EPSC Abstracts
Vol. 5, EPSC2010-699, 2010
European Planetary Science Congress 2010

Real-time on-board determination of ion composition from Time of Flight Plasma Spectrometers measurements

J. J. Berthelier (1), C. Verdeil (2), and D. Delcourt (2)
(1) LATMOS/IPSL, CNRS-UVSQ-UPMC, 4 Place Jussieu, 75252 Paris Cedex, France,
(2) LPP, CNRS-Ecole Polytechnique-UPMC, 4 avenue de Neptune, 94100 Saint-Maur

Abstract

Time of Flight (TOF) Plasma Spectrometers appear as the most efficient and widely used instruments to study planetary plasmas by measuring the ion composition and their energy and angular distribution. These instruments produce a very large amount of information that exceeds by far the telemetry capabilities of planetary spacecraft. In the past, simple techniques such as data averaging and decimation were often used to cope with limited data rates, resulting in a significant loss of scientific return. Adding a dedicated processor has also been considered at the expense of H/W resources while achieving only limited temporal resolution. The most efficient, and of highest interest for plasma physics, compression scheme consists in computing on-board and in real-time the moments of the plasma distribution function. This, of course, requires that the ion composition is known with a sufficient accuracy to allow that reliable moment values are obtained. This is difficult because the fast measuring channels of plasma spectrometers have a rather low mass resolution while most planetary magnetospheres display complex ion compositions and usual computer algorithms of TOF spectra de-convolution largely exceed the capabilities of space instruments.

We present in this poster a fast and simple method to retrieve in real time the ion composition with a good accuracy. This method is currently being developed for the Mass Spectrum Analyzer (MSA) instrument of the MPPE consortium on the MMO/BEPI COLOMBO spacecraft but can be readily adapted to other similar instruments. The proposed algorithm is based on a probabilistic approach to retrieve the ion composition by processing in real-time each measured TOF event independently. In order to reduce the on-board processor load, the processing is limited to major ion species that are expected to be present with significant densities and play a role in the physics of the planetary plasma. We have considered in this study a maximum of N=16 different ion species which is certainly enough even in the case of the apparently very complex composition of the magnetospheric plasma at Mercury. All the data used by the algorithm are stored in LU tables, thus modifying the list of selected ion species is straightforward.

The approach of the method can be briefly summarized as follows. The TOF spectra of all selected ion species are discretized along an appropriate resolution ΔT thus leading to a total number *NTOF* of possible TOF values T_k. For any given ion of species *J* the TOF spectrum allows to derive a set of $NTOF$ normalized probability values π_k^J which correspond to the probability that an ion of species *J* gives a TOF event T_k. Due to the limited mass resolution of the spectrometer, a number of ion species can be associated with any given TOF event and the basic principle of the method is to define for any T_k a *N* dimensional "instantaneous composition vector" $[C_k]$ the coordinates of which represent the probability that T_k arise from the detection of an ion of species *J=1,…N*. Adopting a vector and matrix formalism $[C_k] = \|P\| * [T_k]$ where $T_k = [000100...00]$ is a *NTOF* dimensional unit vector with its k^{th} coordinate equal to 1 and $\|P\|$ is a $NxNTOF$ matrix (N rows corresponding to the *N* selected ion species, $NTOF$ columns corresponding to the *NTOF* possible TOF values) with elements $P_{ij} = P_k^J$ where $P_k^I = \pi_k^I / \sum_{J=1,N} \pi_k^J$ is the probability that a TOF T_k arises from the detection of an ion of species J. In case of a perfectly mass resolving spectrometer with no overlap among the TOF spectra of the *N* ion species, for a given ion species I entering the instrument and giving a TOF T_k, $C_k^J = \delta_{IJ}$ where the delta function $\delta_{IJ} = 0$ for $I \neq J$ and $\delta_{II} = 1$ if $I = J$.

Starting from this probabilistic approach and keeping the vector and matrix formalism one can defines, for each ion species *I*, (i) a *N* dimensional "point spread vector" C^I with components C_l^I equivalent to the "point spread function" for ion species *I* in ordinary mass spectrometry and (ii) a *N*x*N* "point spread matrix" $\|A\| = \|C^1 C^2 ... C^N\|$. One can write: $[C^I] = \|A\| * [H^I]$ with H^I being the *N* dimensional "species vector" which represents the probabilistic ion composition, or $H^I = \|A^{-1}\| * [C^I]$. In the ideal case of a perfectly mass resolving instrument $H_l^I = \delta_{Il}$. When a mixed flux of K_1 ions of species *1*, K_2 ions of species *2*, … K_M ions of species *M* with $K = K_1 + K_2 + ... K_M$ enters the instrument one gets the following relation:

$$K.\|A^{-1}\| * [C_{av}] = K_1.\|A^{-1}\| * [C^1] + K_2.\|A^{-1}\| * [C^2] + ... + K_M \|A^{-1}\| * [C^M]$$

or

$$K.[H^{av}] = K_1.[H^1] + K_2.[H^2] + ... + K_M.[H^M]$$

with the probabilistic ion number flux of species *I* equal to $N^I = K_I . H_I^I = K.H_I^{av}$

This probabilistic method has been tested using simulated TOF spectra provided by a numerical model of MSA that were proved by initial ion beam tests to be in perfect agreement with measured spectra. The probabilistic method provides statistically good results when the number of processed TOF is larger than about 30 to 40. An interesting outcome of the study is the necessity, for the algorithm to work, to group "neighbour" ions such as Na^+ and Mg^+ or Al^+ and Si^+ into single "virtual" species. Mathematically this stems from the singularity of matrix *A* when neighbour ions are included separately, physically this is a simple consequence of the limited mass resolution of the spectrometer. This has no significant impact on the calculated moments since the error on the mass is only ~ 2%. All the results from matrix operations for the various TOF values are stored in LU tables so that the probabilistic method has the definite advantage to require, for each TOF event, a maximum of N additions of numbers read from LU table.