Investigation of a capacitively coupled RF exited APGD in He-water mixtures by molecular beam mass spectrometry

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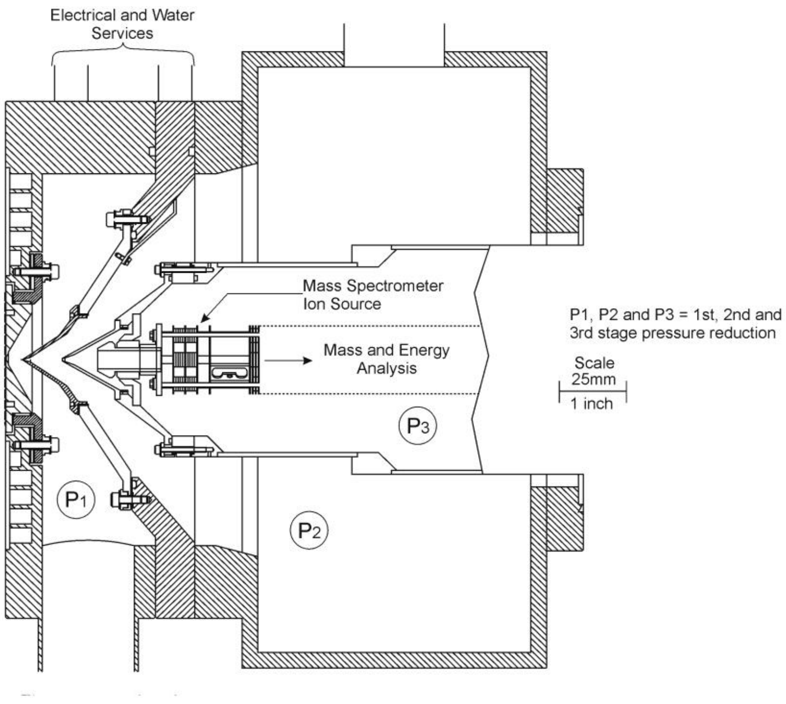
Introduction

This presentation includes details of:

- **Mass spectrometry analysis for atmospheric plasmas, MBMS (Molecular Beam Mass Spectrometry)**
- **Discussion of the ion energies observed in the MBMS**
- **Mass spectrometry results for positive and negative ions with different H_2O concentration in He**
- **Conclusions**

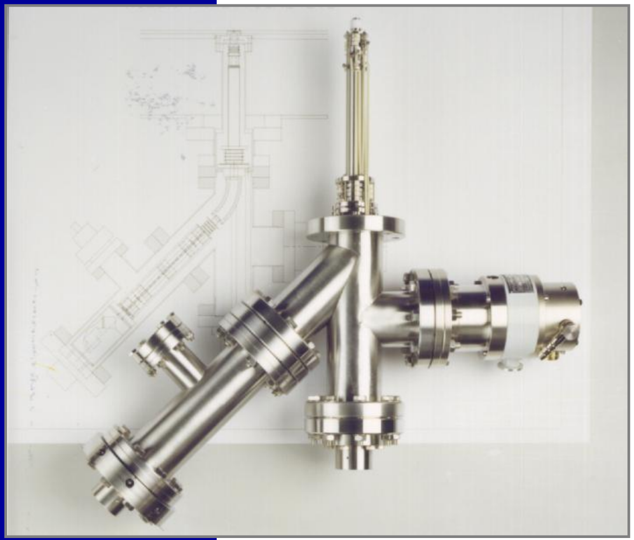
HPR60, Schematic of the Molecular Beam Mass spectrometer (MBMS)

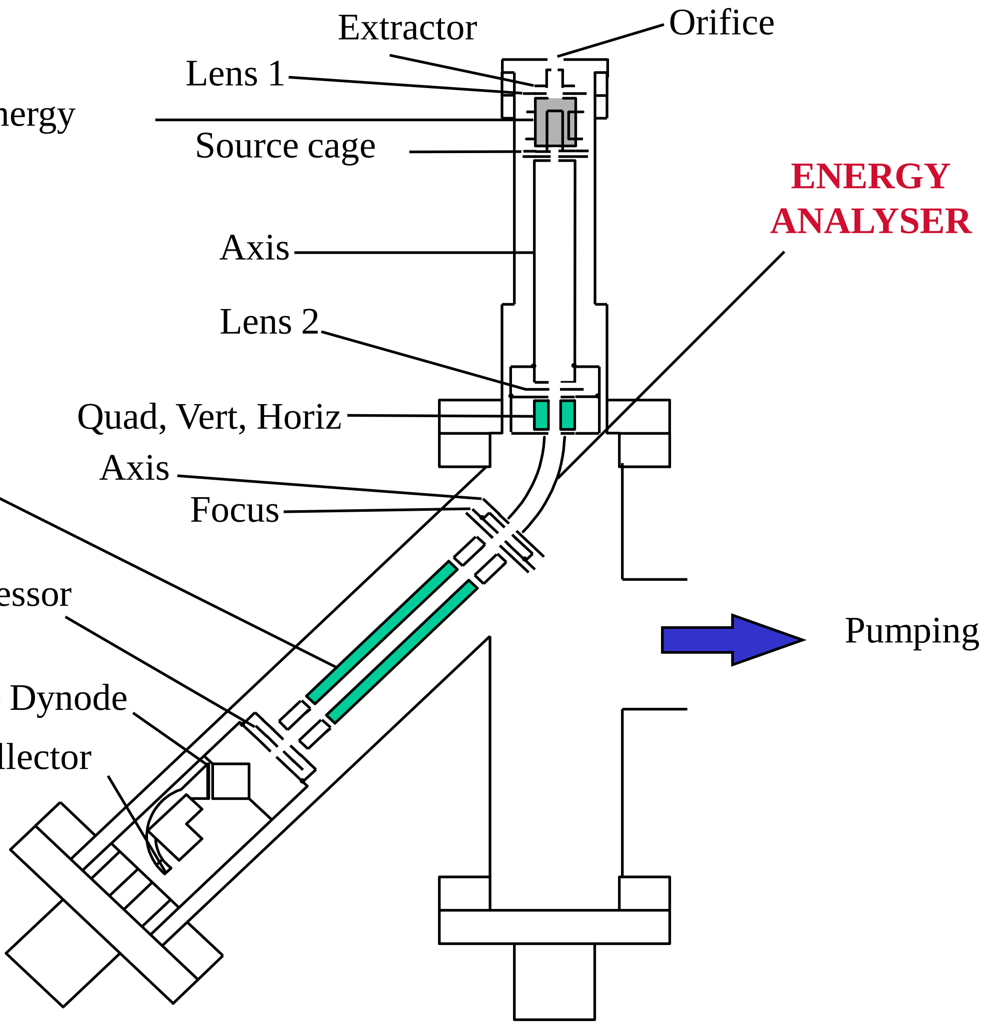


$P_1 > P_2 > P_3$ **P_1=2.5 mTorr, P_2=7.3x10^{-6} Torr, P_3=1.9x10^{-7} Torr**

The skimmer cone of the mass spectrometer is aligned with the MBMS entrance orifice and the second stage skimmer cone to form a molecular beam which minimise the collisions of the sampled particles with each other or with surfaces.

Mass/Energy Analyser, EQP





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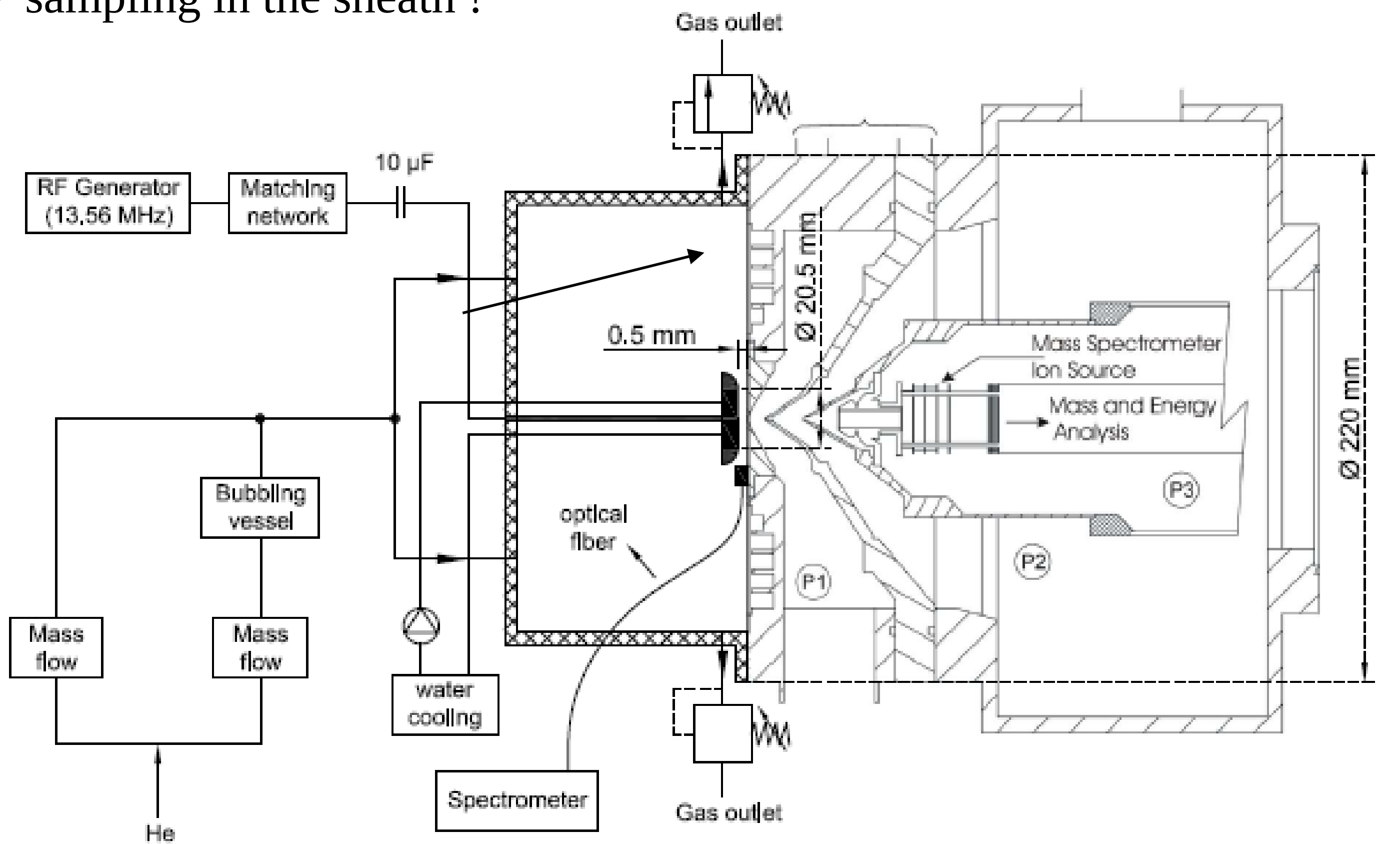
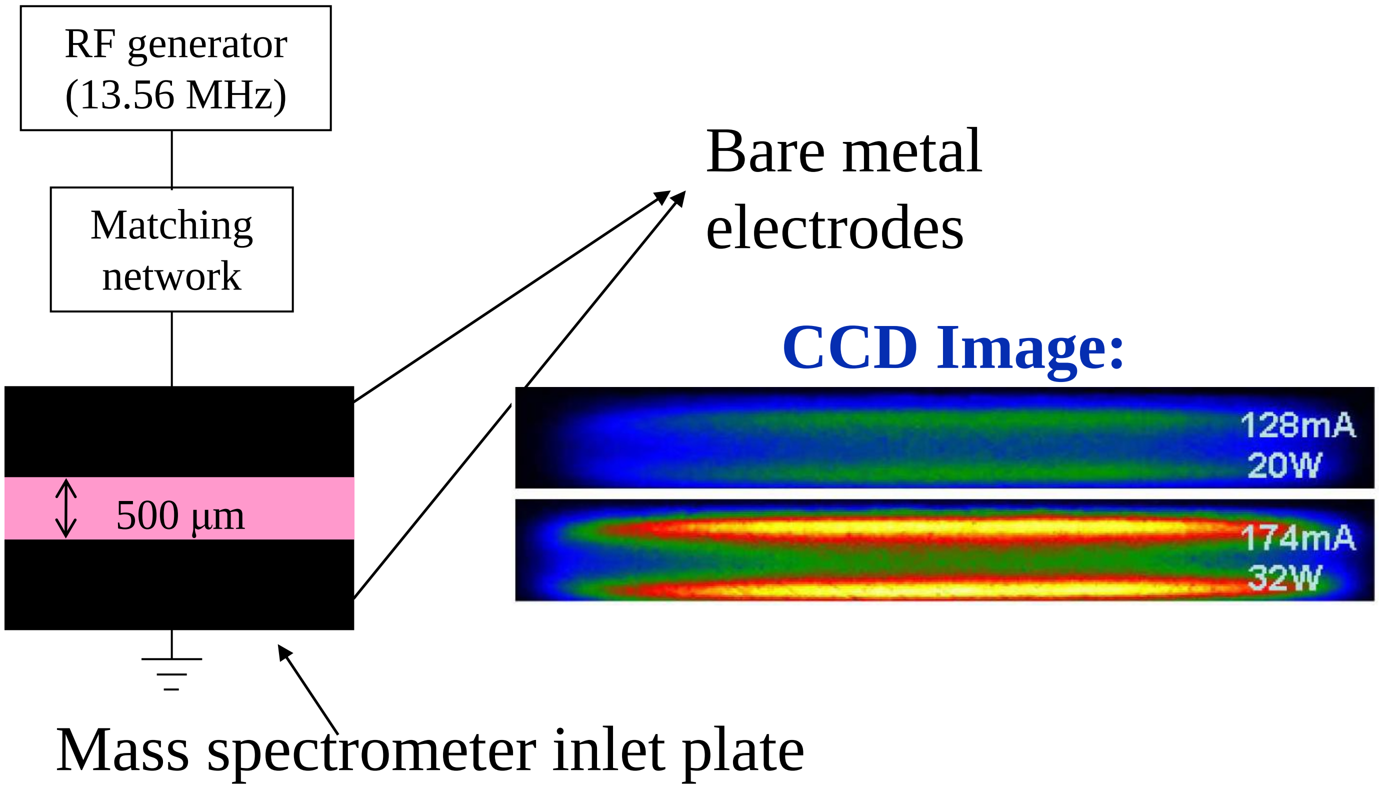
Experiment setup

- Reactor volume 2.5 l
- He (99.995%) Flow rate 5 lm
- sampling orifice diameter 20µm
- sampling in the sheath !



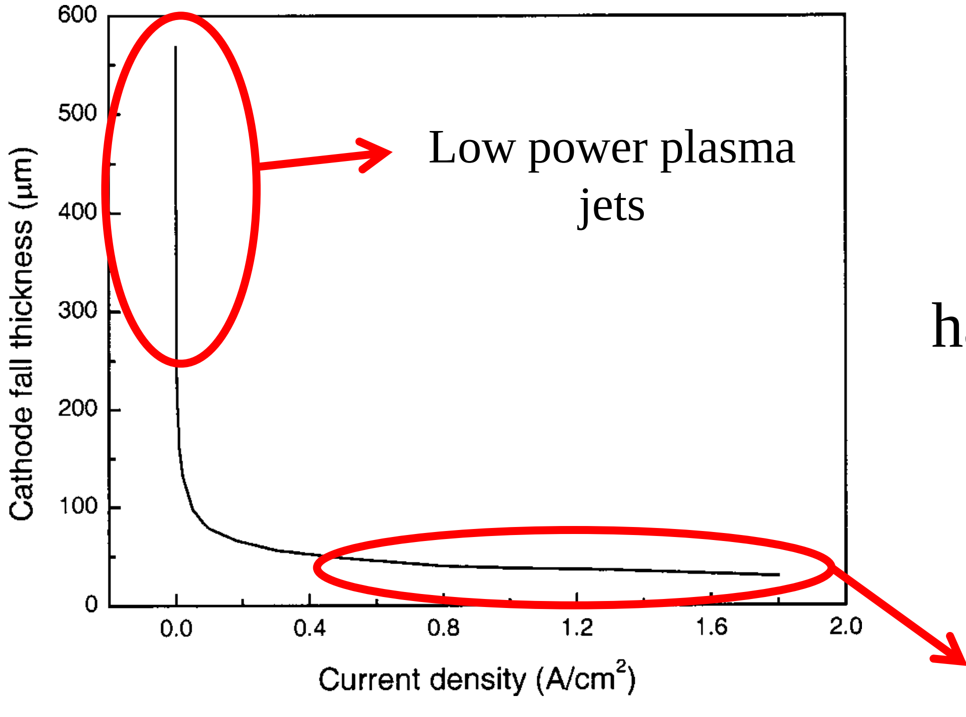
Experiment setup: zoom in



- diffuse RF APGD 13.56MHz
- bare metal electrodes (Φ = 20.5 mm)
- gap distance = 500 µm
- gas temperature 350 K

Liu et al. IEEE Trans. Plasma Sci. **36**, (4), 2008
Bruggeman, Iza et al. Plasma Sources Sci. Technol**.** **19**, 2010

Validity of ion energies measured in the MBMS?



drift region of coronas has no sheath

- **Diameter of sampling orifice < sheath thickness**
  - **Otherwise potential plasma penetration!**
  - **Not critical for corona and low power plasma jets but critical for glow discharges !**

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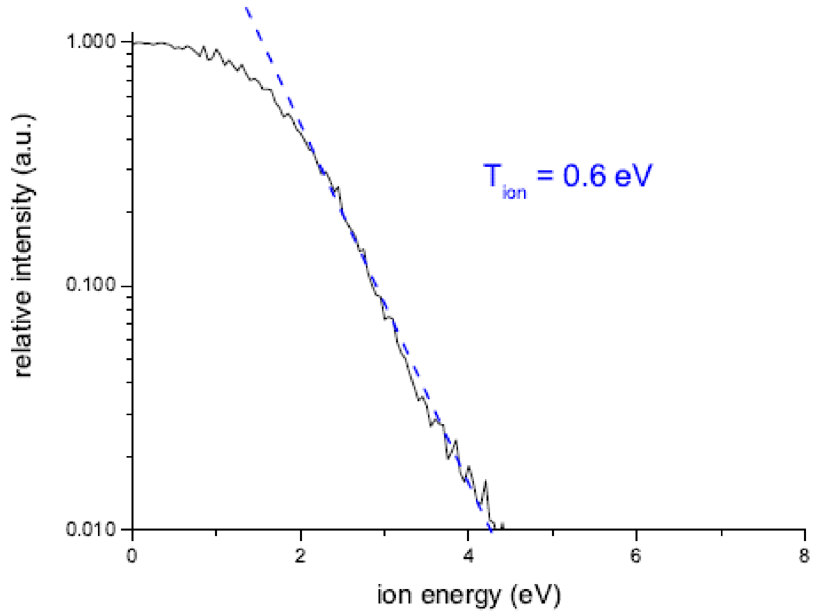
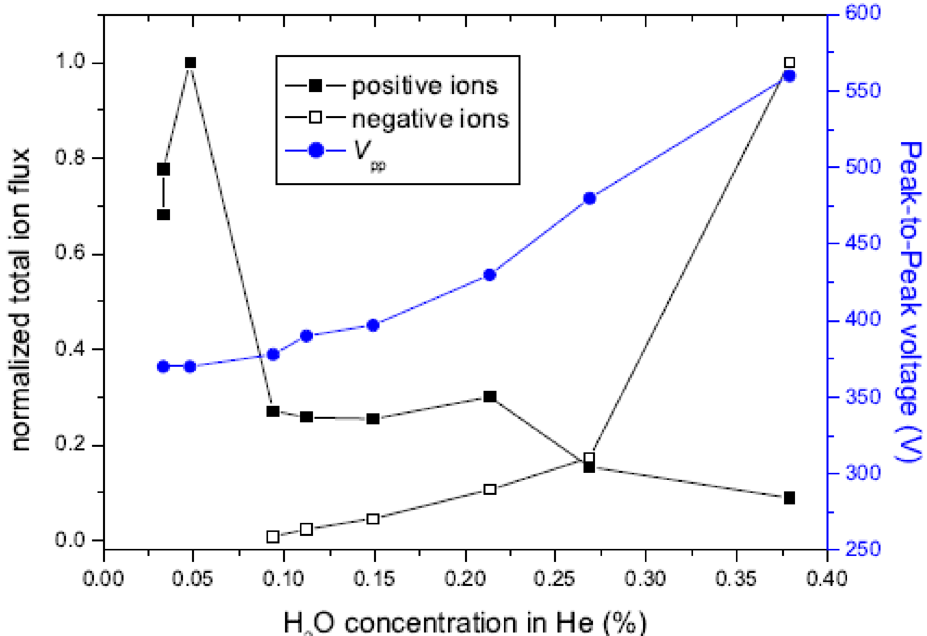
Shi and Kong JAP **94**, 9 (2003)

Ion Energy Distribution Function



- Collisional sheath: mean free path at atmospheric pressure < 1µm and the sheath is typical > 30 µm.
- Ion distribution presents low values but higher than the neutral gas temperature (350 K).
- Ion energy is not depending on the water concentration and the ionic species.

Variation of the Voltage discharge and ion flux in function of the H_2O concentration in He



At 900 ppm H_2O in He:

- Negative ions are detectable
- Increase in voltage (and phase shift)
- Drop in positive ions

  → the discharge becomes electronegative (consistent with global kinetic chemistry model)

Liu, Bruggeman et al PSST **19** (2010)

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Positive ions as a function of H_2O concentration

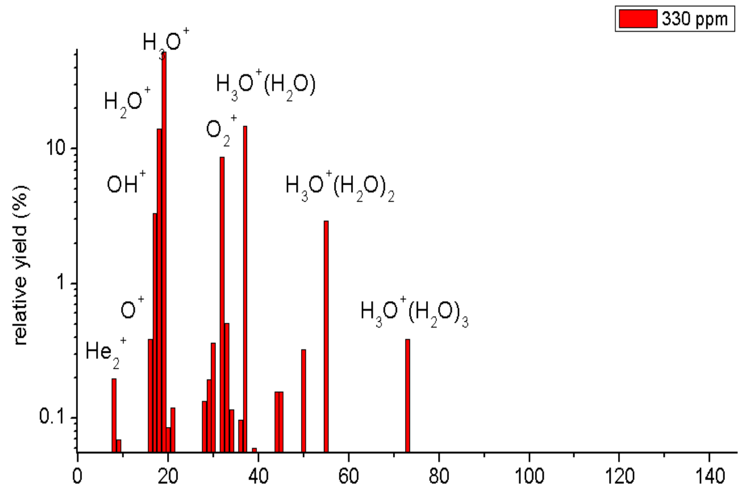
- Relative yield

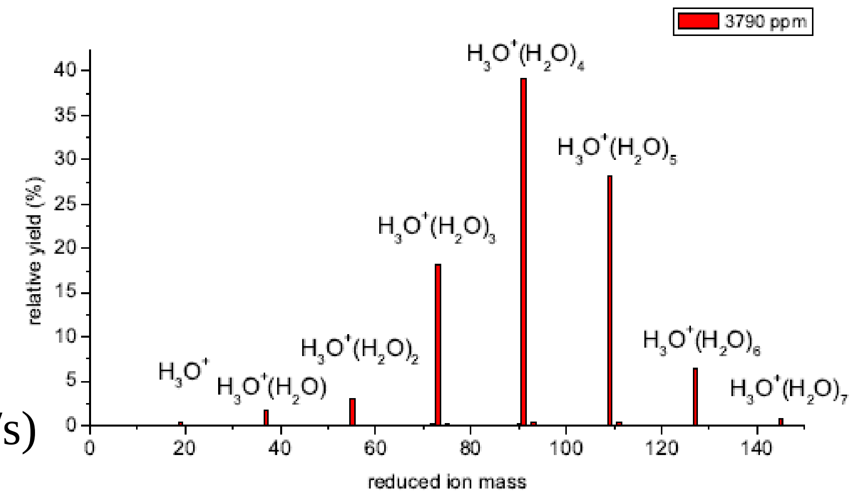
$$Y_i^r[\%] = \frac{Y_i^a}{\sum_i Y_i^a} \times 100$$

Absolute yield Y_i^a where i is the reduced mass index of the positive ions

Dominant positive ions are OH^+, O^+, O_2^+, He_2^+, O_2^+ and H_3O^+ and clusters

No He^+ !





Fast hydration reaction ($10^{15} m^3/s$)

$$H_2O^+ + H_2O \rightarrow H_3O^+ + HO$$

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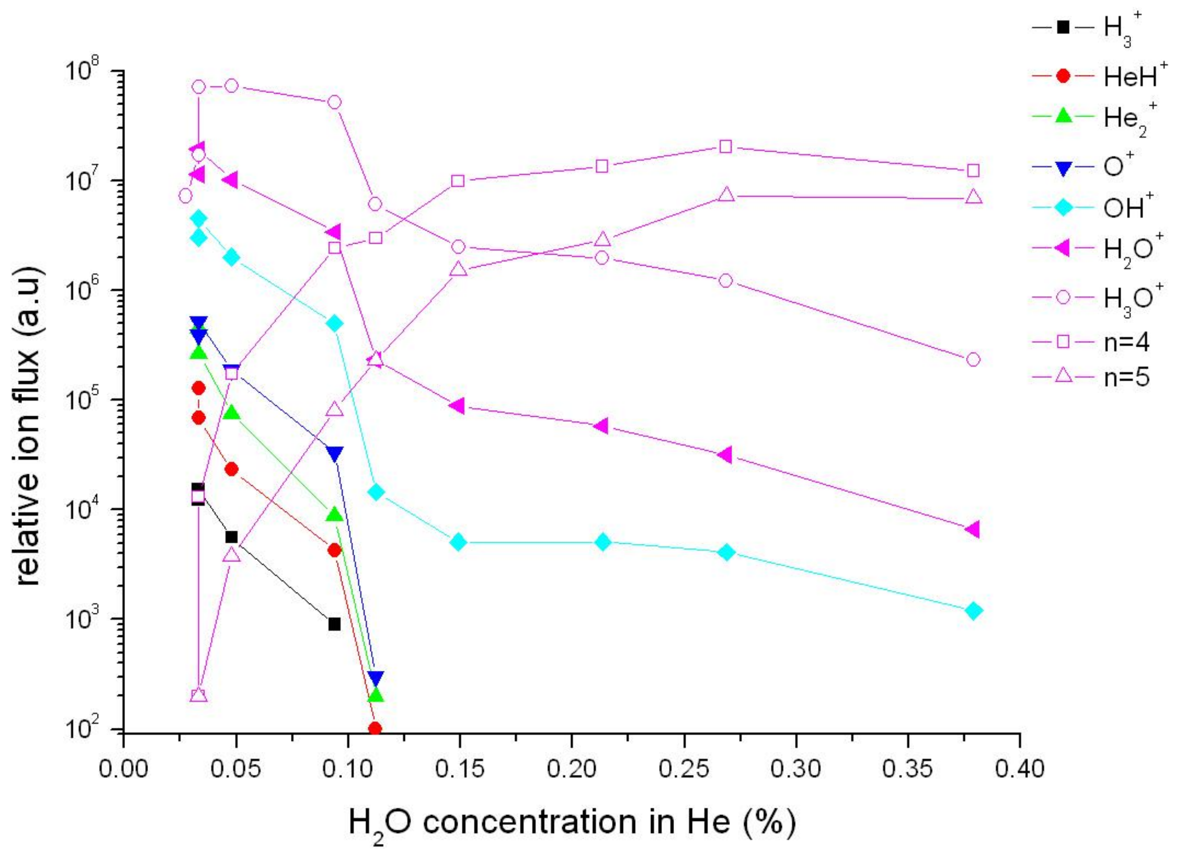
Relative positive ion flux in function of H_2O concentration



A drop in non-hydrated ions is observed at 0.1% of H_2O in He. This corresponds at the concentration where negative ions start to be detected.

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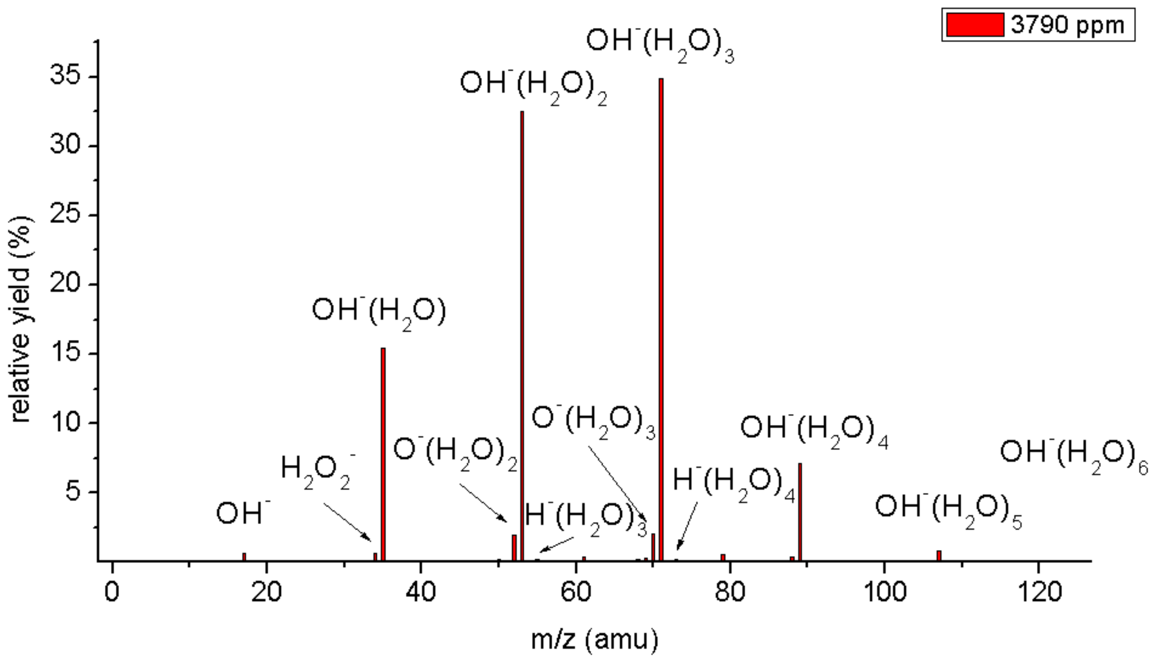
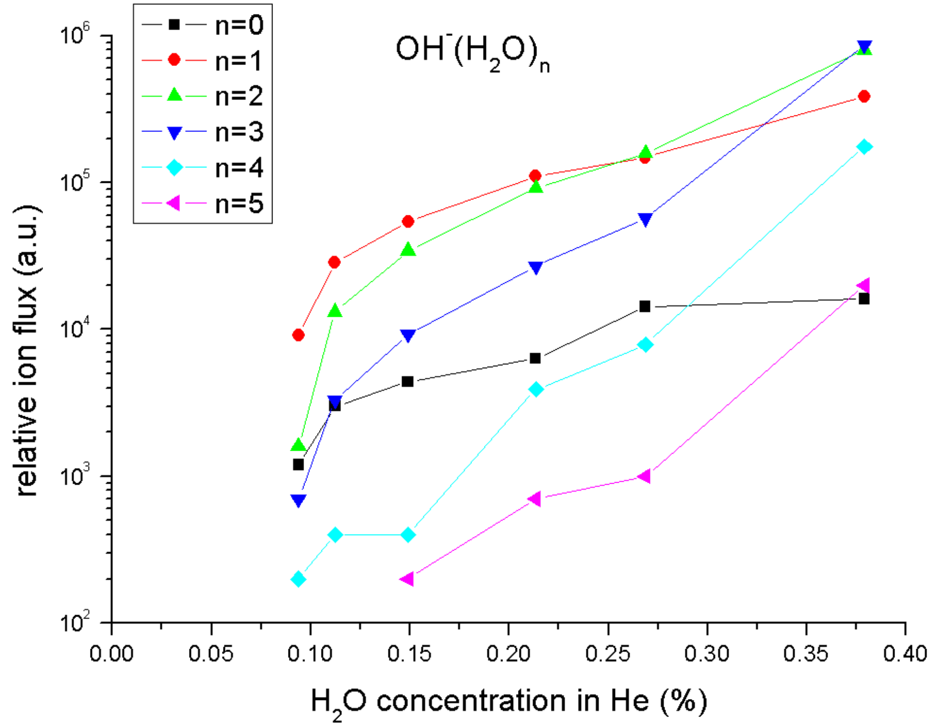
Negative ions?



- Normally RF sheaths trap negative ions. To be able to detect they need to be produced in the sheath close to the electrode (dissociative attachment).

Relative negative ion flux as a function of H_2O concentration



- The dominant negative ions are the OH^- and its clusters
- The dissociative attachment rate to produce H^- is faster than OH. Why is H^- not observed?

$$H^- + H_2O \rightarrow OH^- + H \ (3.8\ 10^{15}\ m^3/s\ ???)$$

Conclusions

- MBMS is able to sample in APGD, an orifice smaller than the sheath thickness is required. This is clearly not critical for corona and low power bio-plasma jets.
- Due the collisional sheath and the small mean free path at atmospheric pressure (< 1µm) and the sheath (> 30 µm) the ion energy remains low.
- Negative ions (OH^- and its hydrates) are observed in the RF glow discharge when the discharges turns electronegative.
- In view of the low water concentration (900 ppm) at which the discharge turns electronegative, negative ions are important in many (cold) atmospheric pressure plasmas.
- The flux of hydrated ions to the electrode increases with increasing water vapour and decreasing power.

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Thank you

Acknowledgements

The assistance of staff at Hiden Analytical Ltd., Warrington, UK in obtaining some of the representative data described in this presentation is gratefully acknowledged.

The presentation has drawn heavily on work published by research groups in many countries. An extensive list of references to this work where it includes a significant amount of data obtained with a Hiden mass spectrometric instrument, is available from:

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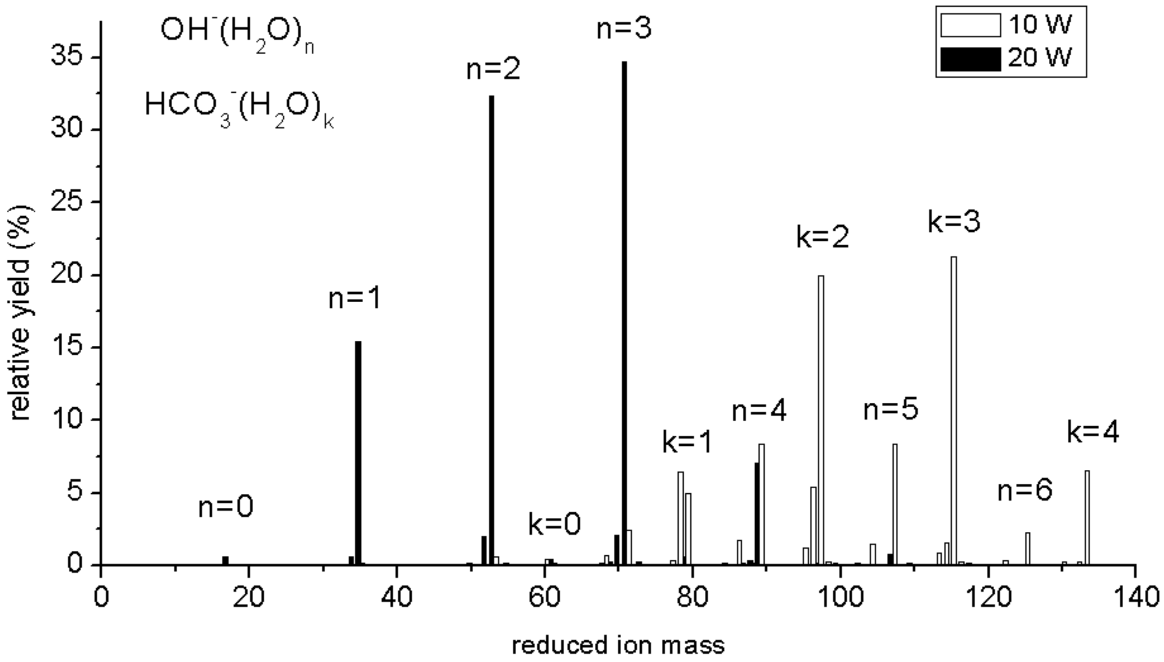
Effect of power: negative ions



- Negative ion clusters go down with decreasing power.
- Impurity negative ions start to become dominant ($HCO_3^-(H_2O)_k$)

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