GRAZING INCIDENCE TIME-OF-FLIGHT MASS SPECTROMETER: PROTOTYPE RESULTS AND POSSIBLE IMPROVEMENTS. A. Cadu[1], P. Devoto[1], P. Louarn[1], J-A. Sauvaud[1], [1]IRAP (Institut de Recherche en Astrophysique et Planétologie, 9 ave du Colonel Roche, 31028 Toulouse Cedex 4, France) alexandre.cadu@irap.omp.eu, pierre.devoto@irap.omp.eu

Introduction: Time of flight mass spectrometry is widely used to study space plasmas in planetary and solar missions. It provides information about the plasma physical and chemical properties by individual analysis of particles and statistical processing. However, scientific needs constantly rise and new performances are necessary to achieve a better understanding of space plasma mechanisms.

A research and development project has been performed at IRAP to improve this kind of instrument. We use grazing incidence microchannel plates (MCP) to replace usual carbon foil for electron emission. We designed a complete spectrometer prototype to validate the entire instrument concept. We present the first results and possibilities of improvements.

Previous analysis and developments: In the last conference, we presented grazing incidence MCPs as a new devices to replace carbon foils in time-of-flight mass spectrometer [1]. Despite of advanced designs [2], carbon foils remain a limitation for simple instruments, in terms of mass resolution and post-acceleration. MCPs are proved to really make these aspects better [3]. Indeed, energy losses are reduced and high voltages can be lowered for typically 15 kV down to 5 kV.

Simulations of ion-surface interactions with the MARLOWE code [4] show that ion reflection is quasi-specular under grazing incidence inferior to 10° from surface. The efficiency is good enough - from 70 to 95 %, depending on energy, species and angle - for ion transmission and electron emission in MCP channels. We then developed a calibration device for MCP samples to confirm this behavior with qualitative results.

This preliminary study gives us main parameters to design the entire instrument prototype. We suit commonly used subsystems [5] [6], such as electrostatic analyzer and time-of-flight section, to improve operation with grazing incidence. We use plates with square channels called Micro Pore Optics (MPO).

Instrument subsystems are presented in Figure1. The instrument includes an electrostatic analyzer to select ion energy. Right below its output, MPO are placed to scatter ions and generate electrons. Both ions and electrons enter the time of flight section, where they are separated by an electric field provided by electrodes. Particles are led to their dedicated MCP detectors. High voltages for the post-acceleration, the analyzer, the electrodes and the detectors are supplied by the HV board. The instrument is controlled by the digital board which is connected to an external computer. MCP pulses are amplified by custom analog front-ends [7]. They provide digital pulses to a Time to Digit Converter with a very high time precision - less than 500 ns. Information is then formatted and sent for spectrum computing.

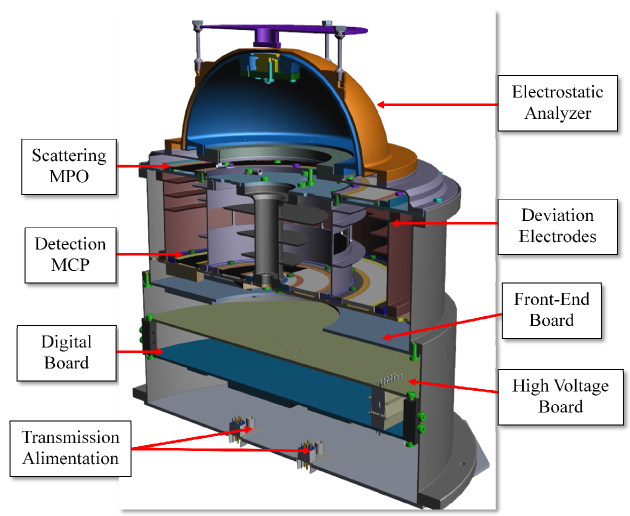

Figure 1. Mass spectrometer prototype subsystems (cut view).

Instrument features and tests: The final instrument we built is about 220 mm (8.7 ") high and as a diameter of 220 mm. It weighs about 2.2 kg with its docking interface and all electronic components. The aluminum shielding is at least 1 mm width. Its thermal equilibrium is below 50 °C at full electric load since we did not perform advanced mechanical and thermal analysis. Venting for vacuum use is sufficient, but electrostatic discharges have shown this point could be improved for faster operations in a laboratory environment.

Figure 2. Picture of the instrument in the vacuum chamber, face to the ion gun.

The electrical consumption is 1400 mW for the high voltage power supply and its analog / digital control interface. The digital electronics consumes about 700 mW, with possible reduction on the high speed LVDS link between the instrument and the computer.

We performed first acquisitions of time-of-flight spectrum without the analyzer. Results with He^+ N^+, O^+, H_2O^+, N_2^+ and O_2^+ ions at 5 keV are shown in Figure 3. The mass resolution is estimated to m/dm = 10. This is really encouraging since the spectrum show a very slow rising edge. This is typical of a bad electron extraction and leading. Indeed, the voltage applied on MPO appears to be insufficient for a proper acceleration of electrons. Consequently, the efficiency and time resolution are lowered.

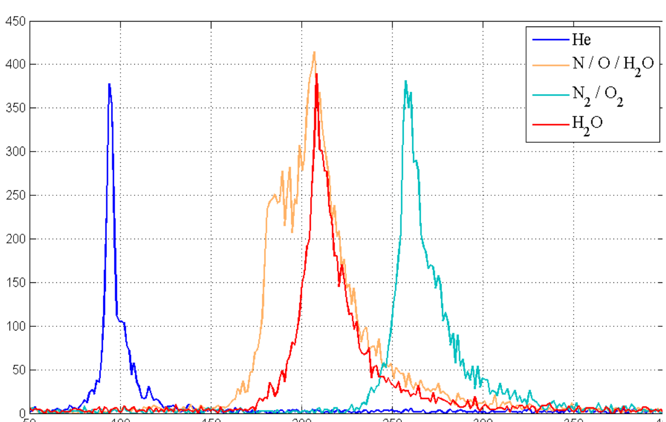

Figure 3. Measured time-of-flight spectra at 5 keV for different species (X-axis is in ns).

We also suspect that MCP is used in the range where typical gain leads to a lower front-end electronics precision - 3 ns instead of 500 ps. MCP voltages were reduced to avoid crosstalk in the detector plane and the electronic board.

Optimization: We recently developed new simulation tools to take into account presented results. We are now able to reproduce more precisely trajectories of ions and interactions with MPO surface. This gives access to relative ion transmission and electron extraction efficiencies (cf. Figure 4). The trajectory analysis also allows ion energy losses computing with an elastic collision approximation.

This simulation provides a good way to study the influence of various parameters, such as channel geometry (L / D ratio), MPO voltage or angular scattering after ion-surface interaction. It is also possible to introduce the electrostatic analyzer beam distribution as an input or to get electron and ion trajectories for time-of-flight section design.

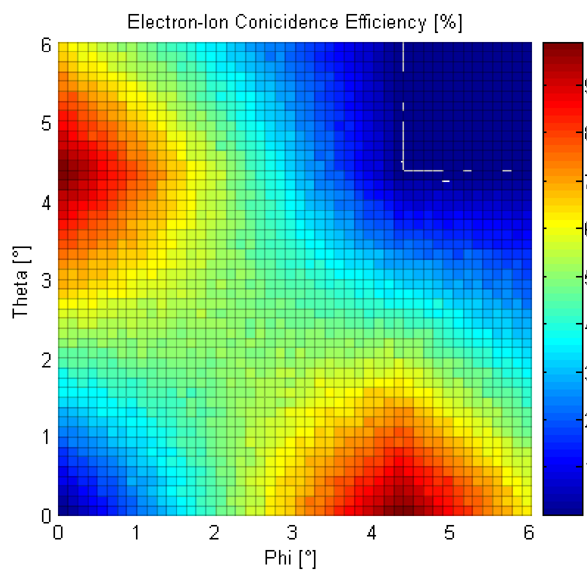

Figure 4. Coincidence of electron extraction from MPO channel and ion transmission (simulation).

The simulation already gives interesting results about second interaction of ion in MPO channels. For instance, it explains the difference of energy distributions computed by MARLOWE and experimental results.

Conclusions: The prototype designed and built presents interesting results for space-borne time of flight mass spectrometry. We demonstrated the ability of grazing incidence devices to fill the gap between classical mass spectrometers and reflectrons in terms of efficiency and resolution. The proposed design also reduces substantially mass and electric consumption by lowering high voltages. Development constraints are then released.

Optimization of MPO sizing and coupling with the rest of the instrument will offer better performances in terms of resolution and efficiency. Other studies and developments are made to improve MCP signal integrity, such as a new front-end electronics and detector plane.

References:

[1] A. Cadu et al., Development of Grazing Incidence Devices for Space-Borne Time-of-Flight Mass Spectrometry, International Workshop on Instrumentation for Planetary Mission, Proceedings (2012).
[2] M. Wüest, Time-of-flight Ion Composition Technique for Space Plasmas, Measurement Techniques in Space Plasmas: Particles Geophysical Monograph 102, Pages 141-155 (1998).
[3] P. Devoto et al., Secondary electron emission from distributed ion scattering off surfaces for space instrumentation, Review of Scientific Instruments 79, 046111 (2008).
[4] http://www-rsicc.ornl.gov/
[5] C.W. Carlson and J.P. McFadden, Design and Application of Imaging Plasma Instruments, Measurement Techniques in Space Plasmas: Particles Geophysical Monograph 102, Pages 125- 139 (1998).
[6] Rème, H., Aoustin, C., Bosqued, J. M. et al.: First multispacecraft ion measurements in and near the Earth's magnetosphere with the identical Cluster ion spectrometry (CIS) experiment, Ann. Geophys., 19, 1303-1354 (2001).
[7] P. Devoto et al., A low-power timing discriminator for space instrumentation, Review of Scientific Instruments 75, 5100 (2004).