The Henryk Niewodniczański
Institute of Nuclear Physics
Polish Academy of Sciences

Radzikowskiego 152
31-342 Kraków, Poland
switchboard: +48 12 6628000
director: +48 12 6628200
fax: +48 12 6628458
www.ifj.edu.pl
dyrektor@ifj.edu.pl

Cracow, 14 February 2018

The search for dark matter: Axions have ever fewer places to hide

If they existed, axions – one of the candidates for particles of the mysterious dark matter – could interact with the matter forming our world, but they would have to do this to a much, much weaker extent than it has seemed up to now. New, rigorous constraints on the properties of axions have been imposed by an international team of scientists responsible for the nEDM experiment.

The latest analysis of measurements of the electrical properties of ultracold neutrons published in the scientific journal *Physical Review X* has led to surprising conclusions. On the basis of data collected in the nEDM (Electric Dipole Moment of Neutron) experiment, an international group of physicists – including the Cracow-based scientists from the Institute of Nuclear Physics of the Polish Academy of Sciences (IFJ PAN) and the Jagiellonian University – showed in an innovative way that axions, the hypothetical particles that may form cold dark matter, if they existed, would have to comply with much stricter limitations than previously believed with regard to their mass and manners of interacting with ordinary matter. The presented results are the first laboratory data imposing limits on the potential interactions of axions with nucleons (i.e. protons or neutrons) and gluons (the particles bonding quarks in nucleons).

“Measurements of the electric dipole moment of neutrons have been conducted by our international group for a good dozen or so years. For most of this time, none of us suspected that any traces associated with potential particles of dark matter might be hidden in the collected data. Only recently, theoreticians have suggested such a possibility and we eagerly took the opportunity to verify the hypotheses about the properties of axions,” says Dr. Adam Kozela (IFJ PAN), one of the participants of the experiment.

The first traces of dark matter were found when analyzing the movements of stars in galaxies and galaxies in galaxy clusters. The pioneer of statistical research on star movements was the Polish astronomer Marian Kowalski. Already in 1859 he noticed that the movements of stars close to us could not be explained solely by the movement of the Sun. This was the first observational premise suggesting the rotation of the Milky Way (Kowalski is thus the man who “shook the foundations” of the galaxy). In 1933, the Swiss Fritz Zwicky went one step further. He analyzed the movements of structures in the Coma galaxy cluster by several methods. He then noticed that they moved as if there were a much larger amount of matter in their surroundings than that seen by astronomers.

Despite decades of searching, the nature of dark matter, which (as background microwave radiation measurements suggest) there should be almost 5.5 times as much of in the Universe as ordinary matter, is still unknown. Theoreticians have constructed a whole plethora of models predicting the existence of particles that are more exotic or less so, that may be responsible for the existence of dark matter. Among the candidates are axions. If they did exist, these extremely light particles would interact with ordinary matter almost exclusively by gravity. Almost, because current models predict that in certain situations a photon could change into an axion, and after some time this would transform back into a photon. This hypothetical phenomenon was and is the basis of the famous "lighting through a wall" experiments. These involve researchers directing an intense beam of laser light onto a thick obstacle, counting on the fact that at least a few photons will change into axions that will penetrate the wall without any major problems. After passing through the wall, some axions could become photons again with features exactly like the photons originally falling on the wall.

Experiments related to measuring the electric dipole moment of neutrons, conducted by a group of researchers from Australia, Belgium, France, Germany, Poland, Switzerland and Great Britain, have nothing to do with photons. The measuring apparatus that was initially located at the Institut Laue-Langevin (ILL) in Grenoble (France) is currently operating at the Laboratory for Particle Physics at the Paul Scherrer Institute (PSI) in Villigen (Switzerland). In experiments that have been conducted for over ten years, scientists measure changes in the frequency of nuclear magnetic resonance (NMR) of neutrons and mercury atoms that are in a vacuum chamber in the presence of electric, magnetic and gravitational fields. These measurements enable conclusions to be drawn about the precession of neutrons and mercury atoms, and consequently on their dipole moments.

To the surprise of many physicists, in recent years theoretical works have appeared that envisage the possibility of axions interacting with gluons and nucleons. Depending on the mass of the axions, these interactions could result in smaller or larger disturbances having a character of oscillations of dipole electrical moments of nucleons, or even whole atoms. The theoreticians' predictions meant that experiments conducted as part of the nEDM cooperation could contain valuable information about the existence and properties of potential particles of dark matter.

"In the data from the experiments at PSI, our colleagues conducting the analysis looked for frequency changes with periods in the order of minutes, and in the results from ILL – in the order of days. The latter would appear if there was an axion wind, that is, if the axions in the near Earth space were moving in a specific direction. Since the Earth is spinning, at different times of the day our measuring equipment would change its orientation relative to the axion wind, and this should result in cyclical, daily changes in the oscillations recorded by us," explains Dr. Kozela.

The results of the search turned out to be negative: no trace of the existence of axions with masses between 10^{-24} and 10^{-17} electronvolts were found (for comparison: the mass of an electron is more than half a million electronvolts). In addition, scientists managed to tighten the constraints imposed by theory on the interaction of axions with nucleons by 40 times. In the case of potential interactions with gluons, the restrictions have increased even more, more than one thousand-fold. So then, if axions do exist, in the current theoretical models they have fewer and fewer places to hide.

CONTACTS:

Dr. **Adam Kozela**
The Institute of Nuclear Physics Polish Academy of Sciences
tel.: +48 12 662 8290, +48 12 662 6120
email: adam.kozela@ifj.edu.pl

SCIENTIFIC PAPERS:

1. "Search for Axionlike Dark Matter through Nuclear Spin Precession in Electric and Magnetic Fields"
   C. Abel et al.
   Physical Review X 7, 041034 (2017)
   DOI: 10.1103/PhysRevX.7.041034

LINKS:

http://www.ifj.edu.pl/
The website of the Institute of Nuclear Physics Polish Academy of Sciences.

http://press.ifj.edu.pl/
Press releases of the Institute of Nuclear Physics Polish Academy of Sciences.

IMAGES:

IFJ180214b_fot01s.jpg **HR:** http://press.ifj.edu.pl/news/2018/02/14/IFJ180214b_fot01.jpg
The distribution of dark matter (colored in blue) in six galaxy clusters, mapped from the visible-light images from the Hubble Space Telescope. (Source: NASA, ESA, STScI, and CXC)