Photodissociation of molecular ions through VUV excited electronic states is of high importance in both laboratory and naturally occurring plasmas as well as in several applications. Moreover, even for the simplest systems, it is a theoretical challenge to describe the photodissociation through the manifolds of coupled excited states that arise from the excitation of outer and inner molecular valence electrons. With the ion beam infrastructure TIFF (Trapped Ion Fragmentation at FLASH) around the PG2 beam line of FLASH, we have investigated the photodissociation through excited states of the simplest heteronuclear molecular ion HeH\(^+\) initiated by absorption at 32 nm. HeH\(^+\) occurs as a molecular coolant in models of the early universe \[1\], and is assumed to exist in several astrophysical plasmas near strong VUV sources like, e.g. planetary nebulae \[2\]. Moreover, HeH\(^+\) is isoelectronic with \(^3\)HeT\(^+\) which is formed in beta decay of T\(_2\); its excited states are responsible for the molecular contribution to the electron energy spectrum relevant for mass measurements of the electron neutrino \[3\].

In a previous measurement at FLASH fragment momentum imaging was performed on neutral He fragments from the dissociation channel He(1snl) + H\(^+\) \[4\]. A dominance of dissociation through electronic states of \(\Pi\)-symmetry was demonstrated with total photoabsorption cross section of 1.4±0.7 cm\(^2\). Two theoretical papers \[5, 6\] have recently confirmed both the major dissociation routes via \(\Pi\)-states as well as the absolute cross section within the experimental accuracy and, moreover, contributed further insight into the dissociation of HeH\(^+\) and, in general, the role of coupled state manifolds in this process. For instance, addressing directly the non-adiabatic dissociation dynamics, Sogoda \textit{et al.} predicted a strong connection between the importance of non-adiabatic interactions and the ratio of dissociation leading to either He(1snl) + H\(^+\) or He\(^+\) + H(nl).

In our recent studies at FLASH, using the setup shown in Fig. 1, we have addressed the photodissociation of HeH\(^+\) leading to both He(1snl)+H\(^+\) and He\(^+\)+H(nl) and studied the dissociation of vibrationally cooled ions. In the experiment, ions were extracted from a newly added duoplasmatron ion source, accelerated to 4.2 keV kinetic energy, and mass analyzed in a magnetic field to form a collimated beam of HeH\(^+\). Short ion pulses (1 \(\mu\)s) were generated either directly from the ion beam or after a period (50-150 ms) of trapping in an electrostatic trap \[7\], and finally guided through the interaction zone (see Fig. 1). Imaging detection of dissociation fragments He and H\(^+\), as well as H was performed with two detectors, DET 1 and DET 2 \[7\]. FLASH delivered trains...
of 30 pulses of 7-15 μJ separated by 5 μs at a 5 Hz repetition rate of which 24 pulses were used in the experiment. A specific experimental timing scheme was developed to make optimal use of the available FLASH pulses: Thus, 4 pulses were crossed by cooled ions, 18 by directly transferred ions and 2 were used for background measurements for each FLASH train. Representative momentum images of H and H\(^+\) fragments obtained with DET 1 for cooled and direct ions are displayed in Fig. 2 and the experimental ability to quantitatively distinguish the two dissociation channels He(1snl) + H\(^+\) and He\(^+\) + H(nl) is illustrated.

Figure 2: Momentum imaging of H and H\(^+\) fragments following photodissociation of HeH\(^+\) at 32 nm obtained with DET 1. The measured coordinates \(\rho_1/\tau_1\) and 1-1/\(\tau_1\) are directly proportional to the longitudinal and transverse fragment momentum release [7], respectively. Momentum spectra are shown (a,b) for ions sent directly from the ion source to the interaction zone, and (c,d) for ions cooled 50 ms in the trap before the irradiation by FLASH. The experimental separation of the two channels He(1snl)+H\(^+\) and He\(^+\)+H(nl) is illustrated by (b,d) showing the fragment momentum spectra taken with a bias potential [7] in the interaction region of +300 V.

References