New Physics Searches with FLASH and Quantum R&D at Liverpool

Paolo Beltrame

1. Axions

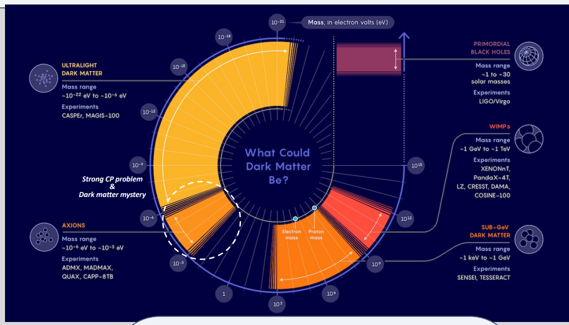
- Peccei-Quinn solution (1977) for QCD
- Invisible axion (1979)
  - Very light (*sub-eV*)
  - Extremely weakly interacting
  - Produced in early Universe

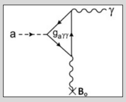
A detergent cleans up the problem!

- Wilczek & Weinberg (1978)

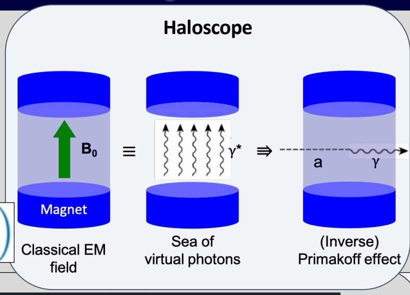
Detecting Axions
(*Turning dark matter into light!*)

- Sikivie (1983): **probing $g_{a\gamma\gamma}$**

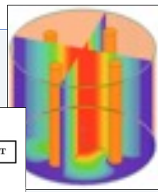


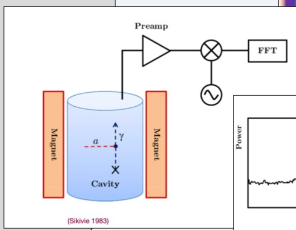


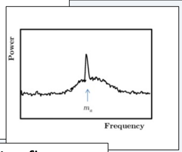
$$P = g^2_{a\gamma\gamma}\frac{\rho_a}{m_a}\left(B_0^2 V C\frac{\beta}{1+\beta}Q_L\right)$$



- Electromagnetic modes in the cavity: TM and TE
- **Resonance cavity tunable with tuning rods**







- Low noise floor
- Scan the frequency

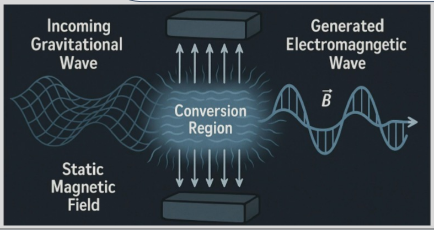
$$t \sim \frac{1}{\Delta\nu}\left(\frac{T_{noise}}{P_{signal}}\right)^2$$

2. High Frequency Gravity Waves

- Same haloscope
Gertsenshtein effect (1962)

- Probing the strain from HFGW

$$P_{\rm sig} = \frac{\beta}{1+\beta}\frac{\omega_g}{2\mu_0}h^2_{\times,+}\langle B_0^2\rangle Q_l C^{\times,+}_{\rm GW} V$$

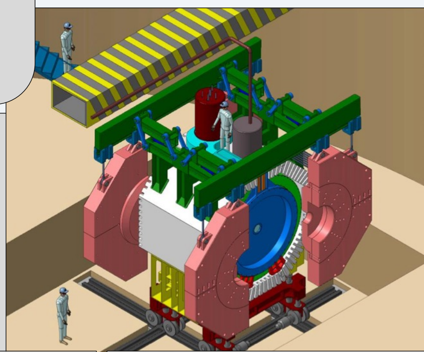


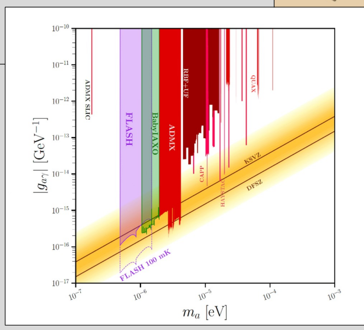
3. FLASH experiment

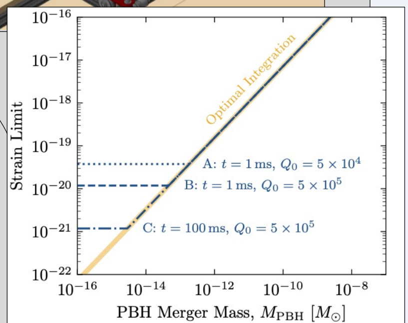
(Physics of the Dark Universe 42 (2023) 101370)

Complete the Technical Design Report by early 2027

- FINUDA magnet for Light Axion Search Haloscope
- FLASH haloscope, inside the 3 *m* diameter magnet FINUDA
- Between 100 – 300 *MHz* at 1.9 *K*
- Quantum sensing as detection devices (tiny variation of the magnetic field)
- Largest experiment with cryogenic cavities!
- Probing QCD axion mass in 0.5 – 1 μeV range!
- New search for HFGW and physics BSM





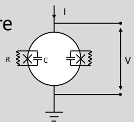


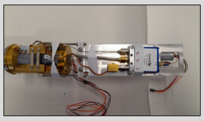
SQUID (Superconducting Quantum Interference Device)

Extremely sensitive magnetometer able to detect *fT*.
Superconducting loop interrupted by Josephson junctions.
Current flowing highly sensitive to the exact magnetic flux threading the loop -> oscillating voltage response as flux changes

DC-SQUID
- Ultra-low dissipation -> operate at *mK* temperatures
- Temperature-Dependent Noise: scales with temperature down to 200-300 *mK*
- Energy resolution approaching the Quantum Limit

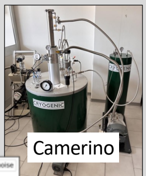
Microstrip SQUID Amplifier
- Gain ≈ 17 *dB*, expected noise T_n ≈ 1.7 *K*

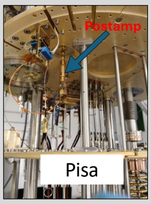


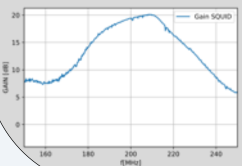


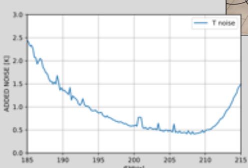
Testing the FALSH Quantum Sensors in Frascati, Camerino and Pisa ...

Thermal noise of the tested SQUID
~ 2.2 *K* @ 120 *MHz*









4. The Liverpool Quantum Program

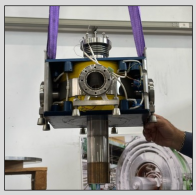
- Quantum Science and Technologies Developments in Liverpool (**recently started**)
- Collaboration with FLASH
+ independent line of R&D and research

- Testing SQUID in high magnetic field
  - Field shielding
  - Electronics and DAQ system

Superconducting (NbTi) Magnet
- Magnetic field: 8 *T* @ 4.2 *K*
- Homogeneity: ± 0.5 % (1 *cm* dsv)
- Max current: 85 *A*

Liquid He facility
- NexGen 160

Quantum Design UK AND IRELAND



Short term Liverpool program for Quantum development
+ Cooperation with Lancaster University

Lancaster University