Molecules and Attosecond Science

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During the past six years the minimum duration of optical (XUV) pulses has fallen from 5 femtoseconds ($5x10^{-15}$ sec) to about 100 attoseconds ($\sim 10^{-16}$ sec)—less than the classical period of a ground-state electron in a hydrogen atom. Lasers drove this revolution by forcing electron wave packets to tunnel from the atom or molecules, move under the force of the time dependent electric field and then re-collide with their parent ions. From the ion's perspective, an attosecond electron wave packet re-collides. Attosecond XUV pulses are the byproduct of this collision.

The attosecond electron, controlled by light, is something unique in science. With wavelength ~ 0.5-3 Ångstrom, it allows us to measure spatial information -- as in a photograph. The "shutter speed" can be attoseconds.

Using N_2, O_2 and CO_2 as examples, I illustrate three ways that the re-collision electron gives give us spatial images.

- **Molecular tunneling**. The lateral momentum distribution of electrons that tunnel measures a filtered projection of the momentum wave function of the ionizing orbital. Rotating the molecule, we gain all information about the orbital.
- **Laser Induced Electron Diffraction:** The re-collision electron elastically scatters from its parent molecular ion. The diffraction pattern gives the position of a molecule's atoms.
- **Orbital Tomography:** Attosecond pulses arise from the interference between the re-collision electron and the initial orbital from which it separated. The amplitude and phase of the XUV radiation contains all information to recreate the orbital image and to observe attosecond dynamics when multiple orbitals simultaneously ionize..