorentz invariance in Space

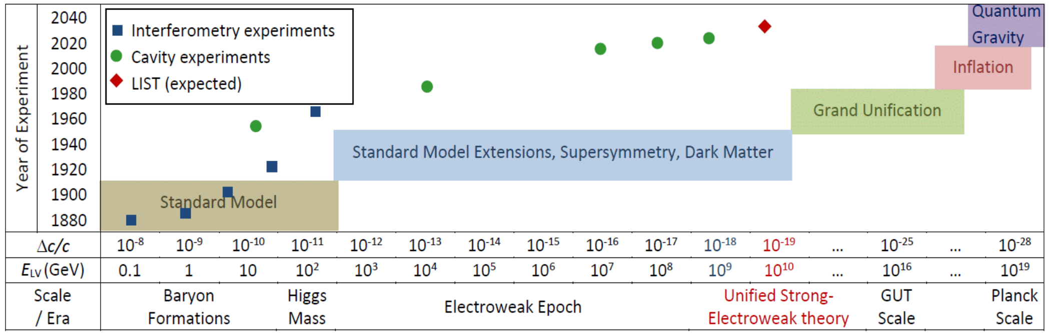
A Michelson-Morley-type of experiment in microgravity

LIST: 1st of kind

Earth-bound experiments limited

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



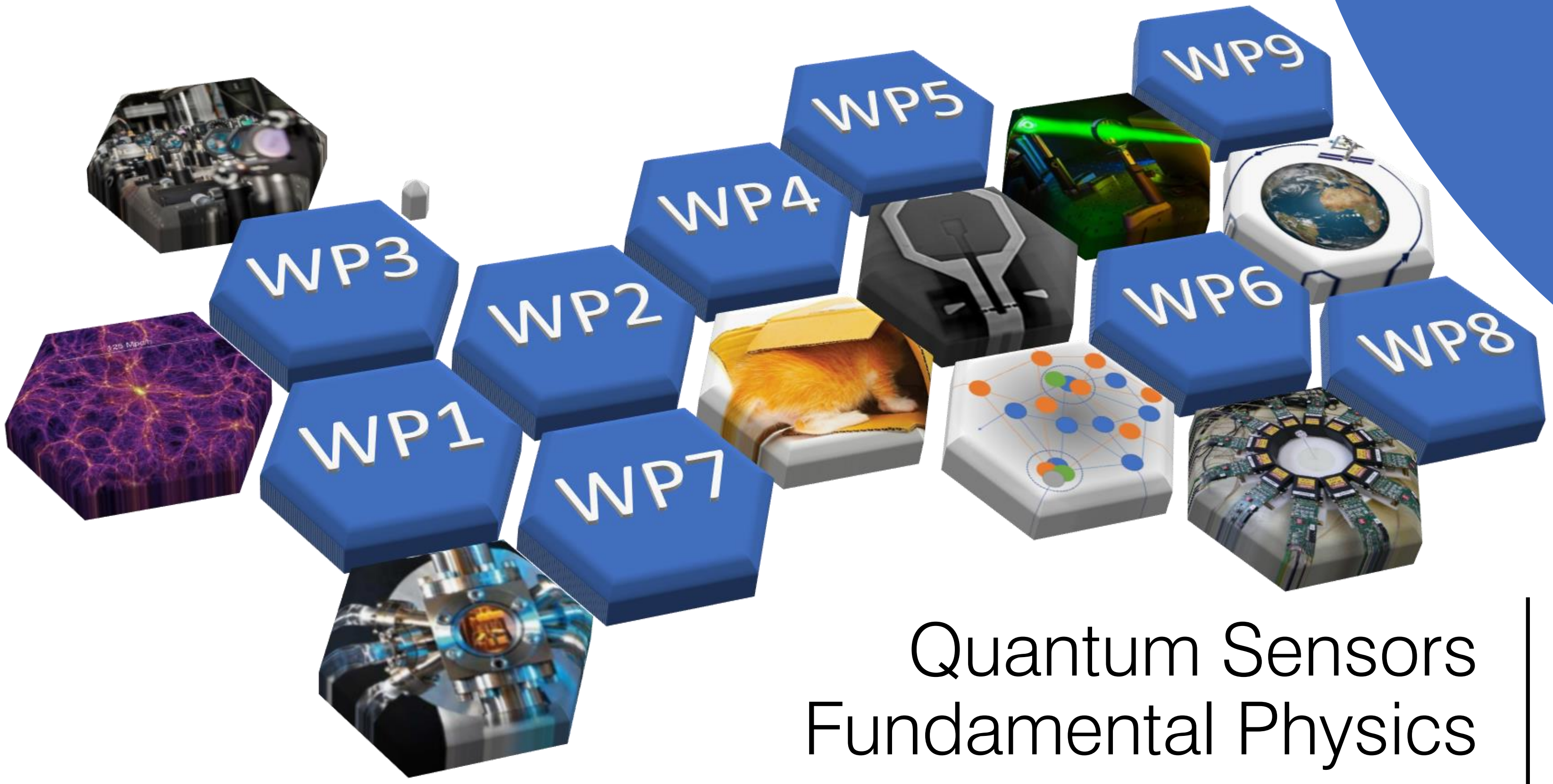


[k£]	Y1	Y2	Y3	Y4	Y5	Y6	SUM
Design & Build phase	1,403	1,939					3,341
Qualification & pre-Launch			926				926
Launch & Data analysis				296	216	206	718
TOTAL							4,985

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

UK Research
and Innovation



Quantum Sensors Fundamental Physics

Consortium

T. Bowcock