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Quantum Control of Electrons in Atoms, Molecules and Materials - from Femtosecond to Attosecond to Zeptosecond Timescales

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This talk will discuss strong field quantum control in atomic, molecular and materials systems with applications across a broad range of chemical, physical and materials sciences. Using mid-infrared femtosecond lasers to drive the high harmonic (HHG) frequency upconversion process, strong time-gated phase matching results in bright *coherent* keV soft X-ray beams on a tabletop for the first time [1]. The new photon energy range accessed of 0.2–1.6 keV (corresponding to wavelengths of 1 – 6 nm) is of particular interest for applications in chemical and materials spectroscopy and imaging. X-rays can penetrate thick (opaque) samples and achieve high spatial resolution (2–50nm) imaging, with the added advantage of elemental and chemical specificity by employing characteristic elemental X-ray absorption edges and chemically-induced fine structure at these edges. Moreover, when atoms are ionized by mid-infrared light, the electron liberated during the HHG process can be driven back to the parent ion multiple times, resulting in quantum interferences and zeptosecond x-ray waveforms [2]. We also recently demonstrated that we can precisely control molecular dynamics on both nuclear (i.e. femtosecond) and electronic (i.e. attosecond) timescales [3,4]. Using vacuum ultraviolet light pulses that are tunable in wavelength and time structure, it is possible to switch population between electronic excited states on attosecond timescales, and use this ability to select specific pathways for ionization or dissociation of a molecule. Ultrafast lasers can also be used to switch the dissociation pathways of molecules as they explode after irradiation by ionizing light. Finally, we used ultrafast x-rays to capture coherent processes in materials, such how fast a material can change its electronic or magnetic state,... or how fast spin currents can control and enhance magnetization in materials.

[1] Popmintchev et al., Science **336**, 1287 (2012).
[2] Hernandez-Garcia et al., PRL **111**, 033002 (2013).
[3] Zhou et al., Nature Phys. **8**, 232 (2012).
[4] Ranitovic at al., submitted (2013).
[5] S. Mathias et al., PNAS **109**, 4792 (2012).
[6] Rudolf et al., Nat. Comm. **3**, 1037 (2012).
[7] Turgut et al., PRL **110**, 197201 (2013).