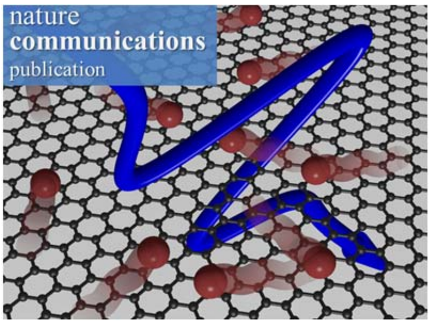
Publishable Summary:

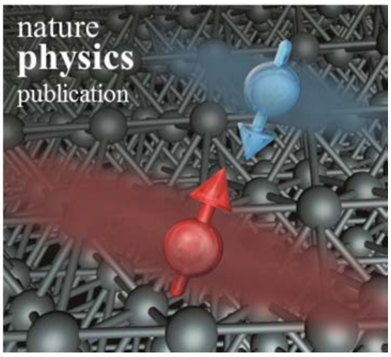
In this project we experimentally studied the behavior of light and matter on the timescales, at which their fundamental properties are being formed. We wanted to find out how fast do some of the fundamental physical phenomena occur, and what exactly governs these critical timescales.
Using linear and nonlinear ultrafast terahertz (THz) spectroscopy as an experimental method, and semiconductors, metals and graphene as material systems, we investigated the key fundamental critical-timescale processes, which underly modern electronics technologies, and are of great fundamental interest at the same time.

Among many other results, we have achieved a number of significant breakthroughs, which led to publications in Nature research journals (4 such papers in total). Below I highlight two of them.

1) Using our method of nonlinear THz spectroscopy, we have established that the conductive properties of graphene on technologically relevant ultrafast (picosecond and faster) timescales are fully governed by the thermodynamic balance maintained within its electronic population, which at all times can be considered as a thermalized electron gas. Our finding, in particular, explains the operation speed barrier for current generation of ultrafast graphene transistors, and paves the way to breaking this barrier. This result has been published in *Nature Communications*, see Ref. [14] in the list of publications.



2) Using our method of THz magneto-spectroscopy, we have been able, for the first time, to directly measure and spin-resolve the duration of elementary electric currents in ferromagnetic nanofilms.



The overall electrical properties of matter is being formed on an extremely short timescale of elementary ultrafast acts of electrical conduction, which only last few tens of femtoseconds. Moreover, as a result of strong electron-electron correlations, these durations are different for the electrons with different spin orientations. Here, for the first time, we were able to observe these elementary currents, and to establish the timescales on which the conductive properties of ferromagnetic metals are being established. This result has been published in *Nature Physics*, see Ref. [15] in the list of publications.