JAGIELLONIAN UNIVERSITY
IN KRAKOW

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Kraków, 10 September 2021

Job offer for a MSc student within the project entitled *Searching for ultralight dark matter*

We are seeking for MSc candidates interested in joining the project entitled ***Searching for ultralight dark matter*** realized within t**he OPUS programme** funded by **the National Science Centre of Poland**. Detailed of the project, along with the important information are given below.

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Details of the offer

Project title: Poszukiwania ultralekkiej ciemnej materii (Searching for ultralight dark matter)

Project leader: Szymon Pustelny

Institution: Marian Smoluchowski Institute of Physics

Advertised position: MSc student

Requirements:

Basic requirements:
1. BSc diploma in physics or related field.
2. General knowledge on optics and atomic physics.
3. Experience in experimental physics.
4. Programming skills (Python).
5. General knowledge of statistics.
6. Good English language abilities.

Required documents:
1 Cover letter.
2. Professional curriculum vitae.
3. Brief description of the research activity to date (if any)
4. Copy of higher education diploma.

Job description:

Assistance in experimental research on ultra-light dark matter using network of synchronized optical magnetometers and processing data achieved using the network in the scope of specific theoretical model.

Project funding: OPUS – ST NCN

Application deadline: 27 September 2021, 00:00

Application form: email

Offer conditions:

1. Possibility to participate in an exciting, international research project searching for signatures of physics beyond the Standard Model.
2. Collaboration with the renown international team.
3. Access to world-class experimental apparatus.
4. Monthly stipend (1500 PLN) for up to three years.

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Additional information
If you are interested in the offer, please send the required documents to **pustelny@uj.edu.pl**.

Based on the received documents, the selection committee will shortlist the best candidates, which may be invited for an interview (in person of online). As a result process, the ranking of applicants will be prepared and position will be offer to the candidates with best ranking (starting from the top of the list).

Project description:
While a number of astronomical observations suggest existence of matter that neither emits, nor absorbs, nor scatters electromagnetic radiation, all to-date attempts to directly capture its existence have been unsuccessful. This led to a significant increase of competing models predicting new dark-matter (DM) candidates and means of its interaction with ordinary matter. A particularly interesting DM constituent would be ultralight bosons (ULBs).

Due to their extremely low mass (<<1 eV/c2, where c is the speed of light), ULBs should behave differently than other DM candidates. In fact, they would manifest as coherent ultralight fields (ULFs) with a high mode-occupation number, but not as individual particles. This feature must be reflected in ULB search strategies. To address this fact, we propose to exploit techniques of modern atomic physics and use one of the most sensitive quantum sensors known today – atomic magnetometers – as tools to search for those particles.

The operation principle of an atomic magnetometer is based on the measurement of the spin state of atoms constituting its active medium, which typically is an alkali-metal atomic vapor. Although an atomic spin state is most prominently affected by the magnetic field, atomic magnetometers are generally sensitive to other spin couplings, too. In principle, they can be used to search for DM, assuming that it exhibits such a coupling.

This project aims at searching for DM characterized with so-called pseudoscalar spin coupling. Such a coupling is expected of ULBs, if the corresponding field is spatially or temporarily inhomogeneous. Therefore, we propose to use atomic magnetometers to search for so-called wavy and clumpy DM. The first type of DM is oscillatory in nature and it would give rise to effects, manifesting as temporal oscillations in observed signals. The source of such oscillations could be, for example, various modes of the bosonic field, that we encounter as Earth moves through space. Alternatively, such oscillatory behavior could be observed when a burst of ULBs generated in a cataclysmic astrophysical events (e.g., supernovae, black-hole merge, neutrino-star merger, fast radio burst), passes though Earth. This also opens means for further embracing capabilities of multi-messenger astronomy, with “exotic physics” channel. The second type of DM could be generated either due to self-interaction or gravity or due to phase transition of primordial boson field. In this case, a sensitive experiment would detect an DM interaction as a short exotic pulse, when Earth collides with DM stars or ULF domain wall.

To increase the capabilities of DM searches using atomic magnetometers, we propose to embed the devices in a network. Such a network, existing in the form of the Global Network of Optical Magnetometers for Exotic physics searches (GNOME), have already demonstrated its capabilities by proving that the search sensitivity can be increased by a factor of N_s^(1/2), where N_s is the number of sensors in the network. It also reduced a false-positive rate by performing consistency checks based

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on specific spatio-temporal pattern of signals time and amplitudes in specific locations. We propose to further improve the capabilities of the network by studying, both theoretically and experimentally, the so-called advanced GNOME sensor with reduced magnetic sensitivity and thus enhanced sensitivity to the other spin couplings. With the development of the magnetometer, we plan to investigate models that have not been explored to date. In particular, we will be investigating models predicting the existence of domain walls of ULFs, DM stars, stochastic fluctuations of the randomized ULFs, and emission of ULFs during violent astronomical events. To test the models, regardless of theoretical and experimental investigations already discussed, we will work on methods of data analysis. We plan to analyze the data using already known techniques (e.g., Fourier transform, excess-power analysis), as well as develop techniques that have never been applied in this context (cyclostationarity, multi-node correlation). Based on them, we will be able to either sample the parameter space of unexplored models or significantly enhanced previous research.

We are certain that with this research we will be able to significantly contribute to the field of DM searches and, in the most conservative scenario, limit the parameter space of the DM-candidates described above.