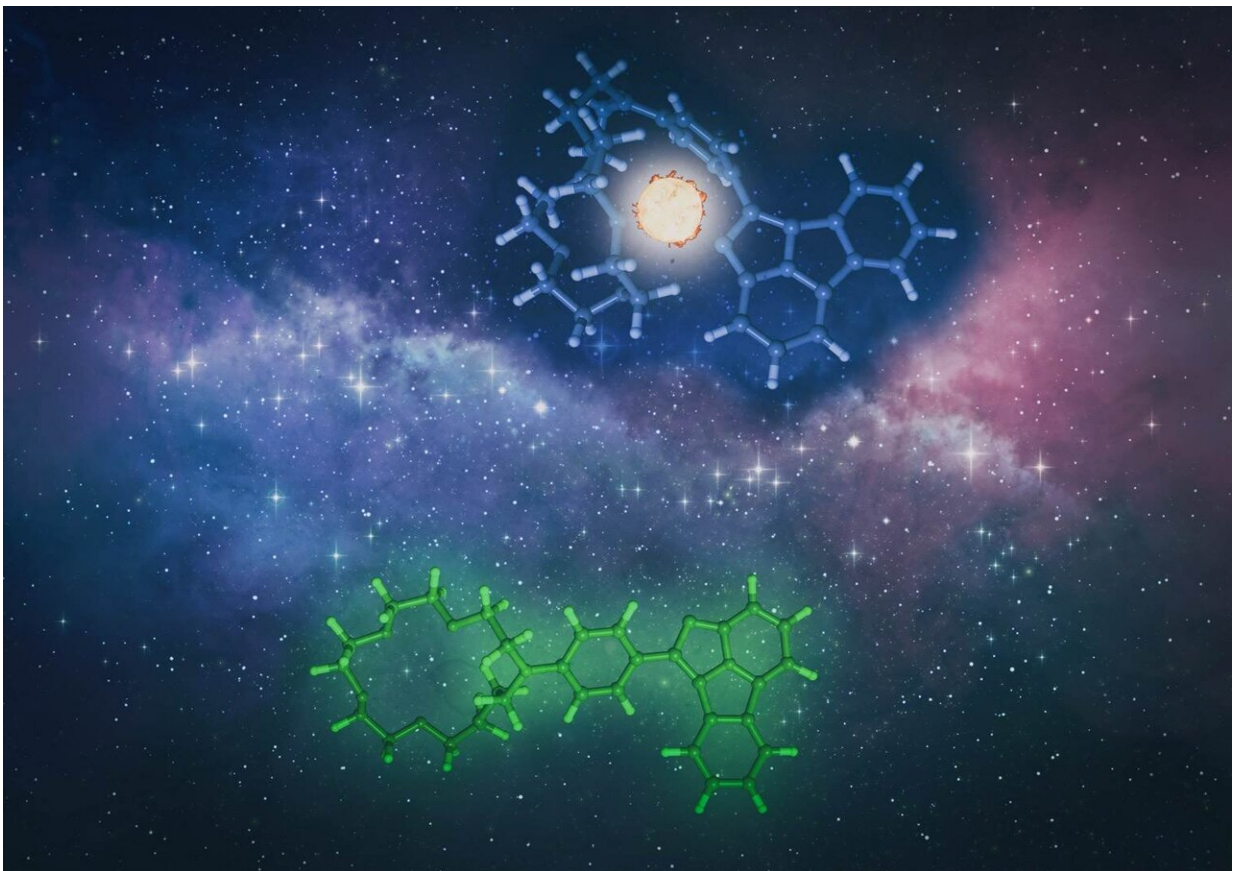


A blue spark to shine on the origin of the universe

June 23 2020



Artistic representation of the new fluorescent molecule that can shed light on the elusive nature of neutrinos. Credit: University of the Basque Country

An interdisciplinary team of scientists led by researchers from DIPC,

Ikerbasque and UPV/EHU, has demonstrated that it is possible to build an ultra-sensitive sensor based on a new fluorescent molecule able to detect the nuclear decay key to knowing whether or not a neutrino is its own antiparticle.

The results of this study, published in the prestigious journal *Nature*, have great potential to determine the nature of the neutrino and thus answer fundamental questions about the origin of the universe.

Why is our universe made of matter? Why does everything exist as we know it? These questions are linked to one of the most important unsolved problems in particle physics. This problem is that of the nature of the neutrino, which could be its own antiparticle, as argued by the unfortunate Italian genius Ettore Majorana almost a century ago. If this were so, it could explain the mysterious cosmic asymmetry between matter and antimatter.

Indeed, we know that the universe is made almost exclusively of matter. However, the Big Bang theory predicts that the early universe contained the same amount of matter and antimatter particles. This prediction is consistent with the "small Big Bangs" that form in proton collisions at CERN's giant LHC accelerator, where a symmetrical production of particles and antiparticles is always observed. So, where did the antimatter of the early universe go? A possible mechanism points to the existence of heavy neutrinos that were its own antiparticle, and therefore, could decay into both matter and antimatter. If a second phenomenon occurs, called violation of charge and parity (that is, if the neutrino slightly favors in its decay the production of matter over that of antimatter), then it could have injected an excess of the first over the second. After all the matter and antimatter in the universe were annihilated (with the exception of this small excess), the result would be a cosmos made only of matter, of the leftovers from the Big Bang. We could say that our universe is the remnant of a shipwreck.

It is possible to demonstrate that the neutrino is its own antiparticle by observing a rare type of nuclear process called neutrinoless double beta decay (bb0nu), in which concurrently two neutrons (n) of the nucleus are transformed into protons (p) while two electrons (e) are emitted out of the atom. This process can happen in some rare isotopes, such as Xenon-136, which has in its nucleus 54 p and 82 n, in addition to 54 e when is neutral. The NEXT experiment (directed by J.J. Gómez-Cadenas, DIPC and D. Nygren, UTA), located in the underground laboratory of Canfranc (LSC), looks for these decays using high pressure gas chambers.

When a Xe-136 atom undergoes spontaneous bb0nu decay, the result of the process is the production of a doubly charged ion of Barium-136 (Ba_2^+); with 54 e and a nucleus made of 56 p and 80 n; and two electrons ($Xe \rightarrow Ba_2^+ + 2e$).

So far, the NEXT experiment has focused on observing these two electrons, whose signal is very characteristic of the process. However, the bb0nu process that is meant to be observed is extremely rare and the signal that is expected is of the order of one bb0nu decay per ton of gas and year of exposure. This very weak signal can be completely masked by background noise due to the ubiquitous natural radioactivity. However, if in addition to observing the two electrons, the barium ionized atom is also detected, the background noise can be reduced to zero, since natural radioactivity does not produce this ion. The problem is that observing a single ion of Ba_2^+ in the midst of a large bb0nu detector is technically so challenging that until recently it was considered essentially unfeasible. However, a number of recent works, the latest of which has just been published in the journal *Nature*, suggest that the feat may be feasible after all.

The work, conceived and led by the researchers F.P. Cossío, Professor at the University of the Basque Country (UPV/EHU) and Scientific

Director of Ikerbasque, and J.J. Gómez-Cadenas, Professor Ikerbasque at the Donostia International Physics Center (DIPC), includes an interdisciplinary team with scientists from DIPC, the UPV/EHU, Ikerbasque, the Optics Laboratory of the University of Murcia (LOUM), the Materials Physics Center (CFM, a joint center CSIC-UPV/EHU), POLYMAT, and the University of Texas at Arlington (UTA). Gómez-Cadenas says, "The result of this interdisciplinary collaboration that combines, among other disciplines, particle physics, organic chemistry, surface physics and optics, is a clear example of the commitment that DIPC has recently shown to developing new research lines. The purpose is not only to generate knowledge in other fields, different from the centre's usual ones, but also to look for hybrid grounds and create interdisciplinary projects that, in many cases, like this one, can be the most genuine."

The research is based on the idea, proposed by one of the authors of the article, the prestigious scientist D. Nygren (inventor, among other devices of the Time Projection Chamber technology applied by many particle physics experiment, including NEXT). In 2016, Nygren proposed the feasibility to capture Ba_2^+ with a molecule capable of forming a supramolecular complex with it and to provide a clear signal when this occurs, thus yielding a suitable molecular indicator. Nygren and his group at UTA then went into designing "on-off" indicators, in which the signal of the molecule is highly enhanced when a supramolecular complex is formed. The group led by Cossío and Gómez-Cadenas has followed a different path, designing a fluorescent bicolor indicator (FBI) which combines a large intensity enhancement and a dramatic color shift when the molecule captures Ba_2^+ . The synthesis of FBI was done under the direction of DIPC researcher I. Rivilla. If an FBI molecule with no barium is illuminated with ultraviolet light, it emits fluorescence in the range of green light, with a narrow emission spectrum of about 550 nm. However, when this molecule captures Ba_2^+ , its emission spectrum shifts towards blue (420 nm). The combination of

both features results in a spectacular enhancement of the signal, thus making it very suitable for a future Ba_2^+ detector.

It is interesting to note that the experimental multiphoton microscopy systems used in the LOUM by P. Artal's group for the green/blue spectral detection are based on those developed previously for imaging the cornea of the human eye in vivo. This is an example of interlacing the use of a unique technology in the world for biomedical applications on a fundamental problem of [particle physics](#). "The effort to combine basic science and new instrumental implementations is essential to open new research avenues to answer the many questions that we scientists ask ourselves every day," says J.M. Bueno, Professor of Optics at LOUM.

As Cossío has explained, "the most difficult task in the chemical part of the work was to design a new molecule that would meet the strict (almost impossible) requirements imposed by the NEXT experiment. This molecule had to be very bright, capture barium with extreme efficiency (bb0nu is a very rare event and no cation could be wasted) and emit a specific signal that would allow the capture to be detected without background noise. In addition, the chemical synthesis of the new FBI sensor had to be efficient in order to have enough ultra-pure samples for installation within the detector. The most rewarding part was to check that, after many efforts by this multidisciplinary team, actually our specific and ultra-sensitive FBI sensor worked as planned."

Besides the design and characterization of FBI, the paper offers the first demonstration of the formation of a supramolecular complex in dry medium. This landmark result has been achieved preparing a layer of FBI indicators compressed over a silica pellet and evaporating over such a layer a salt of barium perchlorate. Z. Freixa, Ikerbasque Professor at the UPV/EHU says, "The preparation of FBI on silica has been a quick-but-not-so-dirty solution for this proof of concept. A bit of home alchemy." The vacuum sublimation experiment was done by the CSIC

scientist at CFM C. Rogero and her student P. Herrero-Gómez. Rogero, an expert in physics of surfaces says: "It was one of those Eureka moments, when we realized that we had in my lab just the tools to carry on the experiment. We evaporated the perchlorate and got FBI shining in blue almost at the first attempt."

The next step of this research project is the construction of an FBI based sensor for the detection of the neutrinoless double beta decay or $bb0\nu$, for which Gomez-Cadenas, F. Monrabal from DIPC and D. Nygren and collaborators at UTA are developing a conceptual proposal.

This work is a significant advance towards building a future 'barium-tagging' NEXT experiment to look for noise-free $bb0\nu$ events through the identification of the two electrons and the barium atom produced in the reaction. This experiment would have a great potential to find out if the neutrino is its own antiparticle, which could lead to answer fundamental questions about the origin of the universe.

More information: Iván Rivilla et al. Fluorescent bicolour sensor for low-background neutrinoless double β decay experiments, *Nature* (2020). [DOI: 10.1038/s41586-020-2431-5](https://doi.org/10.1038/s41586-020-2431-5)

Provided by University of the Basque Country

Citation: A blue spark to shine on the origin of the universe (2020, June 23) retrieved 26 April 2024 from <https://phys.org/news/2020-06-blue-universe.html>

This document is subject to copyright. Apart from any fair dealing for the purpose of private study or research, no part may be reproduced without the written permission. The content is provided for information purposes only.