ARCHIVAL OF THE CLUSTER ION SPECTROMETRY (CIS) DATA IN THE CLUSTER ACTIVE ARCHIVE (CAA)

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ABSTRACT

The Cluster Active Archive (CAA) aims at preserving the 4 Cluster spacecraft data, so that they are usable in the long-term by the scientific community as well as by the instrument team PIs and Co-Is. This implies that the data are filed together with the descriptive and documentary elements making it possible to select and interpret them. The CIS (Cluster Ion Spectrometry) experiment is a comprehensive ionic plasma spectrometry package onboard the four Cluster spacecraft, capable of obtaining full three-dimensional ion distributions (about 0 to 40 keV/q) with a time resolution of one spacecraft spin (4 sec) and with mass-per-charge composition determination. The CIS package consists of two different instruments, a Hot Ion Analyser (HIA) and a time-of-flight ion Composition Distribution Function (CODIF) analyser, plus a sophisticated dual-processor based instrument control and data processing system (DPS). For the archival of the CIS data a multi-level approach has been adopted. The CAA archival will include processed raw data (Level 1 data), moments of the distribution functions (Level 2 data), and calibrated high-resolution data in a variety of physical units (Level 3 data). Furthermore, the calibration files and high-level processing software will be also archived. This approach provides "ready to use" high-resolution data products, archived in ASCII (CEF-2 format), which are expected to have a long lifetime. However, should a user wish to re-analyse the raw data and the instrument calibrations, he will also be able to do it. The CIS data archive will also include experiment documentation, graphical products for browsing through the data, and data caveats. Given the complexity of an ion spectrometer, and the variety of its operational modes, each one being optimised for a different magnetospheric region or measurement objective, consultation of the data caveats by the end user will always be a necessary step in the data analysis.

1. INTRODUCTION

The Cluster Active Archive (CAA) aims at preserving the 4 Cluster spacecraft data, so that they are usable in the long-term by the world-wide scientific community as well as by the instrument team PIs and Co-Is. Its purpose is to maximise the scientific return from the mission, and to ensure that the unique data set returned by the Cluster mission is preserved in a stable, long-term archive for scientific analysis beyond the end of the mission. This implies that the data are filed together with the descriptive and documentary elements making it possible to select and interpret them [1].

The CAA home page is at **http://caa.estec.esa.int/caa/**.

2. THE CIS EXPERIMENT

The CIS (Cluster Ion Spectrometry) experiment is a comprehensive ionic plasma spectrometry package onboard the four Cluster spacecraft, capable of obtaining full three-dimensional ion distributions (about 0 to 40 keV/e) with a time resolution of one spacecraft spin (4 sec) and with mass-per-charge composition determination [2].

The prime scientific objective of the CIS experiment is the study of the dynamics of magnetized plasma structures in and in the vicinity of the Earth's magnetosphere, with the determination, as accurately as possible, of the local orientation and the state of motion of the plasma structures required for macrophysics and microphysics studies.

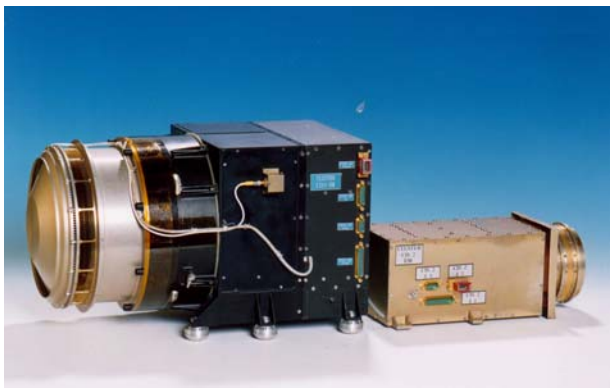

Fig. 1. The CODIF (on the left) and the HIA (on the right) ion detectors of the CIS experiment

The CIS package consists of two different instruments (Fig. 1), a time-of-flight ion Composition and Distribution Function analyser (CODIF, or CIS-1) and a Hot Ion Analyser (HIA, or CIS-2). It includes also a sophisticated dual-processor based instrument control and data processing system (DPS).

This CIS home page is at **http://cluster.cesr.fr:8000/**.

2.1 The CODIF (CIS-1) Instrument

The CODIF instrument is a high-sensitivity mass-resolving spectrometer with an instantaneous 360° x 8° field of view to measure full 3D distribution functions of the major ion species (in as much as they contribute significantly to the total mass density of the plasma), within one spin period of the spacecraft. Typically these include H^+, He^+, He^{++} and O^+, with energies from ~ 25 eV/e to 40 keV/e and with medium (22.5°) angular resolution.

The CODIF instrument combines ion energy per charge selection, by deflection in a rotationally symmetric toroidal electrostatic analyser, with a subsequent time-of-flight analysis after post-acceleration to ~15 keV/e. In the time-of-flight (TOF) section the velocity of the incoming ions is measured. Microchannel plate (MCP) electron multipliers are used to detect both the ions and the secondary electrons, which are emitted from a carbon foil at the entry of the TOF section, during the passage of the ions. These secondary electrons give the "start" signal, for the time-of-flight measurement, and the position information.

In order to cover populations ranging from magnetosheath protons to tail lobe ions, a dynamic range of more than 10^5 is required. CODIF therefore consists of two sections, each with 180° field of view, with geometry factors differing by a factor of ~ 100. This way, one section will always have counting rates which are statistically meaningful and which at the same time can be handled by the time-of-flight electronics. However, intense ion fluxes can in some cases saturate the CODIF instrument (particularly if data are acquired from the high sensitivity side), but these fluxes are measured with HIA. The operation of the high-sensitivity side ("high-G", or "HS") and of the low-sensitivity side ("low-g", or "LS") on CODIF is mutually exclusive, and only one of the two sides can be selected at a time to supply data.

With an additional Retarding Potential Analyser (RPA) device in the aperture system of the CODIF sensor, and with pre-acceleration for the energies below 25 eV/e, the range is extended to energies as low as the spacecraft potential. The retarding potential analyser operates only in the RPA mode, and provides an energy range between about 0.7 and 25 eV/e (with respect to the spacecraft potential).

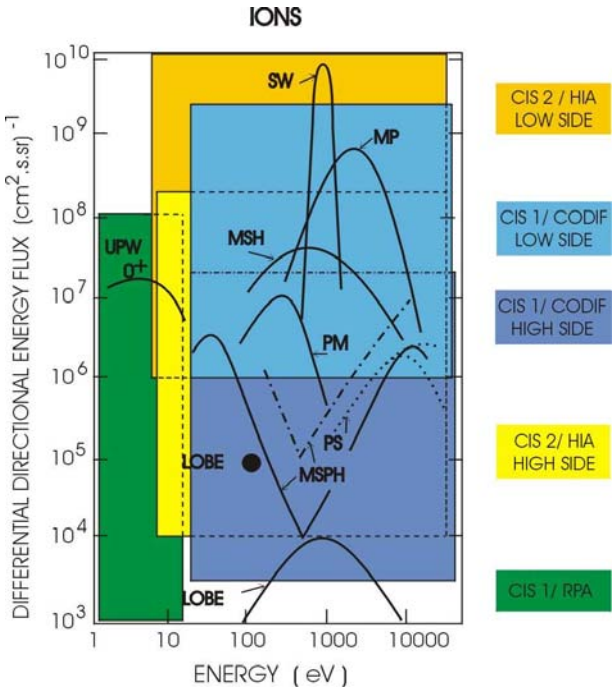

Fig. 2. Representative ion fluxes encountered along the Cluster orbit. The range of the different sensitivities of CODIF (Low Side, High Side and RPA) and HIA (Low Side and High Side) are shown with different colours.

2.2 The HIA (CIS-2) Instrument

The HIA instrument is an ion energy-spectrometer, capable of obtaining full three-dimensional ion distributions with good angular and time resolution (one spacecraft spin). HIA combines the selection of incoming ions, according to the ion energy per charge by electrostatic deflection in a quadrispherical analyser, with a fast imaging particle detection system. This particle imaging is based on microchannel plate (MCP) electron multipliers and position encoding discrete anodes.

In order to cover populations ranging from magneto-sheath ions to tail lobe ions, a dynamic range of more than 10^5 is required. HIA therefore consists of two 180° field-of-view sections, with two different sensitivities (with a ~20 ratio), corresponding respectively to the high-sensitivity ("high-G", or "HS") and to the low-sensitivity ("low-g", or "LS") side. The "low g" side allows detection of the solar wind and the required high angular resolution is achieved through the use of 8 sectors, 5.625° each, the remaining 8 sectors having 11.25° resolution. The 180° "high G" side is divided into 16 sectors, 11.25° each. For each sensitivity side a full 4π steradian scan, consisting of 32 energy sweeps, is completed every spin of the spacecraft, i.e., 4 s, giving a full three-dimensional distribution of ions in the energy range ~ 5 eV/e – 32 keV/e.

Fig. 2 shows the dynamic range of the different sensitivities of CODIF (Low Side, High Side and RPA) and HIA (Low Side and High Side), and how they cover representative ion fluxes encountered along the Cluster orbit.

2.3 CIS Operational Modes

The CIS instruments have a large amount of flexibility either in the selection of the operational mode or in the reduction of the data necessary to fit the available telemetry bandwidth. CIS can thus operate in any combination of the 6 Spacecraft Telemetry Modes and the 16 CIS Operational Modes.

These 16 modes can be grouped into solar-wind tracking modes, solar-wind study modes with the priority on the upstreaming ions, magnetospheric modes, magnetosheath modes, an RPA mode and a calibration test mode (Table 1). These modes correspond to different combinations of telemetry products transmitted and different energy sweep schemes. On-board calculated moments are always transmitted to the telemetry with a high-time resolution (1 spin), and a combination of 2-D and 3-D ion distribution functions, plus other telemetry products, are transmitted in parallel to on-board calculated moments, with a mode-dependent and product-dependent time resolution. Mode change is performed by time-tagged commands, according to the plasma populations anticipated along the Cluster orbit.

Table 1. CIS Operational Modes

Mode Number	CIS Mode	Data Compression	Mode Group
0	SW-1		Solar Wind Modes
1	SW-2		
2	SW-3		
3	SW-4		
4	SW-C1	✓	
5	SW-C2	✓	
6	RPA		RPA Mode
7	PROM		
8	MAG-1		Magnetospheric and Magnetosheath Modes
9	MAG-2		
10	MAG-3		
11	MAG-4		
12	MAG-5		
13	MAG-C1	✓	
14	MAG-C2	✓	
15	CAL		

3. CIS DATA ARCHIVAL CONCEPT

For the archival of the CIS data a multi-level approach has been adopted. The CAA archival includes processed raw data (Level 1 data), moments of the distribution functions (Level 2 data), and calibrated high-resolution data in a variety of physical units (Level 3 data). Furthermore, the calibration files and high-level processing software are also archived.

This approach provides “ready to use” high-resolution data products, archived in ASCII (CEF-2 format), which are expected to have a long lifetime. However, should a user wish to re-analyse the raw data and the instrument calibrations, he will also be able to do it.

The CIS data archive includes also experiment documentation, graphical products for browsing through the data, and data caveats.

4. CIS – CAA ARCHIVAL PRODUCTS

4.1 CIS Level 1 Data

CIS Level 1 data are decommutated, decompressed, and time-tagged telemetry data. They are in raw instrument units (no corrections for MCP efficiencies etc.), represent the complete CIS Telemetry, and are the input for all higher-level processing. They are organised in one file per telemetry product - spacecraft - day, and each file is a time-series of equal-length records. Each data record is complete: time tag, product type, mode info, ... Data are in IEEE integers or floats.

4.2 CIS Level 2 Data

CIS Level 2 data are moments of the particle distribution functions: ion density, velocity, temperature.

They correspond to the PPDB [3]: onboard calculated moments, then reprocessed on ground (calibration adjustments, coordinate transformations etc.). Onboard calculated moments provide 1-spin time resolution, and are calculated from the full angular and energy resolution 3-D ion distributions.

In addition to the onboard calculated moments, CIS Level 2 data will also include moments calculated on ground from the 3-D ion distributions. These provide better calibration adjustments (per anode), but have a reduced time and energy resolution. Onboard calculated moments and on ground calculated moments from the 3-D ion distributions are thus complementary.

4.3 CIS Level 3 Data

CIS Level 3 data are processed high-resolution data: 3-D ion distributions. They are produced by correcting

the Level 1 data for detector efficiencies, geometric factors and other information available from the calibration tables, and give measurements in several physical units (in separate files):

- (differential) particle flux (ions cm^{-2} s^{-1} sr^{-1} keV^{-1})
- particle energy flux (keV cm^{-2} s^{-1} sr^{-1} keV^{-1})
- corrected-for-efficiency particle count rate (ions s^{-1})
- raw particle counts (ions per counter bin)

The 3-D distributions are in the pseudo-GSE reference frame (X sunward, Z is the spacecraft axis and northward pointing).

These Level 3 archival files are constructed by joining files from similar telemetry data products (same ion species, different angular, energy or time resolution). Fig. 3 shows how these files are organised, from top to bottom, as a function of:

- the instrument (HIA or CODIF);
- the operational mode (magnetospheric, solar wind, magnetosheath, or RPA);
- the instrument sensitivity side (high-sensitivity or low-sensitivity side);
- the ion species.

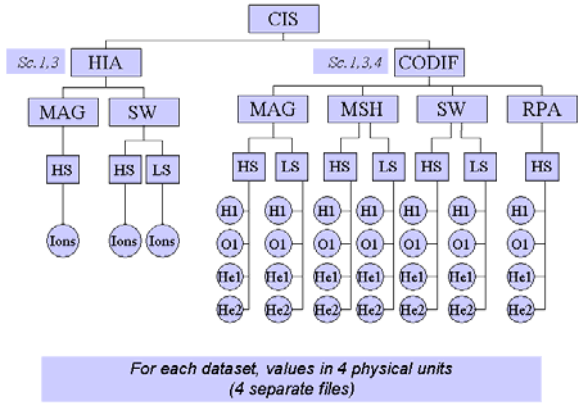

Fig. 3. CIS Level 3 data archival scheme. Each circle corresponds to a dataset.

In addition to these 3-D distributions, some uncalibrated CODIF data sets are also included in the CIS Level 3 data: files with onboard selected ion detection events, MCP monitor rates, and low-angular resolution distributions in 64 m/q ranges. These data sets are useful for monitoring instrument performance against eventual background and ion mass species separation, or for searching for minority ion species.

Level 3 archival files are labelled with metadata, i.e. information that describes the dataset and its contents, so as to be easily understandable by the CAA user. These metadata follow the specifications given in the Cluster Metadata Dictionary [4], which has been produced for the CAA project by the CAA Metadata Working Group and the CDPP, the French Plasma Physics Data Centre (**http://cdpp.cesr.fr/**).

The CIS Level 3 archival data file format is CEF-2 (ASCII), which is a CAA standard [5].

4.4 CIS Graphical Data Products

The CIS graphical data to be archived are 6-hour energy-time ion spectrograms. They are pre-formatted displays: PNG graphic files embedded in HTML pages, and they are given at two levels of resolution: browsing and detailed.

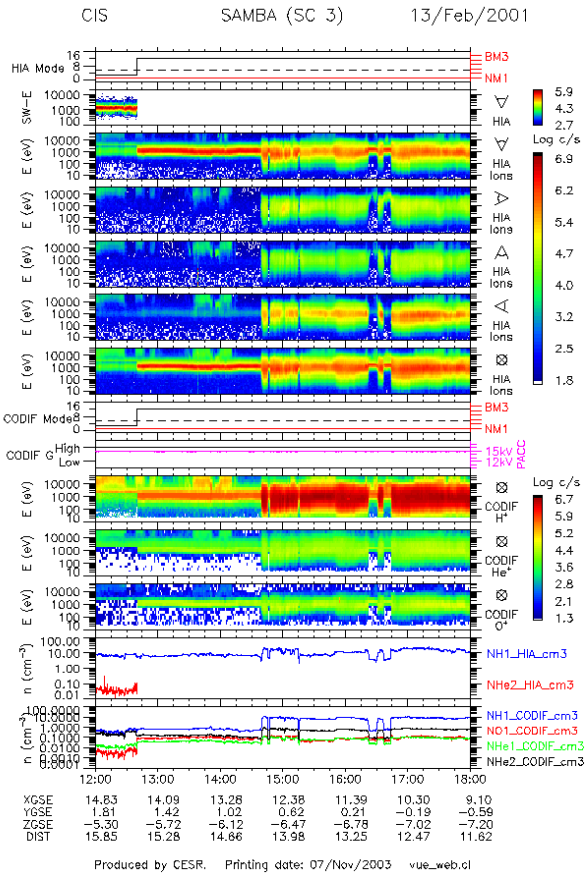

Fig. 4. CIS energy-time ion spectrogram

Fig. 4 shows an example of a CIS spectrogram. It includes HIA data from the low-sensitivity side (ions in the 45° x 45° sector centred in the solar wind direction), HIA data from the high-sensitivity side (separately for four azimuthal sectors), omnidirectional HIA data, omnidirectional CODIF data for H^+, He^+ and O^+ ions respectively, and ion densities measured by HIA and by CODIF. Instrument operational mode and spacecraft telemetry mode data are also included, as well as spacecraft coordinates. These spectrograms are supplied separately for each spacecraft.

4.5 CIS Calibration Files

CIS calibration files are ASCII files, self-documented (including comments), machine-readable and human-readable. They include parameters such as geometric factors, MCP anode detection efficiencies (for the 4 main ions species), on how many spacecraft spins each 3-D ion distribution is accumulated (for the various modes), etc.

Due to the evolution of the MCP detection efficiencies as a function of time, the CIS calibration files are updated regularly. A calibrations catalogue file, which is provided with the calibration files, serves as a pointer to which calibration files to use for each data time period. This catalogue file evolves in an incremental way through the mission, to take into account the existence of new calibration files.

Updating the calibration files for the detection efficiency evolution, with respect to the pre-launch calibrations, is a multi-step process. The HIA density values are compared and cross-calibrated with the density values supplied by the Whisper sounder experiment [6]. This is performed in the Magnetosheath (High Sensitivity Side) and in the Solar Wind (Low Sensitivity Side). Note that outside these regions in some cases the HIA and Whisper supplied densities may not agree, due to factors such as the presence of plasma outside the HIA energy range.

The CODIF calibrations updating is a more complex process. It involves the determination of the start-MCP efficiency, the stop-MCP efficiency, the fraction of coincidences between the "start" and the "stop" signal that also have a single position signal, allowing thus to calculate the total efficiency. In addition, the efficiencies of the individual anodes (22.5° sectors) have to be cross-calibrated, and this is performed by using time periods when the ion distributions are expected to be gyrotropic. CODIF calibrations involve also separate efficiencies determination for H^+ and O^+ ions. The CODIF H^+ measurements are finally cross-checked with the HIA measurements, for periods when the plasma is composed mainly from H^+ ions.

4.6 CIS Data Processing Software

The CIS data processing software to be archived is delivered as IDL source code (+ instructions). It includes various software packages: *cl*, *CCATi*, *IFSIDL*, which read Level 1 CIS data and calibration files; are interactive, and generate a large variety of high-resolution graphics (spectrograms, distribution functions, PADs …).

The *cl* software, developed at CESR, can also export the results as ASCII (CEF) data files. In addition to the CIS data, this software can also read generic CDF and CEF data files, for correlation studies.

These software packages will be available "as documents", for installation and execution on the end user's machine. They run on Linux and Solaris systems, whereas for the *cl* software a Windows version has also been developed.

4.7 CIS Caveats

CIS caveat files to be archived include both general caveats for the CIS data, and caveats for specific data intervals.

Given the complexity of an ion spectrometer, and the variety of its operational modes, each one being optimised for a different magnetospheric region or measurement objective, consultation of the data caveats by the end user will always be a necessary step in the data analysis (independently of the data level).

4.8 CIS Documentation

CIS documentation for the CAA includes:

- The CIS-CAA Interface Control Document [7].
- A description of the instrument [2].
- A description of how raw particle counts are converted into physical units.
- Calibration documentation.

5. SCHEDULE

At the time of the 5th anniversary of Cluster in Space Symposium (September 2005), the CIS Team had delivered to the CAA:

- All CIS Level 1 data for years 2001 and 2002.
- All onboard calculated moments Level 2 data for years 2001 and 2002.
- CODIF Level 3 data for protons, in all physical units, 1 data set type (HS side magnetospheric modes), for January 2001 – July 2002.
- HIA Level 3 data in all physical units, 1 data set type (HS side magnetospheric modes), for January 2001 – July 2002.
- All CIS Graphical data products for years 2001 and 2002.
- All CIS Calibration files for years 2001 and 2002.
- The *cl* software.
- All CIS Caveat files for years 2001 and 2002.
- The CIS-CAA Interface Control Document and other associated documents.

Software development for the generation of the remaining CIS Level 3 data products is an ongoing

activity. Pipeline processing is scheduled with at least 2 years of data per year. Later data redeliveries are also anticipated, following refinements in the calibration files and processing software, consistently with the concept of the active archive.

Following the 5th anniversary of Cluster in Space Symposium, the Cluster Active Archive data search utility opened for registration and beta testing (October 2005).

Acknowledgments

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