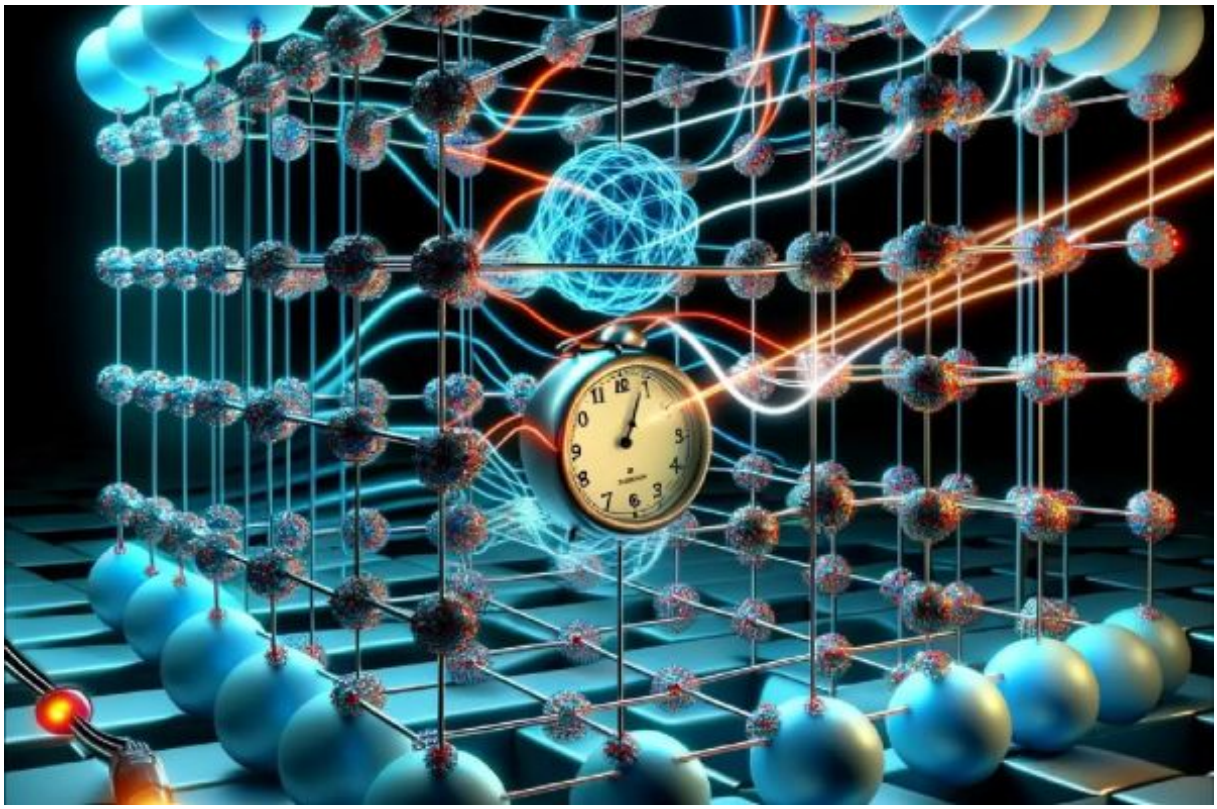

Synthetic dimensions: recent progress and future perspectives

In a review published in Communications Physics, researchers from ICFO, UPC, UAB, DIPC, HRI and Adam Mickiewicz University present the recent progress on utilizing synthetic dimensions of quantum matter for exploration of exotic quantum phenomena.

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We live in a space with three dimensions: length, height and width. Imagining 3D objects is thus very natural to us, but there are some physics phenomena that happen in higher dimensional spaces, what makes directly observing them virtually impossible. The only way to circumvent this obstacle is to engineer artificial matter that does behave according to higher dimensional physics. Then, one can access these extra dimensions, known as synthetic dimensions.

There are multiple platforms to generate the aforementioned artificial matter, which use atoms, molecules or light as their main ingredient. They are particularly useful for quantum simulation (the field that, by using quantum resources, solves specific problems that are impossible or extremely demanding for classical computers), since synthetic dimensions

provide access to aspects of interacting quantum matter that otherwise would have remained in the dark.

A new perspective article, published in Communications Physics, reports on the **recent progress on synthetic dimensions studies** developed in an international collaboration between **ICREA Prof. at ICFO Leticia Tarruell** and **ICREA Prof. at ICFO Maciej Lewenstein**, with ICFO researchers **Dr. Javier Argüello**, **Dr. Utso Bhattacharaya**, **Dr. Tobias Grass**, **Dr. Marcin P?odzien**, **Dr. Tymoteusz Salamon**, **Dr. Paolo Stornati** as well as with the contribution of Universitat Politecnica de Catalunya (UPC), Universitat Autonoma de Barcelona (UAB), Adam Mickiewicz University (UAM), Donostia International Physics Center (DIPC) and Harish-Chandra Research Institute (HRI).

It is important to note that synthetic dimensions have much more practical applications than going from 3 dimensions to (quasi) 4 or even 5 dimensions. In many situations in theory or experiment, working with 1-dimensional or 2 dimensional systems is relatively easier. The synthetic dimensions approach transforms them into (quasi) 2 or (quasi) 3-dimensional systems, respectively. In this way, one can realize, for instance, 2-dimensional quantum Hall effect physics in 1 dimension, or twisted bilayer physics in 2 dimensions.

The article provides a comprehensive overview over the state-of-the-art avenues on utilizing synthetic dimension technique for studies on exotic and higher dimensional phenomena with the help of quantum random walks or time crystals, among others. Authors describe the major applications of synthetic dimensions, mainly based on atomic platforms, in fields as diverse as quantum gravity, solid-state physics or particle physics, **specially focusing on what quantum simulation can bring to all these areas when it exploits synthetic dimensions**.

They also detail several experiments that were either not possible using conventional 3D space realizations or for which the experimental complexity was much higher, expecting novel experimental efforts to keep shedding light on a wide variety of physics phenomena.

Bibliographic reference:

Argüello-Luengo, J., Bhattacharya, U., Celi, A. et al. Synthetic dimensions for topological an quantum phases. Commun Phys 7, 143 (2024).https://doi.org/10.1038/s42005-024-01636-3