BERGISCHE UNIVERSITÄT WUPPERTAL

Physical & Theoretical Chemistry

University of Wuppertal

From Plasma to Mass Spectrum: A Novel Ion Guide Coupled to HR-TOF-MS Benchmarked Against Conventional Plasma Diagnostics

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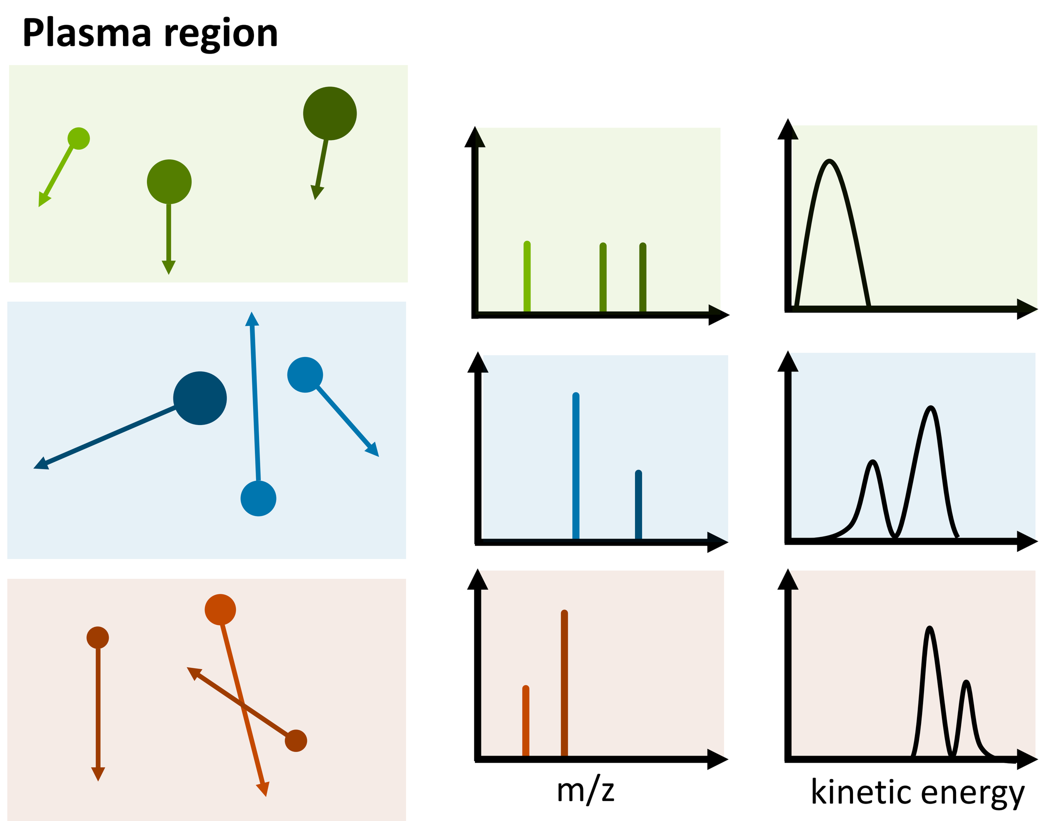
Motivation

Plasmas are found in numerous industrial systems, serving either as an integral part of the process or as an unintended by-product. They inevitably generate ions that interact with surrounding surfaces.

The impact these ions have on surfaces depends not only on their **chemical identity** but also by their **kinetic energy and spatial distribution.**

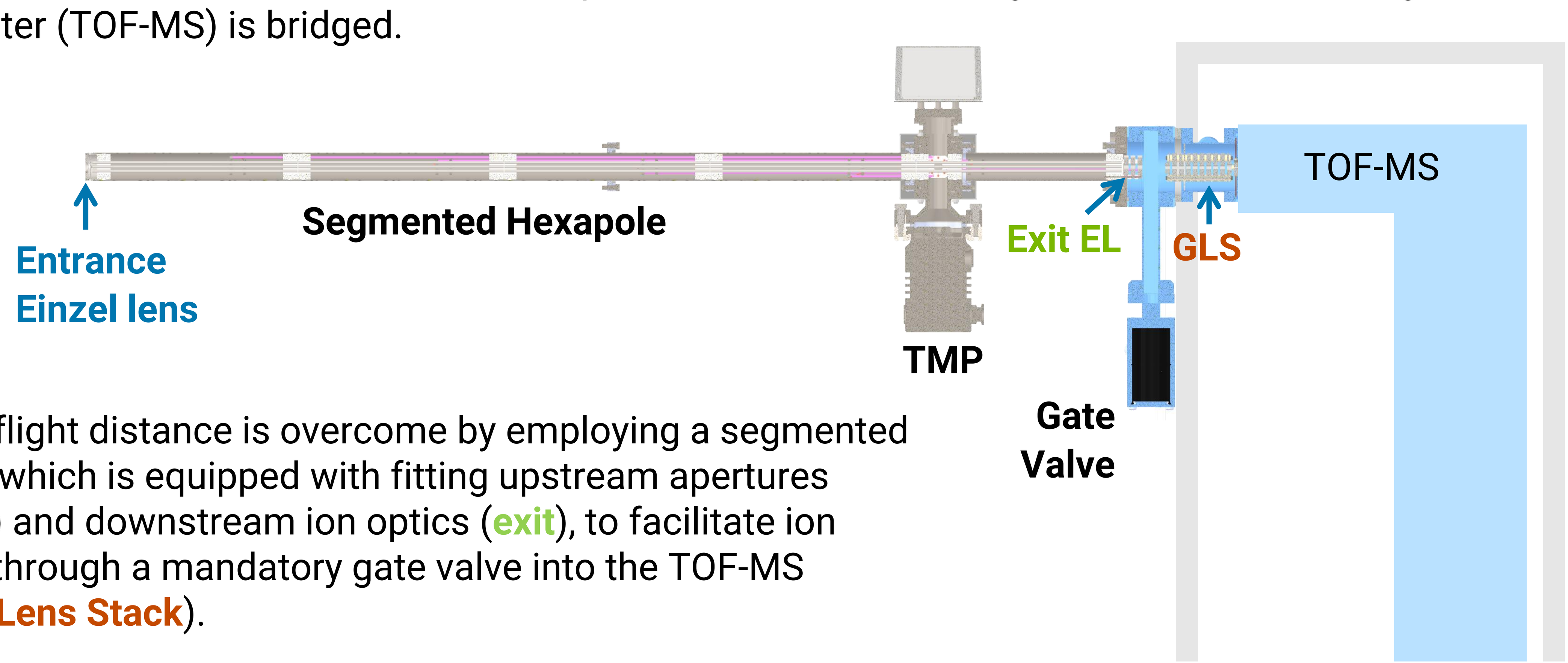


Goal

Develop a mass spectrometric approach that allows the analysis of ionic mass and kinetic energy in different locations.

Novel Ion Guide Coupled to HR-TOF-MS

In this work, **a distance of 170 cm** between a plasma chamber and a high-resolution time-of-flight mass spectrometer (TOF-MS) is bridged.

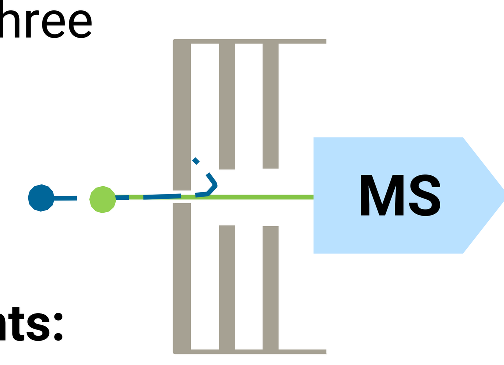


The main flight distance is overcome by employing a segmented **hexapole**, which is equipped with fitting upstream apertures (**entrance**) and downstream ion optics (**exit**), to facilitate ion transport through a mandatory gate valve into the TOF-MS (**Gradient Lens Stack**).

Kinetic Energy Measurement

Entrance consist of an **Einzel lens** with three electrodes to

1. **focus and guide** Ions
2. **restrict gas flow** to reduce pressure inside the hexapole and
3. Allow for **kinetic energy measurements:**



The inner electrode potential is gradually increased. As ions with insufficient kinetic energy are successively blocked, the decrease in count rate (cps) reflects the **ion kinetic energy distribution.**

Spatial Resolution

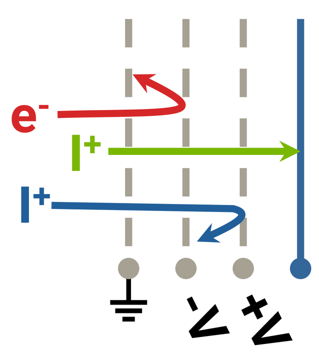
Spatial resolution is achieved by mounting the entire transfer stage and TOF-MS on a linear manipulator (Vab Vakuum-Anlagenbau GmbH, Elmshorn, Germany),

The hexapole ion guide and inlet were manufactured by Fasmatech (Athens, Greece).

Commercial Approaches and their Operational Principles

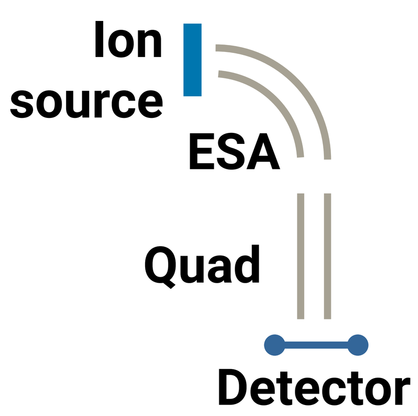
RFEA

Uses the same retarding-field principle with a grid-based design and a detector positioned behind the final electrode.



EQP

Measures ion mass-to-charge ratios and energy distributions using a quadrupole mass filter and electrostatic energy analyzer.



Langmuir Probe

Operates by varying a probe bias relative to the plasma and measuring the resulting current–voltage (I–V) characteristic.

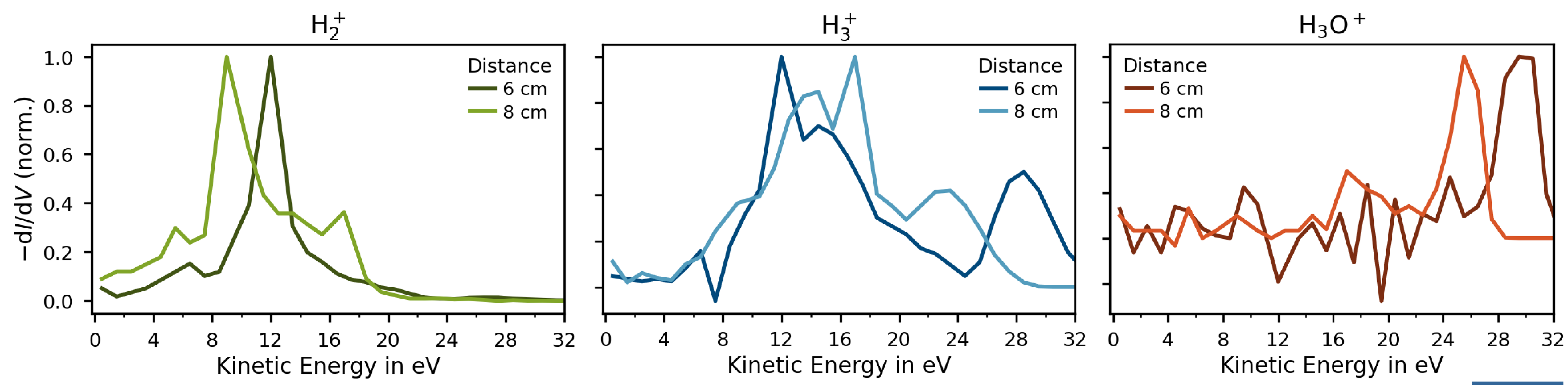
OES

Identifies excited species and monitors plasma composition by analyzing the emitted light spectrum.

Exemplary Results and Comparison

Exemplary Results

Measurements of a radio-frequency (RF) hydrogen plasma reveal **distinct ion energy** populations. The measured kinetic energies depend systematically on both the **ion species** and the **distance** from the RF electrode.



Key Advantages

1. **High sensitivity and high-resolution**
   Clear identification of very weak ion signals
   Unique among the compared diagnostic methods
2. **Robust against high electron current densities**
   Additional flight path rejects unwanted ion currents
   Not achievable with RFEA or Langmuir probes
3. **Continuously adjustable spatial resolution**
4. **Very low kinetic energy uncertainty (< 0.1 eV)**
   Through einzel lens design rather than grid structure

Limitations

1. **Requires sufficiently separated ion kinetic energies for temporal resolution**
   Single-lens energy analyzer can be operated in RFEA mode for high temporal resolution
2. **Currently only tested for kinetic energies up to 120 eV**
   Higher kinetic energies measurable, but uncertainty rises to > 2 eV

	OES	RFEA	EQP	Langmuir	Our Method
Mass-to-charge	Emission-limited				
Kinetic Energy	Plasma-dependent				
Spatial resolution	Sight integrated				
Non-invasive					