MAX PLANCK INSTITUTE
FOR SOLAR SYSTEM RESEARCH

Cluster Science Archive: Interface Control Document for RAPID

Version 9.0

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Document Status Sheet

Issue	Date	Details
Version 0.9	2005-04-07	Last pre-release draft
Version 1.0	2005-04-21	Release for CAA Implementation Review
Version 2.0	2006-05-04	Release for first Operations Review
Version 2.1	2007-04-16	For online distribution via CAA
Version 3.0	2008-05-01	For 2nd release of RAPID CAA products
Version 3.1	2008-11-11	Status after ingestion of 2nd release
Version 3.1	2009-04-22	For 4th Operations Review
Version 3.2	2010-03-19	Revised and added products, including PADs with FGM data; revise names of final products, conforming to new GUI
Version 3.3	2010-04-28	Corrected delivery schedule
Version 4.0	2011-05-01	For 6th Operations Review
Version 4.1	2012-05-01	For 7th Operations Review
Version 4.2	2013-05-10	For 8th Operations Review
Version 5.0	2014-05-15	For 9th Operations Review
Version 5.1	2015-03-11	After 2014 Progress Meeting
Version 5.2	2015-11-01	For 10th Operations Review
Version 5.3	2016-09-15	Document updates for 2016
Version 5.4	2017-03-22	Update to add new product DSETTINGS
Version 6.0	2018-07-01	Update for 4th calibration release
Version 6.1	2019-07-01	Add appendix on raw data compression
Version 7.0	2020-04-15	Add products MTRX and RMTRX
Version 7.1	2020-09-14	Update reference documents versions.
Version 7.2	2021-04-01	Revise section on data compression.
Version 8.0	2022-10-01	Add ENA products and description.
Version 9.0	2024-04-01	Conforming to User Guide and Cal Report updates.

Document Change Record

Issue	RID/Ref	Details
Version 1.0	2005-04-21	Rework parts, which needed updating because of calibration revision and the introduction of `sci2caa` software. Paragraphs on calibration were shortened. Release document for the CAA implementation review.
Version 1.1	2006-04-10	Add short description of IDL RAPID visualization software. Add product description of EPADEX, IPADEX, DE, PED, HK, caveats, instrument settings. Correct descriptions of omnidirectional electron products and all helium and hydrogen products due to changes in energy levels and introduction of fill values for several channels.
Version 1.2	2006-04-26	Update description of calibration files; revise instrument settings, caveats; add PEDPOS.
Version 2.0	2006-05-04	Update delivery schedule and summary plot description. Release document for the 1st CAA operations review.
Version 2.1	2006-05-11	Split PEDPOS_BM up into two variables, page 49.
Version 2.1	2006-11-01	Change name of CAA Assistant, page 11.
Version 2.1	2006-11-23	Revise delivery schedule; MPS addresses for software and data, page 28. Add a statement on reprocessing due to major recalibration, page 26. State that the IPADEX, EPADEX and diagnostic products will be delivered later.
Version 2.1	2007-02-10	Add phase space density calculation.
Version 2.1	2007-04-16	Revise delivery schedule; Released for distribution by CAA.
Version 3.0	2008-04-23	Add table of energy levels, page 19 and descriptive section. Revised summary plot sample, Figure 6
Version 3.0	2008-04-25	Revise delivery schedule. Rewrite parts of data processing description. Revise recalibration and reprocessing section. Add descriptions of new products, explain new release.
Version 3.0	2008-05-07	Add appendices on I3DD sector timing and direct event clarification. Summary plots are png only (no pdf) and only for diff. flux, not rates.
Version 3.0	2008-05-29	Add revised I3DD product with record key, with new name I3D. Add description of dataset version code, Section 4.7.
Version 3.0	2008-06-10	Released.
Version 3.0	2008-06-26	Change INST_SET to SETTINGS; release again.

Document Change Record *(continued)*

Issue	RID/Ref	Details
Version 3.1	2008-11-11	Revise delivery schedule after ingestion of recalibrated (2nd release) data; remove 1st release products.
Version 3.1	2009-02-27	Explain reprocessing of ion fluxes for 2006.
Version 3.1	2009-03-05	Add relativistic phase space density formula.
Version 3.1	2009-04-21	Add table for phase space density conversion factors. Second release treated as current and not future release. Correct a number of obsolete descriptions, text.
Version 3.1	2009-04-23	Add future products HIST, SGL, IES_BG. Finalize and release.
Version 3.2	2009-11-06	Revised products: CNO fluxes have the first channel removed; I/EPITCH now done with FGM data from CAA; I/EPADEX variable names changed. New products: merged ion 3-D fluxes, pitch angle distributions for ion and electron fluxes, using FGM data; singles and histogram datasets.
Version 3.2	2010-03-15	Name the final CAA products by their dataset names, to conform with the (new) CAA GUI.
Version 3.2	2010-03-19	Revise delivery schedule; replace sample summary plot with V2.3.
Version 3.3	2010-04-28	Correct delivery schedule for 2008 data.
Version 3.3	2010-05-12	Update references to User Guide and Calibration Report.
Version 4.0	2011-05-01	Remove delivery schedule, too variable. Move calculation of fluxes and phase space density to the Calibration Report. Move description of RAPID CAA software to an appendix. Reorganize many descriptions, emphasizing clarification and removal of redundant and obsolete texts, including visualization software, since it is no longer supplied.
Version 4.1	2012-05-01	Various text revisions to update to current situation Revision of first electron energy channel to 41.2 keV.
Version 4.2	2013-05-10	Minor text revisions First electron energy channel changed once more, to 39.2 keV.
Version 5.0	2014-05-15	Change address of MPS, and URL for documentation Add new product IES_BG, IES_BG_R Text revisions, clarifications, removal of obsolete documents.
Version 5.1	2015-03-11	Remove section on IES_BG as future product. Add Quality Flags as future product. Rename CAA to CSA.
Version 5.2	2015-11-01	Rewrite Appendix D on running production software.
Version 5.3	2016-09-15	Replace Figure 3 so detectors numbered from 1, not 0, consistent with usage in text.
Version 5.4	2017-03-22	Add description of new DSETTINGS product, the compressed SETTINGS.

Document Change Record *(continued)*

Issue	RID/Ref	Details
Version 6.0	2018-07-01	Update for the calibration series 4 (4th release), and clean up older texts that are no longer relevant or correct.
Version 6.1	2019-07-01	Add appendix on the raw data compression method.
Version 7.0	2020-04-15	Add descriptions of new products MTRX and RMTRX, both as rates only.
Version 7.1	2020-09-14	Update versions of Userguide and Cal Report in reference list.
Version 7.2	2021-04-01	Revise section on data compression in view of new appendix on this topic.
Version 8.0	2022-10-01	Add descriptions of new ENA products.
Version 9.0	2024-04-01	References to User Guide and Calibration Report updated.

Table of Contents

List of Acronyms

BM	Burst Mode, Cluster high telemetry rate
CAA	Cluster Active Archive
CDF	Common Data Format (NASA format)
CEF	Cluster Exchange Format (CSA format)
CSA	Cluster Science Archive
DARD	Data Analysis Reference Document
DPU	Digital Processing Unit
EDB	Experiment Data Block
ENA	Energetic Neutral Atoms
ESA	European Space Agency
ESOC	European Space Operations Centre
IEL	Inter-Experimental Link
IES	Imaging Electron Spectrometer (part of RAPID)
IIMS	Imaging Ion Mass Spectrometer (part of RAPID)
LUT	Look-Up Table (for IES)
MCP	Multichannel Plate
MPS	Max-Planck-Institut für Sonnensystemforschung, Göttingen, Germany
MSF	Merged Science File (RAPID raw data)
NM	Nominal Mode, Cluster low telemetry rate
PAD	Pitch Angle Distributions
PI	Principal Investigator
RAPID	Research with Adaptive Particle Imaging Detectors (Cluster Experiment)
SCENIC	Spectroscopic Camera for Electrons, Neutral, and Ion Composition (part of RAPID)
SCI	SCIence file, RAPID-specific format for processed data
SCU	Signal Conditioning Unit
TOF	Time-Of-Flight

Reference Documents

1. Escoubet, C. P., Russell, C. T., and Schmidt, R. The Cluster and Phoenix Missions. *Space Science Reviews*, **79**, 1997. DOI:10.1023/A:1004923124586.

2. RAPID Flight Operation User Manual. Version 3.0, Max-Planck-Institut für Aeronomie, Katlenburg-Lindau, Germany, June 2000. URL http://caa.esac.esa.int/documents/teams/RAPID/CL_CP_RAP_FOP_Manual__20000617_V30.pdf.

3. Perry, C. H. Cluster Active Archive: System Specification Document. Report CAA–EST–SS–0001, Issue 1.0, European Space Agency, Paris, France, November 2003.

4. Allen, A. and Sanderson, T. User Requirments for the Cluster Active Archive Programme. Report CAA–QMW–UR–0001, Issue 1.2, European Space Agency, Paris, France, November 2003.

5. Perry, C. H. Cluster Active Archive: Management Plan. Report CAA–EST–MP–0001, Issue 1.5, European Space Agency, Paris, France, November 2003.

6. Daly, P. W. and Kronberg, E. A. User Guide to the RAPID Measurements in the Cluster Science Archive (CSA). RAPID Report CAA–EST–UG–RAP, Issue 6.2, Max-Planck-Institut für Sonnensystemforschung, Göttingen, Germany, April 2024. URL http://caa.esac.esa.int/documents/UG/CAA_EST_UG_RAP_v62.pdf.

7. Daly, P. W. and Kronberg, E. A. RAPID Products at the Cluster Active Archive. In *The Cluster Active Archive, Studying the Earth's Space Plasma Environment*, edited by H. Laakso, M. G. T. T. Taylor, and C. P. Escoubet, Astrophysics and Space Science Proceedings, pp. 145–158. Springer, Berlin, 2010. DOI: 10.1007/978-90-481-3499-1_9.

8. Kronberg, E. A., Daly, P. W., and Vilenius, E. Calibration Report of the RAPID Measurements in the Cluster Science Archive (CSA). RAPID Report CAA–EST–CR–RAP, Issue 10.0, Max-Planck-Institut für Sonnensystemforschung, Göttingen, Germany, April 2024. URL http://caa.esac.esa.int/documents/CR/CAA_EST_CR_RAP_v100.pdf.

9. Kronberg, E. A., Daly, P. W., Dandouras, I., Haaland, S., and Georgescu, E. Generation and validation of ion energy spectra based on Cluster RAPID and CIS measurements. In *The Cluster Active Archive, Studying the Earth's Space Plasma Environment*, edited by H. Laakso, M. G. T. T. Taylor, and C. P. Escoubet, Astrophysics and Space Science Proceedings, pp. 301–306. Springer, Berlin, 2010. DOI: 10.1007/978-90-481-3499-1_20.

10. Wilken, B. et al. RAPID: The Imaging Energetic Particle Spectrometer on Cluster. In [Ref. 1], pp. 399–473. DOI:10.1023/A:1004994202296.

11. Dinse, H. and Dierker, C. RAPID: Data Analysis Reference Document. Part 1: EDB Decoding. Version 2.7, Institut für Datenverarbeitungsanlagen, Technische Universität Braunschweig, May 2003. URL http://caa.esac.esa.int/documents/teams/RAPID/CL_CD_RAP_Data_Ref__20030506_V27.pdf.

12. Allen, A., Schwartz, S. J., Harvey, C., Perry, C., Huc, C., and Robert, P. Cluster Exchange Format – Data File Syntax. Report DS–QMW–TN–0010, Issue 2, Rev. 0.5, CSDS Archive Task Group, October 2009. URL http://caa.esac.esa.int/documents/DS-QMW-TN-0010.pdf.

13. Laakso, H. Cluster Metadata Dictionary. Report CAA–MDD–0001, Issue 3, Rev. 4, European Space Agency, Paris, France, February 2020. URL http://caa.esac.esa.int/documents/CAA-MDD-0001_v34.pdf.

14. Müllers, A., Rathje, R., and Dierker, C. RAPID: Instrument User's Guide. Version 2.8, Institut für Datenverarbeitungsanlagen, Technische Universität Braunschweig, May 2001. URL http://caa.esac.esa.int/documents/teams/RAPID/CL_CD_RAP_Inst_Manual__20010522_V28.pdf, annex 1 of [Ref. 2].

1 Purpose

The Cluster Science Archive (CSA) has the objective of archiving all the relevant scientific data, metadata, documentation, support files from the Cluster Mission (launched July-August 2000, see Escoubet et al. [Ref. 1] for payload description) while the Mission is still operating and the experiment teams still functioning. This project is defined by the Systems Specification Document [Ref. 3] User Requirements Document [Ref. 4], and the Management Plan [Ref. 5].

The purpose of this document is to specify the interfaces between the

CSA as operated by the European Space Agency (ESA)

and the

RAPID Archiving Team at the Max-Planck-Institut für Sonnensystemforschung (MPS)

In addition, it is expected that this document may also be helpful to the users of CSA, in that much detail is given about the RAPID instrument and the datasets that are generated.

Additional information can be found in the *User Guide to the RAPID Measurements in CSA* [Ref. 6] as well as in the overview of the RAPID products by Daly and Kronberg [Ref. 7].

A description of the calibration procedures with more internal information about the RAPID instrument as well as results of cross-calibrations with the CIS and PEACE data is in the *Calibration Report of the RAPID Measurements in CSA* [Ref. 8]. There is also an overview of the cross-calibration efforts by Kronberg et al. [Ref. 9].

Note: The CSA is the successor to the original Cluster Active Archive (CAA), and much of the older documentation still refers to it. The CAA still acts as the primary interface for the instruments teams when uploading new datasets, which are then mirrored to the CSA, which remains as the sole interface for downloading the Cluster data to the scientific community.

2 Points of Contact

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3 Instrument Description

3.1 Science Objectives

The Cluster polar orbit (4 × 19 R_E), provides excellent opportunities for energetic particle studies. The physics at the magnetopause, the bow shock, and the near-earth magnetotail are key regions of interest for the RAPID investigation. The state-of-the-art detection techniques, the large energy range for nuclei and electrons, and the complete coverage of the unit sphere in velocity space lead to the following capabilities:

- Remote sensing of local density gradients over distances comparable with particle gyroradii. Species dependent structures in gradients can be studied, gradient motions can be resolved to one spin period ($T \approx$ 4 sec).

- Determination of major ion species (H, He, CNO) in the energetic plasma component. A special operational mode allows the identification and analysis of energetic neutral atoms (ENA).
- Characterization of magnetic field line topologies using the fast motion of energetic electrons.

These observational features allow detailed studies in all regions of geospace visited by Cluster. The RAPID instrument uses two different and independent detector systems for the detection of nuclei and electrons, i.e., The **I**maging **I**on **M**ass **S**pectrometer (IIMS) and the **I**maging **E**lectron **S**pectrometer (IES).

3.2 Hardware Overview

The RAPID experiment is described by Wilken et al. [Ref. 10], and also in the Flight Operational Manual [Ref. 2]. The instrument is physically a single structure which contains all major elements like the IIMS and IES sensor systems, the front-end electronics (called SCU), and the digital processing unit (DPU) with the low-voltage power-supply (LVPS) and the spacecraft interface. The characteristics of the IIMS and IES sensors are listed in Table 1.

3.2.1 The IIMS Instrument

The centerpiece of the IIMS sensor system is the so-called SCENIC (Spectroscopic Camera for Electrons, Neutral, and Ion Composition) detector head, shown in Figure 1. In essence, this is a miniature telescope composed of a time-of-flight and an energy detection system. The particle identifying function of the SCENIC spectrometer is obtained from a two-parameter measurement: the particle's velocity V and its energy E are measured as independent quantities; the particle's mass A is then uniquely determined either by computation ($A \sim E/2$) or by statistical analysis in two-dimensional (V, E) space with the mass A as the sorting parameter. Actually the velocity detector measures the flight time T take by the particle to travel a known distance in the detector geometry.

Each SCENIC head has a field-of-view that is 6° wide (in the direction of the spacecraft spin) and 60° in the other direction (in the plane containing the spin axis). By means of the imaging features of this instrument, the particle's incident direction is assigned to one of 4 subdivisions of this field-of-view, each of 15° height. With three detector heads in all, the full range of 0–180° is covered by 12 polar angular segments (left side of Figure 3).

There are two sampling modes for IIMS heads:

serial mode: only one of the three SCENIC heads is active at any one time, each being turned on for a fixed time; after all three have had their accumulation time, they wait until the next sector starts before accumulating once more, one after another.

parallel mode: all three heads are active at the same time, for a fixed time, after which they are turned off until the start of the next sector.

See Section 3.2.3 for more information.

There is additionally a mode for **energetic neutral atoms** (ENA), in which a cross voltage of up to 10 kV is applied just behind the entrance aperture, to sweep out ions of up to $\sim$ 150 keV. In this mode, only neutral atoms are detected and processed. This mode has only been used on SC4 in the solar wind during the first two years of operation. The times are listed in Appendix D of the Calibration Report [Ref. 8]. There are separate products for the omnidirectional and 3-D flux data, to distinguish them from the corresponding ion fluxes.

3.2.2 The IES Instrument

Electrons with energies from 20 keV to 400 keV are measured with the IES (Imaging Electron Spectrometer). Advanced microstrip solid state detectors having a 0.5 cm × 1.5 cm planar format with three individual elements form the image plane for three acceptance "pin-hole" systems. Each system divides a 60° segment into 3 angular intervals, Figure 2. Three of these detectors provide electron measurements over a 180° fan (middle of Figure 3).

The 800 micron thick ion-implant solid state devices are covered with a 450 μg/cm^2 (Si eq) absorbing window which eliminates ions up to 350 keV through the mass dependent range-energy relationship.

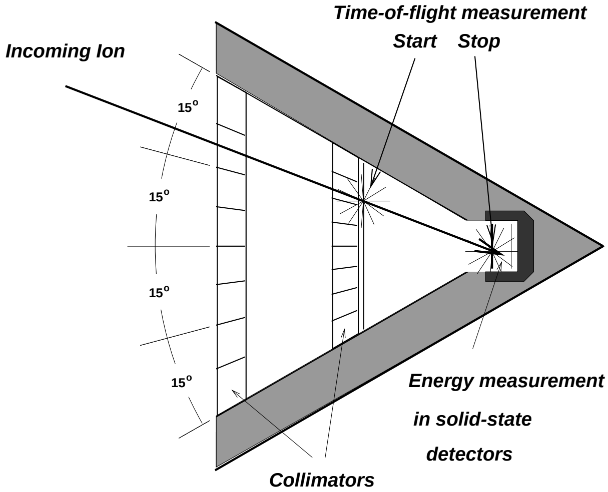

Figure 1: One of the three SCENIC heads making up the IIMS part of RAPID. Shown is an incoming ion that triggers a start signal at a foil, which also serves to determine the fine direction, and a stop signal when it enters the solid state detector, where its energy is measured.

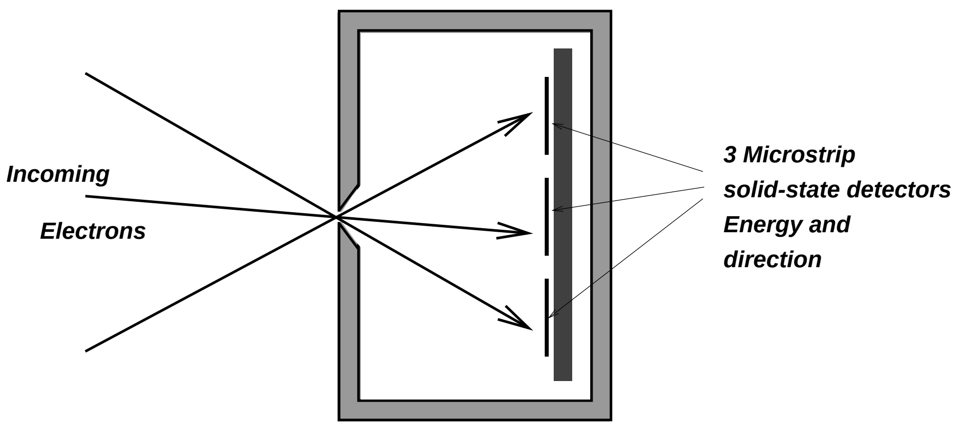

Figure 2: One of the three IES heads, containing three solid state detectors to determine the direction of the incoming detected electron to within 20°.

	IIMS	IES
Protons	28 – 1500 keV	—
Helium	138 – 1500 keV	—
CNO	90 – 1500 keV	—
Electrons	—	35 – 400 keV
Mass Resolution (A/dA)	4 (oxygen)	—
Field–of–view	$\pm 3° \times 180°$	$\pm 17.5° \times 180°$
Angular coverage		
Polar (Range/intervals)	180°/12	180°/9
Azimuthal (Range/intervals)	360°/16	360°/16
Geometric Factor(per segment)	2.2×10^{-3} cm$^2 \cdot$ sr	2.2×10^{-3} cm$^2 \cdot$ sr

Table 1: Characteristics of the IIMS and IES sensors.

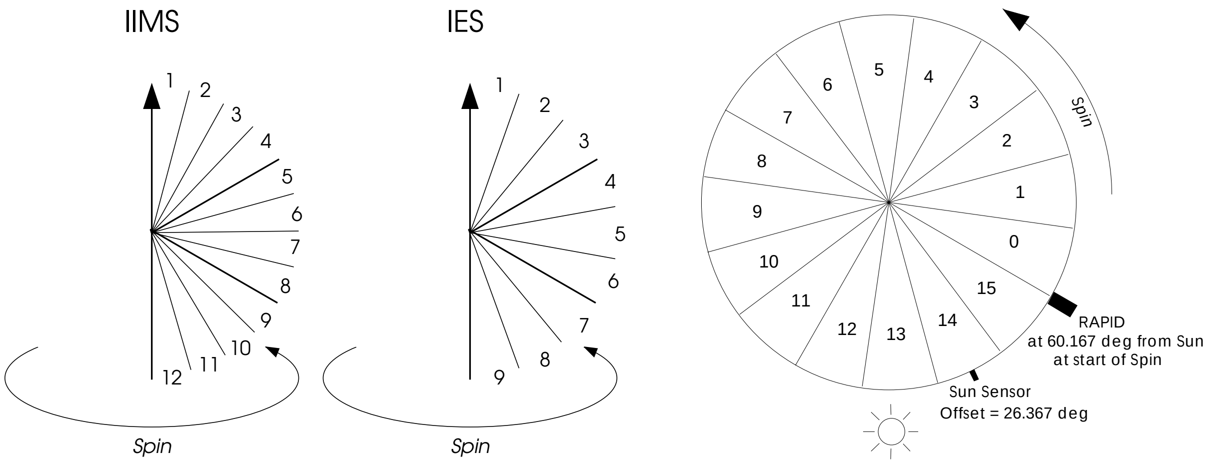

Figure 3: The IIMS and IES polar segments relative to the spin axis (left and center) and the RAPID sectorization relative to the sun (right). Note that the spin axis actually points towards the $-Z$ GSE axis (southward).

The 9 individual strips on the three focal plane detectors are interrogated by a multichannel switched-charge/ voltage-converter (SCVC) in monolithic technology. The SCVC provides for each particle coded information on the strip number and particle energy. This primary information is transferred to the DPU for further evaluation, as explained in Section 3.3.2.

3.2.3 Spin Sectorization

For both IIMS and IES, the azimuthal distribution of particle fluxes is obtained by sorting the counts into 16 sectors during one rotation of the spacecraft (right side of Figure 3).

The DPU measures the rotation period as indicated by the spacecraft sun reference pulses, and takes 1/16 of this as the sector time.

At the start of each sector, there is a preset *dead time* of 55 ms during which the accumulations from the previous sector, or spin, are written to the EDB (experiment data block) buffer, and during which other tasks are carried out. When these tasks are finished, or when the preset dead time is over, whichever is longer, the DPU begins to accumulate IIMS events. In serial mode, it addresses the 3 SCENIC heads one after the other, accumulating for 60 ms in each. In parallel mode, all 3 are active simultaneously for 180 ms. At the end of this time, it stop accumulating IIMS events, and waits for the start of the next sector.

The times given above can be adjusted by command from the ground. The values of 60 and 180 ms are those in effect since the major patch upload in May, 2001.

Electrons are accumulated during the entire sector. However, for heads 1 and 3, there are really only 8 sectors in the raw data. These are artificially expanded to 16 in the processed data.

If the DPU tasks at the start of the sector take longer than the predetermined time, the IIMS accumulation is delayed accordingly, and if the next sector then starts before the accumulation time is finished, a *dead time flag* is set (housekeeping word) to indicate that the IIMS accumulation has been truncated in that spin. This normally occurs when a new LUT for IES is loaded during sector 0, causing a reduction in accumulation time for IIMS in that sector.

3.2.4 The Digital Processing Unit

Each of the two sensor systems (IIMS and IES) is followed by dedicated circuitries called the **S**ignal **C**onditioning **U**nit (SCU). The primary task of the SCU is to provide proper analogue amplification and signal shaping, event-definition logic, control functions for configuring the detector system and to interface with the **D**igital **P**rocessing **U**nit (DPU).

The internal RAPID-DPU serves the SCUs and sensor systems, evaluates and compresses the primary event data rate to a level which is compatible with the telemetry capacity and arranges the output data in the format of an **E**xperiment **D**ata **B**lock (EDB). A more detailed description of the onboard data processing is given in Sections 3.3.1 and 3.3.2.

3.3 On Board Data Processing Chain

3.3.1 IIMS Onboard Data Processing

The main task of the DPU is to distill the large amount of input information from the detectors to a small set of numbers for output to the EDB.

In incoming ion (an *event*, Figure 1) creates a burst of electrons when it passes through the start foil, losing some of its energy as it does so. The electrons are collected on multi-channel plate detectors, initiating the *start* signal, and also determining the incoming direction to within 15°. (It is possible that the direction is not uniquely determined, in which case only the coarse direction is known, i.e., in which head the event occurred.) The ion traverses the remaining distance (34 mm) to the solid state detector, where it is absorbed, emitting further electrons on the surface (leading to the *stop* signal). The ion energy is deposited in the solid state detector, producing an analog signal proportional to that energy, less an amount loss in the dead layer. If the ion is very energetic, over 4 MeV, it passes completely through the front detector, and triggers an *overflow* signal in the back detector. The start and stop signals generate an analog TOF (time-of-flight) pulse.

The DPU processes the various digital signals generated by the event. The analog energy and TOF pulses are digitized as integers from 0 to 255 for 0 to 1500 keV, and 0 to 80 ns. There are 4 possible situations:

Valid E and TOF the mass of the ion is determined by matching the E and TOF to one of 32 mass curves in $E-T$ space; the energy per mass, E/A is found directly from the time-of-flight (essentially V^2 or T^{-2}. E/A is a number from 0 to 63.

Valid TOF, no E the underrange region, E is less than the minimum 30 keV needed for an E signal. Mass and E/A are found from T alone with the knowledge that $E < 30$ keV.

Valid TOF, max E, no overflow the overrange region, mass and E/A are determined from T alone with the knowledge that $4000 > E > 1500$ keV.

Max E, overflow the event is rejected.

The mass and E/A numbers are then used to classify the event, to sort it into one of 57 bins. For each of 4 ion groups (H, He, C-N-O, Si-Fe) there are 8 bins of different energies. Figure 4 shows how the $E-T$ space is divided into these bins. Note that the lowest energy bins are (mainly) from the underrange region, where no energy signal has been detected.

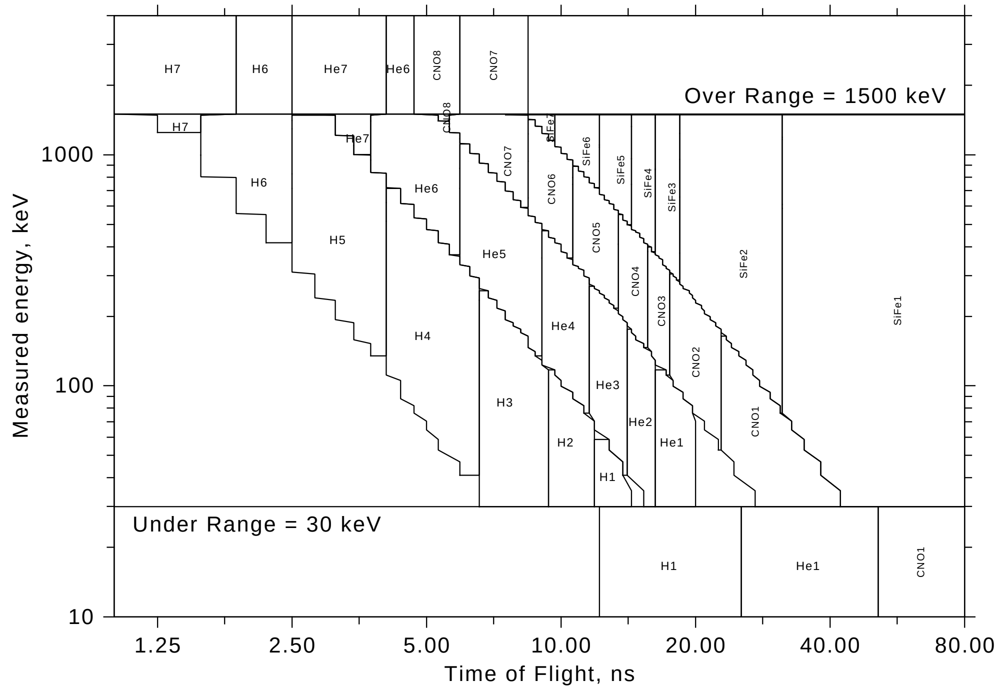

Figure 4: The division of the IIMS E–T space into various bins for species and energy.

The fundamental IIMS datasets delivered by RAPID are listed in the Data Analysis Reference Document, DARD [Ref. 11] and are described in Section 3.5.2

3.3.2 IES Onboard Data Processing

The IES micro-strip detectors deliver signals to the DPU that are proportional to the charge accumulated on them during a set *integration time*. This charge is proportional to the energy deposited by absorbed electrons, plus a constant charge due to a background current. If no electrons arrive during the integration time, the signal represents this *pedestal* charge; if a single electron is absorbed, the signal is enhanced by an amount proportional to the electron's energy.

The analog signal is initially sorted into 256 bins, at ~2.2 keV per bin. The total energy of all electrons detected during one integration period is registered as a single count in one of these bins; after the integration interval, that count is read out and the energy accumulation reset. The integration time must be selected to avoid multiple incidences in single strips. Possible values are 2, 5, 15, and 50 μs. IES normally operates in *autoswitching* mode, meaning the integration time automatically follows the observed count rates.

The bin corresponding to zero energy is different for each strip and also depends on the integration time. Here electronic noise accumulates, the so-called *pedestal*. Its position determines the energy offset and its width the first useful lower energy threshold.

Broad energy bins (8 in NM, 12 in BM) are defined in terms of the 256 fine bins, relative to the known pedestal position, as shown in Figure 5. (Since the pedestal can wander slowly with time, or can vary even with count rate, it is necessary to monitor it and occasionally redefine the broad bins.) The broad energy bins are specified by *Look-Up Tables* (LUT), one for each detector strip and integration time. Whenever the integration time is switched, a new set of LUTs must be loaded.

Full energy resolution of 256 bins is available only in *histogram* mode, a test mode for monitoring the pedestals.

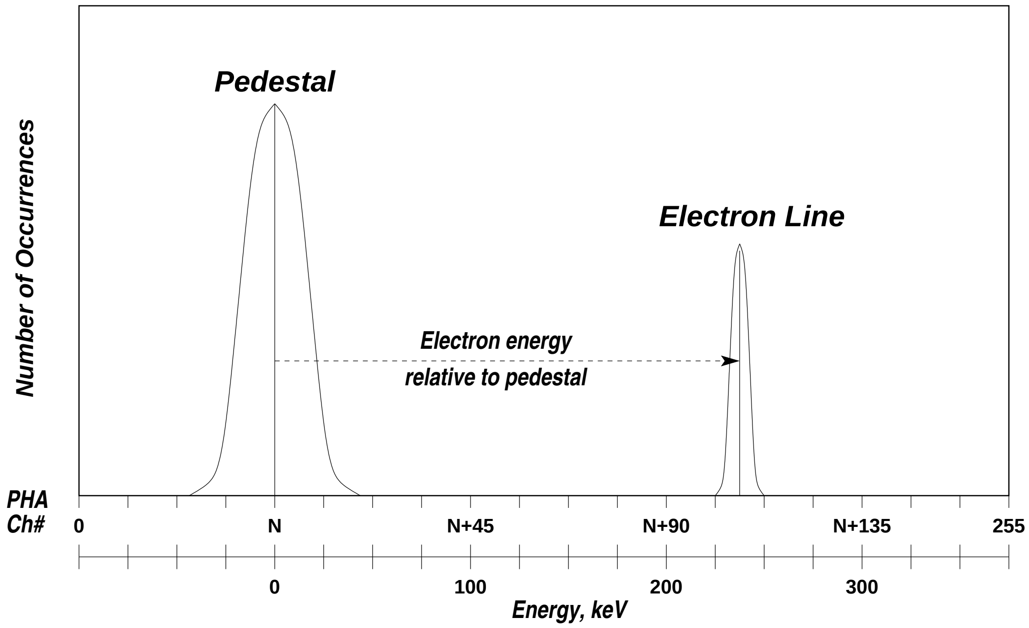

Figure 5: An idealized histogram plot for IES data. The number of measurements per second is constant, depending on integration time. The majority of measurements are empty, contain just a background charge but no electrons, and they form the *pedestal* (large peak at left). True electrons deposit an additional charge, so that a monoenergetic beam could create the peak at the right. The center of the pedestal thus corresponds to the zero of energy.

The fundamental IES datasets delivered by RAPID are listed in the Data Analysis Reference Document, DARD [Ref. 11] and are described in Section 3.5.3

3.3.3 Compression of Counts

All the summed counts mentioned above are accumulated in 23-bit counters, but are written to the output EDB as a single byte each. A 23-to-8 bit compression algorithm is used to accomplish this. Numbers up to 32 are encoded without loss, but higher numbers retain only the 5 most significant bits with a mantissa and exponent system. Thus the delivered data have an accuracy of no more than 3%. (Since counts are subject to Poisson statistics with a standard deviation equal to their square root, the compression error is usually smaller than this intrinsic statistical noise.)

Ground-based science software must decode the compressed bytes to the original full count. This is done by assigning it a value that is the middle of the range of numbers producing that byte value. For example, counts between 176 and 183 all are compressed to 46 (hex), so 46 is decoded to the central value of 179.5.

See Appendix C for more details and examples.

3.3.4 Onboard Pitch Angle Computation

The RAPID spectrometer is connected to the magnetic field instrument FGM via an inter-experiment link (IEL). FGM sends 64 uncorrected magnetic field vectors per spacecraft spin. With this information, RAPID calculates the perpendicular to the magnetic field within the current sector, which is then used to select 3 of the 9 IES or 12 IIMS directions for the EPAD and IPAD distributions. These 3 directions, each within the half-plane of the one sector, are:

1. the one closest to 90° to the magnetic field;

2. the one perpendicular to the first, but still in the same half-plane;
3. one closest to the spin or anti-spin.

The MDATA and MSIGNS products give information to decode the direction assignments, using various look-up tables. Since this whole procedure is so complex, we provide *expanded* products EPAD_EX and IPAD_EX to CSA, with the full set of directions per sector, with fill values in all but the 3 for which the measurements are made. In this way, the CSA user does not need to know anything about MDATA or MSIGNS, for the decoding has already been done.

3.4 Ground Data Processing

3.4.1 Level 1: The Raw Dataset

The RAPID data ground processing begins by merging the raw data from the CD-ROMs (level 0) to *Merged Science Files* (MSF, or level 1). Each such file contains the RAPID raw data for one spacecraft for a single day, regardless of how many CDs originally contributed to it. Records of instrument housekeeping data, selected spacecraft housekeeping data, and instrument science data (nominal or burst mode, whichever is current) are interspersed on a common time basis. Whereas the instrument data records are identical to those on the CD-ROMs, the spacecraft housekeeping records are limited to the sun reference pulse data plus a temperature byte.

3.4.2 Level 2: Science Data Processing

A particle instrument like RAPID delivers only a set of counts accumulated over a known time period. Thus, after having processed the raw dataset to the so-called MSF, the data have to be calibrated before providing them to the CSA. The standard RAPID software (`msf2sci`) produces counts-per-sec or fluxes from the MSF data and calibration files. These are written to files in an ASCII format specific to RAPID (called SCI files), for further processing, plotting, analysis. For CSA, an additional conversion program `sci2caa` transfers them into CEF (Cluster Exchange Format); subsequent conversion to CDF can take place with existing translation software.

Calibration is performed with appropriate files, one per spacecraft and particle type (electron/ions) making 8 calibration files in all. Each one contains all the temporal changes to the various parameters. In addition to the raw data processing, caveat and instrument mode files are provided. Knowledge of the instrument mode is required to understand the products. Caveats give information about instrument behaviour, explanations for problems, warnings when the data are unreliable, and why.

Calibration and Auxiliary Files

To get some impression of the way how calibration files are working one has to be familiar with a couple of definitions described in the following.

Calibration set: is a set of parameters needed for calculating flux from counts, valid for one spacecraft and for a given period of time.

Calibration file: is the file that the processing software reads, containing a collection of calibration sets.

The software reads this file until it finds the set that is valid for the time being processed, noting the end time as well. When the current process time exceeds this end time, the calibration file is read once more, to find the next valid set. Thus the current calibration set can change at any time, not just at day boundaries.

Caveat file: contains lines of text (with date indicators) that are written into the SCI files for the appropriate days; they provide explanations and warnings about any problems with the processing. The CSA caveat files are generated from such SCI files.

Parameter file: sets values for various parameters used during processing, including the names and locations of the calibration and caveat files and various flags to control the processing software. There is one pa-

Chan	Protons	Helium	CNO	Electrons	
				BM	NM
1	27.7–64.4*	29.9†	83.8†	39.2‡	39.2‡
2	75.3	137.8	274.4	50.5	50.5
3	92.2	172.3	414.	68.1	68.1
4	159.7	235.1	498.	94.5	94.5
5	374.	351.	638.	127.5	127.5
6	962.	737.	948.	175.9	244.1
7	1885.	1689.	1414.	244.1	—
8	—	—	2539.	336.5	—
Upper	4007.	3799.	4046.	406.5	406.5

Lower thresholds, all units keV

* Energy gap between protons 1 & 2

† Chan 1 He and CNO contaminated, suppressed

‡ Revised value, was originally 37.3 keV, then 41.2 keV

Table 2: Energy channel definitions for IIMS and IES.

rameter file containing the values of all spacecraft. The name of this file is stored in the environment PDB_PARAMETER.

This file contains date stamps to allow values to change with time. It is input until a date in found exceeding the processing date, so all the parameter values at that point become the current ones used.

Since this file is read only once per processing day, values can only be changed at a day boundary.

This complicated arrangement has the advantage that per spacecraft and IIMS/IES, there is only one calibration file containing all the time-dependent changes in any of the parameters. This avoids having several files valid for only certain times. The RAPID calibration files as a whole are valid for the whole time period, although the sets they contain may have time-limited validity. As the Mission goes on, the calibration files will be extended, but without altering the earlier parameters.

Of course, if it should be decided to completely revise the existing parameters from the beginning, as opposed to adding a new time-dependent change, then new files are issued containing totally new sets. An example of this is the replacement of the calibration *sets* (in new files) after each of the major recalibrations. On the other hand, time-dependent additions are made when the IES pedestals and energy channel definitions are altered, or when the IIMS high-voltages are increased. In these cases, the new sets are appended to the existing calibration files.

3.4.3 Output Energy Channels

There are nominally 8 energy channels for both the ion and electron science products. However, there are certain caveats to be noted.

- For IIMS, because of the nature of the first channel (the underrange part in Figure 4) there is a gap between the upper limit of first proton channel and the lower limit of the second one.
- The first He channel is heavily contaminated with protons; as a reliable correction is not possible, this channel has been suppressed; it exists in the product files but it contains only fill values.
- Similarly for the first CNO channel, which is also contaminated, probably by both protons and helium. It too is suppressed.

- The 8th channel of both protons and He is in fact out-of-range, having effectively a zero geometry factor. Hence both these channels are also suppressed.
- The electons in burst mode have 12 channels, but 4 are used for monitoring the pedestal; thus only 8 science channels are available.
- In nominal mode, the electrons have 8 channels, but two are used to monitor the pedestal. Thus there are only 6 science channels in NM: numbers 5 and 6 are equivalent to BM 5+6 and 7+8 respectively.
- For both IIMS and IES, the individual sensors have slight variations in their energy thresholds, both among those on one spacecraft and between different spacecraft. Spectral analysis during data processing adjusts the fluxes in each channel to simulate a common set of energy thresholds, the values of which are shown in Table 2.

3.5 Instrument Data Products

3.5.1 EDB Formats

The Experimental Data Block contains the compressed science data produced by the DPU. One EDB is generated per spin (∼4 s). There are two different EDB structures, one intended for nominal mode (NM) telemetry, and the other for burst mode (BM). RAPID must be commanded to output the EDB in the matching spacecraft telemetry mode.

The spacecraft recognize 6 different telemetry modes:

NM1: The regular nominal mode used most of the time. All the NMs have an allocated bitrate of 1024.8 bits/second. For NM1, the RAPID DPU formats EDBs of 512 bytes per spin; spin period: 4 s ± 10%.

NM2: The same as NM1 as far as RAPID is concerned; rarely used.

NM3: Since June 2003 on SC2, and since January 2010 on SC3, RAPID receives some of the CIS telemetry in NM3, enough to allow it to output the BM EDBs even in nominal mode. This was done periodically for one year on SC2, and for a special investigation on SC2 and SC3 in March-April 2011.

BM1: The regular burst mode, with an allocated bitrate of 4620.92 bits/second. In this mode EDBs have a size of 2304 bytes, which allow a greater resolution in time of measurement data.

BM2: For RAPID, this is the same as NM1.

BM3: A special mode with a bitrate of 1925.38 bits/second. This mode is intended to read out scratch memories of the instrument. It takes about $4\frac{3}{4}$ minutes to dump that memory content through telemetry. For RAPID, BM3 represents a data gap, that is used to correct for randomly occurring spontaneous resets that turn off the patches and high voltages; during BM3 (twice an orbit or roughly once a day), commands are issued to reactivate patches, to restore MCP voltages, and to reset the position of the sun sector.

Table 3 shows the structure of the EDB intended for the nominal (NM) and burst mode (BM1) telemetry.

As can be seen in this Table, the principal difference between NM EDBs and BM EDBs is the higher sampling rate in the BM mode. Exceptions are the EPAD and E3DD. The former is omitted from the BM EDB because it can be computed on the ground from the E3DD distribution. The E3DD data really only exist in BM, since in NM, the data are summed over a whole spin and so is effectively a 2-D distribution only.

The following describe the raw data (counts) in the EDB which are then used to create the processed science data (rates and fluxes).

3.5.2 IIMS Raw Science Data

HSPCT: Counts of protons (hydrogen ions) accumulated over one spin in all directions, in 8 different energy ranges; this input consists of 8 bytes.

	Bytes per record		Bytes per Spin		Accumulation period per counts [spins]		Download time [spins]	
	NM	BM1	NM	BM	NM	BM	NM	BM
DE 3×20(NM) ions 3×106(BM) ions	60	318	60	318	1	1	1	1
SGL0 2 counters	4	–	1	–	4	–	4	–
SGL1 3 counters	3	5	1	80	4	1/16	4	1
SGL2 18 counters	18	18	3	9	4	2	8	2
SGL3 22 counters	22	22	1	3	4	2	32	8
HSPCT	8	8	8	8	1	1	1	1
ISPCT	16	16	4	4	4	4	4	4
IPAD	96	96	96	96	1/16	1/16	1	1
I3DD	288	288	144	576	8/16	8/16	32	8
MTRX	2048	2048	8	32	64	64	256	64
EPAD	96	–	96	–	1/16	–	1	–
E3DD	72	1152	72	1152	1	1/16	1	1
(*L3DD*)*	(*192*)	–	(*192*)	–	(*1/16*)	–	(*1*)	–
m	8	8	8	8	1/16	1/16	1	1
m-signs	2	2	2	2	1/16	1/16	1	1
Sync marker	3	9	3	9	–	–	1	1
Subcommutation INDEX	1	1	1	1	–	–	1	1
Content descriptors	2	2	2	2	–	–	1	1
E/T–CAL	2	2	2	2	–	–	1	1
spare	–	2	–	2	–	–	1	1
			Σ 512	Σ 2304				

*In April–May 2004, a new patch was uploaded to replace the data in the IPAD and EPAD areas in nominal mode with data from 2 channels of burst mode E3DD. This pseudo data product is called L3DD (for E3DD-Lite).

Table 3: The EDB for Nominal Mode and Burst Mode.

ISPCT: Counts of He and CNO ions accumulated over 4 spins in all directions, in 8 different energy ranges; this input consists of 8 bytes for each mass selection for a total of 16 bytes.

I3DD: Counts of H, He, and CNO sorted by energy and direction.

IPAD: Proton pitch angle distribution: for each sector, the counts are accumulated in three different polar segments, in two different energy ranges (1–4 and 5–8); a total of 96 bytes.

SGL-Data: Various counters with differing accumulation times and sampling rates are transferred to the EDB, as “singles” data, SGL0, SGL1, SGL2, SGL3. These include: start and stop rates (for time-of-flight), TOF rates, TOF-plus-energy, energy detection rates, directional signals, overflow and back detector rates.

DE-Data: A fraction of unprocessed (E, T, D) events is selected to bypass the classification for transmission to the ground (so-called direct events DE). These are described in Appendix B.

MTRX: A-E/A matrix consisting of 32 mass classes (A) over 64 energy/mass classes (EA) summing up to 2048 individual counters.

3.5.3 IES Raw Science Data

E3DD: Electron counts sorted by energy and direction.

L3DD: Electron counts sorted by energy and direction.

EPAD: Electron pitch angle distribution: analogous to IPAD, 96 bytes; only in normal mode; in burst mode, must be simulated from the E3DD data.

3.6 Processed Science Products

The RAPID software produces the following products from the compressed data in the EDB. These level 2 products are the inputs to the RAPID datasets to be provided to CSA science users as counts/s and as flux, produced using the best calibration data known at the time of archiving.

Many of these have the same names as the corresponding raw science datasets, while others are new ones generated from the raw datasets. The corresponding names for the CSA product names (Section 4.7) are also similar, but in some cases bear a suffix **_NM** or **_BM** for those that differ with telemetry mode, or **_He**, **_CNO** for those where the ions have been extracted separately. Some other differences have arisen because of developments in the product formats.

HSPCT omnidirectional protons in 8 energy channels, 1 per spin.

ISPCT omnidirectional He and CNO in 8 energy channels, 1 per 4 spins.

I3DD 12×16 directions for 3 ion species, 8 energies,
NM: 8 spins out of 32 (SC 1,3,4) – 1 spin out of 32 (SC 2)
BM: 8 spins out of 8 (SC 1,3,4) – 1 spin out of 8 (SC 2)
(SC2 is different because it is the survival unit from Cluster-I which was programmed differently.)

See Appendix A on page 52 for time-stamping complications.

IFLOW Two 12×16 arrays listing GSE polar and azimuth angles of the I3DD flow direction, 1 per hour (slowly changing).

IPITCH Two 12×16 arrays listing the ion pitch angle and magnetic azimuth angle relative to the Sun, from the on-board magnetic data or optionally with calibrated FGM 5VPS data from CSA. Once per spin.

PAD_I3DD The I3DD ion data sorted into 9 pitch angle bins, 20° width, for 3 species and 8 energy channels; pitch angles can be determined either by the on-board magnetic data or with calibrated FGM 5VPS data from CSA, 1 per spin.

E3DD BM: 9×16 directions for 8 electron energies, 1 per spin
NM: 9 directions for 6 electron energies, 1 per spin.

L3DD (since May 2004) L3DD records (one per spin) are very much like those for E3DD in BM: for each energy, there are fluxes in 9×16 directions, but for 2 instead of 8 energies (channels 1 and 3 from E3DD).

ESPCT6 Generated product from E3DD: electrons in 6 energy channels, omnidirectional, 1 per spin.

IES_BG Generated product from E3DD: a 6×9 array of electron backgrounds in 6 energy channels and 9 directions, accumulated over 1 hour; a result is given only if the variations within that hour are consistent with a Poisson distribution of constant mean; else fill value is given.

EFLOW Two 9×16 arrays listing GSE elevation and azimuth angles of the E3DD flow direction, 1 per hour (slowly changing).

EPITCH Two 9×16 arrays listing the electron pitch angle and magnetic azimuth angle relative to the Sun, from the on-board magnetic data or optionally with calibrated FGM 5VPS data from CSA. Once per spin.

PAD_E3DD (BM only) The E3DD electron data sorted into 9 pitch angle bins, 20° width, for 8 energy channels; pitch angles can be determined either by the on-board magnetic data or with calibrated FGM 5VPS data from CSA.

PAD_L3DD (since May 2004) The L3DD electron data sorted into 9 pitch angle bins, 20° width, for 2 energy channels; pitch angles can be determined either by the on-board magnetic data or with calibrated FGM 5VPS data from CSA.

PED electron “pedestal” counts below zero energy, for diagnostic purpose
NM: 2 energies × 9 polar directions
BM: 4 energies × 9 × 16 directions

PEDPOS calculated electron spectral shifts in keV as calculated on ground, the basis of the electron spectral corrections, for diagnostic purposes
NM: 9 polar directions
BM: 9 polar directions × 16 sectors

EPAD Electrons in 2 (wide) energy bins, 3 polar directions, 16 sectors. The 3 directions are determined by the onboard magnetic field measurements, and are intended to be perpendicular to B in that sector, 90° to first direction, and another direction. Just which of the 9 available directions these are is determined by the on-board magnetic field data. This product exists only in NM; in BM, it is emulated from E3DD data. 1 set per spin.

EPADEX Expanded EPAD, to simplify interpretation for the user, the values are placed into their locations within the 9×16 direction array, with all other values set to the pad value (no data).

IPAD Similar to EPAD but for protons. The 3 directions are selected from 12 available according to on-board magnetic data. Available both in BM and NM. 1 set per spin.

IPADEX Expanded IPAD, the output is sorted into the 12×16 ion direction array with all other values set to the pad value (no data).

DE Direct events, 20 (NM) or 106 (BM) per spin. Each event consists of 4 numbers, for energy (0–255), time-of-flight (0–255), sector (0–15), ion polar direction. A priority system is used to ensure that higher mass ions are included over protons. Use of this data product requires considerable understanding of the instrument.

MTRX Matrix of 32 mass and 64 energy-per-mass bins, accummulated over 64 spins, and read out over 256 (NM) or 64 spins (BM). No directional information, omnidirectional only. The elements of this matrix are mapped from the much larger DE space, via internal formulas for various ions. Again, considerable understanding of the instrument is required to correctly interpret these data. See Section 13.2 of Kronberg et al. [Ref. 8]. This product exists only as count rates.

RMTRX Reduced MTRX data, repackaged into 5 mass ranges (H, He, CNO, Si, Fe) and 8 energy channels, using newly calculated formulas (not the internal ones) for the behaviour of these species in the Direct Event space. That is, the elements of MTRX data are remapped into this reduced space that can be more readily understood by the general user. See Section 13.2 of Kronberg et al. [Ref. 8] for details. This product too exists only as count rates.

MDATA Result of the the on-board magnetometer measurements. For each sector, a number 0–15 indicating the perpendicular to the magnetic field in that sector, and a second number (0–1) to indicate the direction of the field in that sector. It is used mainly with EPAD and IPAD, to construct EPADEX and IPADEX. 32 words per spin.

HK Housekeeping parameters, 137 words per spin. Needs documentation to interpret.

HIST Special mode for electrons, with 256 energy bins. Only used occasionally (once a month) to analysis electron sensor performance.

SGL*n* “Singles” counters, allowing analysis of time-of-flight performance; require understanding of the instrument. Diagnostic, but should be archived.

In addition to the counts/s and flux, variances derived from compression losses and Poisson statistics are available.

4 Production Provision—General Conventions

4.1 Formats

4.1.1 Data Products

The final data format produced by the RAPID CSA software is the Cluster Exchange Format version 2 [Ref. 12].

The level 2 data used as input for the CEF generation is stored in so-called SCI files, an ASCII format specific for the RAPID software.

4.1.2 Graphical Products

In addition to the RAPID data products, summary plots in png format are also delivered to the CSA. The purpose of these graphical products is to provide the CSA user with a quicklook onto the RAPID science data and instrument performances. The graphics contain 4 panels showing 6-hour time series of energy spectra of electron, hydrogen, helium, and CNO, and 3 panels displaying the status and settings of the IES and IIMS instrument. The spectra are presented as differential fluxes with a time resolution of 1 min.

4.2 Standards

The RAPID CSA data products are delivered in the CEF format specified in Allen et al. [Ref. 12]; the corresponding metadata conforms to the CAA/CSA Metadata Dictionary [Ref. 13].

Time is represented as a text string in the strict ISO format as specified by the CEF format. This is of the form:

yyyy-*mm*-*dd*T*hh*:*mm*:*ss*.*sss*Z

e.g., 2003-01-30T13:30:00.000Z for January 30, 2003 at 1.30 pm. The time stamp refers to the middle of the accumulation time interval.

The 3-D particle distributions (like E3DD and I3DD) are provided in a RAPID-based coordinate system with the polar direction relative to the spacecraft spin axis and the azimuth relative to the start of the RAPID spin sector 0.

Additional datasets are available to translate each of the RAPID polar/azimuth bins into the particle flow direction in true GSE, also allowing for the slight offset of the spin axis from the GSE southern pole. These numbers change only very slowly over the course of a day, hence they are provided only once an hour, or whenever a large change occurs, such as when the RAPID sun sector is reset.

Note: strictly speaking, it is sufficient to provide only a 3×3 rotation matrix to effect the above conversions. However, to avoid any ambiguities that could arise from such an application (of which there are many) it was decided to provide the user with the much larger set of finished results.

This rotation matrix is included in the GSE angle files IFLOW_GSE and EFLOW_GSE.

Differential flux is given in $1/(\mathrm{cm}^2\,\mathrm{s\,sr\,keV})$ with a conversion factor of 6.242×10^{19} to get units in the SI system $(1/(\mathrm{m}^2\,\mathrm{s\,sr\,J})$. If there is no differential flux given, data are presented in counts/s.

4.3 Various Releases of the RAPID Data at CSA

4.3.1 Second Release

From June to October 2008, all the RAPID data at CAA/CSA for the years 2001–2006 were reprocessed as the *second release*. Apart from the question of recalibration (Section 4.6), the set of data files and products has been extended and revised.

Afterwards, the data for 2007 were reprocessed for the first time, conforming to this second release.

The essential differences between the first and second issues are:

- the use of header files to specify non-varying product metadata; previously, these metadata were explicitly included in each CEF file, making replacement and correction extremely difficult;
- omnidirectional nominal mode electron data products have been replaced by new ones containing the true 6 energy channels; the earlier products were artificially expanded to 8 channels (same as BM), something that led to errors and confusion;
- additional products were added, including some specialized data as well as diagnostic products (housekeeping, instrument settings); CEF caveat files were also added;
- the GSE flow direction product files now include the rotation matrix to transfer from the RAPID spacecraft frame to GSE;
- the 3-D ion distributions are split to more accurately reflect the times when they were accumulated (see Appendix A).

The product descriptions of Section 5 contain only the current ones, without the removed obsolete ones.

In February 2009, the ion flux data for 2006 were reprocessed once more, to correct an error found in the geometry factors. The data for other years were not affected. These ion products bear the calibration version of 3 (first digit in the dataset version of Section 4.7).

In November 2009, some products were reissued once more, and some new products added (these also bear calibration version 3):

- the CNO fluxes have been redone to remove the first energy channel, since it is now clear that this is strongly contaminated with hydrogen, or even helium;
- the names of the variables in the IPADEX (page 41) and EPADEX (page 40) have been changed to avoid confusion with the new pitch angle distributions (PAD);
- the IPITCH (page 38) and EPITCH (page 38) products have been redone using true calibrated FGM magnetometer data (5 vectors per sec, 5VPS), instead of with the on-board IEL data;
- new merged 3-D ion flux distributions have been added, to accompany the existing “split” ones for fluxes and rates, as described in Appendix A;
- new products for pitch angle distributions (PAD) are included for electrons (BM), electrons-lite (after May 2004), and ions.

4.3.2 Third Release

Starting in September 2015, a complete reprocessing was undertaken of all the RAPID data at CSA, at that point up to the end of 2014. All these bear the calibration version number 3 (Section 4.7).

The major changes are:

- The electron fluxes are further corrected for the decay of the middle detectors, with correction factors 10.2; previously no correction was applied. See Section 9 of Kronberg et al. [Ref. 8].
- A spike detection procedure is applied to automatically remove spurious noise spikes that occur at the boundaries of mode changes and switch-ons. See Section 8 of Kronberg et al. [Ref. 8].
- In flux products, any record containing only fill values is removed. In this way, files for products that no longer exist (such as ions on spacecraft where IIMS has failed) will be empty, and the corresponding inventory plots at CSA will indicate that. (The inventory plots cannot distinguish fill values from real data.) The rates products will still deliver numbers, which are meaningless or fills.
- All products, both rates and fluxes and diagnostics, were redone in order to ensure proper synchronization among them; the previous partial reprocessings had led to discrepancies because of slight changes in the timing algorithms over the course of the Mission.

4.3.3 Fourth Release

As of June 2018, a completely revised set of calibration parameters for the IIMS ions is available (Section 5.3 of Kronberg et al. [Ref. 8]). At the same time, an updated set of correction factors for the IES electron decay, version 13.2, is ready. These two changes form the basis for a fourth release of the RAPID data at CSA.

This release was first applied to the delivery of data for 2017, and has since been used to gradually reprocess all earlier data, with priority for electrons from 2015 and ions from 2010.

> *As of February 2020, the reprocessing with the fourth release has been completed for all years.*

The products of this release bear the calibration version number 4 (Section 4.7).

4.4 Production Procedures — The RAPID CSA Software

The raw data in MSF format are generated locally by the RAPID Team from the original raw data files delivered by ESOC and then uploaded to CAA, where they are installed by the CAA/CSA Team.

The production of the RAPID products from the MSF files is carried out at CAA on one of their machines by means of software maintained and run by the RAPID Team. See Appendix D.

4.5 Quality Control Procedures

Data quality: Quality flags in the final CEF files depend on the set of calibration files used. These range from 0 for "Not applicable" to 4 for "Excellent data which has received special treatment". For further details, see the Metadata Dictionary [Ref. 13].

Validation control: After the installation of the RAPID software at CAA, the RAPID team will perform quality checks of final products, to verify the full and correct functionality of the software. After installation of software and template updates sample CEF files will be generated and compared with the same ones at MPS. During regular processing, spot checks will be carried out by the MPS Team on selected CEF files downloaded from CSA.

4.6 Recalibration and Reprocessing

Since CAA/CSA is an *active* archive, it is expected that the data will require reprocessing and redelivery in the course of the active phase.

An extensive recalibration has been undertaken, and was completed in September 2007. The first release of the 2005 data includes the new calibration factors. The data from 2001–2004 were reprocessed starting in the 2nd half of 2008. The delay was in order to allow for the planning of the second release (additional and replaced products) to be finished, so that the reprocessed data conform to it.

The value of the quality flag was set to 3 ("Good for publication, subject to PI approval") for the reprocessed data; the data from the first release had 2 ("Survey data, not for publication").

In January 2009, an error was discovered in the ion geometry factors. This error was in effect since the beginning of 2006 and had the result that all ion fluxes were roughly 50% too high. As a result, the 6 ion flux products were reproduced in February 2009. This change is indicated by a different dataset version number, as explained in the next section.

Earlier years were not affected by this error; later years had not yet been ingested in CAA/CSA.

In November 2009, some products were reprocessed and some others were added, as described in Section 4.3.1.

As of January 2012, revised calibrations for the IES electrons are available. These were applied starting with the data for 2011, and were then applied to earlier years as part of the third release. These data carry the calibration version number of 3 (Section 4.7).

As explained above in Section 4.3.3, a complete recalibration of the ions, plus updated electron decay corrections, was ready in June 2018, and a 4th release, with calibration version number 4, was then undertaken.

4.7 The Dataset Version Code

The set of calibration files is only one factor determining the quality of the processed data. There are also spectral shifts to align the various detectors to a common set of energy thresholds, pedestal shift corrections for the electrons, and possibly background removal.

In order to specify the factors going into the data production at any time, RAPID makes use of the CSA file metadata entry `DATASET_VERSION`. Rather than using a sequence number, RAPID employs a 4-digit code to indicate the various factors, which could change independently of each other. This code is slightly different for electrons and ions.

```
┌──────────────→ Calibration version
│  ┌───────────→ Pedestal determination (electrons), Cal subset (ions)
│  │  ┌────────→ Spectrum correction
│  │  │  ┌─────→ Background subtraction
X  X  X  X
```

Calibration version corresponds to the release number and has the value of 3 or 4 for the current calibration data; (1 and 2 are obsolete, any such datasets should be deleted).

For versions 3 and later we have:

Ions: the corrected geometry factor for 2006 and later, and the suppression of CNO channel 1;

Electrons: revised value of channel 1 threshold, as well as other refinements.

And for version 4 we have:

Ions: the new calibrations of 2018;

Electrons: revised decay correction factors version 13.2 (or later).

Pedestal determination for electrons; how the pedestal (Fig. 5) is determined: 0 for no correction, 1 for the "stepping" method, the only method used at the moment. Improved algorithms may be added later, which will obtain a different code number.

Cal subset for ions; for internal RAPID usage: 0 and 1 refer to preliminary calibrations used to generate the final set with number 2.

Spectrum correction how the varying energy thresholds between detectors, spacecraft, and (for electrons) integration times are corrected to a uniform set of values. The pedestal shift for electrons is also corrected with spectral shifting. Possible values are: 0 for no correction, 2 and 3 for power law fitting between two adjacent channels. With 2, the pedestal shift is the spin average, while for 3, it is done for each sector. (Method 1 no longer exists.)

Background subtraction was originally allowed for, but in fact is not done: 0 for no subtraction; 1 for some background removal.

The only background removed is some solar noise in some IES heads on SC3; a value of 3 indicates that this has been applied.

Typical values are 4220 for ions (calibration version #4, final set, with spectral alignment, no bg removal) and 4120 for electrons (calibration #4, pedestals determined, spectral alignment, no bg removal) and 4123 on SC3 with solar noise removed.

For certain products (HK, CAVEATS, IPITCH, EPITCH, IFLOW, EFLOW, PEDPOS, DSETTINGS) which do not really depend on calibration parameters, the dataset version is *n*000, where *n* is the calibration version number, currently 4.

Note that these dataset version numbers also appear at the bottom of the summary plots, Fig. 6.

4.8 Delivery Procedures

The level 1 raw data as MSF files are prepared by the RAPID Team, are made available online at MPS and then transferred by FTP by the CAA/CSA Team to the CAA computers. As these rarely change, this normally needs to be done only once per time period.

The software and calibration files needed to convert from level 1 to level 2 products is maintained by the RAPID Team at MPS. These are uploaded to a CAA computer by the RAPID Team, and are updated whenever necessary.

Similarly, the software that reformats the level 2 data into CEF files for CAA is maintained by the RAPID Team and uploaded to CAA.

The processing from level 1 to CEF via level 2 is carried out on the CAA machine, but *executed remotely by the RAPID Team*, who then verify that the processing was successful. The CEF files are thus generated directly at CAA and do not need to be transferred from externally.

When satisfied, the RAPID Team produces the required listing files, transfers them to the appropriate location, which thus initiates the automatic ingestion procedures.

Finally, the files are transferred from CAA to CSA for downloading by the scientific community.

5 Production Provision—Specific Descriptions

In this section, we describe the RAPID products as they are named and formatted for CSA; obsolete products that were removed in the second issue (Section 4.3.1) are no longer listed here.

In the following sections, the RAPID products are named and listed as they appear at CSA, with their descriptive name (e.g., *Electron omnidirection flux*) and with the internal designation (e.g., *ESPCT6*). The former is more useful to the user, while the latter is what appears in the downloaded file and variable names.

The products are sorted as *Science* for the most commonly needed ones, and *Ancillary* for those aimed at more expert users. These include more specialized science products as well as diagnostic ones.

For each product, the filename as in the CSA database is given, as well as the list of variables belonging to it. Only the base names of the variables are given; the complete name actually contains the additional suffix

`__Cn_CP_RAP_prod`

where `n` is the spacecraft number 1–4 and `prod` is the internal designation mentioned above.

Variables common to all files (without the additional suffix):

`Time_tags` the time stamp of the middle of the accumulation interval

`Time_half_interval` half the width of the accumulation interval, in seconds

`Quality` a data quality indicator, defined by CSA, for the dataset. For RAPID, this is determined by the particular set of calibration files being used.

Recall that *differential flux* is the particle flux per unit energy, in units of $\mathrm{cm^{-2}\,s^{-1}\,sr^{-1}\,keV^{-1}}$. Omnidirectional differential flux is averaged over all directions, and has the same units.

Count rates are the number of particles per second measured within the given energy range and direction, without allowance for any bin sizes. The count rates include an *effective accumulation time* which is the conversion factor between the measured counts and the count rates. This differs from the measurement *time interval* since it also contains possible duty cycle effects.

5.1 Science Data Products

The products listed in this section are the ones that are most commonly required by regular users. The fundamental ones are available both as differential flux and as count rates; those that are derived from other products, such as the pitch angle distributions, are given only as flux.

5.1.1 Electron Omnidirectional Flux — ESPCT6

Omnidirectional electron differential fluxes in 6 energy channels and their standard deviations.

File name: `C`*n*`_CP_RAP_ESPCT6__`*yyyymmdd*`_V`*xx*`.cef`

Variables:

`Electron_Dif_flux` [6] differential particle flux for electrons in 6 energy channels

`Electron_Dif_flux_SD` [6] standard deviations of the above

5.1.2 Electron Omnidirectional Rates — ESPCT6_R

Omnidirectional electron count rates in 6 energy channels, their standard deviations, and accumulation time.

File name: `C`*n*`_CP_RAP_ESPCT6_R__`*yyyymmdd*`_V`*xx*`.cef`

Variables:

`Electron_Rate_Acc_time` effective accumulation time in seconds

`Electron_Rate` [6] count rates for electrons in 6 energy channels

`Electron_Rate_SD` [6] standard deviations of the above

5.1.3 Electron 3-D Flux (Standard) — L3DD

Differential fluxes for electrons in 2 (non-contiguous) energy channels, 16 azimuthal sectors and 9 polar directions, and their standard deviations. The directions are defined in a RAPID-referenced spacecraft system, which are converted to GSE with the `EFLOW_GSE` variables described later.

This product exists in both burst and nominal modes, but only after May 2004. It is a “light” version of the burst mode `E3DD`.

File name: `C`*n*`_CP_RAP_L3DD__`*yyyymmdd*`_V`*xx*`.cef`

Variables:

`Electron_L_Dif_flux_3D` [2,16,9] differential particle flux for electrons in 2 energy channels, 16 sectors, 9 polar directions

`Electron_L_Dif_flux_3D_SD` [2,16,9] standard deviations of the above

5.1.4 Electron 3-D Rates (Standard) — L3DD_R

Count rates for electrons in 2 (non-contiguous) energy channels, 16 azimuthal sectors and 9 polar directions, their standard deviations, and accumulation time. The directions are defined in a RAPID-referenced spacecraft system, which are converted to GSE with the `EFLOW_GSE` variables described later.

This product exists in both burst and nominal modes, but only after May 2004. It is a “light” version of the burst mode `E3DD`.

File name: `Cn_CP_RAP_L3DD_R__yyyymmdd_Vxx.cef`

Variables:

- `Electron_L_Rate_3D_Acc_time` effective accumulation time in seconds
- `Electron_L_Rate_3D` [2,16,9] count rates for electrons in 2 energy channels, 16 sectors, 9 polar directions
- `Electron_L_Rate_3D_SD` [2,16,9] standard deviations of the above

5.1.5 Electron 3-D Flux (Best) — E3DD

Differential fluxes for electrons in 8 energy channels, 16 azimuthal sectors and 9 polar directions, and their standard deviations. The directions are defined in a RAPID-referenced spacecraft system, which are converted to GSE with the `EFLOW_GSE` variables described later.

This product exists only in burst mode (or in the special NM3 mode on SC2).

File name: `Cn_CP_RAP_E3DD__yyyymmdd_Vxx.cef`

Variables:

- `Electron_Dif_flux_3D` [8,16,9] differential particle flux for electrons in 8 energy channels, 16 azimuthal sectors and 9 polar directions
- `Electron_Dif_flux_3D_SD` [8,16,9] standard deviations of the above

5.1.6 Electron 3-D Rates (Best) — E3DD_R

Count rates for electrons in 8 energy channels, 16 azimuthal sectors and 9 polar directions, their standard deviations, and accumulation time. The directions are defined in a RAPID-referenced spacecraft system, which are converted to GSE with the `EFLOW_GSE` variables described later.

This product exists only in burst mode (or in the special NM3 mode on SC2).

File name: `Cn_CP_RAP_E3DD_R__yyyymmdd_Vxx.cef`

Variables:

- `Electron_Rate_3D_Acc_time` effective accumulation time in seconds
- `Electron_Rate_3D` [8,16,9] count rates for electrons in 8 energy channels, 16 azimuthal sectors and 9 polar directions
- `Electron_Rate_3D_SD` [8,16,9] standard deviations of the above

5.1.7 Proton Omnidirectional Flux — HSPCT

Omnidirectional proton differential fluxes in 8 energy channels and their standard deviations.

File name: `Cn_CP_RAP_HSPCT__yyyymmdd_Vxx.cef`

Variables:

- `Proton_Dif_flux` [8] differential particle flux for protons in 8 energy channels
- `Proton_Dif_flux_SD` [8] standard deviations of the above

Comment: Measurements in energy channel 8 are set to fill values because the instrument is not sensitive to particles in this energy range.

5.1.8 Proton Omnidirectional Rates — HSPCT_R

Omnidirectional proton count rates in 8 energy channels, their standard deviations, and accumulation time.

File name: `Cn_CP_RAP_HSPCT_R__yyyymmdd_Vxx.cef`

Variables:

`Proton_Rate_Acc_time` effective accumulation time in seconds

`Proton_Rate` [8] count rates for protons in 8 energy channels

`Proton_Rate_SD` [8] standard deviations of the above

5.1.9 Proton 3-D Flux (Standard) — I3DM_H

This product exists as of the second release; it replaces a product named `I3DD_H` which lacks the `Rec_Key` variable.

Since this product is constructed from others, it is provided only as flux; there is no raw count rate equivalent.

Differential fluxes for protons in 8 energy channels, 16 azimuthal sectors and 12 polar directions, and their standard deviations. The directions are defined in a RAPID-referenced spacecraft system, which are converted to GSE with the `IFLOW_GSE` variables described later.

Note: this is the *merged* version of I3D_H described later.

File name: `Cn_CP_RAP_I3DM_H__yyyymmdd_Vxx.cef`

Variables:

`Rec_Key` an integer to indicate how many split records have been merged together (see Appendix A); values are 1, 2, or 3.

`Proton_Dif_flux_3DM` [8,16,12] differential particle flux for protons in 8 energy channels, 16 azimuthal sectors and 12 polar directions

`Proton_Dif_flux_3DM_SD` [8,16,12] standard deviations of the above

Comment: Measurements in energy channel 8 are set to fill values because the instrument is not sensitive to particles in this energy range.

5.1.10 Helium Omnidirectional Flux — ISPCT_He

Omnidirectional helium differential fluxes in 8 energy channels and their standard deviations.

File name: `Cn_CP_RAP_ISPCT_He__yyyymmdd_Vxx.cef`

Variables:

`Helium_Dif_flux` [8] differential particle flux for helium in 8 energy channels

`Helium_Dif_flux_SD` [8] standard deviations of the above

Comment: Measurements in energy channel 1 are set to fill values because this channel is contaminated by hydrogen particles and measurements in channel 8 are set to fill values because the instrument is not sensitive to particles in this energy range.

5.1.11 Helium Omnidirectional Rates — ISPCT_He_R

Omnidirectional helium count rates in 8 energy channels, their standard deviations, and accumulation time.

File name: `Cn_CP_RAP_ISPCT_He_R__yyyymmdd_Vxx.cef`

Variables:

- `Helium_Rate_Acc_time` effective accumulation time in seconds
- `Helium_Rate` [8] count rates for helium in 8 energy channels
- `Helium_Rate_SD` [8] standard deviations of the above

5.1.12 Helium 3-D Flux (Standard) — I3DM_He

This product exists as of the second release; it replaces a product named `I3DD_He` which lacks the `Rec_Key` variable.

Since this product is constructed from others, it is provided only as flux; there is no raw count rate equivalent.

Differential fluxes for helium in 8 energy channels, 16 azimuthal sectors and 12 polar directions, and their standard deviations. The directions are defined in a RAPID-referenced spacecraft system, which are converted to GSE with the `IFLOW_GSE` variables described later.

Note: this is the *merged* version of I3D_He described later.

File name: `Cn_CP_RAP_I3DM_He__yyyymmdd_Vxx.cef`

Variables:

- `Rec_Key` an integer to indicate how many split records have been merged together (see Appendix A); values are 1, 2, or 3.
- `Helium_Dif_flux_3D` [8,16,12] differential particle flux for helium in 8 energy channels, 16 azimuthal sectors and 12 polar directions
- `Helium_Dif_flux_3D_SD` [8,16,12] standard deviations of the above

Comment: Measurements in energy channel 1 are set to fill values because this channel is contaminated by hydrogen particles and measurements in channel 8 are set to fill values because the instrument is not sensitive to particles in this energy range.

5.1.13 CNO Omnidirectional Flux — ISPCT_CNO

Omnidirectional CNO differential fluxes in 8 energy channels and their standard deviations.

File name: `Cn_CP_RAP_ISPCT_CNO__yyyymmdd_Vxx.cef`

Variables:

- `CNO_Dif_flux` [8] differential particle flux for CNO in 8 energy channels
- `CNO_Dif_flux_SD` [8] standard deviations of the above

5.1.14 CNO Omnidirectional Rates — ISPCT_CNO_R

Omnidirectional CNO count rates in 8 energy channels, their standard deviations, and accumulation time.

File name: `Cn_CP_RAP_ISPCT_CNO_R__yyyymmdd_Vxx.cef`

Variables:

CNO_Rate_Acc_time effective accumulation time in seconds

CNO_Rate [8] count rates for CNO in 8 energy channels

CNO_Rate_SD [8] standard deviations of the above

5.1.15 CNO 3-D Flux (Standard) — I3DM_CNO

This product exists as of the second release; it replaces a product named I3DD_CNO which lacks the Rec_Key variable.

Since this product is constructed from others, it is provided only as flux; there is no raw count rate equivalent.

Differential fluxes for CNO in 8 energy channels, 16 azimuthal sectors and 12 polar directions, and their standard deviations. The directions are defined in a RAPID-referenced spacecraft system, which are converted to GSE with the IFLOW_GSE variables described later.

Note: this is the *merged* version of I3D_H described later.

File name: C*n*_CP_RAP_I3DM_CNO__*yyyymmdd*_V*xx*.cef

Variables:

Rec_Key an integer to indicate how many split records have been merged together (see Appendix A); values are 1, 2, or 3.

CNO_Dif_flux_3D [8,16,12] differential particle flux for CNO in 8 energy channels, 16 azimuthal sectors and 12 polar directions

CNO_Dif_flux_3D_SD [8,16,12] standard deviations of the above

Comment: Measurements in energy channel 1 are set to fill values because this channel is contaminated by hydrogen and/or helium particles.

5.1.16 Electron Pitch Angle Distribution (Standard) — PAD_L3DD

This product was added in November 2009.

Since this product is constructed from others, it is provided only as flux; there is no raw count rate equivalent.

The L3DD electron fluxes sorted into 9 pitch angle bins of width 20°, for 2 energy channels.

This product exists in both burst and nominal modes, but only after May 2004.

File name: C*n*_CP_RAP_PAD_L3DD__*yyyymmdd*_V*xx*.cef

Variables:

B_mean [3] spin-averaged magnetic field, GSE coordinates

B_Stability indicates how stable the field is: 1 for steady, 0 for extremely variable

PAD_Electron_L_Dif_flux [2,9] differential flux for electrons in 2 energy channels and 9 pitch angle bins

PAD_Electron_L_Dif_flux_SD [2,9] standard deviations of the above

5.1.17 Electron Pitch Angle Distribution (Best) — PAD_E3DD

This product was added in November 2009.

Since this product is constructed from others, it is provided only as flux; there is no raw count rate equivalent.

The E3DD electron fluxes sorted into 9 pitch angle bins of width 20°, for all 8 energy channels.

This product exists only in burst mode (or in the special NM3 mode on SC2).

File name: `C`*n*`_CP_RAP_PAD_E3DD__`*yyyymmdd*`_V`*xx*`.cef`

Variables:

- `B_mean` [3] spin-averaged magnetic field, GSE coordinates
- `B_Stability` indicates how stable the field is: 1 for steady, 0 for extremely variable
- `PAD_Electron_Dif_flux` [8,9] differential flux for electrons in 8 energy channels and 9 pitch angle bins
- `PAD_Electron_Dif_flux_SD` [8,9] standard deviations of the above

5.1.18 Proton Pitch Angle Distribution — PAD_H

This product was added in November 2009.

Since this product is constructed from others, it is provided only as flux; there is no raw count rate equivalent.

The I3DM_H proton fluxes sorted into 9 pitch angle bins of width 20°, for all 8 energy channels.

Since this is derived from the *merged* distributions, the records cover the same time intervals as that dataset.

File name: `C`*n*`_CP_RAP_PAD_H__`*yyyymmdd*`_V`*xx*`.cef`

Variables:

- `B_mean` [3] spin-averaged magnetic field, GSE coordinates
- `B_Stability` indicates how stable the field is: 1 for steady, 0 for extremely variable
- `PAD_Proton_Dif_flux` [8,9] differential flux for protons in 8 energy channels and 9 pitch angle bins
- `PAD_Proton_Dif_flux_SD` [8,9] standard deviations of the above

5.1.19 Helium Pitch Angle Distribution — PAD_He

This product was added in November 2009.

Since this product is constructed from others, it is provided only as flux; there is no raw count rate equivalent.

The I3DM_He helium fluxes sorted into 9 pitch angle bins of width 20°, for all 8 energy channels.

Since this is derived from the *merged* distributions, the records cover the same time intervals as that dataset.

File name: `C`*n*`_CP_RAP_PAD_He__`*yyyymmdd*`_V`*xx*`.cef`

Variables:

- `B_mean` [3] spin-averaged magnetic field, GSE coordinates
- `B_Stability` indicates how stable the field is: 1 for steady, 0 for extremely variable
- `PAD_He_Dif_flux` [8,9] differential flux for helium in 8 energy channels and 9 pitch angle bins
- `PAD_He_Dif_flux_SD` [8,9] standard deviations of the above

5.1.20 CNO Pitch Angle Distribution — PAD_CNO

This product was added in November 2009.

Since this product is constructed from others, it is provided only as flux; there is no raw count rate equivalent.

The I3DM_CNO ion fluxes sorted into 9 pitch angle bins of width 20°, for all 8 energy channels.

Since this is derived from the *merged* distributions, the records cover the same time intervals as that dataset.

File name: `Cn_CP_RAP_PAD_CNO__yyyymmdd_Vxx.cef`

Variables:

- `B_mean` [3] spin-averaged magnetic field, GSE coordinates
- `B_Stability` indicates how stable the field is: 1 for steady, 0 for extremely variable
- `PAD_CNO_Dif_flux` [8,9] differential flux for CNO in 8 energy channels and 9 pitch angle bins
- `PAD_CNO_Dif_flux_SD` [8,9] standard deviations of the above

5.2 Ancillary Data Products

The products listed in this section are auxiliary ones, like caveats, instrument settings, flow directions and pitch angles. This includes some science data that are of a complex nature, like the expanded 3-D ion distributions (Appendix A) and the direct events (Appendix B).

5.2.1 CAVEATS

File name: `Cn_CQ_RAP_CAVEATS__yyyymmdd_Vxx.cef`

Variables:

- `Time_Range` Validity of a specified caveat as time range (start date-and-time plus stop date-and-time).
- `Caveat_text` A string containing caveat information.

This set does not contain the variables `Time_tags` or `Time_half_interval`.

5.2.2 SETTINGS

Instrument settings consist of 11 integer values providing information on instrument modes and other flags that help to understand the state of the data. These are also contained in the housekeeping data, but are provided here separately in a more user-friendly manner.

File name: `Cn_CP_RAP_DSETTINGS__yyyymmdd_Vxx.cef`

These are *differential* settings, with one record when ever one of the values changes, together with the time range. There is an alternative `SETTINGS` described below with one record per spin and a time stamp.

Variables (see also Table 4 for information on possible values):

- `Time_Range` Validity of a given set of values, as time range (start date-and-time plus stop date-and-time).
- `Telemetry` An integer value giving the telemetry mode.
- `IIMS_Mode_A` The *A* flag in the current configuration mode of the IIMS instrument, indicating serial or parallel mode.
- `IIMS_Mode_B` The *B* flag in the current configuration mode of the IIMS instrument, giving the status of the time-of-flight voltages.

Variable	Description	Values	Meaning	Notes
Telemetry	Telemetry	0	Nominal mode	Low bitrate, small data block
		1	Burst mode 1	High bitrate, large data block
		2	Burst mode 2	Never used
		3	Burst mode 3	6 min. per day, for RAPID no data
		4	NM 3	Only on SC2, same as BM1
Notes: Telemetry mode must be known because many products are differently formatted or only exist in one telemetry. NM3 used on SC2 only from July 2003 to April 2004, exploiting CIS telemetry.				
IIMS_Mode_A	Data Status	0	Off	
		1	Serial mode	3 IIMS heads cycle within each sector
		2	Parallel mode	3 heads active simultaneously
		4	In-flight test	Calibration test, no data
		5	DPU dump	Download of DPU contents, no data
IIMS_Mode_B	HV Status	0	Cold Standby	The high voltage relay is turned off
		1	Hot Standby	The relay is on, but voltages down
		2	HV on	Voltages up, but not at operating levels
		3	Defl HV on	Deflection voltage non-operating level
		4	HV ok	Voltages at operating levels
		5	ENA	Neutral mode, deflection voltage ok
Notes: The high voltages are those on the start and stop MCPs, needed for the time-of-flight processing; the deflection voltage sweeps ions away, so only neutrals enter the device (only used rarely at the start of mission). Fluxes are only calculated when the voltages are at the operating levels, i.e., for values 4 or 5.				
IIMS_Trigger	Trigger mode	0	E+T	Ion event if either energy or time-of-flight signal present (normal case)
		1	E+(D*T)	Energy or (direction and TOF)
		2	E*D*T	Energy and direction and TOF
		3	E*T	Energy and TOF
		4	E	Energy
		5	T	TOF
Start_Volt	Start HV	0–6700	HV on start MCP	voltage (V) on the MCP giving the start signal
Stop_Volt	Stop HV	0–6700	HV on stop MCP	voltage (V) on the MCP giving the stop signal
Def_Volt	Def HV	0–11900	HV on defl. plate	voltage (V) on ion deflection plates
IES_Mode_L	IES Test	0	Normal	Regular measurements
		1	In-flight test	Calibration test, no data
IES_Mode_M	IES Hist	1	Normal	Regular measurements
		3	Histograms	Dumping HIST data, no regular data
IES_Int_Time	IES Int. Time	2–50	Integration time	Values 2, 5, 15, 50 (μs)
IES_Autosw	IES Autoswitch	0	Off	The integration time is fixed
		1	On	Integration time switches automatically as needed

Table 4: The instrument mode settings and their meanings.

IIMS_Triggering The triggering mode for ion classifications.

Start_Volt The current voltage on the start MCP.

Stop_Volt The current voltage on the stop MCP.

Def_Volt The current voltage on the ion deflection plates.

IES_Mode_L The *L* flag in the current configuration mode of the IES instrument, indicating normal or test data.

IES_Mode_M An integer value standing for the *M* flag in the current configuration mode of the IES instrument, indicating normal or histogram data.

IES_Int_Time The current integration time of the IES instrument, in μs.

IES_Autosw An integer value of 0 or 1 telling if the IES autoswitching is turned off or on

This set does not contain the variables Time_tags or Time_half_interval.

Alternative SETTINGS

File name: C*n*_CP_RAP_SETTINGS__*yyyymmdd*_V*xx*.cef

An alternative to the differential settings described above, this set contains the same data but with one record for every spin (∼4 s) together with the time stamp Time_tags, but without Time_half_interval.

Since these files are very large, containing about 20 000 records per day, most of which are simply duplicates, they are considered obsolete, being retained only for backward compatibility; they have now been replaced by the more compact DSETTINGS.

5.2.3 Electron Flow Directions GSE — EFLOW_GSE

Conversion of the E3DD flow directions in 16 azimuthal sectors × 9 polar directions from spacecraft frame to GSE. These values are normally given only once an hour or whenever the spacecraft attitude changes "suddenly".

File name: C*n*_CP_RAP_EFLOW_GSE__*yyyymmdd*_V*xx*.cef

Variables:

SC2GSE [3,3] Rotation matrix from RAPID spacecraft coordinates to GSE

Electron_Pol [16,9] GSE polar (0–180°) angle for the flow direction of the corresponding E3DD direction/sector

Electron_Az [16,9] GSE azimuth (0–360°) angle for the flow direction of the corresponding E3DD direction/sector

This set does not contain the variable Time_half_interval.

5.2.4 Ion Flow Directions GSE — IFLOW_GSE

Conversion of the I3DD flow directions in 16 azimuthal sectors × 12 polar directions from spacecraft frame to GSE. These values are normally given only once an hour or whenever the spacecraft attitude changes "suddenly".

File name: C*n*_CP_RAP_IFLOW_GSE__*yyyymmdd*_V*xx*.cef

Variables:

SC2GSE [3,3] Rotation matrix from RAPID spacecraft coordinates to GSE

Ion_Pol [16,12] GSE polar (0–180°) angle for the flow direction of the corresponding I3DD direction/sector

Ion_Az [16,12] GSE azimuth (0–360°) angle for the flow direction of the corresponding I3DD direction/sector

This set does not contain the variable `Time_half_interval`.

5.2.5 Electron Pitch Angle Assignments — EPITCH

Electron pitch angle and magnetic azimuth angle relative to the Sun for 16 azimuthal sectors × 9 polar directions of the `E3DD` array.

> This product was reissued in November 2009 using calibrated FGM data (5VPS) from CSA; previously, the pitch angles were calculated with the on-board IEL data.

File name: `Cn_CP_RAP_EPITCH__yyyymmdd_Vxx.cef`

Variables:

`Electron_Pitch` [16,9] Electron pitch angle for 16 azimuthal sectors and 9 polar directions

`Electron_MagAz` [16,9] Magnetic azimuth angle for 16 azimuthal sectors and 9 polar directions

5.2.6 Ion Pitch Angle Assignments — IPITCH

Ion pitch angle and magnetic azimuth angle relative to the Sun for 16 azimuthal sectors × 12 polar directions of the `I3DD` array.

> This product was reissued in November 2009 using calibrated FGM data (5VPS) from CSA; previously, the pitch angles were calculated with the on-board IEL data.

File name: `Cn_CP_RAP_IPITCH__yyyymmdd_Vxx.cef`

Variables:

`Ion_Pitch` [16,12] Ion pitch angle for 16 azimuthal sectors and 12 polar directions

`Ion_MagAz` [16,12] Magnetic azimuth angle for 16 azimuthal sectors and 12 polar directions

5.2.7 Direct Events — DE

A number of unprocessed events allowing exact identification of particles within an energy and time-of-flight range of 256 bins, 16 azimuthal sectors and 16 polar directions. The 256 bins cover an energy range from 0 to 1500 keV and a TOF range from 0 to 80 ns. For the classification scheme see also Figure 4. Up to 20 (NM) or 106 (BM) events from one spin and their classifications are given, as single records, all with the same time tag.

File name: `Cn_CP_RAP_DE__yyyymmdd_Vxx.cef`

Variables:

`Direct_events` [7] For one event:
counter (1– maximum for this spin)
energy bin (0–255)
time-of-flight bin (0–255)
sector (0–15)
polar (0–11 for 12 directions, 12–14 for 3 heads, 15 for unknown)
species (1–5 for e, H, He, CNO, Si/Fe)
energy channel (1–8)

For further information, see Appendix B on page 55.

5.2.8 Ion Matrix, Omnidirectional Rates — MTRX_R

> *This product was added in May 2020.*

Omnidirectional ion count rates in 32 mass bins and 64 energy-per-mass channels, and their standard deviations. The relationship between the mass index and the energy-per-mass index numbers is complex, depending on internal functions that are not correct. This is explained in Section 13.2 of Kronberg et al. [Ref. 8].

File name: `Cn_CP_RAP_MTRX_R__yyyymmdd_Vxx.cef`

Variables:

`Ion_Matrix_Rate_Acc_time` effective accumulation time in seconds.

`Ion_Matrix_Rate` [64,32] count rates of ions in 32 mass bins and 64 energy-per-mass channels.

`Ion_Matrix_Rate_SD` [64,32] standard deviations of the above.

5.2.9 Ion Reduced Matrix, Omnidirectional Rates — RMTRX_R

This product was added in May 2020.

Omnidirectional ion count rates from the MTRX_R product repackaged into 8 energy channels for 5 ion species. The energy values are determined and the ion species specified. See Section 13.2 of Kronberg et al. [Ref. 8].

File name: `Cn_CP_RAP_RMTRX_R__yyyymmdd_Vxx.cef`

Variables:

`Ion_ReMatrix_Rate_Acc_time` effective accumulation time in seconds.

`Ion_ReMatrix_Rate_H` [8] count rates for protons in 8 energy channels.

`Ion_ReMatrix_Rate_He` [8] count rates for helium in 8 energy channels.

`Ion_ReMatrix_Rate_CNO` [8] count rates for CNO in 8 energy channels.

`Ion_ReMatrix_Rate_Si` [8] count rates for silicon in 8 energy channels.

`Ion_ReMatrix_Rate_Fe` [8] count rates for iron in 8 energy channels.

`Ion_ReMatrix_Rate_H_SD` [8] standard deviations for proton rates.

`Ion_ReMatrix_Rate_He_SD` [8] standard deviations for helium rates.

`Ion_ReMatrix_Rate_CNO_SD` [8] standard deviations for CNO rates.

`Ion_ReMatrix_Rate_Si_SD` [8] standard deviations for silicon rates.

`Ion_ReMatrix_Rate_Fe_SD` [8] standard deviations for iron rates.

5.2.10 Electron Flux Distribution (spin-averaged detector) — E2DD6

Differential fluxes for electrons in 6 energy channels, and 9 polar directions (summed over all sectors), and their standard deviations.

This product exists only in nominal mode. It is the nominal mode variant of burst mode 3-D distributions (E3DD).

File name: `Cn_CP_RAP_E2DD6__yyyymmdd_Vxx.cef`

Variables:

`Electron_Dif_flux_2D` [6,9] differential particle flux for electrons in 6 energy channels, 9 polar directions, summed over 16 sectors.

`Electron_Dif_flux_2D_SD` [6,9] standard deviations of the above

5.2.11 Electron Rates Distribution (spin-averaged detector) — E2DD6_R

Count rates for electrons in 6 energy channels, and 9 polar directions (summed over all sectors), their standard deviations, and accumulation time.

This product exists only in nominal mode. It is the nominal mode variant of burst mode 3-D distributions (E3DD_R).

File name: `C`*n*`_CP_RAP_E2DD6_R__`*yyyymmdd*`_V`*xx*`.cef`

Variables:

`Electron_Rate_2D_Acc_time` effective accumulation time in seconds

`Electron_Rate_2D` [6,9] count rates for electrons in 6 energy channels, 9 polar directions, summed over 16 sectors.

`Electron_Rate_2D_SD` [6,9] standard deviations of the above

5.2.12 Electron 3-D Flux (sparse) — EPADEX*m*

Sparse 3-D distributions for electrons as differential fluxes in 2 energy channels, 16 azimuthal sectors and 9 polar directions, and their standard deviations. For each sector, particles are registered in only 3 of the 9 directions, the others being set to fill values. The 3 directions are determined by the onboard magnetic field measurements, and are intended to be perpendicular to the magnetic field in that sector, 90° to first direction, and another direction.

Since May 2004 this product is replaced by L3DD.

File name: `C`*n*`_CP_RAP_EPADEX`*m*`__`*yyyymmdd*`_V`*xx*`.cef`

Variables:

`Electron_Dif_flux_Sparse_3D` [2,16,9] differential particle flux for electrons in 2 energy channels, 16 azimuthal sectors and 9 polar directions

`Electron_Dif_flux_Sparse_3D_SD` [2,16,9] standard deviations of the above

The energy channel definitions have changed over time, hence 3 separate products must be given, distinguished by *m*=1, 2, 3:

m	From	To
1	—	May 2001
2	May 2001	July 2002
3	July 2002	April 2004

The above dates are approximate, and vary for each spacecraft. The data files are empty for the times for they do not apply.

After May 2004, all three `EPADEX`*m* are empty.

5.2.13 Electron 3-D Rates (sparse) — EPADEX*m*_R

Sparse 3-D distributions for electrons as rates in 2 energy channels, 16 azimuthal sectors and 9 polar directions, and their standard deviations. For each sector, particles are registered in only 3 of the 9 directions, the others being set to fill values. The 3 directions are determined by the onboard magnetic field measurements, and are intended to be perpendicular to the magnetic field in that sector, 90° to first direction, and another direction.

Since May 2004 this product is replaced by L3DD.

File name: `C`*n*`_CP_RAP_EPADEX`*m*`_R__`*yyyymmdd*`_V`*xx*`.cef`

Variables:

`Electron_Rate_Sparse_3D_Acc_time` effective accumulation time in seconds

`Electron_Rate_Sparse_3D` [2,16,9] differential particle flux for electrons in 2 energy channels, 16 azimuthal sectors and 12 polar directions

`Electron_Rate_Sparse_3D_SD` [2,16,9] standard deviations of the above

As for `EPADEX`*m*, there are 3 different version of this product corresponding to different, time-dependent, energy definitions.

5.2.14 Proton 3-D Flux (sparse) — IPADEX

Sparse 3-D distributions for protons as differential fluxes in 2 energy channels, 16 azimuthal sectors and 12 polar directions, and their standard deviations. For each sector, particles are registered in only 3 of the 12 directions, the others being set to fill values. The 3 directions are determined by the onboard magnetic field measurements, and are intended to be perpendicular to the magnetic field in that sector, 90° to first direction, and another direction.

File name: `C`*n*`_CP_RAP_IPADEX__`*yyyymmdd*`_V`*xx*`.cef`

Variables:

`Proton_Dif_flux_Sparse_3D` [2,16,12] differential particle flux for protons in 2 energy channels, 16 azimuthal sectors and 12 polar directions

`Proton_Dif_flux_Sparse_3D_SD` [2,16,12] standard deviations of the above

Because of gaps due to the missing central ion head, this product is not very useful; it is only provided for completeness. As of May 2004, it exists only in burst mode, since in NM it is overwritten by L3DD.

5.2.15 Proton 3-D Rates (sparse) — IPADEX_R

Sparse 3-D distributions for protons as rates in 2 energy channels, 16 azimuthal sectors and 12 polar directions, and their standard deviations. For each sector, particles are registered in only 3 of the 12 directions, the others being set to fill values. The 3 directions are determined by the onboard magnetic field measurements, and are intended to be perpendicular to the magnetic field in that sector, 90° to first direction, and another direction.

File name: `C`*n*`_CP_RAP_IPADEX_R__`*yyyymmdd*`_V`*xx*`.cef`

Variables:

`Proton_Rate_Sparse_3D_Acc_time` effective accumulation time in seconds

`Proton_Rate_Sparse_3D` [2,16,12] differential particle flux for protons in 2 energy channels, 16 azimuthal sectors and 12 polar directions

`Proton_Rate_Sparse_3D_SD` [2,16,12] standard deviations of the above

Because of gaps due to the missing central ion head, this product is not very useful; it is only provided for completeness. As of May 2004, it exists only in burst mode, since in NM it is overwritten by L3DD.

5.2.16 Proton 3-D Flux (Expanded) — I3D_H

Differential fluxes for protons in 8 energy channels, 16 azimuthal sectors and 12 polar directions, and their standard deviations. The directions are defined in a RAPID-referenced spacecraft system, which are converted to GSE with the `IFLOW_GSE` variables described later.

> *Split (expanded) distributions: On SC1, 3, 4, in NM, different parts of the 3-D distributions are accumulated at different times, each part being put into a separate data record. There are thus 2 or 3 records per distribution, as described in Appendix A.*

File name: `Cn_CP_RAP_I3D_H__yyyymmdd_Vxx.cef`

Variables:

`Rec_Key` an integer to help reconstruct split records, see Appendix A

`Proton_Dif_flux_3D` [8,16,12] differential particle flux for protons in 8 energy channels, 16 azimuthal sectors and 12 polar directions

`Proton_Dif_flux_3D_SD` [8,16,12] standard deviations of the above

Comment: Measurements in energy channel 8 are set to fill values because the instrument is not sensitive to particles in this energy range.

5.2.17 Proton 3-D Rates (Expanded) — I3D_H_R

This product exists as of the second release; it replaces a product named `I3DD_H_R` which lacks the `Rec_Key` variable.

Count rates for protons in 8 energy channels, 16 azimuthal sectors and 12 polar directions, their standard deviations, and accumulation time. The directions are defined in a RAPID-referenced spacecraft system, which are converted to GSE with the `IFLOW_GSE` variables described later.

Split (expanded) distributions: On SC1, 3, 4, in NM, different parts of the 3-D distributions are accumulated at different times, each part being put into a separate data record. There are thus 2 or 3 records per distribution, as described in Appendix A.

File name: `Cn_CP_RAP_I3D_H_R__yyyymmdd_Vxx.cef`

Variables:

`Proton_Rate_3D_Acc_time` effective accumulation time in seconds

`Rec_Key` an integer to help reconstruct split records, see Appendix A

`Proton_Rate_3D` [8,16,12] count rates for protons in 8 energy channels, 16 azimuthal sectors and 12 polar directions

`Proton_Rate_3D_SD` [8,16,12] standard deviations of the above

5.2.18 Helium 3-D Flux (Expanded) — I3D_He

Differential fluxes for helium in 8 energy channels, 16 azimuthal sectors and 12 polar directions, and their standard deviations. The directions are defined in a RAPID-referenced spacecraft system, which are converted to GSE with the `IFLOW_GSE` variables described later.

Split (expanded) distributions: On SC1, 3, 4, in NM, different parts of the 3-D distributions are accumulated at different times, each part being put into a separate data record. There are thus 2 or 3 records per distribution, as described in Appendix A.

File name: `Cn_CP_RAP_I3D_He__yyyymmdd_Vxx.cef`

Variables:

`Rec_Key` an integer to help reconstruct split records, see Appendix A

`Helium_Dif_flux_3D` [8,16,12] differential particle flux for helium in 8 energy channels, 16 azimuthal sectors and 12 polar directions

`Helium_Dif_flux_3D_SD` [8,16,12] standard deviations of the above

Comment: Measurements in energy channel 1 are set to fill values because this channel is contaminated by hydrogen particles and measurements in channel 8 are set to fill values because the instrument registrates particles beyond its realistic sensitivity.

5.2.19 Helium 3-D Rates (Expanded) — I3D_He_R

This product exists as of the second release; it replaces a product named `I3DD_He_R` which lacks the `Rec_Key` variable.

Count rates for helium in 8 energy channels, 16 azimuthal sectors and 12 polar directions, their standard deviations, and accumulation time. The directions are defined in a RAPID-referenced spacecraft system, which are converted to GSE with the `IFLOW_GSE` variables described later.

Split (expanded) distributions: On SC1, 3, 4, in NM, different parts of the 3-D distributions are accumulated at different times, each part being put into a separate data record. There are thus 2 or 3 records per distribution, as described in Appendix A.

File name: `Cn_CP_RAP_I3D_He_R__yyyymmdd_Vxx.cef`

Variables:

`Helium_Rate_3D_Acc_time` effective accumulation time in seconds

`Rec_Key` an integer to help reconstruct split records, see Appendix A

`Helium_Rate_3D` [8,16,12] count rates for helium in 8 energy channels, 16 azimuthal sectors and 12 polar directions

`Helium_Rate_3D_SD` [8,16,12] standard deviations of the above

5.2.20 CNO 3-D Flux (Expanded) — I3D_CNO

Differential fluxes for CNO in 8 energy channels, 16 azimuthal sectors and 12 polar directions, and their standard deviations. The directions are defined in a RAPID-referenced spacecraft system, which are converted to GSE with the `IFLOW_GSE` variables described later.

Split (expanded) distributions: On SC1, 3, 4, in NM, different parts of the 3-D distributions are accumulated at different times, each part being put into a separate data record. There are thus 2 or 3 records per distribution, as described in Appendix A.

File name: `Cn_CP_RAP_I3D_CNO__yyyymmdd_Vxx.cef`

Variables:

`Rec_Key` an integer to help reconstruct split records, see Appendix A

`CNO_Dif_flux_3D` [8,16,12] differential particle flux for CNO in 8 energy channels, 16 azimuthal sectors and 12 polar directions

`CNO_Dif_flux_3D_SD` [8,16,12] standard deviations of the above

Comment: Measurements in energy channel 1 are set to fill values because this channel is contaminated by hydrogen and/or helium particles.

5.2.21 CNO 3-D Rates (Expanded) — I3D_CNO_R

This product exists as of the second release; it replaces a product named `I3DD_CNO_R` which lacks the `Rec_Key` variable.

Count rates for CNO in 8 energy channels, 16 azimuthal sectors and 12 polar directions, their standard deviations, and accumulation time. The directions are defined in a RAPID-referenced spacecraft system, which are converted to GSE with the `IFLOW_GSE` variables described later.

> *Split (expanded) distributions: On SC1, 3, 4, in NM, different parts of the 3-D distributions are accumulated at different times, each part being put into a separate data record. There are thus 2 or 3 records per distribution, as described in Appendix A.*

File name: `Cn_CP_RAP_I3D_CNO_R__yyyymmdd_Vxx.cef`

Variables:

- `CNO_Rate_3D_Acc_time` effective accumulation time in seconds
- `Rec_Key` an integer to help reconstruct split records, see Appendix A
- `CNO_Rate_3D` [8,16,12] count rates for CNO in 8 energy channels, 16 azimuthal sectors and 12 polar directions
- `CNO_Rate_3D_SD` [8,16,12] standard deviations of the above

5.2.22 IES Background Rates — IES_BG_R

> *This product was added April 2014.*

Hourly values of the background count rates in the 9 IES detectors for each of 6 energy channels. A statistical analysis is done on ∼900 individual measurements of the counts per spin, over an interval of one hour; if the variance is consistent with that of a Poisson distribution of constant mean, at the 95% confidence level, then that mean value is taken as the background level for that time. Otherwise, fill values are given. Each channel and detector are analysed separately.

The count rates delivered here are the mean counts per spin divided by the effective accumulation time, including duty cycle.

File name: `Cn_CP_RAP_IES_BG_R__yyyymmdd_Vxx.cef`

- `IES_BG_Rate_Acc_time` effective accumulation time in seconds, over the entire hour
- `IES_BG_Rate` [6,9] count rates of background for 6 energy channels and 9 polar directions
- `IES_BG_Rate_SD` [6,9] standard deviations of the above, derived from the variance

5.2.23 IES Background Fluxes — IES_BG

> *This product was added April 2014.*

These are the differential fluxes derived from the count rates described above in IES_BG_R. For statistical purposes, it is the rates or even the counts themselves that are most meaningful, but if one wishes to correct the fluxes for background, then these flux values are needed.

File name: `Cn_CP_RAP_IES_BG__yyyymmdd_Vxx.cef`

- `IES_BG_Dif_flux` [6,9] differential flux of background for 6 energy channels and 9 polar directions
- `IES_BG_Dif_flux_SD` [6,9] standard deviations of the above

5.2.24 Neutral Hydrogen Omnidirectional Flux — HSPCT_ENA

> *This product was added in October 2022.*
>
> *This product is essentially the same as HSPCT, but for times when the ENA mode is active. It only applies to SC4, and only before May 2002. Since the raw count rates are already included in the product HSPCT_R, no additional rates product is provided.*

Omnidirectional differential fluxes of hydrogen atoms in 8 energy channels and their standard deviations.

File name: `Cn_CP_RAP_HSPCT_ENA__yyyymmdd_Vxx.cef`

Variables:

`Neutral_Hydrogen_Dif_flux` [8] differential particle flux for neutral hydrogen atoms in 8 energy channels

`Neutral_Hydrogen_Dif_flux_SD` [8] standard deviations of the above

5.2.25 Neutral Hydrogen 3-D Flux — I3DM_H_ENA

This product was added in October 2022.

This product is essentially the same as I3DM_H, but for times when the ENA mode is active. It only applies to SC4, and only before May 2002. Since the raw count rates are already included in the product I3DM_H_R, no additional rates product is provided.

Differential fluxes for hydrogen atoms in 8 energy channels, 16 azimuthal sectors and 12 polar directions, and their standard deviations. The directions are defined in a RAPID-referenced spacecraft system, which are converted to GSE with the `IFLOW_GSE` variables described later.

File name: `Cn_CP_RAP_I3DM_H_ENA__yyyymmdd_Vxx.cef`

Variables:

`Rec_Key` an integer to indicate how many split records have been merged together (see Appendix A); values are 1, 2, or 3.

`Neutral_Hydrogen_Dif_flux_3DM` [8,16,12] differential particle flux for protons in 8 energy channels, 16 azimuthal sectors and 12 polar directions

`Neutral_Hydrogen_Dif_flux_3DM_SD` [8,16,12] standard deviations of the above

5.2.26 Neutral Helium Omnidirectional Flux — ISPCT_He_ENA

This product was added in October 2022.

This product is essentially the same as ISPCT_He, but for times when the ENA mode is active. It only applies to SC4, and only before May 2002. Since the raw count rates are already included in the product ISPCT_He_R, no additional rates product is provided.

Omnidirectional differential fluxes of helium atoms in 8 energy channels and their standard deviations.

File name: `Cn_CP_RAP_ISPCT_He_ENA__yyyymmdd_Vxx.cef`

Variables:

`Neutral_Helium_Dif_flux` [8] differential particle flux for helium in 8 energy channels

`Neutral_Helium_Dif_flux_SD` [8] standard deviations of the above

5.2.27 Neutral Helium 3-D Flux — I3DM_He_ENA

This product was added in October 2022.

This product is essentially the same as I3DM_He, but for times when the ENA mode is active. It only applies to SC4, and only before May 2002. Since the raw count rates are already included in the product I3DM_He_R, no additional rates product is provided.

Differential fluxes for helium atoms in 8 energy channels, 16 azimuthal sectors and 12 polar directions, and their standard deviations. The directions are defined in a RAPID-referenced spacecraft system, which are converted to GSE with the `IFLOW_GSE` variables described later.

File name: `C`*n*`_CP_RAP_I3DM_He_ENA__`*yyyymmdd*`_V`*xx*`.cef`

Variables:

`Rec_Key` an integer to indicate how many split records have been merged together (see Appendix A); values are 1, 2, or 3.

`Neutral_Helium_Dif_flux_3D` [8,16,12] differential particle flux for helium in 8 energy channels, 16 azimuthal sectors and 12 polar directions

`Neutral_Helium_Dif_flux_3D_SD` [8,16,12] standard deviations of the above

5.2.28 Neutral CNO Omnidirectional Flux — ISPCT_CNO_ENA

This product was added in October 2022.

This product is essentially the same as ISPCT_CNO, but for times when the ENA mode is active. It only applies to SC4, and only before May 2002. Since the raw count rates are already included in the product ISPCT_CNO_R, no additional rates product is provided.

Omnidirectional differential fluxes of CNO atoms in 8 energy channels and their standard deviations.

File name: `C`*n*`_CP_RAP_ISPCT_CNO_ENA__`*yyyymmdd*`_V`*xx*`.cef`

Variables:

`Neutral_CNO_Dif_flux` [8] differential particle flux for CNO in 8 energy channels

`Neutral_CNO_Dif_flux_SD` [8] standard deviations of the above

5.2.29 Neutral CNO 3-D Flux — I3DM_CNO_ENA

This product was added in October 2022.

This product is essentially the same as I3DM_CNO, but for times when the ENA mode is active. It only applies to SC4, and only before May 2002. Since the raw count rates are already included in the product I3DM_CNO_R, no additional rates product is provided.

Differential fluxes for CNO atoms in 8 energy channels, 16 azimuthal sectors and 12 polar directions, and their standard deviations. The directions are defined in a RAPID-referenced spacecraft system, which are converted to GSE with the `IFLOW_GSE` variables described later.

File name: `C`*n*`_CP_RAP_I3DM_CNO_ENA__`*yyyymmdd*`_V`*xx*`.cef`

Variables:

`Rec_Key` an integer to indicate how many split records have been merged together (see Appendix A); values are 1, 2, or 3.

`Neutral_CNO_Dif_flux_3D` [8,16,12] differential particle flux for CNO in 8 energy channels, 16 azimuthal sectors and 12 polar directions

`Neutral_CNO_Dif_flux_3D_SD` [8,16,12] standard deviations of the above

5.3 Diagnostic Products

The products listed in this section are intended for expert users who need to examine the functioning of the RAPID instrument.

5.3.1 Singles

There are four diagnostic products for the *singles* counts, which monitor the behaviour of the IIMS ion instrument, including the time-of-flight mechanism and solid state detectors. These are described the DARD [Ref. 11].

Because of different cadence intervals, it is necessary to break them up into 3 sets; and because the first set is different between burst and nominal mode, this too is split once again.

5.3.2 Ion Diagnostic Singles 1 (NM) — SGL1

The first set of Singles are sums over all three detector heads:

`ENY` the count rate for all 3 energy detectors

`TCR` the rate of *triple coincidences*, i.e., a start, stop, and and energy signal

`TAC` the rate of TOF signals, i.e., a start and stop signal within 80 ns

`STA0-7` the rate of start signals within sectors 0–7

`STA8-15` the rate of start signals within sectors 8–15

`STO0-7` the rate of stop signals within sectors 0–7

`STO8-15` the rate of stop signals within sectors 8–15

File name: `Cn_CP_RAP_SGL1__yyyymmdd_Vxx.cef`

Variables:

`Singles_1_Acc_time` [7] effective accumulation time in seconds

`Singles_1` [7] the 7 singles-1 rates listed above

`Singles_1_SD` [7] standard deviations of the above

Note that the accumulation times vary with the different items.

During burst mode, the SGL1 set is reconstructed from the BM data, so it always exists.

5.3.3 Ion Diagnostic Singles 1 (BM) — SGL1_BM

In burst mode, the 5 rates ENY, TCR, TAC, STA, STO are accumulated for each sector. This data product is empty during nominal mode.

File name: `Cn_CP_RAP_SGL1_BM__yyyymmdd_Vxx.cef`

Variables:

`Singles_1_BM_Acc_time` [5] effective accumulation time in seconds

`Singles_1_BM` [16,5] the 5 rates in each of the 16 sectors

`Singles_1_BM_SD` [16,5] standard deviations of the above

Note that the accumulation times vary with the different items.

5.3.4 Ion Diagnostic Singles 2 — SGL_2

The second set contains rates that are for different detector heads, and directions.

`EDIx` count rate in energy detector x=1,2,3

`BDIx` count rate in back detector x=1,2,3

EDI*xy* count rate in energy detector *x*=1,2,3 and direction *y*=1,2,3,4

File name: C*n*_CP_RAP_SGL_2__*yyyymmdd*_V*xx*.cef

Variables:

Singles_2_Acc_time [18] effective accumulation time in seconds

Singles_2 [18] the 18 rates indicated above

Singles_2_SD [18] standard deviations of the above

Note that the accumulation times vary with the different items.

5.3.5 Ion Diagnostic Singles 3 — SGL_3

The third set contains rates that are for different detector heads, and directions.

OVF*x* count rate in overflow detector *x*=1,2,3

SDIR-S*x* rate of directional signals, head *x*=1,2,3

SDIR-3S rate of directional signals in all heads

TAC-S*x* rate of TOF signals, head *x*=1,2,3

TAC*xy* rate of TOF signals, head *x*=1,2,3 and direction *y*=1,2,3,4

File name: C*n*_CP_RAP_SGL_3__*yyyymmdd*_V*xx*.cef

Variables:

Singles_3_Acc_time [22] effective accumulation time in seconds

Singles_3 [22] the 22 rates indicated above

Singles_3_SD [22] standard deviations of the above

Note that the accumulation times vary with the different items.

5.3.6 IES Pedestal Counts (NM) — PED_NM

IES pedestal counts in 2 energy channels and 9 polar directions, nominal mode only.

File name: C*n*_CP_RAP_PED_NM__*yyyymmdd*_V*xx*.cef

Variables:

Pedestal_counts_NM [2,9] IES pedestal counts in 2 energy channels and 9 polar directions

5.3.7 IES Pedestal Counts (BM) — PED_BM

IES pedestal counts in 4 energy channels, 16 azimuthal sectors and 9 polar directions, burst mode only.

File name: C*n*_CP_RAP_PED_BM__*yyyymmdd*_V*xx*.cef

Variables:

Pedestal_counts_BM [4,16,9] IES pedestal counts in 4 energy channels, 16 azimuthal sectors and 9 polar directions.

5.3.8 IES Pedestal Positions (NM) — PEDPOS_NM

Calculated position of the IES pedestal relative to its standard location, in keV, one value for 9 polar directions, once per spin, nominal mode only.

The pedestal is the true energy origin for all energy channels; if it is shifted, usually to lower, negative values, then all energy channels are effectively at higher values and must be corrected (see Figure 5).

File name: `Cn_CP_RAP_PEDPOS_NM__yyyymmdd_Vxx.cef`

Variables:

- `Pedestal_pos_NM` [9] IES pedestal position in keV 9 polar directions

5.3.9 IES Pedestal Positions (BM) — PEDPOS_BM

Calculated position of the IES pedestal relative to its standard location, in keV, for 9 polar directions, spin averaged and for 16 sectors per spin, burst mode only.

File name: `Cn_CP_RAP_PEDPOS_BM__yyyymmdd_Vxx.cef`

Variables:

- `Pedestal_pos_BM` [9,16] IES pedestal position in keV for 9 polar directions for 16 sectors
- `Pedestal_pos_BM_omni` [9] Spin averaged IES pedestal position in keV for 9 polar directions

5.3.10 IES Histogram Data — HIST

Approximately once a month a special test mode is run on the IES electron instrument. In this *histogram* mode, the entire 256 spectral bins are are read out for a single spin. The test cycles through all the detector strips and integration times. The purpose is to monitor the detector behaviour, especially the width and location of the pedestal. Normally up to 4 such cycles are done. The test always takes place during burst mode.

File name:`Cn_CP_RAP_HIST__yyyymmdd_Vxx.cef`

Variables:

- `HIST_Acc_time` effective accumulation time in seconds
- `IES_Inttime` integration time, 2, 5, 15, 50 μs
- `IES_Detector` detector (strip) number, 1–9
- `HIST` [256] raw counts in the 256 bins for that detector and integration time

5.3.11 Housekeeping Data — HK

Housekeeping parameters as 137 unsigned bytes. For more information see `.cef` header meta data information on housekeeping parameters or Table 4.2 of the Instrument Users Guide [Ref. 14].

File name: `Cn_CP_RAP_HK__yyyymmdd_Vxx.cef`

Variables:

- `HK_para` [137] 137 housekeeping parameters.

This set does not contain the variable `Time_half_interval`.

5.4 Future Products

There are a number of products that will be added later, before the active phase of the Archive is ended. These are mainly additional diagnostic ones.

5.4.1 Quality Flags

It is planned to provide a product containing various data quality parameters, indicating when certain unfavourable conditions are encountered. For example, when high count rates are likely to produce pile-up effects that would make the results questionable (both ions and electrons). For the ions, there is also a danger that high rates of incoming particles that do not meet time-of-flight and energy conditions will effectively reduce the live-time, making the apparent count rates lower than they really are. This could be corrected for.

The quality parameters would indicate the degree of these problems (e.g. percent of pile-up). This is preferred to actually removing (setting to fill value) suspect data because it would allow future users the possibility of determining their own limiting values before rejection.

5.5 Graphical Products

In this section we give a short description of the layout of RAPID summary plots available for differential fluxes. In Figure 6 we present an example plot of Cluster 1. From top to the bottom omnidirectional differential energy flux spectra of electrons, hydrogen, helium, and CNO with 1 min time resolution for January 25, 2005 within a 6 hour period from 12:00 to 18:00 UT are shown. At the right hand side of each plot panel a colorbar defines the color code of the spectra. This range is autoscaled, which has to be considered when comparing several plots.

The second part of the plot (panels 5-7) reflects the IES and IIMS instrument settings. For more information about instrument settings and their meaning see also the instrument description at the beginning of this document.

At the top of panel 5 the status of the IES autoswitching is drawn, i.e., green line – Autoswitching on; red line – Autoswitching off; orange – Histogram mode, an internal test mode. In autoswitching mode, the integration time *t* in the detector read-out system is not fixed but changes automatically with count rate. The second line in panel 5 displays the current IES integration time.

Panel 6 provides some general information about the IIMS status and operation settings.

color code	top line IIMS status	center line high voltages (HV)	bottom line telemetry
red	Standby	HV off	BM
green	IIMS in serial mode	HV operational	NM
orange	IIMS in parallel mode	HV on but not operational	NM3
blue	Inflight functional test	ENA operational	BM3

NM3 is a special mode on SC2 only, used between July 2003 and April 2004; the data are in BM format even though the spacecraft telemetry mode is NM.

BM3 occurs about once a day for 4–5 minutes; for RAPID it means “no data”.

Finally, the last panel shows to which level the high voltages, Start HV (green), Stop HV (blue), and Deflector HV (red) are set.

At the bottom of the summary plots orbit information in GSE coordinates is given.

File name: `C`*n*`_CG_RAP_SUMPLOT_D__`*yyyymmdd*`_`*hhmm*`_`*hhmm*`_V`*xx*.png

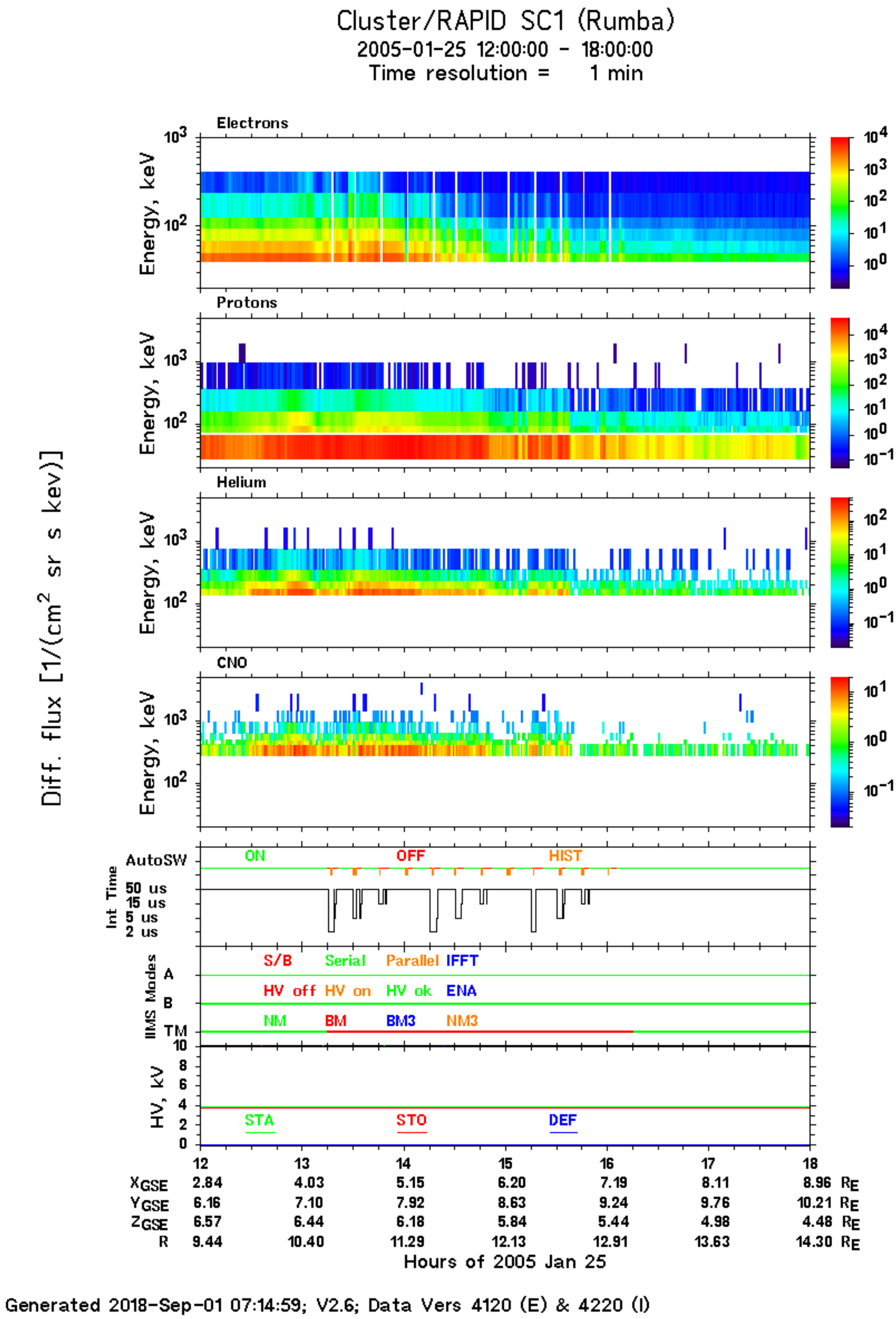

Figure 6: Example of a CSA RAPID summary plot. Panels 1-4 show from top to bottom differential fluxes of omnidirectional electrons, protons, helium, and CNO. Panels 5-7 display several instrument settings.

Appendices

A I3DD Timing

The 3-D ion data have some peculiarities regarding accumulation times and time stamping. The accumulation times and intervals are shown in the table below. The RAPID unit on SC2 being a survivor from the original Cluster I, it has some different properties, such as, the 3-D ions are accumulated over a single spin (out of 8 or 32), whereas the other later units were reprogrammed to accumulate over 8 spins.

	Nominal Mode		Burst Mode	
Spacecraft	Accum.	Int.	Accum.	Int.
2	1	32	1	8
1 3 4	8	32	8	8

The question arises in NM for SC 1, 3, 4 as to which 8 spins out of the 32 are those for the accumulation. This is important for time-stamping. In fact, due to a DPU bug, different sectors are accumulated in different sets of 8 spins! To make matters even worse, there are two alternating sector patterns! These patterns are illustrated in Figure 7. Note that in one case, the sectors fall into two groups, while in the other into three.

Since a proper time-stamping under these circumstances is extremely complicated to reproduce, we have decided to break up the 3-D data according to sectors with the same accumulation time; there are thus 2 or 3 records per complete 3-D distribution, each containing fill values for those sectors that are not represented.

Figure 8 demonstrates this. The top and third rows are the partial distributions as they are found in the (second issue) CSA data. These 10 partial distributions in fact cover 4 complete ones, shown in rows 2 and 4. The representation is RAPID spacecraft frame, so time goes rigorously from left to right in rows 1 and 3 (the time stamp is the center time of each partial distribution). In rows 2 and 4, time is mixed up.

A time-aliasing effect is shown in the bottom right plot, circled in red. Here there appears to be an enhancement in the distribution at 45°–90°, but in fact, this is due to a temporal decrease; these sectors were accumulated earlier than the others.

Incidently, Figure 8 also illustrates the so-called “donut effect”, the hole in the middle of the distribute due to the failure of the central ion head early in the Mission.

In order to indicate how the partial distributions are to be merged to regenerate the full distribution, a *record key* variable named `Rec_Key` is provided for each record. This is an integer with the following values:

Value	Meaning	Sectors included
11	Rec 1 of 1	0–15 (all)
21	Rec 1 of 2	2–7
22	Rec 2 of 2	0, 1, 8–15
31	Rec 1 of 3	2, 3
32	Rec 2 of 3	0, 1, 4–11
33	Rec 3 of 3	12–15

Note that the value 11 is provided for burst mode and SC2 for which no splitting is done: each record is a complete simultaneous distribution.

> ***Note:*** *the expanded distributions are provided both as differential flux and count rates; they represent the true time stamping. Additional merged (or “standard”) distributions are provided for fluxes only, as an aid to users who are more interested in the full distribution without worrying about detailed timing. For these distributions, the record key is the number of records merged together: 1, 2, or 3.*

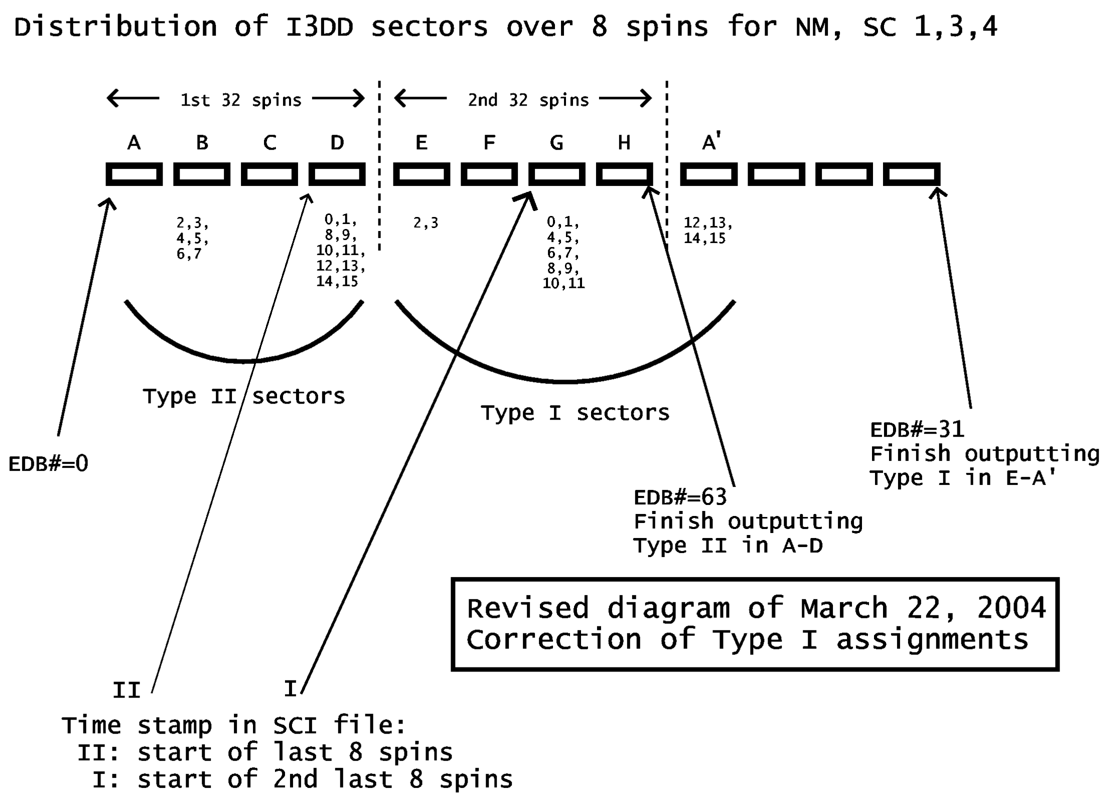

Figure 7: The two patterns of sector distributions over 32 spins. Each block labelled A B . . . H A′ represents 8 spins. Sectors are numbered from 0 to 15.

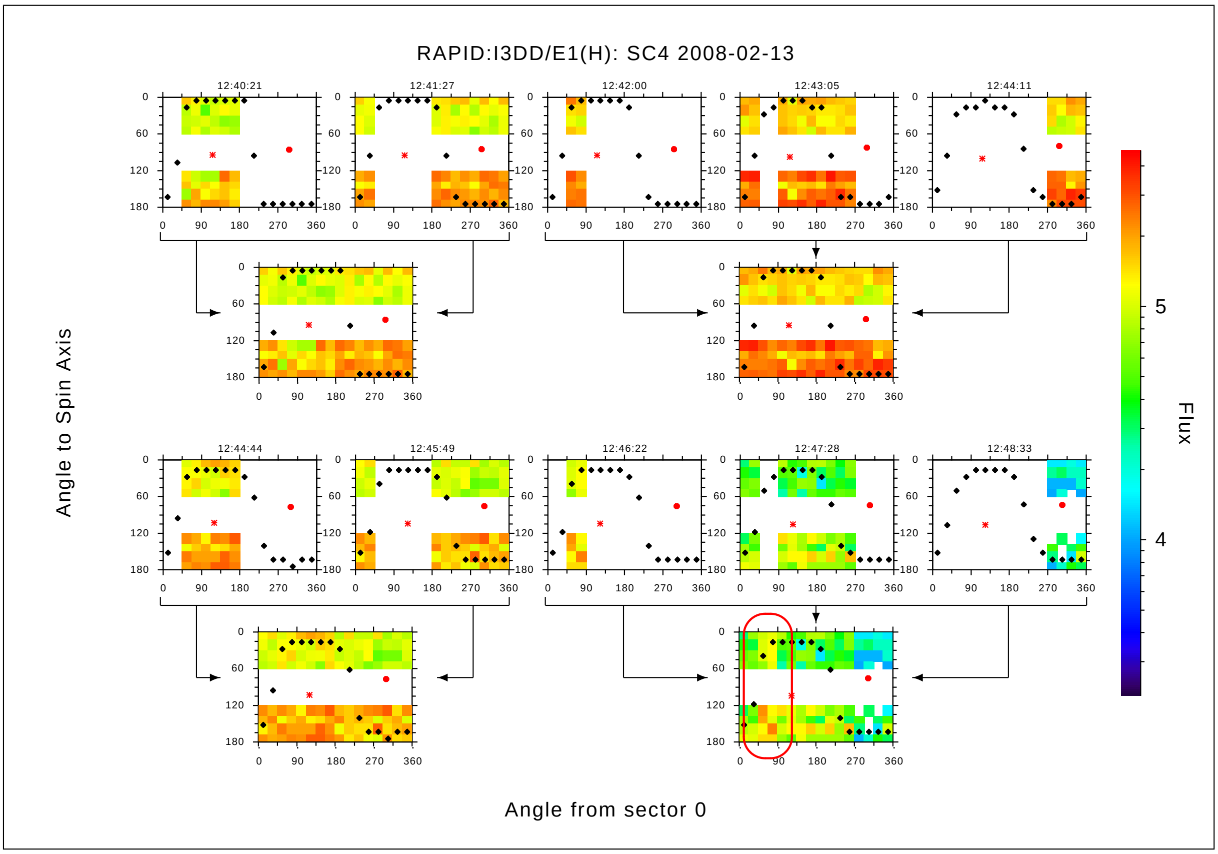

Figure 8: Example of the 3-D ion timing problem. Rows 1 and 3 show the partial distributions as contained in the "expanded" or `I3D` (flux and count rates) data, while rows 2 and 4 are the merged full distributions provided as the "standard" or `I3DM` distributions (flux only). The red oval at the lower right indicates a spurious anisotropy that is really time-aliasing.

B Direct Events

The "direct events" product (Section 5.2.7) is described briefly on pages 23 and 38, but some further clarification should be made to better understand it.

A direct event can be viewed as a point in the Energy-TOF space of Figure 4: it consists of an energy bin number from 0–255 (covering 0–1500 keV, linearly) and a time-of-flight bin number, also 0–255 (covering 0–80 ns, linearly). These can be translated with on-board algorithms into a species (1–5) and energy channel (1–8) and the result used to increment the appropriate counters.

The raw direct event data consists of a limited number of such pairs for each spin: 20 in NM and 106 in BM. The sector and polar direction are also given for each event. *This is the most detailed information available on the individual events.*

The polar direction number has the following values:

- 0–11: for the full polar (elevation) determination, as in the left-hand part of Figure 3;
- 12–14: for heads 1, 2, 3, if the sub-division within the head could not be unambiguously determined;
- 15: if no polar information available.

A value of 15 only occurs when there is no energy signal (E=0), in the underrange area of Figure 4. This is because the energy signal itself determines which head receives the incoming particle. Underrange events are classified solely by the time-of-flight data plus the fact that they are below 30 keV.

The CSA direct event product DE also provides the decoded species and channel numbers, using the same on-board algorithm. Each record gives the values for a single event, plus an event counter for that spin. All events from one spin have the same time stamp, the middle time of that spin. (The events of course actually have their own event time, but this information has been lost.)

There is a priority scheme for selecting which events are output in each spin:

1. Starting in one particular sector, the first 5 Si/Fe events are taken,
2. followed by the first 4 CNO events,
3. followed by the first 3 He events,
4. followed by the first 2 proton or electron events.
5. If there are still events in this sector, the procedure is repeated, or
6. it moves on to the next sector and restarts the procedure.
7. For the next spin, the starting sector is incremented.

Thus the rare heavy ion events have highest priority; the protons the lowest. It takes 16 spins to get coverage over all directions, when there are high count rates.

Note: this priority scheme was introduced with the patch uploads in May 2001; prior to that, the events were selected in the order in which they came, meaning that protons dominate.

C On-board Data Compression

All the counters used on RAPID have 23 bits internally; but for downloading, these numbers must be reduced to a single byte, 8 bits. This is done by a logarithmic compression algorithm, which has the effect that higher numbers lose precision. This is not a serious problem since such large numbers have a high variance anyway.

The result is that the downloaded counts have at most 5-bit accuracy, or a maximum precision of about 3%.

The algorithm works as follows:

Count < 32 The output is the same as the count.

$32 \leqslant$ **Count** $< 2^{15}$ Take the 5 most significant bits, drop the leading `1` to form a 4-bit mantissa. For the (4-bit) exponent, take the position of that leading `1` and subtract 4. The output is exponent $\times$ 16 + mantissa. The other bits to the right are then lost.
Example: to encode 179:

$$\texttt{0 0 ... 0 1}\ \overbrace{\texttt{0 1 1 0}}^{\text{mantissa=6}}\ \underbrace{\texttt{0 1 1}}_{\text{ignored}}$$

exponent = 4 (position 8 – 4)

Result is `46` (hex), which is also the result for all numbers 176–183.
The maximum in this range is `BF` which covers 31 744–32 767 ($= 2^{15} - 1$).

$2^{15} \leqslant$ **Count** $< 2^{23}$ Take the 4 most significant bits, drop the leading `1` to form a 3-bit mantissa. For the (5-bit) exponent, take the position of that leading `1` and add 8. The output is exponent $\times$ 8 + mantissa. Again the other bits to the right are lost.
Example: to encode 900 000 = `DBBA0` (hex):

$$\texttt{0 0 ... 0 1}\ \overbrace{\texttt{1 0 1}}^{\text{mantissa=5}}\ \underbrace{\texttt{1 0 1 1 \ 1 0 1 1 \ 1 0 1 0 \ 0 0 0 0}}_{\text{ignored}}$$

exponent = 28 (position 20 + 8)

Result is $8 * 28 + 5 =$ `E5` (hex), which is the result for all numbers 851 968–917 504.
Note `E5` is the combination of the 5 bits for 28 (`1 1 1 0 0`) and the 3 bits for 5 (`1 0 1`).
The first value in this range is `C0` which covers 32 768–36 863.
The highest value possible is `FF` covering 7 864 320–8 388 607 ($= 2^{23} - 1$).

A complete table of decompressed values is given in Appendix 5 of the Instrument Users Guide [Ref. 14].

For the data processing, we always take the middle value of the given range. So for the example above, `46` is decoded to 179.5 counts, since it applies to the range 176–183.

D The RAPID CAA/CSA Software

The software to generate the RAPID CSA products in CEF format is maintained by the RAPID Team. It is uploaded and installed on one of the CAA computers and run remotely by the RAPID Team.

Here an outline is given of how this software functions.

D.1 RAPID production support files

The RAPID production support files include those files, which are necessarily used for the correct calibration of data streams and which provide important additional information, i.e., parameter files, caveat files, calibration files, and CEF template files.

D.1.1 Parameter file

The SCI production software begins by reading the parameter file `pdb_parameter.dat` to set various parameters for the processing. Among these are the names of the calibration files themselves. The names of the caveat files are also included in the parameter file. The parameter file can also contain time markers of the form `yyyymmdd`, indicating that all the parameters that follow are effective as of that date. Thus certain parameters can be made time dependent in this way. It should also be mentioned that the parameter file has an expiry date to assure that no data are processed outside the validity range of these parameters.

D.1.2 Calibration files

The RAPID calibration files contain necessary information for the conversion of raw data to physical parameters, e.g. geometry factors of the instruments, high voltage settings, accumulation times for count rates and other timing relevant data, etc. Calibration files are time dependent and thus need a regular update.

D.1.3 Caveat files

The caveat files pointed to by the parameter file contain texts that are written to the SCI files. They indicate background problems to explain why the processed data may be missing. Some caveats are generated automatically during processing, whereas those in the caveat files are always inserted, provided the date is correct. For CSA, caveats are extracted from the SCI files to generate separate caveat CEF files.

D.1.4 Configuration File

The program `sci2caa` that repackages the SCI files into CEF files is controlled by a configuration file `sci2caa.cfg`. This contains all the instructions for each output CEF file: which SCI file is needed, the time limits of its validity, the values of various logical variables, and most importantly, which template files are to used. It is the master plan behind the repackaging procedures.

D.1.5 CEF template files

CEF template files are generic CEF files, containing the complete text, with logical variables in place of the parts that are to be replaced when the true CEF file is created. These are dates, names, spacecraft number, and of course, the actual data, and how it is to be selected and possibly reordered from that in the SCI file itself.

The template files are all generated from a single master template; in this way, entries common to all templates exist only once, and variable entries are kept together to simplify comparison and editing.

D.1.6 CEF header files

Header files exist containing the non-varying metadata for each product. Each CEF data file contains a pointer to the corresponding header file, indicating that its contents are to be included at that point when it is downloaded from CSA by a user. The header files are not part of the generated CEF data files; their contents may be changed without having to regenerate the entire database.

The header files themselves are also generated from template files, which in turn originate from the master template.

D.1.7 FGM cef files

For generating the pitch angle distributions, the magnetic field dataset from FGM is required. (An alternative would be to use the on-board IEL data from FGM, which RAPID has in its own raw dataset, but this is not as accurate or reliable as the calibrated FGM set.) The 5-vectors-per-second data are used for this purpose, which are obtained directly at CAA via special scripts.

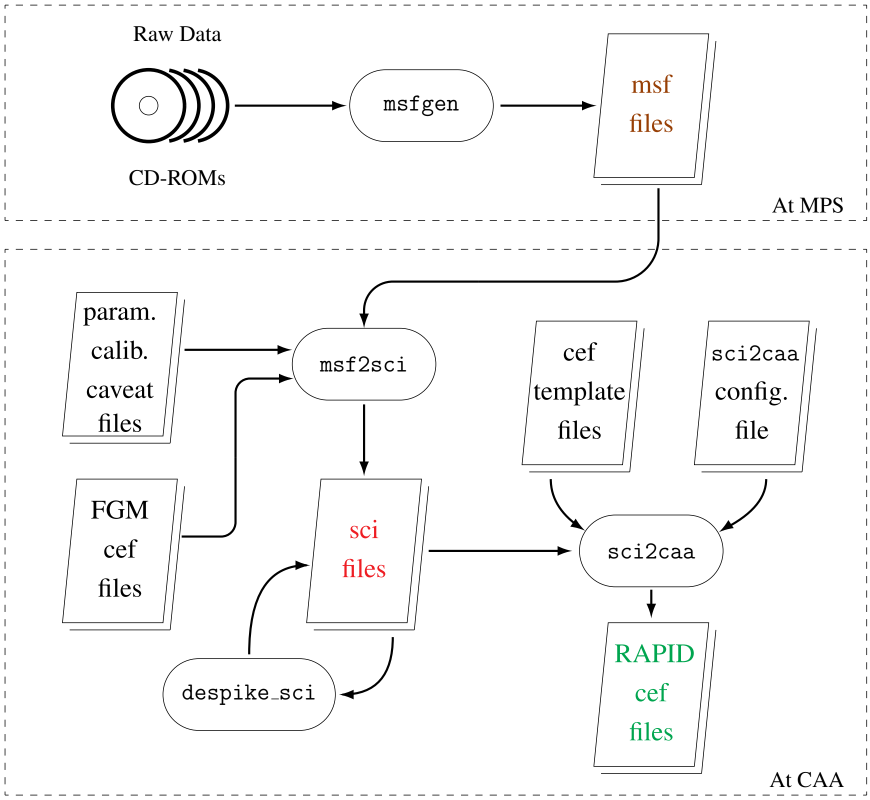

Figure 9: Flow diagram for the production of RAPID datasets for CAA/CSA

D.2 Running the software

Figure 9 shows the production flow sequence, from raw data on CD-ROMs (which since 2006 are no longer physical CDs, but online only) through to the final CEF files.

The programs involved here are:

`msfgen` to repackage the raw data from the different data streams (NM, BM, housekeeping) into *merged science files* (MSFs) for convenience in further processing;

`msf2sci` to generate SCI files with physical, scientific parameters converted from the raw data with calibration files and other support data; this is the heart of the data processing;

`despike_sci` to post-process and rewrite the SCI files with noisy records removed; these often arise at times when there is a mode change, turn-on, or other data gaps;

`sci2caa` to repackage the contents of the SCI files into CEF format according to the outlines in the template files, and following instructions contained in the configuration file; this specifies for example which SCI files are needed for each data product, plus many other details; no additional data processing is done at this stage.

There are two perl scripts that are used to simplify the whole pipeline processing at CAA.

`gen_rap_caa` *day1 day2*

This cycles through all the days within the given range, running the second script for each day, passing any further options on to it.

`gen_caa_one_day` *day*

This invokes `sci2caa` for the specified day, and also maintains protocol files, lists the files successfully created, and registers any error messages.

If no further options are given, all products for all spacecraft are produced. However, one can also specify a spacecraft mask and only certain products to a more limited output.

It is thus very easy to start a long data production run, say for several months, with a single command. Once the run is completed (some days later) the protocols and error files can be inspected to ensure that all went well, or to take corrective measures if there were any problems.