

New Applications of a Multiple-Reflection Time-of-Flight Mass Spectrometer in Environment Sciences and in Medicine

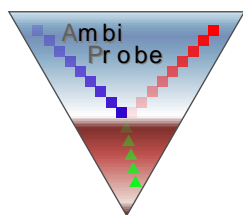
T. Dickel^{1,2}, W.R. Plaß^{1,2}, J. Lang¹, J. Ebert¹, H. Geissel^{1,2},
E. Haettner^{1,2}, W. Lippert¹, C. Scheidenberger^{1,2}, M.I. Yavor³

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² GSI Helmholtzzentrum für Schwerionenforschung, Darmstadt, Germany

³ Institute for Analytical Instrumentation, RAS, St. Petersburg, Russia

Overview



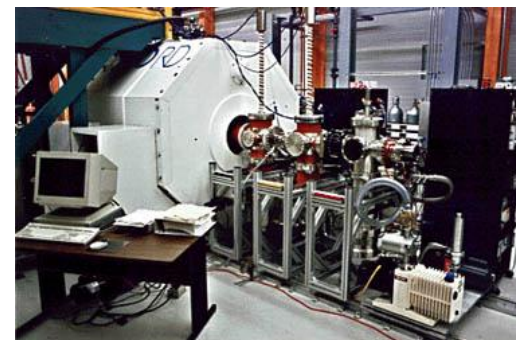
- Motivation
- Mobile MR-TOF-MS for Analytical Sciences
- Current and Future in-situ Applications
- Summary

Mobile High-Performance Mass Spectrometry

(Ultra-)High-Performance Mass Spectrometers

Very high resolving power ($m/\Delta m > 10^5$)

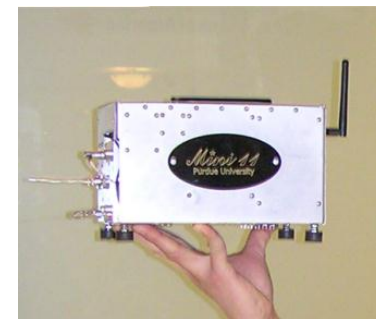
- Resolution of isobars at low/medium mass
- Isotopic resolution at high mass
- Very high mass accuracy ($\delta m/m < 10^{-6}$)
- Determination of composition and structure



A. Marshall et al., 9.4 T FT-ICR-MS

Mobile Mass Spectrometers

- In-situ measurements
- Prompt results
- Investigation of time-dependent processes
- No sample storage required
- Novel applications (medicine, environment science, space missions,...)



R.G. Cooks et al., Mini 11 RIT-MS

There is no mobile ultra-high performance MS yet

Goal: develop mobile ultra-high performance MS

Advantages of Time-of-Flight Mass Spectrometry

Enables high performance

- Very high mass resolving power and accuracy almost mass-independent
- No principle high mass limit
- Fast, allows to study time-dependent processes
- Sensitive, broadband

Enables compact instrument

- No magnet
- Analysis time ~ ms → moderate vacuum requirements compared to other high-performance MS
- Size reduction is straight forward

Single-reflecting TOF-MS achieve medium mass resolving power only
→ Multiple-reflection time-of-flight mass spectrometer (MR-TOF-MS)

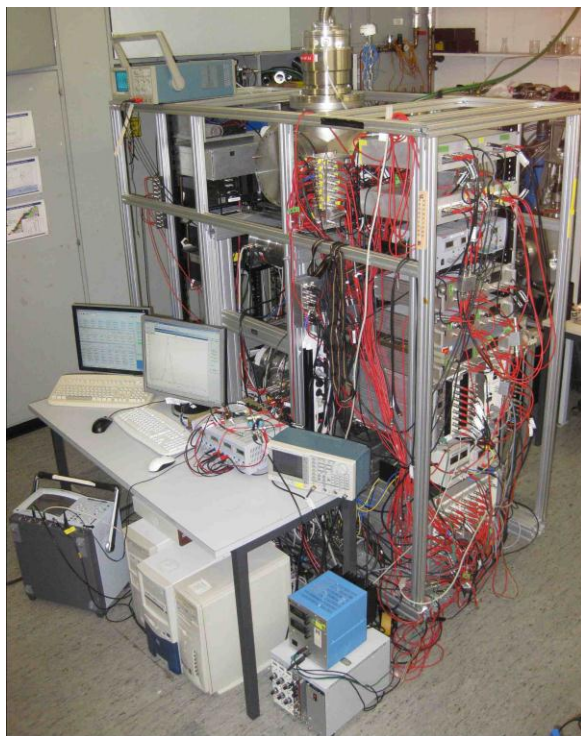
Presentations of various powerful MR-TOF-MS for nuclear physics

Giessen/GSI: H. Geissel, W. R. Plaß

RIKEN: M. Wada, P. Schury, S. Naimi, Y. Ito

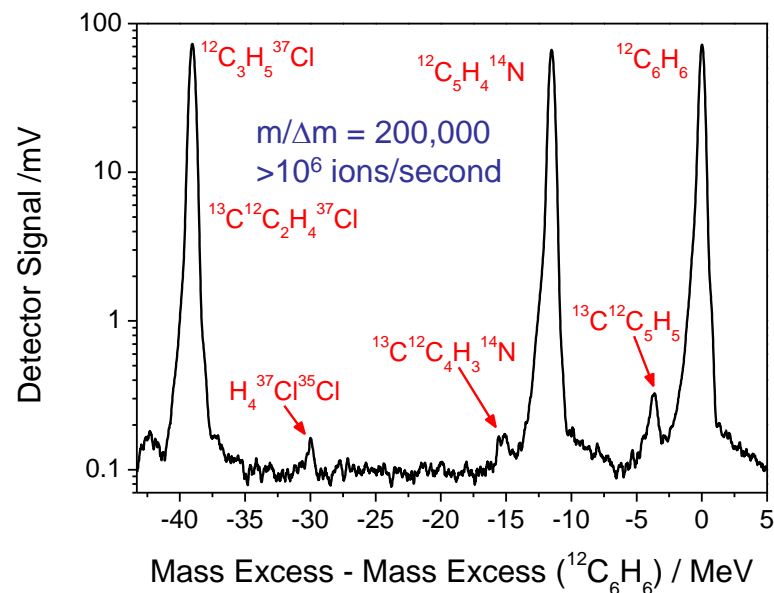
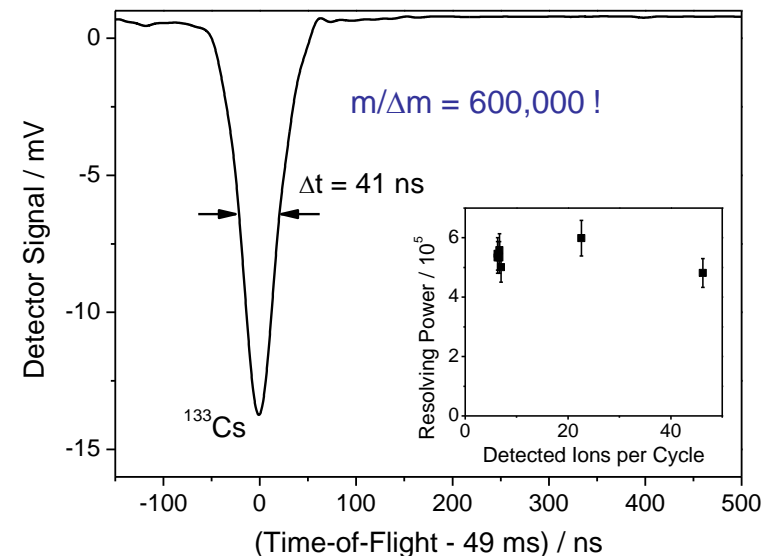
ISOLDE: R. Wolf, S. Kreim

MR-TOF-MS for Nuclear Physics



Performance

- Mass resolving power 600,000
- Mass accuracy $\sim 10^{-7}$
- Single ion sensitivity, efficiency up to 70%
- Ion capacity $\sim 10^6 / \text{s}$
- Measurement duration $\sim 10 \text{ ms}$
- Isobar separator



W.R. Plaß et al., Nucl. Instrum. Methods B 266 (2008) 4560; T. Dickel, PhD thesis, JLU Gießen, 2010

T. Dickel, New Applications of a MR-ToF-MS in Environment Science and in Medicine, EMIS 2012, Matuse, Japan, December 2 - 7, 2012

Transportable MR-TOF-MS



- MR-TOF-MS is designed to be easily transportable
- Time between MR-TOF-MS spectra at different location at an accelerator facility: 4 hours!

Basis for the first mobile ultra-high-performance mass spectrometer !

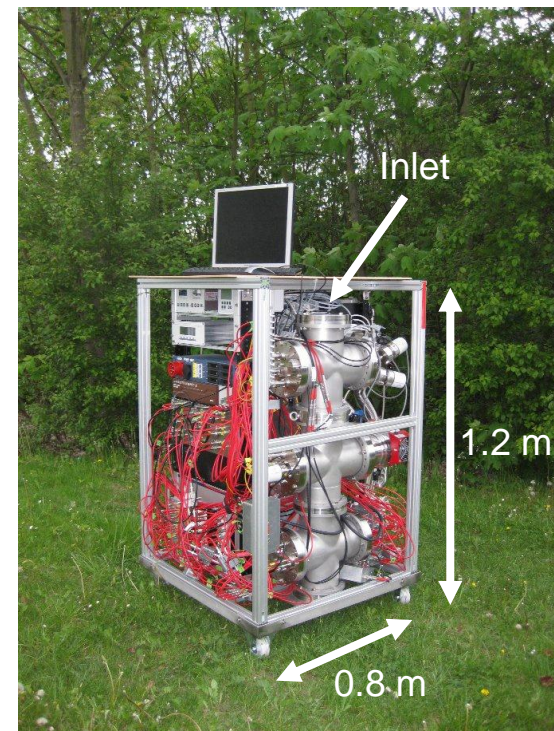
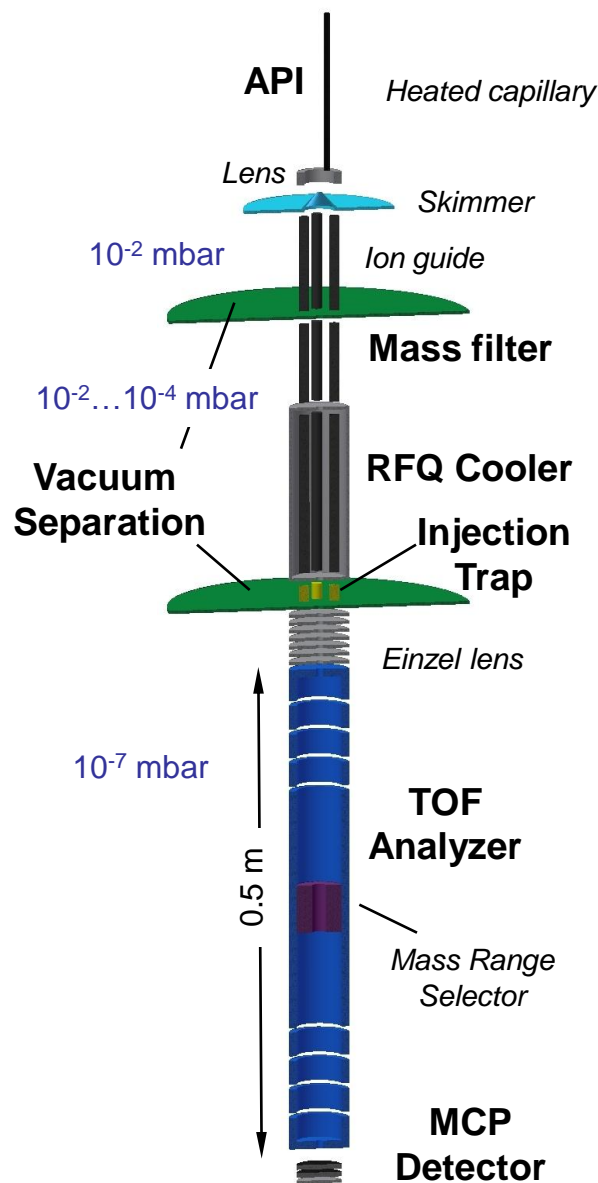
Mobile MR-TOF-MS for Analytical Mass Spectrometry

Design goals

- Mobile
- $m/\Delta m > 100,000$
- $\delta m/m < 1$ ppm
- Repetition rate \sim kHz
- Compatible with atmospheric ion sources

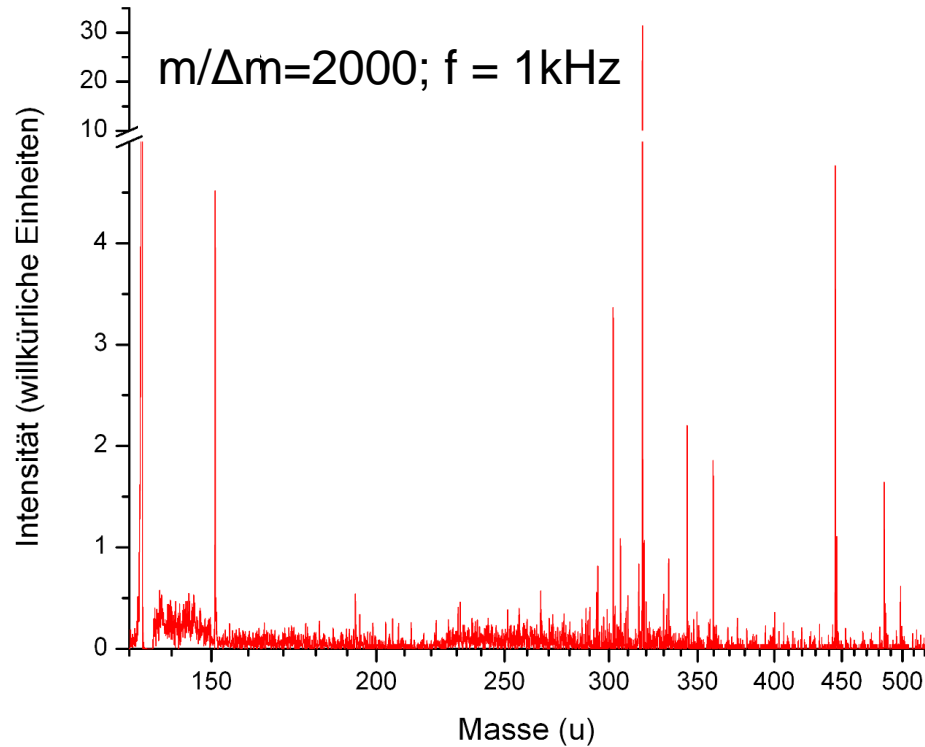
Rugged Setup

- 3 stacked DN150CF vacuum crosses as recipient
- 30 m³/h rough pump integrated
- Volume \sim 0.8 m³
- Weight \sim 200kg
- Fits into a van
- Power consumption $<$ 1.5 kW
- No further infrastructural needs except one power line
- Remote controlled

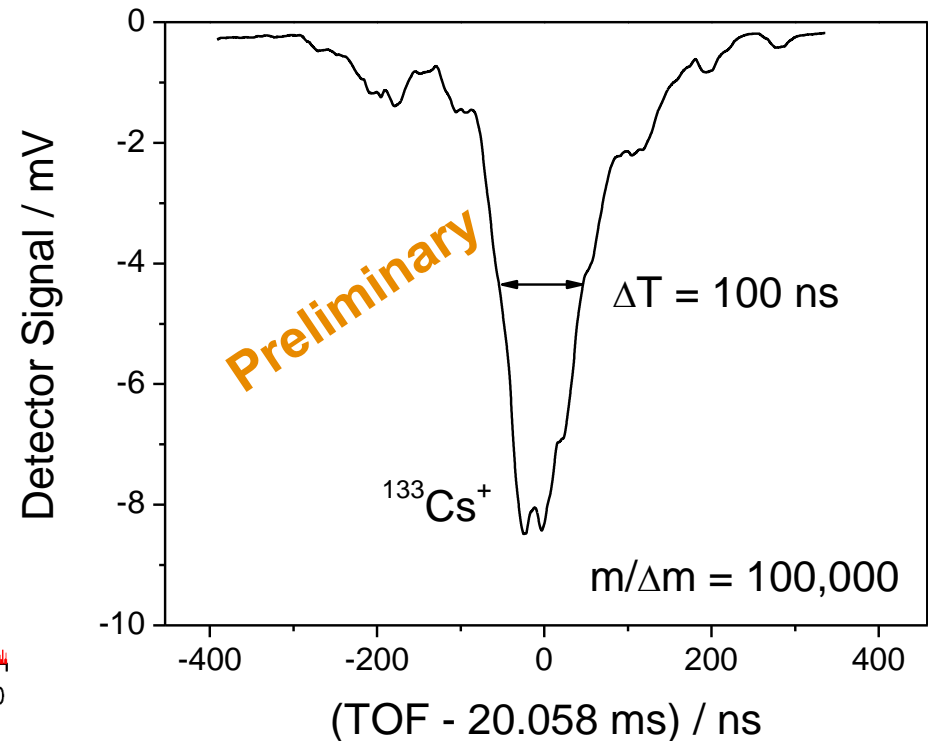


Commissioning and Preliminary Performance

Broadband Spectrum



High-resolution Spectrum



Optimization and performance enhancements underway

- Improved Voltage stabilization
- Increase in kinetic energy

→ Mass resolving power of several 10^5 expected

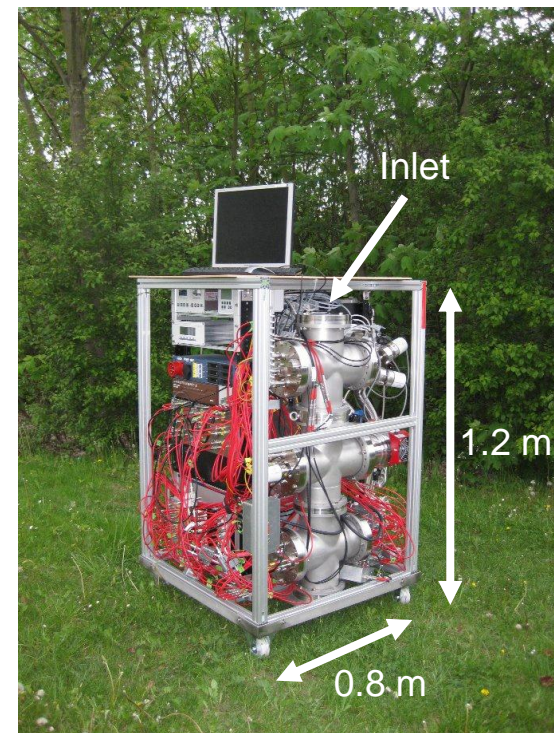
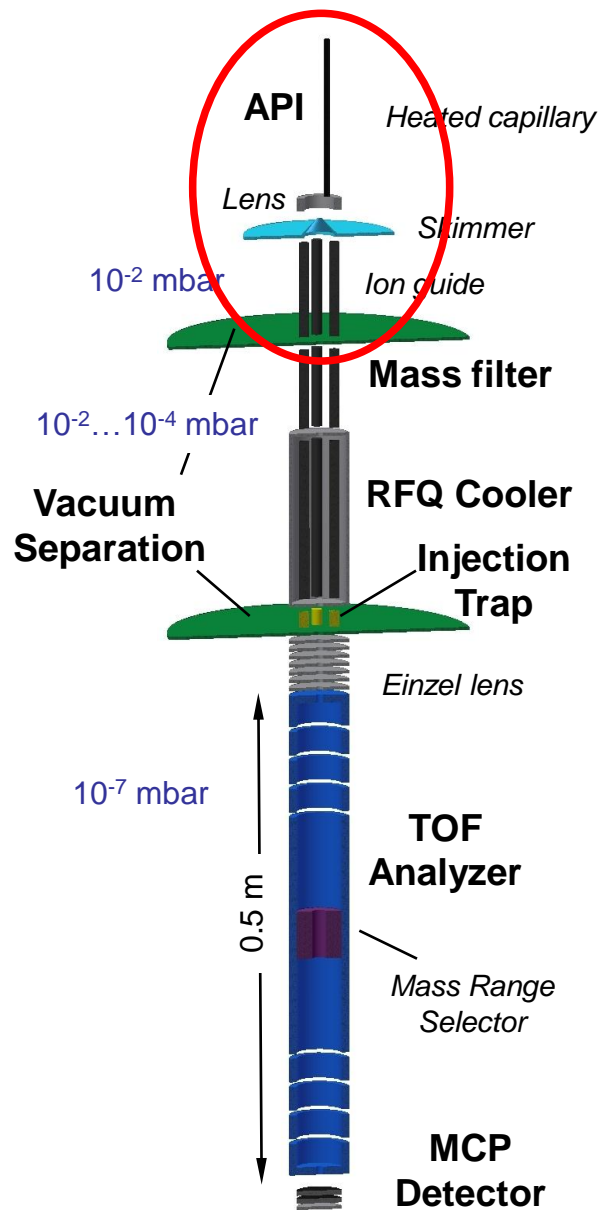
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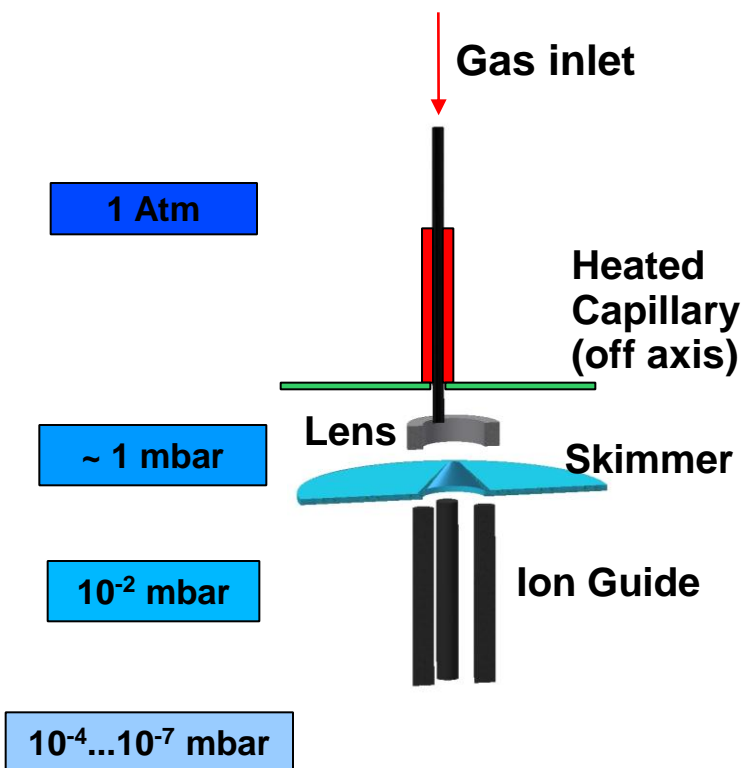
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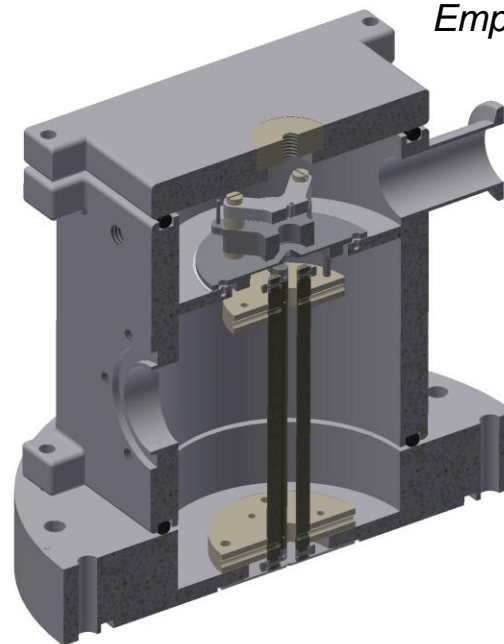
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Athmospheric Pressure Inlet



Collaboration with Z. Takats, et al.
Empirical College London



- Sample introduction
atmosphere → 10⁻⁴...10⁻⁷ mbar
- Coupling to LC/GC
- Compatible with various ion atmospheric sources:
 - ESI: Electrospray Ionisation
 - DESI: Desorption Electrospray Ionisation
 - REIMS: Rapid Evaporation Ionisation Mass Spectrometry

Electrospray Ionisation

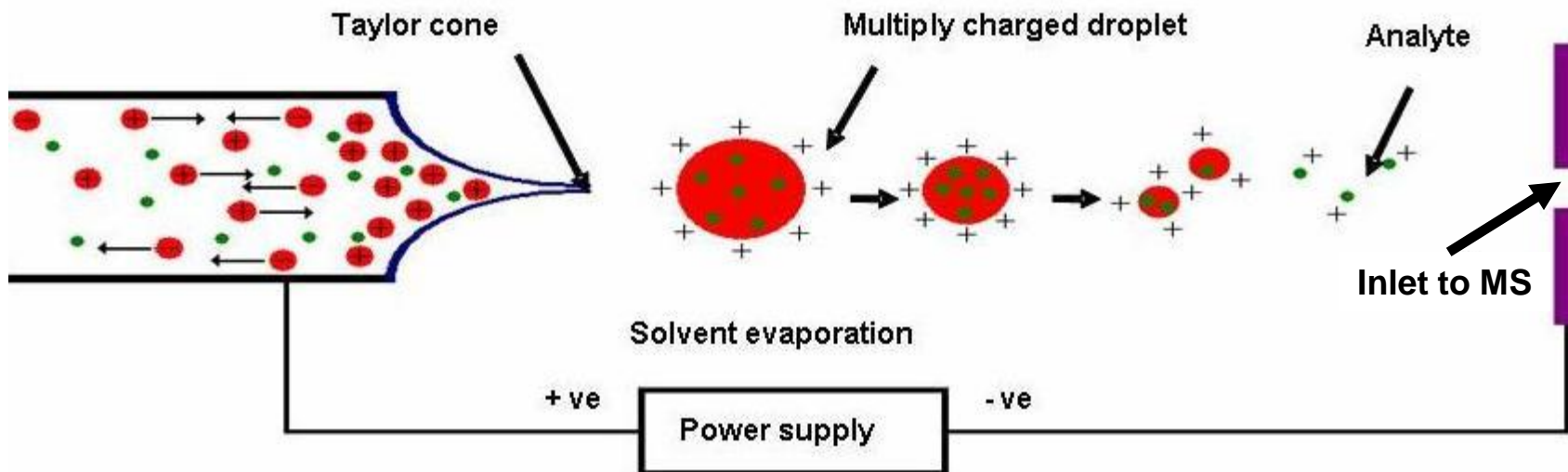
Soft Ionisation technique for large molecules, e.g. proteins

Multistep process:

1. Analyte in solvent
2. Spray solvent towards the inlet of the mass spectrometer
3. Charged solvent droplets evaporate and intact charged macromolecule remain



Nobel Prize in Chemistry to John Bennett Fenn in 2002



Electrospray Ionisation

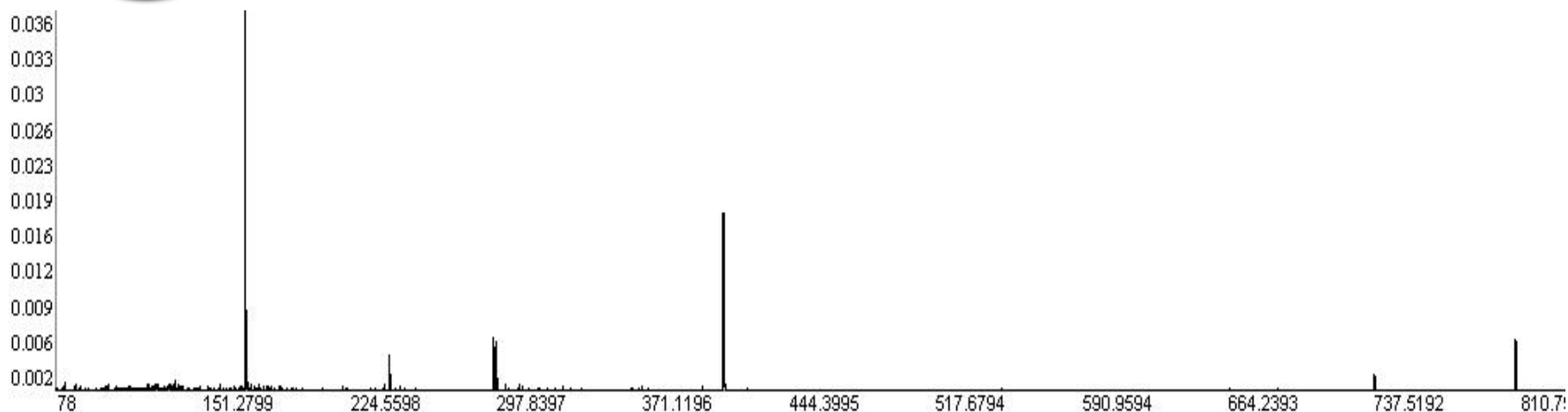
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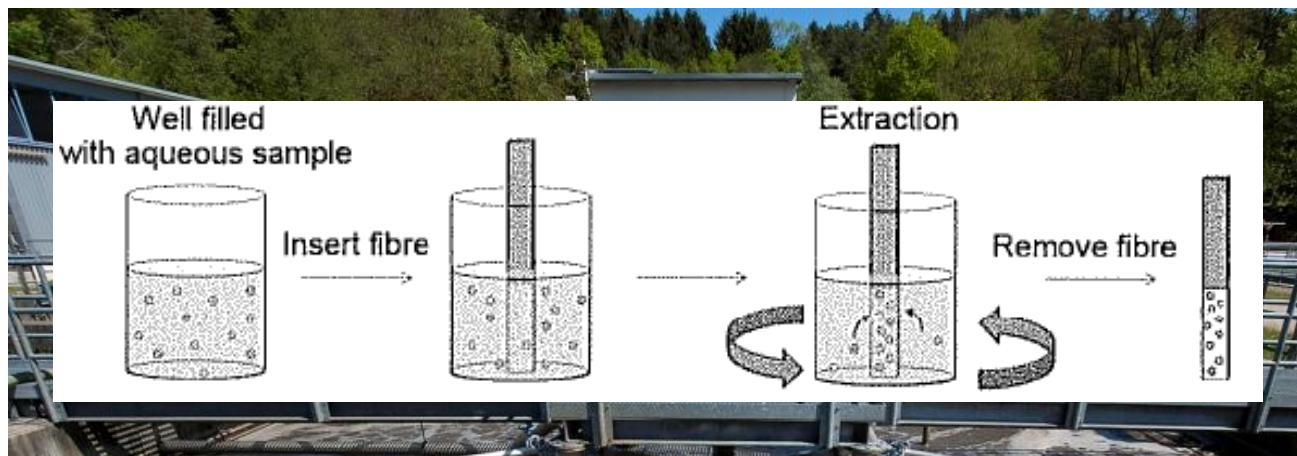
10/22/2011 10:55:10 AM/Positive Detection/API-test211011-56

Application I: Water-Monitoring at “Hot Spots”

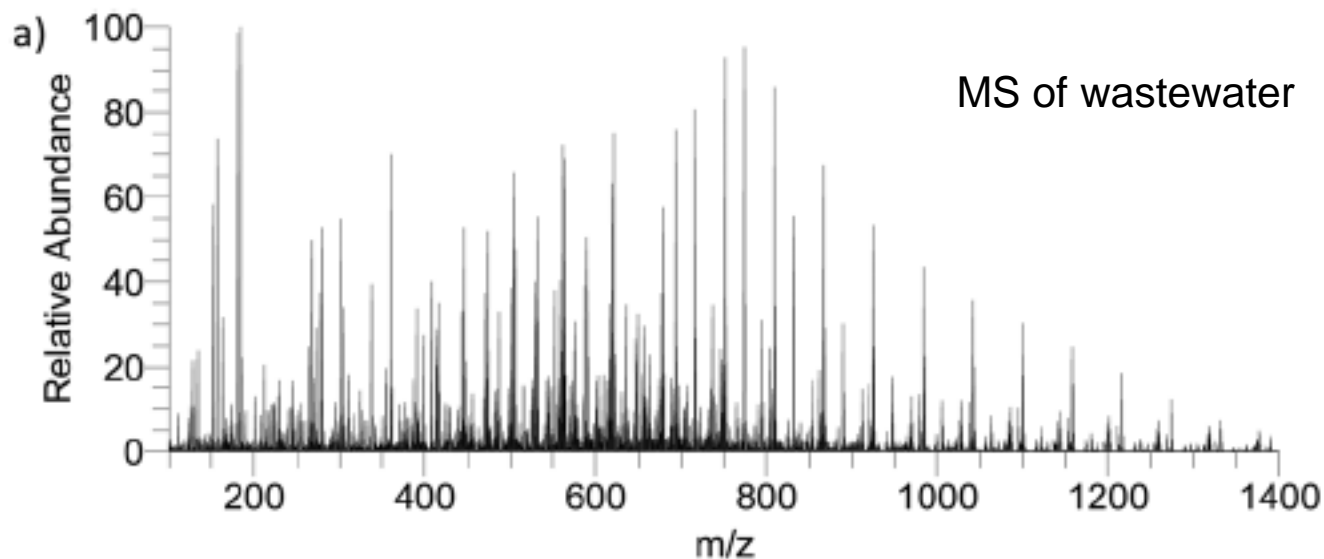
Check and monitor wastewater for pharmaceuticals (eg. Carbamazepine) and antibacterial agents (eg. Triclosan)

Two-step process:

1. Enrichment of analyte by thin-film microextraction



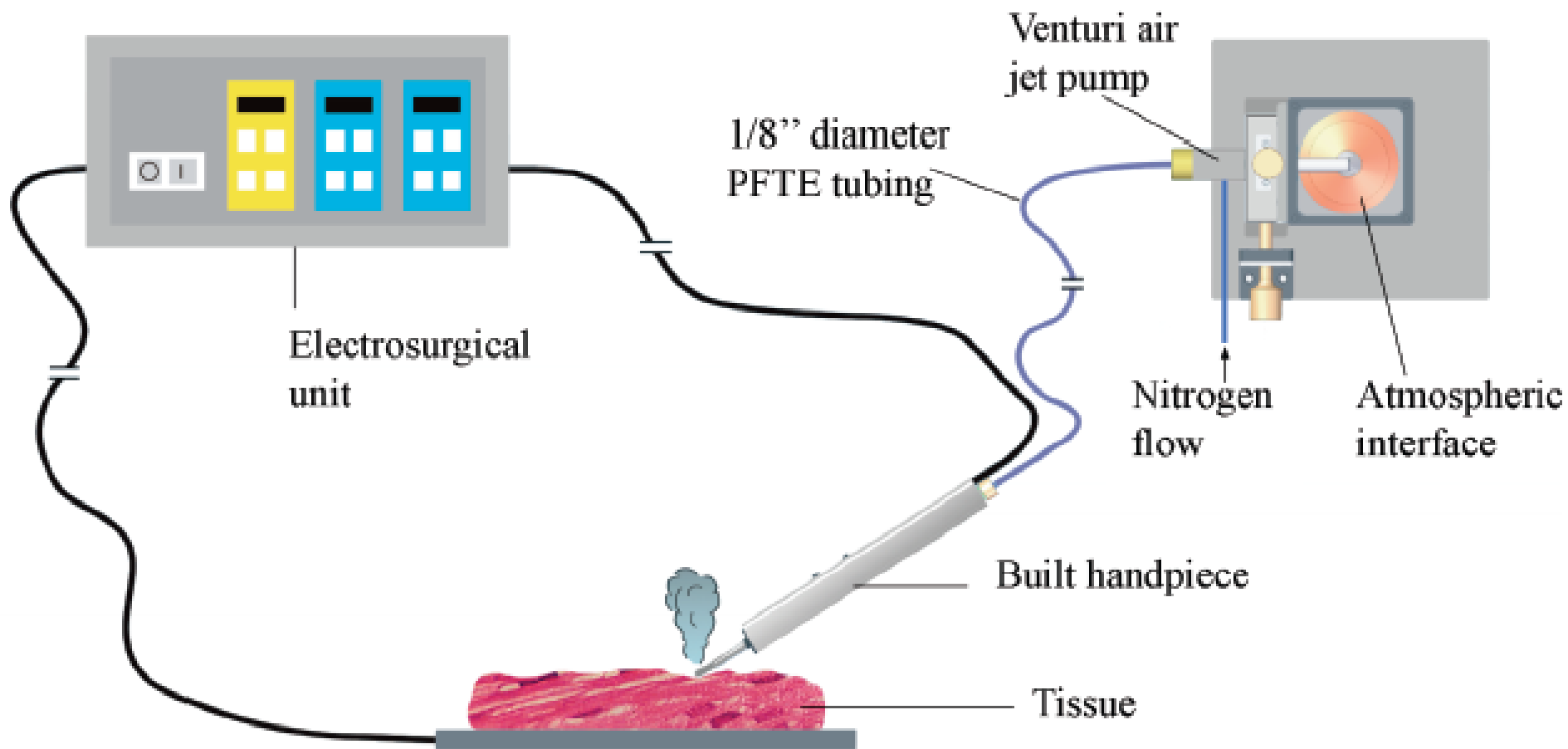
2. Sample analysis by high resolution DESI-MS



R. Düring, et al, *Analyst*, 2012, 137, 4037

Rapid Evaporation Ionisation Mass Spectrometry

Vapor generated by a electrosurgery is pumped to API of mass spectrometer



Z. Takats, et al., Anal. Chem. 2010, 82, 7343-7350

Application II: Real-time Tissue Recognition

Problem:

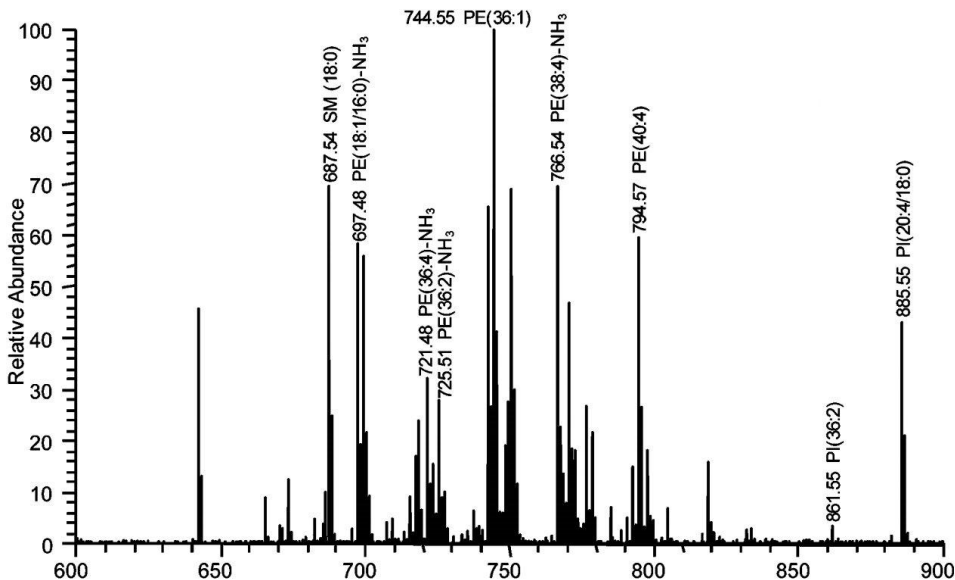
- Histological examination of tissue is slow (hours)
- intraoperative, faster (~30 min.) techniques are less reliable

Solution: REIMS

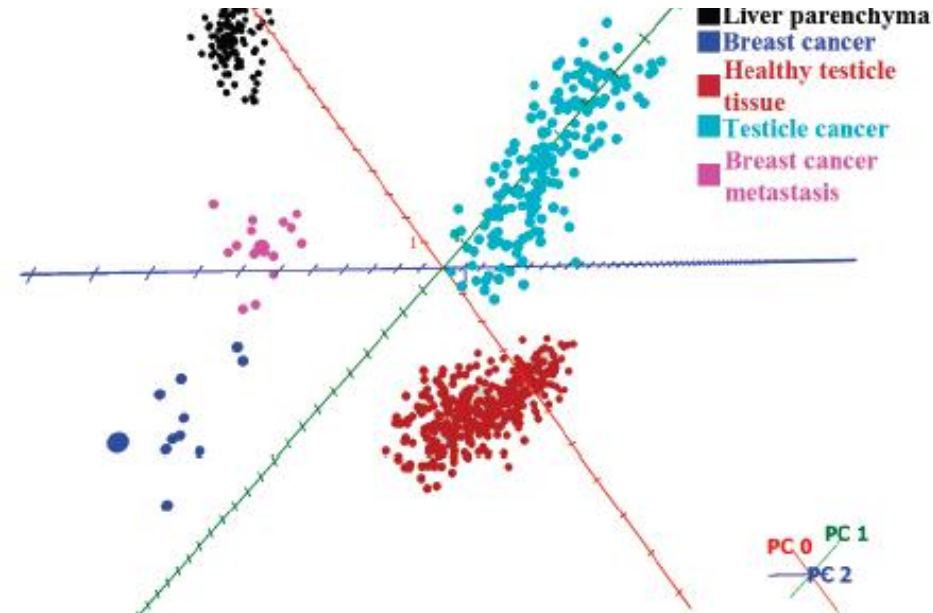
Identification of healthy and cancerous tissue in less than a second by principale component analysis (PCA) of the mass spectra



Mass Spectrum of canine stomach mucosa



PCA (60 dimensions)

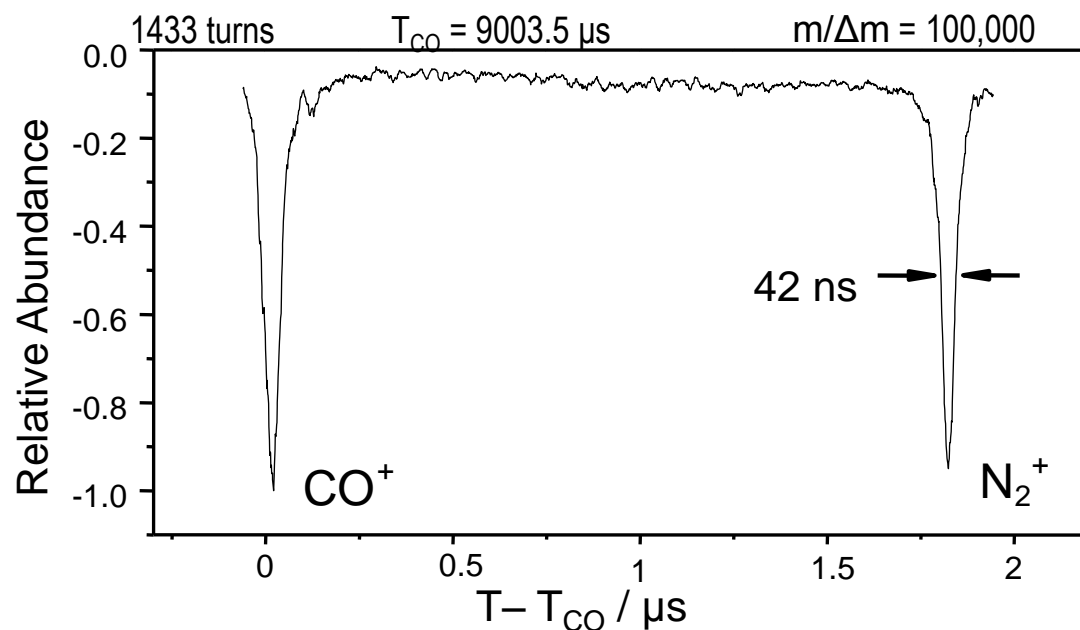
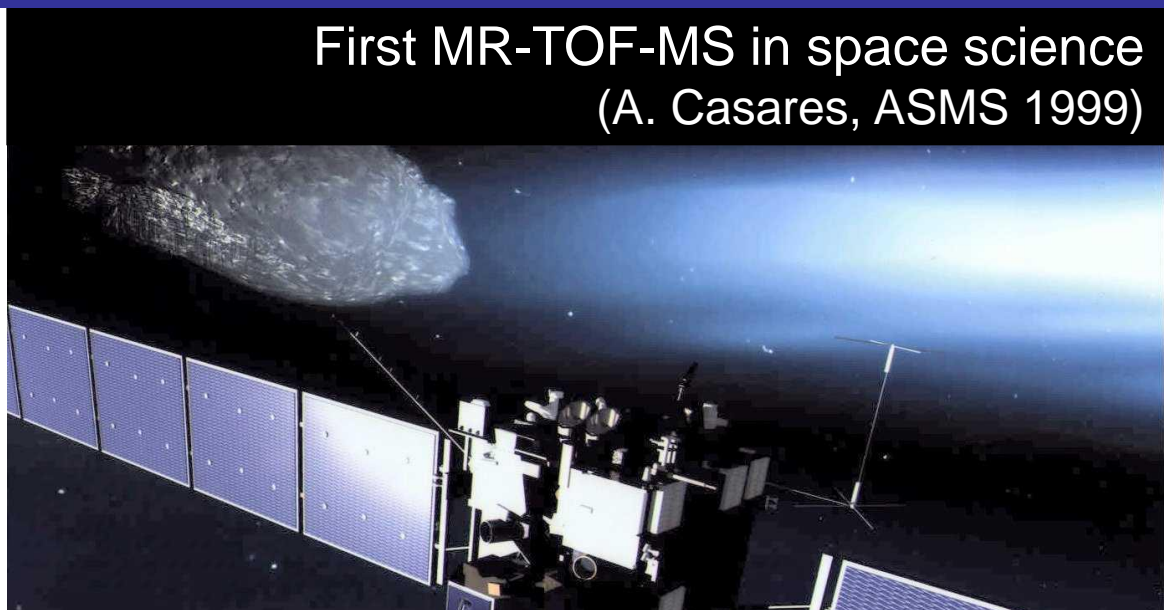


Future Applications: Space Science

MS in Space Science (Planets, Moons, Comets)

Questions:

- Is there life in outer space?
- Origin and transport of biological matter
- Cell damages by cosmic rays



Next generation devices:
Miniaturized MR-TOF-MS
with higher resolution,
accuracy and dynamic range

Summary

- Motivation: High-resolution in-situ mass spectrometry
Method: Mobile multiple-reflection time-of-flight mass spectrometry
- Device has been developed and commissioned:
 - $m/\Delta m \sim 10^5$
 - Operation with up to 1 kHz
 - Atmospheric Pressure Inlet
- Various in-situ applications planned
 - Real-time tissue recognition
 - Wastewater monitoring
- Next generation device: portable (?)
 - Replace standard components by customized components
→ further saving in size, weight, power consumption, ...
 - Envisaged applications include space missions



Acknowledgements

AG Scheidenberger, II. Physikalisches Institut, JLU Gießen



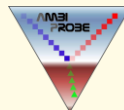
Funding: Land Hessen (LOEWE-Schwerpunkt AmbiProbe) and BMBF (06GI185I, 06GI9114I)

HESSEN



Hessisches
Ministerium für
Wissenschaft
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 **LOEWE** – Landes-Offensive
zur Entwicklung Wissenschaftlich-
ökonomischer Exzellenz



Bundesministerium
für Bildung
und Forschung

(Unambiguous) Mass Range

Unambiguous mass range is limited because light ions may undergo more turns than heavy ions

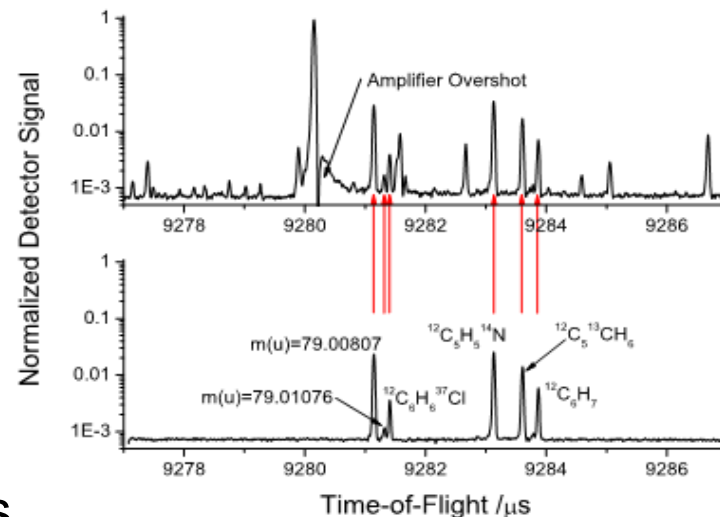
$$\frac{m_{\max}}{m_{\min}} = \left(\frac{N_{\text{tum}}}{N_{\text{tum}} - 1} \right)^2 \approx 1 + \frac{2}{N_{\text{tum}}}$$

Mass Range Selector

- Purifies spectrum
- Makes spectrum unambiguous
- Tool for mass range investigations

Mass Range Extension

- Medium resolution: small number of turns
- Scan full mass range
- Reconstruct full mass spectrum from shots with different turns
- Survey and zoom mode



T.Dickel, PhD thesis, JLU Gießen, 2010

