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Application of Surface Physics for Instruments in Space Science

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vorgelegt von
Martina Föhn

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Leiter der Arbeit
Prof. Dr. Peter Wurz

Physikalisches Institut der Universität Bern

Abstract

Contents

List of Acronyms

BCVD	Boron-doped Chemical Vapour Deposition
DLC	Diamond-Like Carbon surface
EMG	Exponentially Modified Gaussian
ENA	Energetic Neutral Atoms
FWHM	Full Width at Half Maximum
IBEX	Interstellar Boundary EXplorer
ILENA	Imager for Low Energetic Neutral Atoms
IMAP	Interstellar Mapping and Acceleration Probe
JNA	Jovian Neutral Atom Analyser
JUICE	JUpiter ICy moon Explorer
L1	Lagrange 1
LISM	Local InterStellar Medium
MCA	MultiChannel Analyzer
MCP	MultiChannel Plate
PA	PostAcceleration voltage
PEP	Particle Environment Package
RPA	Retarding Potential Analyser

1 Introduction

JUICE PEP NIM

2 Theory

2.1 Requirements

2.2 Basic Theory about a TOF masspectrometry

2.2.1 Principle

This chapter explains the function of a TOF instruments. A TOF mass spectrometer consists of, an ion-source, a mass analyser and a detector. The mass analyser has an ion-mirror which increases the flight distance of the ions by keeping the instrument on a certain length. A longer flight distance increases the mass resolution of the instrument.
In the ion source, the ions are produced. An electric field in the source generated such that ions get trapped in it. Then ions get accelerated by applying a high voltage pulse on the extraction grid. If the pulse width is long enough that all ions leave the source during the time the pulse is applied, the ions get all the same amount of energy W

$$W = \int_0^{s_0} q_0 E_s ds = q_0 U_0 \tag{1}$$

With s_0 the distance the ions get accelerated, in our case 1mm which is half the height of the ion source, q_0 the elementary charge, E_s the applied electric field and U_0 the voltage applied on the extraction grid. This energy is equal to the kinetic energy the ions have after leaving the ion-source

$$q_0 U_0 = \frac{1}{2} m v^2 \tag{2}$$

With m the mass of the particle and v the particle velocity. Rearranging this formula we get

$$\frac{m}{q_0} = 2 U_0 \frac{t^2}{s^2} \tag{3}$$

With t the time of flight and s the flight distance. Therefore, m/q_0 is proportional to t^2.
Ions starting at different positions also get a different amount of energy. Ions starting closer to the extraction grid will get less energy than ions further away from the grid. At a certain point after the source, the ions with higher energy have overtaken the slower ions. This point is at around $2 \cdot s_0$ which corresponds to a very short flight distance. To shift this focal point onto to the detector, additional fields after the ion-source are applied.
The ions have different thermal energies. Therefore ions of the same mass and starting at the same distance from the extraction grid will not have all the same energy when they leave the ion source. This energy spread leads to a difference in their velocity and to different flight times. This energy spread can be partially compensated by an ion-mirror also referred to as reflectron (Fig. 1). Ions with a higher energy will penetrate deeper into the ion-mirror and have a bigger flight path than ions with less energy. Therefore, the ion-mirror is able to compensate the different start energies of the ions. In the worst case scenario we have one particle flying toward the extraction grid and the other particle flying with the same velocity

in the opposite direction. The second particle gets decelerated and has to turn in the source. When it reached its initial position, it has the same amount of energy as the first particle. But it will always be behind the first particle by a constant time it needed to turn around and reach its initial position. To minimize this effect, one has to minimise the distance of the ionisation region or increase the voltage of the HV pulse. But a smaller ion source means less ions and therefore less signal. Increasing the HV pulse results in bigger electronic noise at the start of the spectrum. The biggest impact is there on the light particles such as H or H_2. Therefore, one has to make a trade-off.

2.2.2 Mass Calibration

In this section we discuss the calibration of the mass axis. According to Eq. (3) the mass/ charge is proportional to the square of time. By rearranging Eq. (3)

$$m = 2q_0 U_0 \frac{t^2}{s^2} \tag{4}$$

Take together all parameter which remain constant to one single constant:

$$C = \frac{2q_0 U_0}{s^2} \tag{5}$$

and considering the time scale has a constant offset t_0, equation (4) results in

$$m = C(t - t_0)^2 \tag{6}$$

In this equation there are two free parameters, C and t_0. To calibrate a mass spectrum at least two species appearing in the spectrum have to be known to solve this equation for the two parameters.

2.2.3 Mass resolution

According to bla the mass resolution is:

$$\frac{m}{\Delta m} = \frac{t}{2\Delta t} \tag{7}$$

2.2.4 Sensitivity

2.3 Ion Optical Design, NIM specific elements

A time of flight mass spectrometer consists of, an ion-source, a mass analyser and a detector.

The NIM instrument is able to measure neutrals and ions. Neutral particles get ionised by electron ionisation. A filament is heated up until it emits electron. Ions enter the ion source
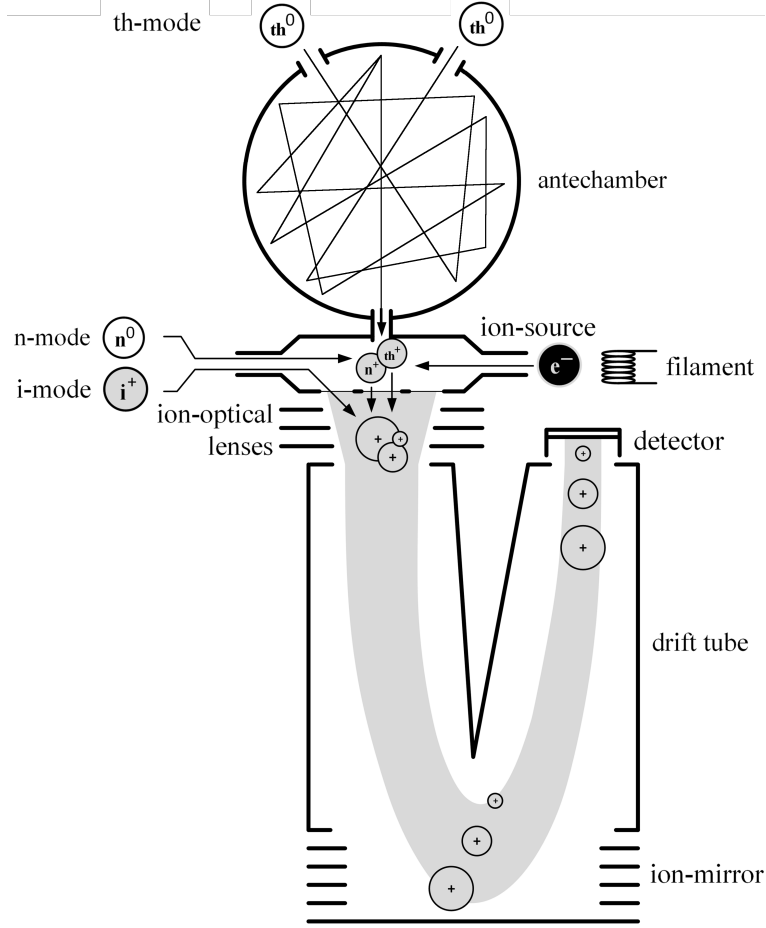
Figure 1: Schematics of the NIM mass spectrometer. Adapted from [2].

directly. All ions then get accelerated to the same energy and fly through the mass analyser. Light particles fly faster through the spectrometer than heavier ones. The different particle species arrive at different times at the detector. To enlarge the flight distance, an ion-mirror, which reflects the ions and leads them back to the detector. The used detector is a MCP detector.

2.3.1 Ion-source

To calculate the number of ions produced in the ion source we use:

$$I_{ion} = \beta \cdot Q_{ion} \cdot L \cdot n \cdot I_{em} \tag{8}$$

With β the extraction efficiency which is 1, L as the effective ionising path in our case 4 mm, n the particle density, I_{em} the electron emission current from the filament and Q_{ion} the ionising cross section. The cross sections of species used in our calibration can be found in table

3 Setup

3.1 NIM Instrument

3.1.1 Prototype

3.1.2 Protoflight Model

3.2 Test facilities/ Test Tools

4 Experiments

In this section , the different tests are described to develop the NIM instrument. All measurements were performed in the STROFIO vacuum chamber.

4.1 Reflectron

The NIM prototype reflectron was exchanged through the flight like reflectron, which was tested. The NIM prototype reflectron consisted of 12 ring electrodes connected with each other with resistors in between them. On the first, 5th and 12th electrode, a voltage can be applied. With the different resistors, a linear voltage gradient in the reflectron is generated.
The flight reflectron consists of a ceramic tube with two resistance spirals on its inner walls. There are three electrodes, where the voltage can be applied. The electrodes are connected via resistance spirals with each other. The two reflectrons can be seen in Fig. 2. This kind of reflectron was also used in the RTOF mass spectrometer which flied in ROSINA [3] and the in the NGMS [1].
Therefore, the two reflectrons are from the electrical point of view the same.
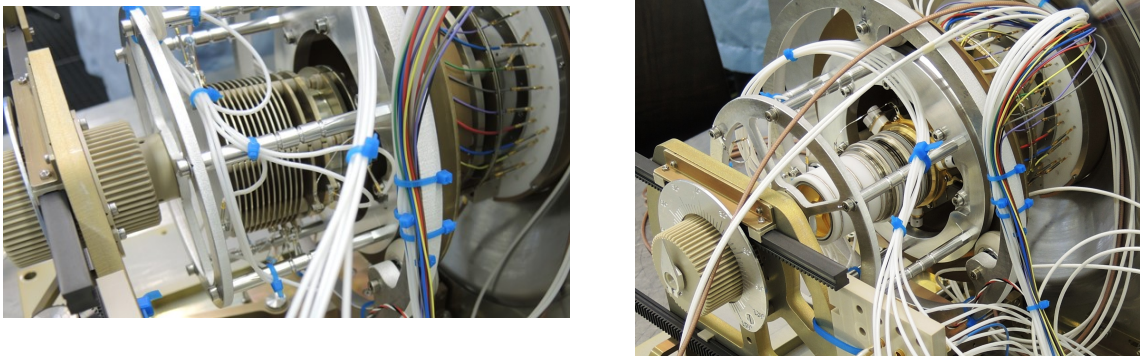

Figure 2: Left: Prototype reflectron with ringelectrodes. Right: Flight reflectron
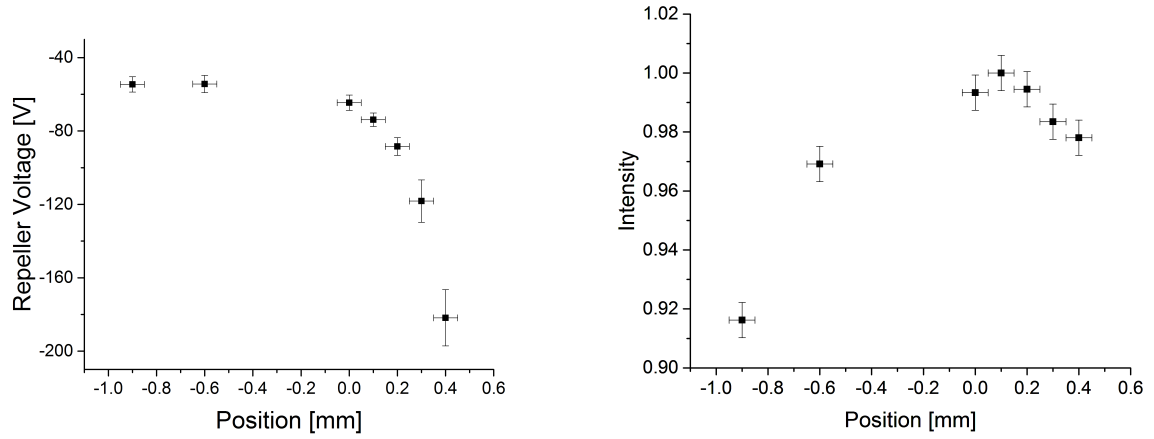
Figure 3: Left: The filament repeller voltage to reach the maximum electron intensity over the volume of the neutral particles. Right: Electron intensity normed on the intensity at position 0.

4.1.1 Measurement Principle

4.1.2 Discussion

4.2 CASYMIR-D/-E

4.3 Simulations

4.4 Pulser

4.5 Detector Tests

4.6 Ionoptics

5 Conclusion

6 Outlook

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[3] S. Scherer. <u>Design of a high-performance Reflect:ron Time-of-Flight mass spectrometer for space applications</u>. Universität Bern, 1999.

7 Appendix

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Name/Vorname: Föhn Martina

Matrikelnummer: 11-105-145

Studiengang: Master of Science in Physics

Bachelor ☐   Master ☑   Dissertation ☐

Titel der Arbeit: Application of Surface Physics for Instruments in Space Science

LeiterIn der Arbeit: Prof. Dr. Peter Wurz

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