# Tutorial : Alexey Kimel

## Institute for Molecules and Materials / Radboud Universiteit

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## Paradoxes of ultrafast antiferromagnetism and writing of antiferromagnetic bits



Alexey Kimel obtained his PhD from the Ioffe Institute (St. Petersburg, Russia) and joined the Institute for Molecules and Materials (IMM) at Radboud University as a postdoctoral researcher in 2002.He was subsequently appointed Assistant Professor in 2007, Associate Professor in 2013, and Full Professor in 2017.He pioneered ultrafast spin dynamics in antiferromagnetic materials [PRL89, 287401 (2002), Nature 435 655–657 (2005)] and his works in a large extent defined the development of ultrafast magnetism during the last two decades. He is a co-inventor of ultrafast all-optical magnetic recording [PRL99, 047601 (2007)] and inertia of spins in antiferromagnets [Nature-Physics5, 727–731 (2009)], as a recognized world-leader in the field he obtained several prestigious research grants (Veni2004, Vidi2006, Vici2017, ERC-SG2010, Russian MegaGrant-2013, ERC-AG2022).Starting from September 2025, he serves as the Research Director of the Institute for Molecules and Materials.

**Abstract:** Ultrafast spin dynamics in antiferromagnets is paradoxical. While commonly accepted Curie-Neumann's principle states that "the symmetries of the causes are to be found in the effects" [1] and implies that a magnetic field cannot control antiferromagnetic Néel vector, rapidly changing THz magnetic field appears to "violate" this principle and can effectively excite spins in antiferromagnets . In this ultrafast regime, laser-induced spin dynamics in antiferromagnets is intrinsically non-linear [2-4], where new channels of spin-lattice interaction open-up [2,3], the principle of superposition fails, i.e. 1+1>2 [4], and antiferromagnets appear to host even more channels to excite spins [5-7] than one can find in ferromagnets. We will review recent progress in ultrafast antiferromagnetic spin dynamics, highlight the recently discovered mechanism enabling control of antiferromagnetic spins by a THz electric field [6], and discuss the conditions required for reliable writing of stable antiferromagnetic bits [8].

[1] P. Curie, "On Symmetry in Physical Phenomena", *J. Phys. Theor. Appl.*, 393–415 (1894).
[2] E. A. Mashkovich et al, "Empowering Control of Antiferromagnets by THz-Induced Spin Coherence**"**, *Science* 374, 1608-1611 (2021).
[3] T. Metzger et al, "Magnon-phonon Fermi resonance in antiferromagnetic $CoF_2$**"***Nature Communications* 15, 5472 (2024).
[4] T. G. H. Blank et al, *Phys. Rev. Lett*. 131, 096701 (2023).
[5] Y. Behovits et al, "Terahertz Néel spin-orbit torques drive nonlinear magnon dynamics in antiferromagnetic $Mn_2Au$" *Nature Communications* 14, 6038 (2023).
[6] V. Bilyk et al, "Control of spins in collinear antiferromagnet $Cr_2O_3$ by terahertz electric fields"*Newton* 1, 6100132, (2025).
**[7]** R. M. Dubrovin, A. V. Kimel, A. K. Zvezdin, "Competition between terahertz magnetoelectric and Néel spin-orbit torque driven spin dynamics in metallic antiferromagnets" *Phys. Rev. B* 112, 064402 (2025).
**[8]** N. Khokhlov *et al*., in preparation

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