

Searching for axion-like particles using quantum sensors

Exploring the Invisible: How Quantum Sensors May Help Unveil Dark Matter

One of the greatest mysteries in modern physics is the nature of **dark matter**, which does not emit light, cannot be seen directly, and yet **makes up about 85% of the matter in the universe**. Its presence is inferred from its gravitational effects on galaxies and the large-scale structure of the cosmos, but we still don't know what it's made of. Among the most **promising candidates** are ultralight particles, such as **axion-like particles (ALPs)**, which could form a kind of invisible field that fills space.

This project explores a new way to **search for such particles using extremely sensitive quantum sensors** and more specifically, **atomic magnetometers**. These devices can detect incredibly tiny changes in magnetic fields by observing the behavior of atoms. When placed in a magnetic environment, the **spins of atoms** (a quantum property related to magnetism) **can shift in response to external influences, including possible interactions with dark matter fields**.

The project combines two key elements. First, we analyze data from the **Global Network of Optical Magnetometers for Exotic physics searches (GNOME)**, an international collaboration that uses synchronized magnetometers placed around the world to look for unusual, coordinated signals that might hint at dark matter. We focus on a special kind of interaction where the ALP field doesn't act directly on atomic spins, but instead through its **intensity**, which varies slowly in space and time. By studying how the intensity of this invisible field might fluctuate and create correlated signals across the globe, we use a method inspired by **intensity interferometry** - a technique originally used in astronomy to analyze light from stars.

Second, we develop and test a next-generation type of atomic magnetometer, called a **rotating-wave (RoW) comagnetometer**. This new design allows us to **fine-tune the sensor's sensitivity to specific frequencies** where dark matter signals may appear. Unlike traditional systems, which are best at detecting slow signals, the RoW method **enables detection of faster oscillations** without losing the ability to filter out unwanted noise. This is important because the predicted dark matter signals may oscillate much more rapidly than typical environmental disturbances.

Together, these two components: data analysis and sensor innovation, will help **push the boundaries of what current technology can detect**. Even if no dark matter is found, the project will **set new limits on the strength of possible interactions** and help guide future searches. Moreover, the techniques developed here have broader applications in precision measurement, including **tests of fundamental symmetries in physics and the development of quantum technologies**.

By combining cutting-edge atomic physics, global collaboration, and new theoretical ideas, this project contributes to the long-term goal of understanding the hidden structure of the universe.