Splitting in the binary ridges of the $O^+ + H_2 \rightarrow O + H^+ + H$ process as a signature of molecular rotation

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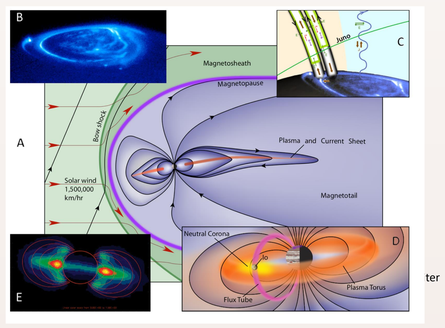
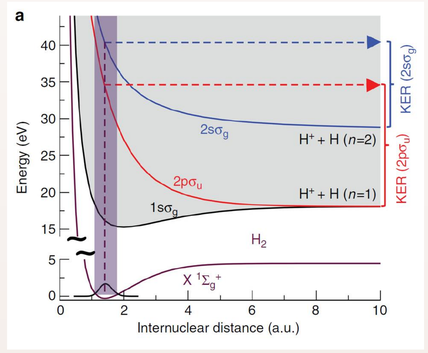
Astrophysical motivations

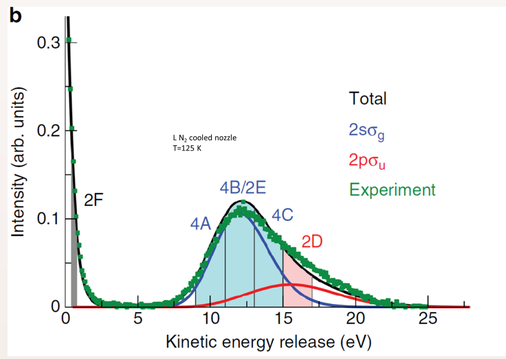
H_2 molecule is of the utmost importance in the universe
Its (rotational) excitation and destruction by ion impact is of significant role in its fate



Experimental challenge

Example photoionization KER spectra of H_2 (COLTRIMS)



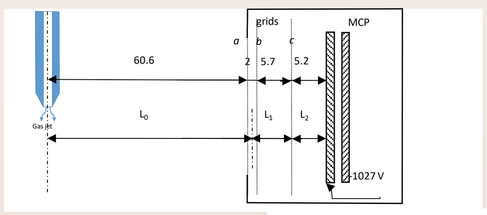


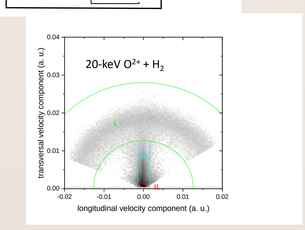
NATURE COMMUNICATIONS 8: 2266 DOI: 10.1038/s41467-017-02437-9

The low kinetic energy (<1 eV) H+ fragments are difficult to measure

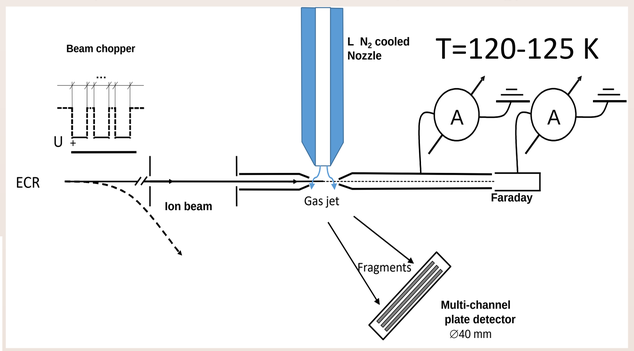
Experimental set-up at Atomki, Debrecen : 2D velocity distribution of (sub-eV) H^+ fragments are measured

Time of flight in electric and magnetic field free space with well shielded MCP detector (3 grids)





Emission from background gases are shielded (active collision volume is only 3mm long)



The investigated processes

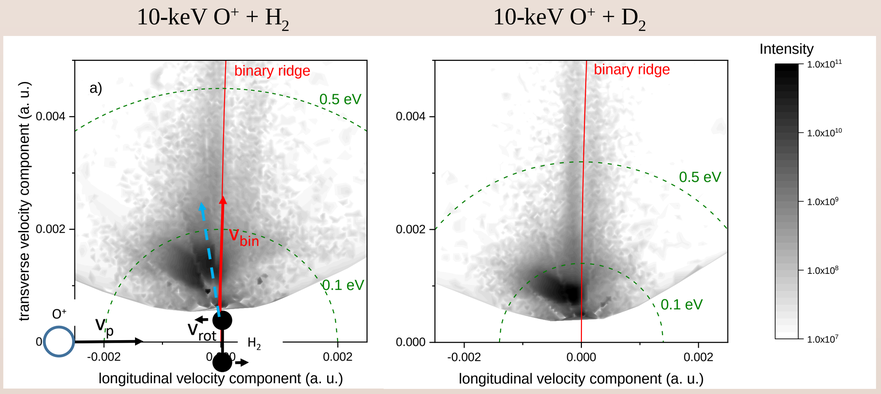
- dissociative capture:
  $O^+ + H_2 \rightarrow O + H_2^+ \rightarrow O + H^+ + H$
  → very low velocity H^+ fragments (isotropic emission)
- dissociative ionization:
  $O^+ + H_2 \rightarrow O^+ + H_2^+ + e^- \rightarrow O^+ + H^+ + H + e^-$
- binary knock out H^+ → higher velocity H^+ (in binary ridge)
- non-dissociative capture
  $O^+ + H_2 \rightarrow O + H_2^+$ → scattered H_2^+ (in binary ridge)

likewise with D_2 target, and we performed some experiment with O^{2+} projectile, too

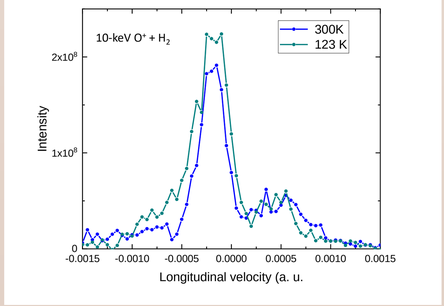
What to see in 2D velocity distributions?

2-D velocity distribution of the fragments from H_2 and D_2

10-keV $O^+ + H_2$ | 10-keV $O^+ + D_2$



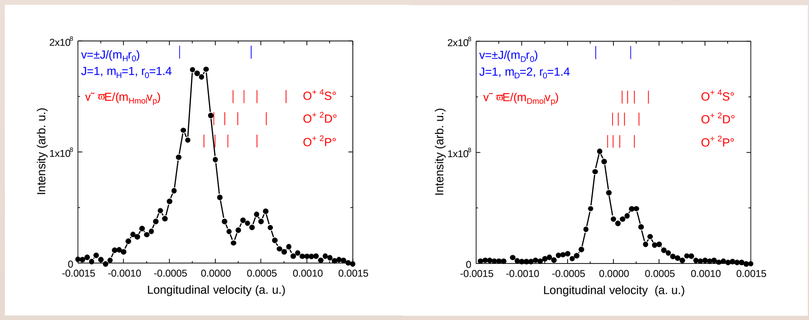
The binary ridges are split! Why?
Rotation of the molecule. For D_2, the rotation speed is half



There is not much influence on the structure of the binary ridges whether or not the target gas jet is cooled. (The rotational levels has not enough time to relax in the rapid cooling.) The normalized intensities, however, are different. This may be explained by target coherence effects.

Projection of the binary ridges

10-keV $O^+ + H_2$ | 10-keV $O^+ + D_2$



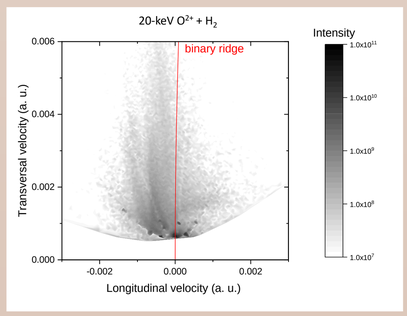
1. Split is due to rotational velocity of the atoms in the molecule

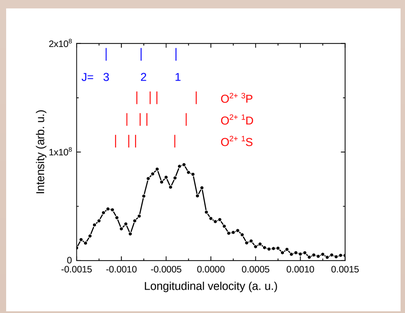
2. Undissociative process (minor contribution) Shifts are due to the energy loss in the inelastic twobody collision $O^+ + H_2$ → $O + H_2^+ + \Delta E$ (Franck-Condon type)

Projections along the transversal velocity, zero is at the binary ridge

The two peaks are asymmetric : asymmetry in the rotational direction due to rotational excitation by the projectile
J=0 to J=1 transitions are spin forbidden (ortho-, parahydrogen). Transitions are allowed in the magnetic sublevels J=1, M=0, ±1

Results with O^{2+} projectiles (higher rotational excitations)





Conclusions

Ionic fragments from H_2 in the sub-eV range were measured with our TOF apparatus

In the obtained 2D-velocity distributions, binary ridges due to collisions with the projectile ions were observed

The binary ridges were found to be split

The split is due to the rotation of the molecule

Asymmetry in the split indicates preliminary rotational excitation of the molecule

Higher charge state projectiles cause higher rotational excitation

Acknowledgements

This work was supported by the National Research, Development, and Innovation Fund of Hungary, financed under the K18 funding scheme through project No. K128621, and the CNRS International Emerging Action (IEA-PICS-CNRS No. 7739/NKM-115/2017). This article is based upon work from COST Action CA18212 – Molecular Dynamics in the GAS phase (MD-GAS), supported by COST (European Cooperation in Science and Technology). D.V. Mifsud is the grateful recipient of a University of Kent Vice-Chancellor's Research Scholarship.