Title: Controlling electrons with attosecond time resolution.

Text: FERMI is unique among the short-wavelength Free Electron Lasers in the world, because it is seeded, whereas other machines operate on the SASE principle (Self Amplified Stimulated Emission.) The seeding process confers a number of desirable properties, such as wavelength stability, and above all, longitudinal coherence, which are not provided by SASE sources. Longitudinal coherence implies that the electromagnetic oscillations of the light field have a well-defined phase relationship over the duration of the pulse. This is manifested as a narrow bandwidth, close to the Fourier limit, and is important in experiments where precise tuning is required. Until recently there has not been an experiment in which the longitudinal coherence of FERMI was exploited directly. Now, using the Low Density Matter beamline of FERMI, an international team has demonstrated that the light from FERMI not is only coherent,is coherent, but when made to contain commensurate wavelength, retains mutual coherence among them.

The team is made up of researchers from Italy (Elettra-Sincrotrone Trieste, the Politecnico of Milano, and the IFN, IOM and ISM institutes of CNR), Japan (University of Tohoku), Russia (Lomonosov Moscow State University), USA (Drake University, Des Moines, Iowa) and Germany (Technical University of Berlin, Freiburg University, European XFEL, Max Planck Institute for Nuclear Physics, Heidelberg). They worked together to devise and perform an experiment in which FERMI was run in a special mode to produce two overlapping coherent beams of light, which then ionized a neon gas sample. Extensive calculations were required to predict both the machine performance, and the outcome of the experiment.

The result has now been published in Nature Photonics. The two beams of light were first and second harmonics of the chosen wavelength, and the first harmonic ionized atoms by a two photon process, while the second harmonic ionized by a single photon process. If, and only if, the two colours are mutually coherent, the emitted photoelectrons may interfere. Mutual coherence means that the electromagnetic oscillations of the wavelengths have a definite phase, or temporal, relationship in a given pulse of light. Interference is observed as an asymmetric photoelectron angular distribution (PAD) - for single photon ionization, the PAD is always symmetric about the direction of propagation of the light. Moreover, when the phase was scanned, the asymmetry varied, as predicted by theory.

This kind of experiment has historically been performed with optical lasers, and is known as a Brumer-Shapiro type experiment. However it has not been demonstrated at the short wavelengths used here, 63 and 31.5 nm. The reason is that the relative phase of the two beams of light must be controlled with a temporal resolution much less than the period of the light, 100 attoseconds, and the techniques used for optical lasers do not work for short wavelength radiation. The experiment achieved a resolution of about 3 attoseconds, using an innovative scheme devised by the FERMI machine physics staff. This excellent result promises well for extension of the technique to much shorter wavelengths.

Demonstration of multi-wavelength coherence and control of the phase opens up new possibilities for FEL research. Modern attosecond science with HHG lasers is based on control of amplitude and phase of multiple wavelengths. As well, the new method permits the manipulation of quantum systems with extreme temporal precision.

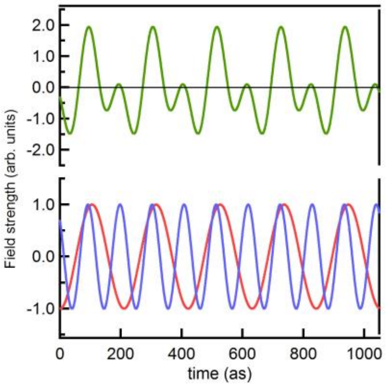

Fig.1

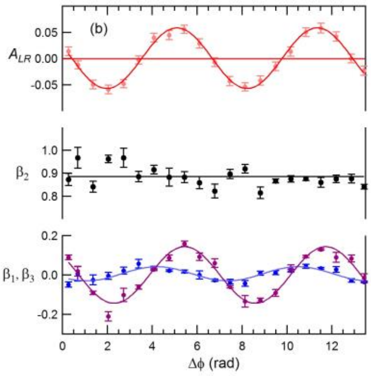

Fig.2

Fig. 1. Schematic drawing of the electric fields of the two harmonics (bottom) and of the total electric field due to the two wavelengths.

Fig 2. β parameters, which describe the angular distribution of the photoelectron patterns. These are the parameters of Legendre polynomials, and the even numbered parameters give rise to symmetric distributions, while the odd numbered parameters describe the asymmetry. The latter oscillate as a function of phase between the two wavelengths. (Copyright Nature Publishing Group, reproduced with permission.)

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