Infrared streak camera

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Abstract. An atomic streak camera has been constructed with a spectral range from 1 to 100 µm and a 2 ps time resolution. Gas-phase Rydberg atoms are used as a infrared sensitive photocathode. Prompt electron emission from the autoionizing Rydberg atoms is obtained when a red Stark states are selected.

1. Introduction: spectral limitation of streak cameras

The spectral range at which conventional streak camera systems operate is limited by the spectral response of the photocathode used. For most photocathode materials the sensitivity is limited to wavelengths shorter than 1.5 µm. Beyond this wavelength the quantum efficiency of the photocathode becomes negligible. Thus the temporal profile of mid- and far-infrared light pulses cannot be measured directly using a conventional streak camera.

We have constructed an atomic streak camera [1-2] in which the photocathode of a conventional streak camera is replaced by a sample of gas phase Rydberg atoms for the conversion from photons to electrons. Due to the low binding energy of the electrons of Rydberg atoms, the IR photon energy is sufficient to photoionize the atoms and create electrons. The combination of a low ionization threshold with the high photoionization cross section makes a Rydberg atom photocathode ideally suited for use in an IR streak camera.

![Fig. 1. Principal of operation of the infrared streak camera](image-url)
2. Infrared streak camera: principle of operation.

The principle of operation of the atomic infrared streak camera is sketched in figure 1. Gas phase atoms are excited to a Rydberg state by a UV laser prior to exposure to the IR radiation. The number of photoelectrons, created by the IR photoionization of the Rydberg atoms, is proportional to the instantaneous IR intensity; therefore the temporal profile of the electron pulse mimics the profile of the IR radiation. Just as in a conventional streak camera, the electron pulse is accelerated towards a position sensitive detector. The electron pulse passes a set of deflection plates. The electric field of this condenser is ramped in time, causing a time-dependent deflection of the electrons. Hence the electron pulse is streaked over the position sensitive detector, and the profile on the detector is a direct measure of the profile of the IR pulse.

3. Limitations at long wavelengths

After the initial demonstration of the infrared streak camera at 2.6 μm [1], we investigated the response at longer wavelength. As an IR source the Free Electron Laser FELIX is used (located in Nieuwegein, The Netherlands). The FEL is tunable from 4 to 100 μm, and from the spectral bandwidth the pulse duration is estimated to be about 1 ps. In this particular case the FEL was tuned near 7 μm and the initial Rydberg state of potassium was \( n=10 \). Although the time resolution of the streak camera is excellent at 6.5 μm (<3 ps) the electron emission from the Rydberg atom is no longer prompt at longer wavelengths. For instance at 7.25 μm the excess energy of the electron is so small that the escape time from the atom becomes of the order of 10 ps. The beats in the electron emission are due to angular momentum oscillations of the electron [3, 4] while the electron is still attached to the ionic K\(^+\) core. Although these quantum beats are certainly interesting from an atomic physics point of view, they are rather disturbing for proper streak camera operation. Thus different initial Rydberg states have to be selected for different spectral regimes. So for λ=7.25 μm we start from \( n=11 \) rather than \( n=10 \). Moreover in the presence of the electric field each \( n \) state fans out in \( n \) Stark states. Some of these Stark states are better candidates for the IR streak camera than others....