Quantum Technologies for Fundamental Physics
The AION project

Kai Bongs, Pawel Majewski and Tristan Valenzuela

RAL/PPD Open Day for PhD students, 23 February 2021

PhD student supervisors

Prof. Kai Bongs (University of Birmingham)

Director of Innovation - College for Engineering and Innovation; PI of the UK National Quantum Technology Hub in Sensors and Timing

Dr. Tristan Valenzuela (STFC/RAL)

Head of Quantum Sensors Group at RAL-Space Department

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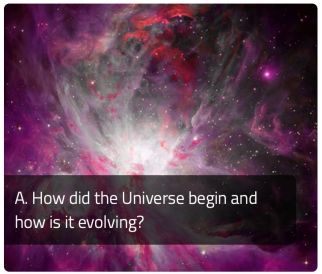
Dark Matter Group Leader at Particle Physics Department

Fundamental science challenges



B:1. How does the Sun and other stars work and what drives their variability?

B:2. What effects do the Sun and other stars have on their local environment?

B:3. What processes govern how planetary systems form and evolve?

B:4. What are the conditions for life and how widespread are they?

B:5. How diverse are exoplanets and is our earth typical?

B:6. What are the processes that drive space weather?

A:1. What are the laws of physics operating in the early Universe?

A:2. How did the initial structure in the universe form?

A:3. How is the universe evolving and what roles do dark matter and dark energy play?

A:4. When and how were the first stars, black holes and galaxies born?

A:5. How do stars and galaxies evolve?

A:6. How Do Nuclear Reactions Power Astrophysical Processes and Create the Chemical Elements?

A:7. What is the True Nature of Gravity?

A:8. What can gravitational waves and high-energy particles from space tell us about the universe?

C:1. What are the fundamental particles and fields?

C:2. What are the fundamental laws and symmetries of physics?

C:3. What is the nature of space-time?

C:4. What is the nature of dark matter and dark energy?

C:5. How do quarks and gluons form hadrons?

C:6. What is the nature of nuclear matter?

C:7. Are there new phases of strongly interacting matter?

C:8. Why is there more matter than antimatter?

C:9. What will precision measurements of the Higgs boson reveal about the Universe?

From : https://stfc.ukri.org/research/science-challenges/

Ultra-sensitive measurements with atomic clocks

Offers powerful new approach for particle physics beyond conventional particles detectors and colliders.

From table-top to hyper-large experiment

UK QTFP consortium

QTFP consortium consists of 32 UK and 7 international institutions.

First Quantum Sensors For Fundamental Physics Community Workshop, Oxford October 2018 with 140 scientists from STFC and EPSRC research councils.

Partners

RAL Space NPL Argonne Fermilab

UK QTFP consortium
AION project

WP1	WP2	WP3	WP4
Using Quantum Technology to Search for Low-mass Particles in the Hidden Sector Participants/Collaborators › Join this group ›	MaQS (pronounced "Max") Macroscopic quantum superpositions for physics beyond the standard model WP2 workshop slides › Participants/Collaborators › Join this group ›	AION A UK Atom Interferometer Observatory and Network Join this group ›	Absolute neutrino mass Participants/Collaborators › Join this group ›
WP5	**WP6**	**WP7**	**WP8**
Quantum Simulators of Fundamental Physics Participants/Collaborators › Join this group ›	QSNET Networked Quantum Sensors for Fundamental Physics Join this group ›	Searches for a Fifth Force and Dark Matter using Precision Atomic Spectroscopy Join this group ›	Fundamental physics from precision studies of exotic atoms Participants/Collaborators › Join this group ›
WP9	**WP10**	**WP11**	
LIST – Lorentz Invariance Space Test Participants/Collaborators › Join this group ›	Quantum sensors for fundamental physics: Collective quantum excitations as quantum sensors Participants/Collaborators › Join this group ›	QI: Quantum-enhanced Interferometry for New Physics	

Birmingham
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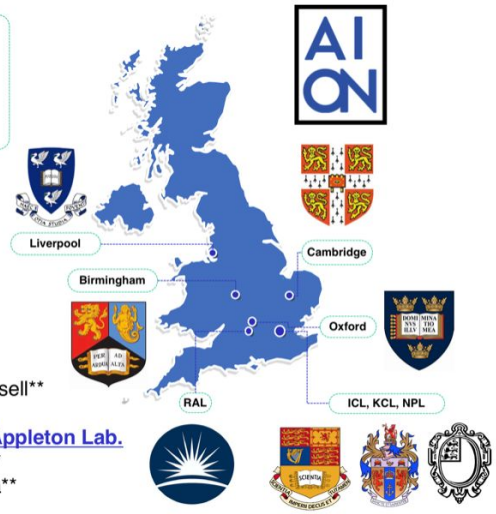
Main UK funding source:
**EPSRC; **STFC, ***NMS*

UK
- 8 Institutes
- 22 Core Members
- Many Associates

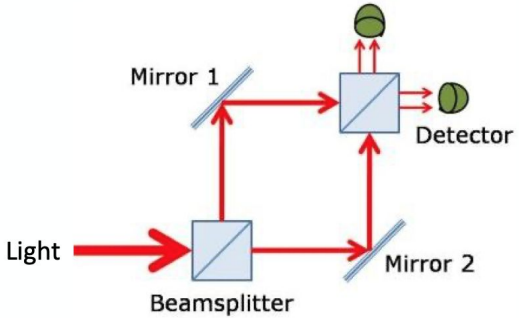


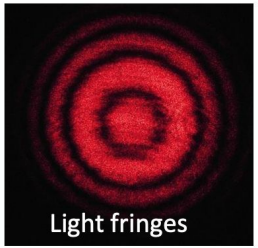
RAL responsibilities:

- Design of 10 m long interferometer (TD)
- Design of the magnetic shield (PPD)
- Establish Sr-lab to support AION programme (RAL-Space)

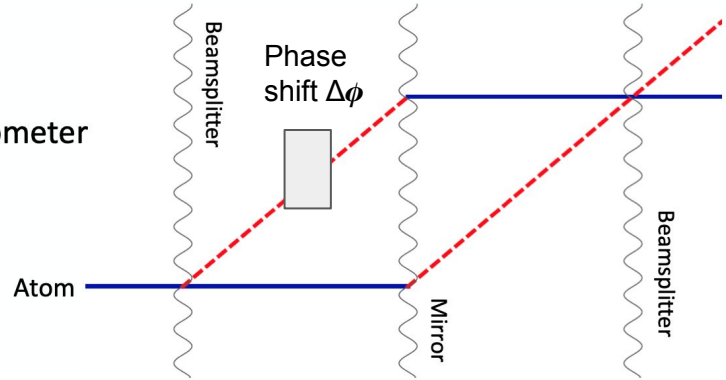
Atom interferometry

Light interferometer

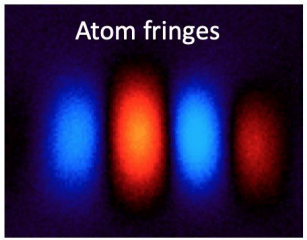




Atom interferometer



Intensity ~ $e^{i\Delta\phi}$



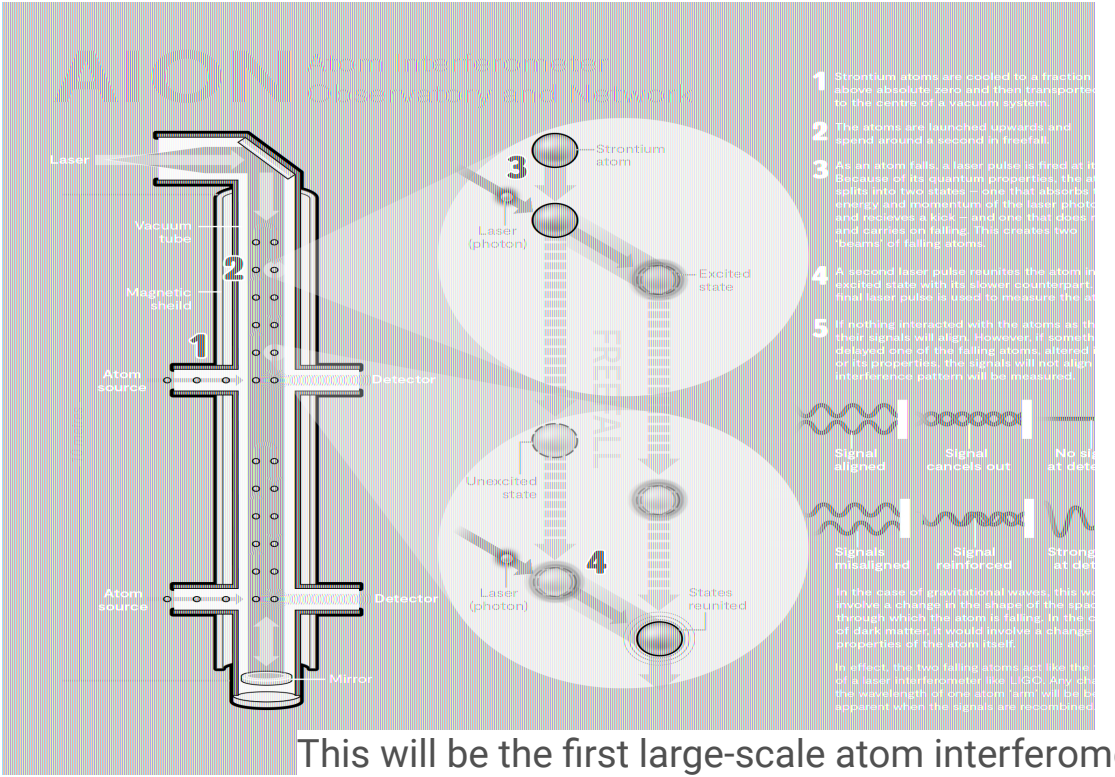
Conceptually based on Mach - Zehnder interferometer and rely on light-pulse atom-optical elements

(More details later from Tristan's slides)

The phase difference is readout by measuring the the atom populations in the interferometer outputs

https://indico.cern.ch/event/760005/contributions/3152410/attachments/1734791/2806986/AI-Fundamental-hogan-final.pdf

*An Atom Interferometer Observatory and Network (**AION**) for the exploration of Ultra-Light Dark Matter And Gravitational Waves*



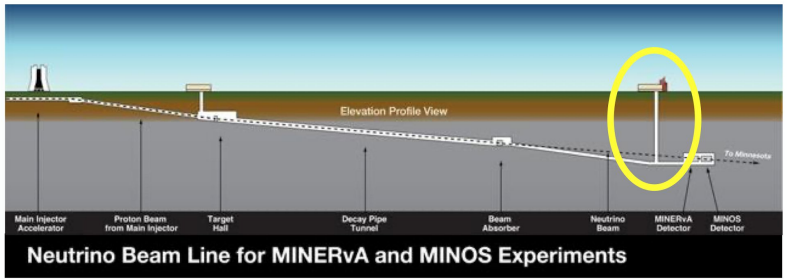
AION project programme

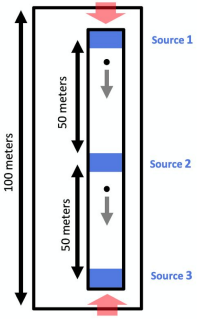
- **Design of 10 m long atom interferometer 2021-2023**
- **Construction and exploitation at Oxford planned 2023-2027**
- **Design/construction/exploitation of 100 m long atom interferometer possibly at Boulby mine**
- **Design/construction/exploitation of 1 km long atom interferometer possibly at Boulby mine**

This will be the first large-scale atom interferometer in the UK.

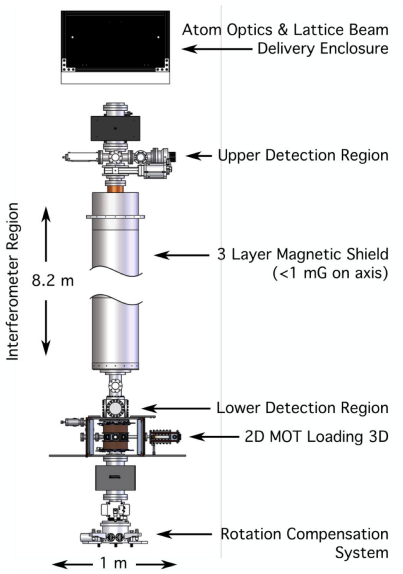
Collaboration with MAGIS-100 project in the US

Matter wave **A**tomic **G**radiometer **I**nterferometric **S**ensor



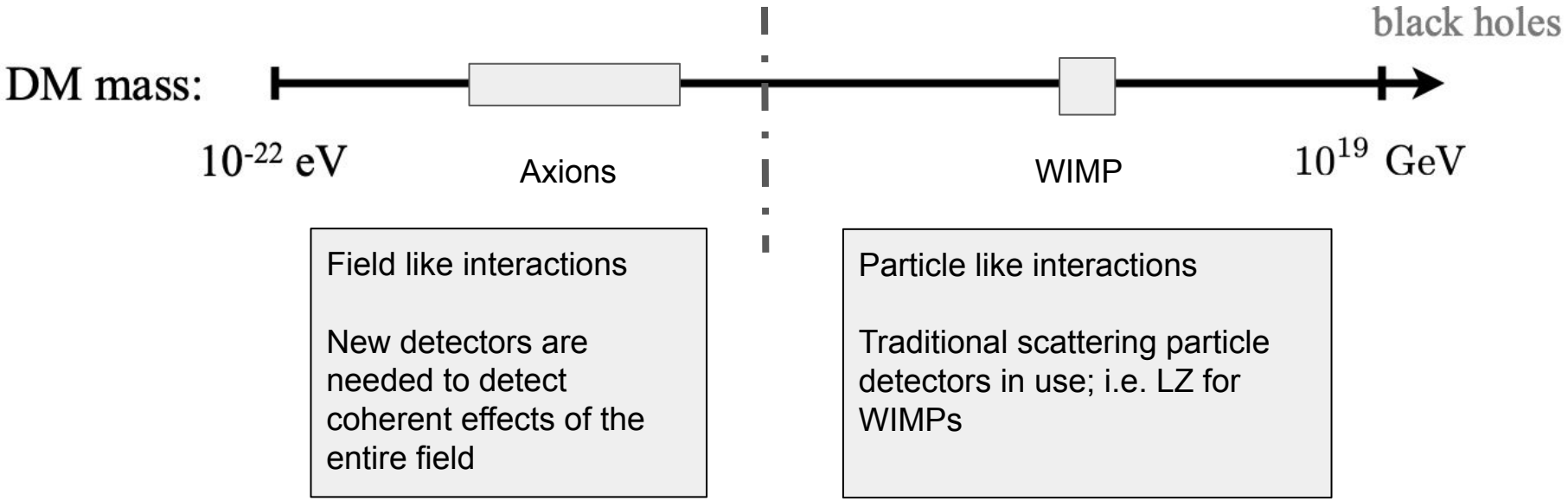


MAGIS will be the world's largest atom interferometer and push the boundaries of how far an atom can be driven apart from itself.



Design based on 10 m long interferometer at the University of Stanford.

Atom interferometer for Ultra Light Dark Matter Searches and Gravitational Waves Observation



Magnitude of contribution to phase shift : $\Delta\phi \sim \omega_A(2L/c)$
Detection of the gravitational waves: $\delta L = hL$ (variation of baseline)
Detection of ultra light dark matter: $\delta\omega_A$ (variation of atom transition frequency)

From : https://indico.cern.ch/event/610112/contributions/2570059/attachments/1456873/2248556/Pheno.pdf


The future is quantum !