

14. SWAP INSTRUMENT DESCRIPTION

14.1 Overview

Solar Wind Around Pluto (SWAP) instrument is designed to measure the properties of solar wind ions for the New Horizons mission to Pluto. The bulk (thermal) solar wind ion distribution is typically Maxwellian. For most of the long journey to Pluto we expect to encounter bulk solar wind cold ion distributions that are nearly Maxwellian since the density and temperature of the solar wind decrease with increasing distance from the Sun. One notable exception is when the New Horizons spacecraft encountered Jupiter's magnetosheath. Ion distributions are known to be hot in sheath regions. Since there have been no prior in situ measurements near Pluto, we do not know if it has a well developed sheath region.

The SWAP instrument is an electrostatic instrument. The SWAP electro-optics control the energy passband of ions entering the instrument. The electro-optics has three parts: the Retarding Potential Analyzer (RPA), the Electrostatic Analyzer (ESA), and the deflector (DFL). shows a cross section of the instrument. The RPA consists of four grids with the inner two having a positive voltage, which repels ions with energies less than the corresponding potential energy (qV) (top right and left of Figure 14-1). The Electrostatic Analyzer has two parts, which are concentrically spaced, an inner dome and an outer spherical shell at ground (Figure 14-1). Only ions with a limited range of energies pass through the ESA to reach the detector.

The SWAP instrument is mounted on the $-Z_{sc}$ side of the spacecraft and the normal to the center of the aperture is aligned with $+Y_{sc}$ (Figure 14-2). Figure 14-3 shows the instrument being mounted to the spacecraft.

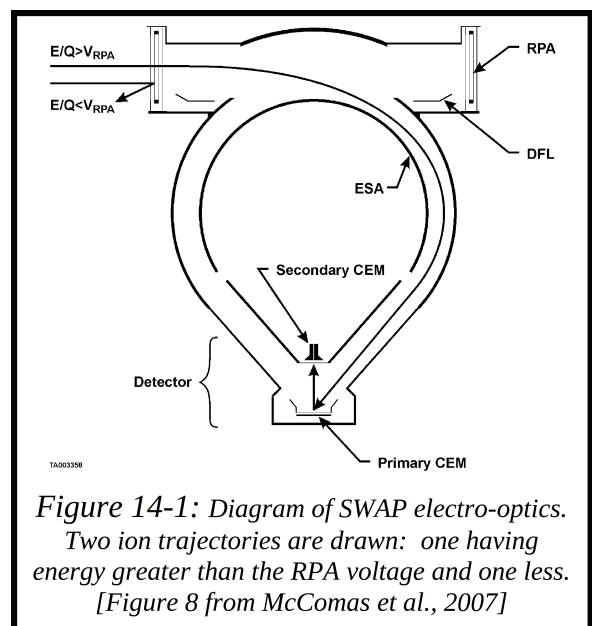


Figure 14-1: Diagram of SWAP electro-optics. Two ion trajectories are drawn: one having energy greater than the RPA voltage and one less. [Figure 8 from McComas et al., 2007]

The deflector is used to adjust the field-of-view (FOV). That is if the solar wind, which is highly collimated (spanning only a few degrees), enters at the bottom of the RPA, the voltage on the deflector could be set so that only ions that are not part of the solar wind beam enter the instrument. This would allow pickup ions, which occur over a wide range of angles, to be studied. In the inner heliosphere the

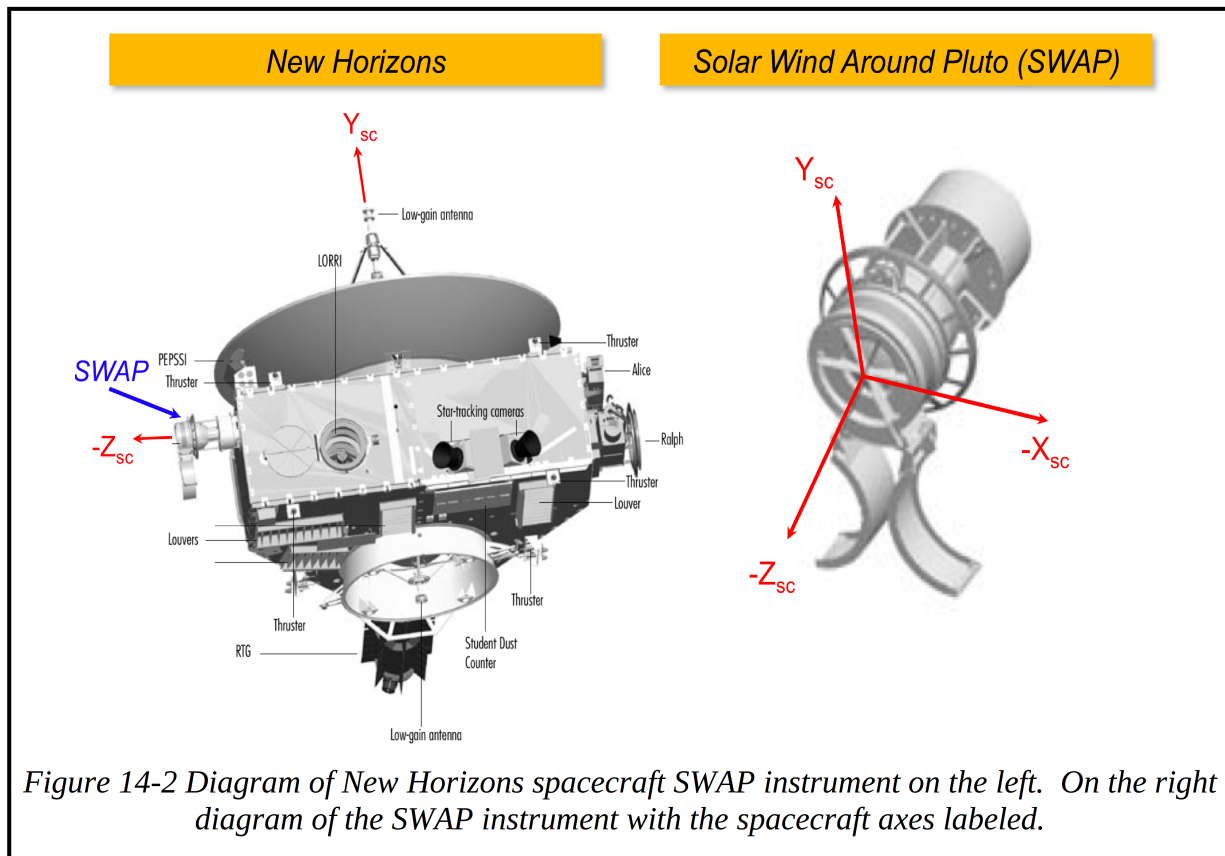


Figure 14-2 Diagram of New Horizons spacecraft SWAP instrument on the left. On the right diagram of the SWAP instrument with the spacecraft axes labeled.

pickup ions have substantially lower fluxes than the solar wind. The SWAP deflector can be used to bring the solar wind into the field of view if the solar wind beam is slightly above the top of the nominal field of view. Operating the deflector affects the energy of the ions that can enter the ESA. The RPA voltage is adjusted to compensate such that the same energy ions enter the ESA as did prior to the deflector voltage change. The deflector voltage can be automatically varied based on the commanded angle. The voltage settings for the ESA, RPA, deflector, and the amount the RPA should be adjusted to compensate for the deflector setting are all specified using lookup tables, which allow many instrument operation changes to be made by uploading new tables without having to make any software changes. Additional information on the electro-optical design is given in the introduction of section 3 and in section 3.1 in the *McComas et al.* [2007] instrument paper. The Channel Electron Multiplier (CEM) detector design is also described in section 3.1.

The SWAP instrument has two kinds of voltage scans (also called sweeps): coarse and fine. The sweeps are performed in pairs. The two possible pair options are either two back-to-back coarse scans or a coarse scan followed by a fine scan. The voltage settings are predefined with onboard voltage tables. In coarse scans large voltage steps are taken with the ESA and RPA holding the ratio of the two voltages fixed. In the fine scans we also hold the RPA and ESA at constant ratio, but take smaller steps. Our voltage tables

allow us to vary the ratio between the RPA and ESA voltages, but typically this ratio is held constant as much as possible. For high ESA voltages we cannot set the RPA to a high enough voltage to keep the RPA and ESA voltage ratio fixed because the highest RPA voltage is 2000 V and the highest ESA voltage is 4000 V. A given step number refers to a pair of RPA and ESA voltages. In the inner heliosphere we set the RPA to ESA voltage ratio high in order to narrow the passband slightly by removing ions at the low energies. All fine scans are approximately centered about the step number where the peak counts are observed in the coarse scan. To determine plasma properties from the detected count rates as a function of step number, the following calibration information is necessary: the ESA and RPA response functions, angular response function, the instrument solid angle, the detector gain, and the effective area.

Onboard there is one ESA table with 1024 steps and 4 RPA tables with 1024 steps each. For a given sweep we use the ESA table and one of the RPA tables. The different RPA tables can be used for coarse and fine scans, but for Jupiter operations we used the same RPA table for both the coarse and fine scans. In a scan/sweep the same step number is used in the software to reference rows in the ESA table and the chosen RPA table. The coarse scans use every 16th step in the 1024 voltage step lookup table where a step refers to a RPA and ESA voltage pairing. A fine scan consists of 64 steps with the coarse step at which the peak counts were detected in the middle of the fine scan.

14.2 Electronics and Flight Software

The instrument electronics are described in section 3.4 of the *McComas et al.* [2007] instrument paper. In subsequent sections of this document some information related to the flight software is provided, but further details are provided in sections 3.6 of the instrument paper.

14.3 SWAP Data Types

There are six types of SWAP science and engineering data: real-time science (0x584), summary (0x585), histogram (0x586), housekeeping, messages, and memory dump. Housekeeping, messages, and memory dump provide engineering data and the other three modes contain science data. Real-time data provide the most detailed science measurements since they contain the full count rate distribution as a function of energy (speed). For science summary and science histogram modes, the full distribution is not recorded. Instead, parameters are derived from the count rate distribution stored by SWAP. These derived parameters require less memory than storing the whole distribution. The science summary and science histogram modes are primarily used during the cruise phase of the mission.

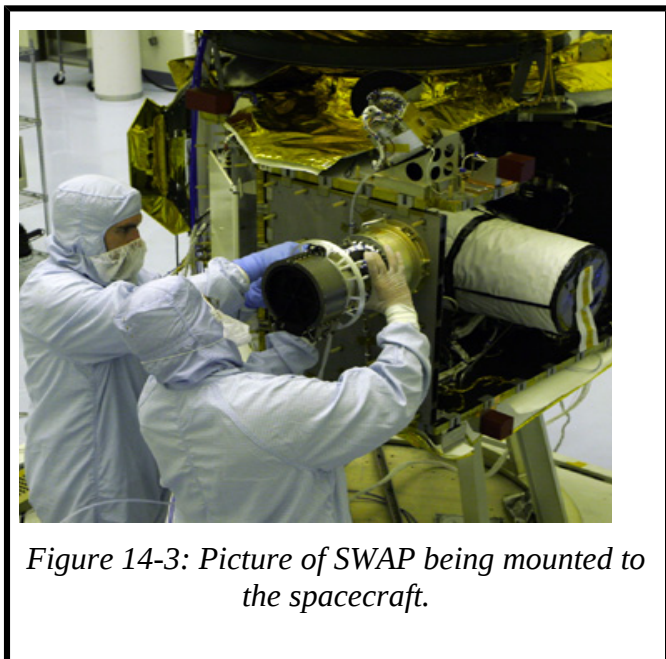


Figure 14-3: Picture of SWAP being mounted to the spacecraft.

The real-time science data contain the full count rate energy distribution for the primary, secondary and coincidence rates. The full distribution is desired because in bow shock and sheath regions plasma

distributions may not be Maxwellian. The shape of the distribution will provide valuable information about what physical processes are occurring. In real-time mode the instrument can take measurements at a rate of 1 Hz, which is crucial for studying plasma boundaries and shocks.

Summary data consist of parameters related to the average speed, temperature, and density. The summary data are designed to study the bulk solar wind. The peak of the count distribution is related to the density, the bin location of the peak is related to the speed, and the distribution width is related to the temperature and speed combined. Along with the average values, the variance, maximum and minimum values of the peak counts, width of the peak, and energy of the peak are also recorded.

The histogram data are designed to study pickup ions. The pickup ion distribution has a characteristic shape once it is normalized by the average solar wind energy (or speed). The histogram data conserve storage space by adding up all the counts detected in given bins. The accumulation time for the histogram is variable. The bins for the histograms are not energy bins, but are bins relative the average solar wind energy (E_{sw}). The steps for the fine scan are roughly centered on the coarse scan step where the peak counts were observed allowing the energy of the solar wind to be more precisely determined in the fine scan. The energy found in the fine scan is then used to place the counts determined in the coarse ESA scan into a new large 1-D histogram array. The coarse scan count rate data array is placed into the larger histogram array such that the bin with the maximum counts in the fine scan is placed into histogram bin 1024. There are 1024 possible voltages in a given onboard voltage table. To understand the histogram data further information about the scans is necessary. Onboard there is one ESA table with 1024 steps and 4 RPA tables with 1024 steps each. For a given sweep we use the ESA table and one of the RPA tables. The different RPA tables can be used for coarse and fine scans, but for Jupiter operations we used the same RPA table for both the coarse and fine scans. In a scan/sweep the same step number is used in the software to reference rows in the ESA table and the chosen RPA table. The coarse scans use every 16th step in the 1024 step table where a step refers to a RPA and ESA voltage pairing. A fine scan consists of 64 steps with the coarse step at which the peak counts were detected in the middle of the fine scan. There are 2048 bins because the peak count rate in a fine scan could occur at any step in the fine scan, and the step in the coarse scan containing the peak counts is always placed in bin 1024.

When another set of coarse-fine scans is performed, the new array of counts is processed in a similar fashion. The new data are placed into bins such that the new peak counts aligned with bin 1024, and then added to the running total number of counts. The amount of data put into each histogram bin is tracked in a separate array. The histogram packets then consist of two 1-D vectors: one for counts in the bins and one for the number of samples placed into each bin (Example shown in **Figure 14-4**).

The histogram data consist of a series of 64 packets to facilitate data transmission. There are two types of histogram packets. For each histogram type 1 packet, there should be 63 histogram type 2 packets. One type 1 and 63 type 2 histogram packets are combined when placed into the Level 2 (raw) files. The histogram type 1 packets contain information about the data collection such as the start and end time of the data collection interval and the plan and sweep numbers. Type 1 contains a small portion of the

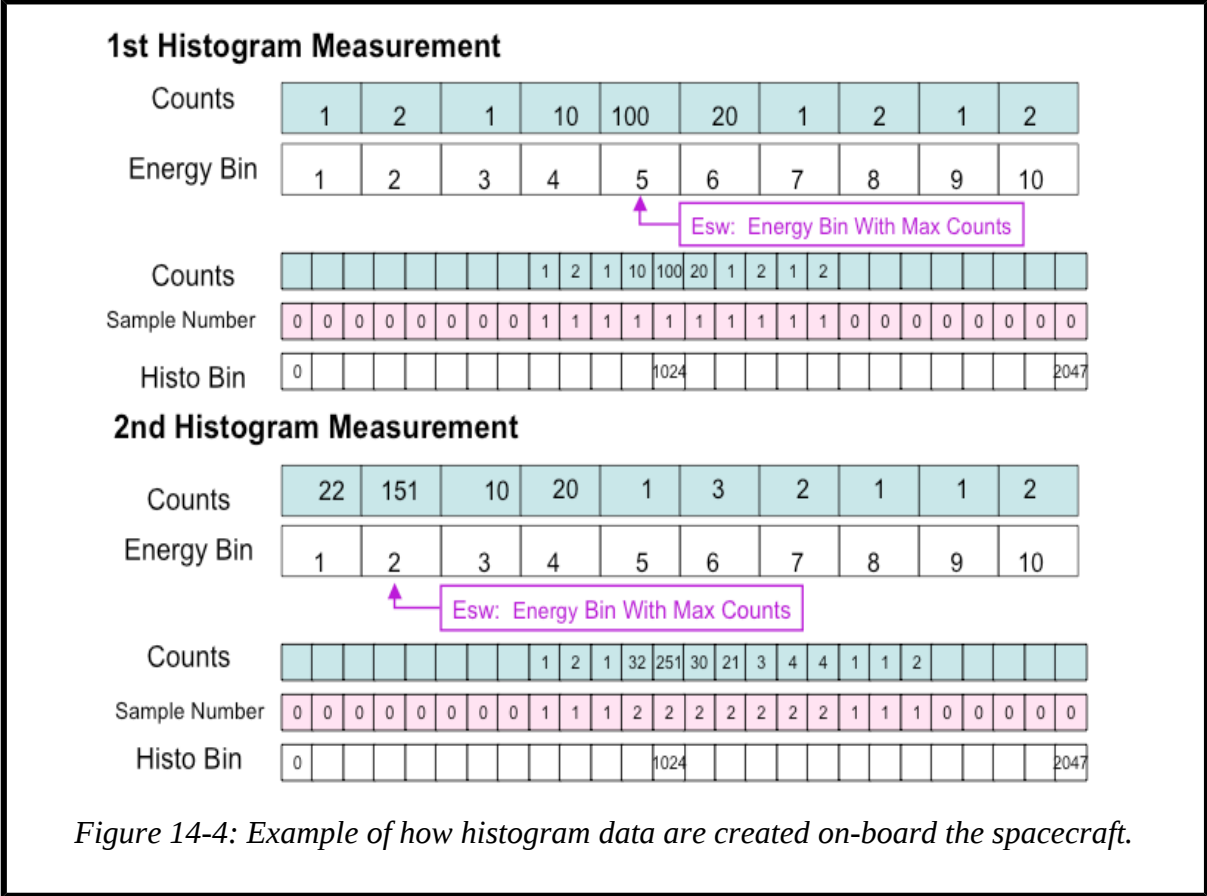


Figure 14-4: Example of how histogram data are created on-board the spacecraft.

histogram data, but most of the histogram data is contained in the Type 2 packets, which hold a larger amount of data since they do not contain information about the data collection.

14.4 Raw File (Level 2) Specifics

14.4.1 Data Format

There are separate files for summary, histogram, and real-time data, and corresponding housekeeping data are placed in each file. Note that not all kinds of packets will be generated every day. For example, during commissioning there may only be housekeeping and memory dump packets, and during cruise there will be housekeeping, summary, and histogram packets. All the packet types have a CHKSUM parameter. This parameter is calculated onboard and is also calculated on the ground to check the data. For the real-time science data (0x584) there are black and white images of the coincidence spectrogram array where the y-axis is energy bin number and the x-axis is time bin number.

Housekeeping packets are included as extensions in the raw (level 2) files. Housekeeping time tags are compared to the time tags in the three types of science packets to insure that each of the three raw (level 2) files includes all the housekeeping data required for processing. Since the summary and histogram packets are assembled over an extended interval, the beginning and ending times of the measurements (included in the summary and histogram packets) are used to determine the correct housekeeping measurements.

Real-time science packets can occur at a rate as high as 1 Hz where each packet contains a set of counts, voltages, etc. Observations for 2 energy steps are stored in one packet. One observation occurs in the 1st half second and a 2nd observation occurs in the 2nd half second. The 1st and 2nd half second measurements correspond to two different steps in a given sweep. Each step consists of an RPA and ESA voltage pairing, and 64 such pairs complete either a coarse-coarse scan or a coarse-fine scan. In a coarse-coarse scan two 64 step (32 packets) coarse scans are done back to back. In a coarse-fine scan a 64 step (32

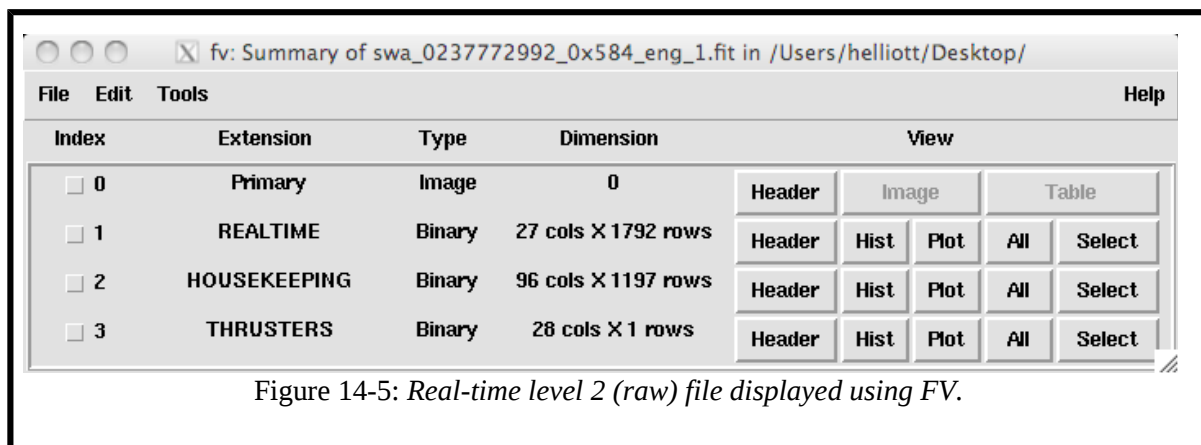


Figure 14-5: Real-time level 2 (raw) file displayed using FV.

packets) coarse scan and then a 64 step (32 packets) fine is performed. Both a complete coarse-coarse, and a coarse-fine scan have 64 packets. There is a parameter called SWAP_RT.sec64_ST, which is included in every real-time science packet and has the value 1 at the start of a pair of scans (a set of 64 packets) and is zero otherwise. We use this parameter to insure that a 64 second cycle (pair of scans) is not split across a day.

The SWAP raw (level 2) data are arranged in a binary table such that the columns are instrument parameters and measurements, and rows are measurement times. The FITS format has a binary table that allows for columns and rows. Figure 14-7 is a picture of what the Level 2 raw real-time files look like using FITS Viewer (FV). As mentioned earlier the housekeeping data are also in a table extension. The histogram counts and the number of samples in each bin are stored as image extensions. The zeroth extension contains only the primary header, the first extension holds the real-time data, the second extension holds the housekeeping data, and the third extension holds the thruster data.

SWAP data are in CCSDS (Consultative Committee for Space Data Systems) packets packetized by the spacecraft from the low-speed bus. Note that on the New Horizons mission, every instrument also outputs a non-packetized portion of telemetry to the S/C. This portion is also called the “instrument state” and this data is incorporated into the general spacecraft housekeeping data and not into the SWAP packets. All the bits in the SWAP packets were defined for the MOC at APL in EXCEL spreadsheets in the form

required by the mission. The New Horizons SOC used the same bit level format description (APL EXCEL spreadsheets) for all the parameters in our packets to decode our raw (level 2) data.

14.4.2 Definition of an “Observation”

A complete histogram observation consists of one histogram type 1 packet and 63 histogram type 2 packets. A complete set of real-time science measurements consists of a full 64-second cycle. This is described in detail in section 14.4.1. One summary packet constitutes a complete measurement. Housekeeping data are required for all science measurements since the housekeeping data are key to interpreting the data and determining error flags.

14.4.3 Housekeeping Needed in Level 2 (Raw) Files (for Calibration)

Unlike some of the other instruments all housekeeping data for SWAP are included into the level 2 (raw) files as an extension.

14.4.4 Raw Science Data and/or Housekeeping Requirements

In addition to the complete housekeeping packets, raw summary, real-time, histogram, and thruster fire packets are included into our raw (level 2) files. The thruster data format for the raw files was reformatted to reduce space (Joe Peterson). In the calibrated (level 3) data the thruster data has been arranged by thruster name and time. The numbers in the table indicate the duration of the thruster firings.

14.5 Calibrated (Level 3) File Specifics

14.5.1 Data Format

The SWAP calibrated (level 3) pipeline requires the following input information, SWAP level 2 (raw) files which include all the housekeeping data, SWAP calibration information and engineering factors, orbit and attitude information, and spacecraft information such as thruster firings. In Figure 14-6 we show a general schematic for our level 3 (calibrated) real-time data files. The main input to the calibration pipeline are the SPICE kernels, and the raw level 2 files, which include the real-time data, thruster firings, a few minor calculations performed using SPICE in the header and the housekeeping data.

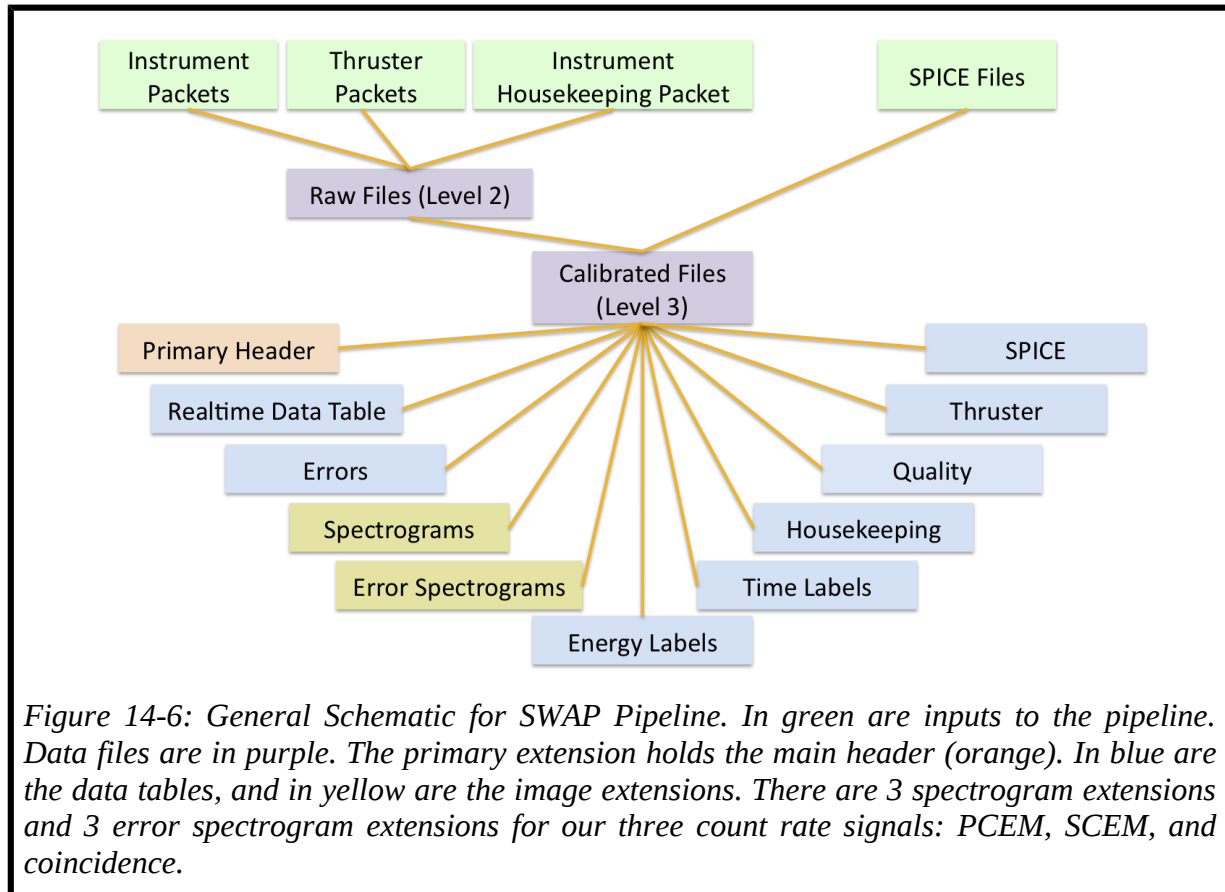


Figure 14-6: General Schematic for SWAP Pipeline. In green are inputs to the pipeline. Data files are in purple. The primary extension holds the main header (orange). In blue are the data tables, and in yellow are the image extensions. There are 3 spectrogram extensions and 3 error spectrogram extensions for our three count rate signals: PCEM, SCEM, and coincidence.

The SWAP level 3 (calibrated) analysis software has four parts corresponding to the different data (packet) types. There are simple algorithms for converting the raw data to engineering units. For example in the raw data the RPA voltage is stored as a step number for the Digital to Analog Converter (DAC), and not the actual voltage. We first make all such engineering conversions. Most information in our calibrated (level 3) files is stored in table format (blue blocks in diagram). The tables contain all the data (science and housekeeping) converted to engineering units, and counts are converted to count rate (Hz). There are extensions for housekeeping data, thruster firing data, and quality flags. In the real-time data there are additional image extensions for spectrograms derived from high voltage science real-time measurements. There are three count rate 2-D arrays for the Secondary Channel Electron Multiplier (SCEM), Primary Channel Electron Multiplier (PCEM), and coincidence (COIN) signals stored as images, and three corresponding count rate error image extensions. These errors will be based on counting statistics. In addition to the 2-D arrays, axis information is also necessary for the spectrograms. The axis information for the spectrograms are contained in two tables one with the energy per charge (E/q) and one with the time tags for each sweep. In Figure 14-7 we show a picture of what the real-time files look like when opened using the FITS viewer FV.

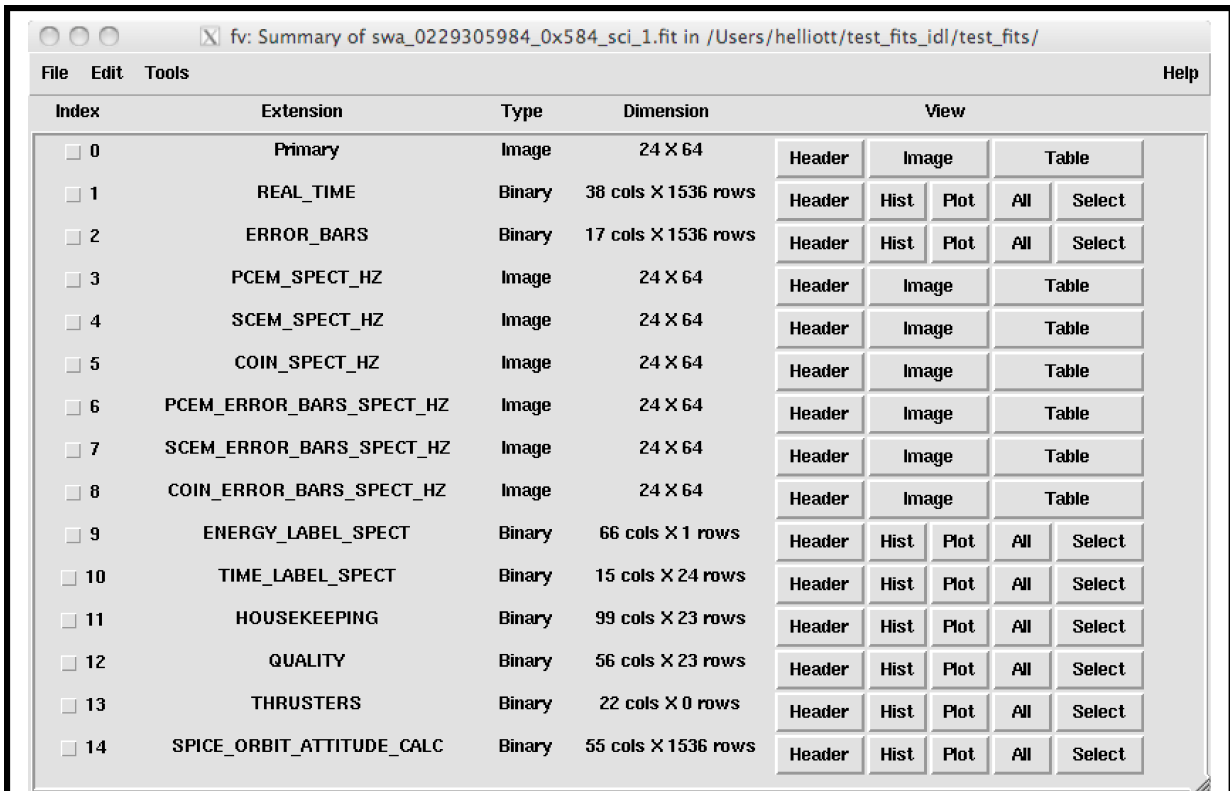


Figure 14-7: Picture of what the real-time calibrated (level 3) files look like using Fv. The numbers listed under index are the extension numbers. All tables are Binary type and all images are image type.

14.5.2 Further Algorithm details for Pipeline

In this section we describe the algorithm for SWAP level 3 (calibrated) processing. As mentioned above, the first step in our processing is to convert all raw values over to engineering units. These conversion factors are also stored in the command and telemetry spreadsheets used in the APL GSEOS system. The details of the housekeeping processing are not discussed further since processing of the housekeeping data consists of simple conversion factors. Analysis of ground calibration data provides critical information used to process the SWAP data, and is consequently a crucial input to our software. A description of the type of calibration information used in the pipeline is given in the calibration document.

14.5.3 Real-time science data processing

The identifier in the SOC filenames for real-time data is the packet ApID (Application Process Identifier; also Application ID) 0x584. Our real-time high voltage science (HVSCI) analysis begins by determining the count rates in Hz as a function of energy for each measurement. A spectrogram is created by sorting the data into sweeps to build a 2-D array where the y-axis is energy per charge and the x-axis is time. A spectrogram spans the time range in HVSCI mode in a given daily level 2 (raw) file. Spectrograms are

created for each of the 3 count signals (PCEM, SCEM, and coincidence). Corresponding count rate error spectrograms are created based on counting statistics for each of the three signals as described in the next paragraph. The x-axis time information is provided in the TIME_LABEL_SPECT extension along with a column indicating if a background has been removed. The background is mentioned in section 14.5.10 and described in detail in the calibration document. Also in the TIME_LABEL_SPECT extension is a column indicating the plan and sweep used since the energy bins are different for different plans and sweeps. The y-axis energy labels for a given sweep and plan number are provided in the ENERGY_LABEL_SPECT extension. These count rate spectrograms provide a way to examine our data at high time resolution over the full energy range of the instrument. These kinds of spectrograms have proven useful for analyzing high time resolution plasma in situ measurements. Having a high time resolution product is critical for identifying plasma boundaries and shocks. In Figure 14-8 we show examples of what coincidence and an error coincidence spectrogram arrays look like when opened in FV.

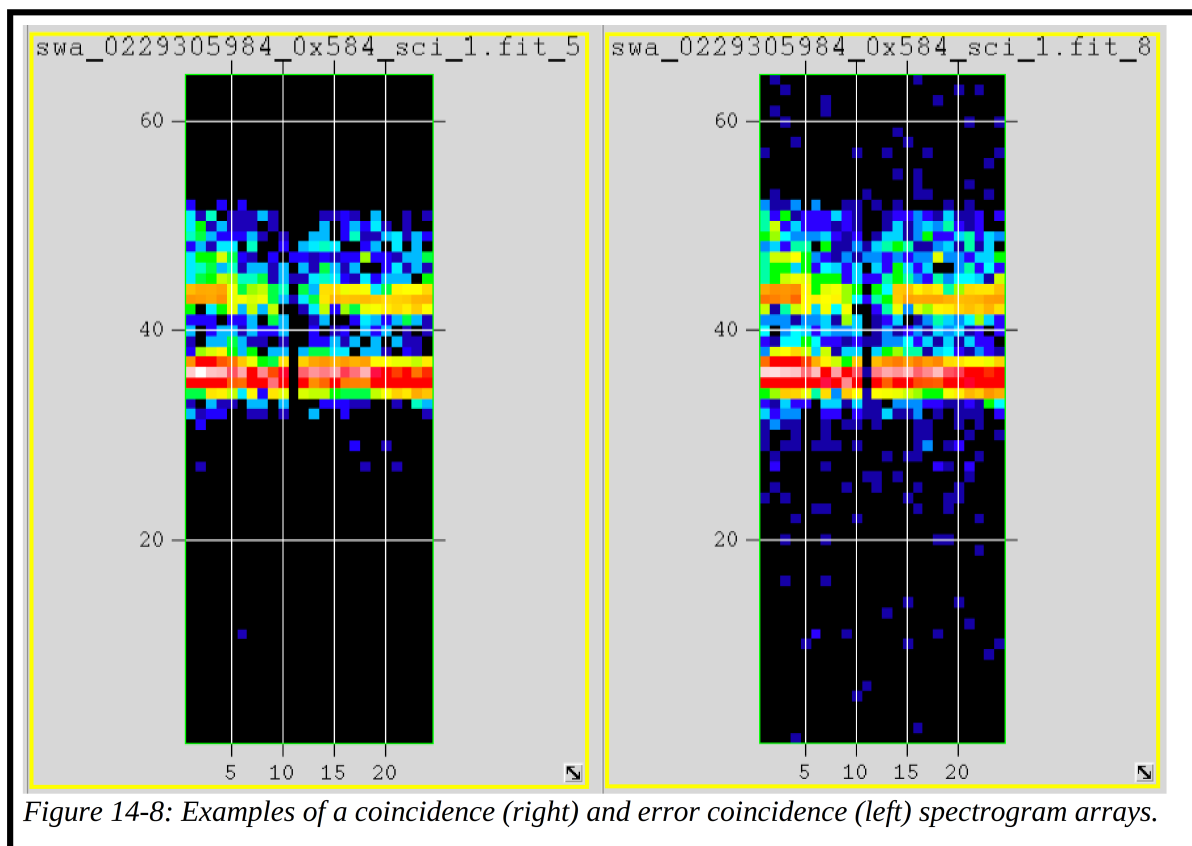


Figure 14-8: Examples of a coincidence (right) and error coincidence (left) spectrogram arrays.

In the level 3 (calibrated) data files an error value for every measurement is given in the extension labeled ERROR_BARS. We also provide spectrogram arrays for each signal type for the errors in the extensions labeled X_ERROR_BARS_SPECT_HZ where X is PCEM, SCEM, or COIN. The errors provided are errors for the rates. The errors and include an error for the sample time, and data compression when compression occurs. The raw rates (count counts per sample (C)) are convert to Hz using the 0.390 sec sample/accumulation time (t) (Equation 1). The error squared is given in Equations 2 and 3, and the fractional error squared is shown Equation 4. Taking the square root the resulting fractional error is given

by equation 5. The final error given in the data files is shown in Equation 6. If the count rates are not compressed (C_{un}) then $C = C_{un}$ and $\Delta C = \sqrt{C_{un}}$. However, if the counts are compressed (C_{comp}) then $C = 16C_{comp} + 7.5$ and $\Delta C = \sqrt{(16C_{comp} + 7.5)}$. In the ERROR table there is a column indicating if a background has been removed. The background is described in mentioned in section 14.5.10 and described in detail in the calibration document.

$$R_c = \frac{C}{t} \quad (\text{Equation 1})$$

$$(\Delta R_c)^2 = \left(\frac{\partial R_c}{\partial t}\right)^2 (\Delta t)^2 + \left(\frac{\partial R_c}{\partial C}\right)^2 (\Delta C)^2 \quad (\text{Equation 2})$$

$$(\Delta R_c)^2 = \frac{C^2}{t^4} (\Delta t)^2 + \left(\frac{1}{t}\right)^2 (\Delta C)^2 \quad (\text{Equation 3})$$

$$\frac{(\Delta R_c)^2}{R_c^2} = \frac{(\Delta t)^2}{t^2} + \frac{(\Delta C)^2}{C^2} \quad (\text{Equation 4})$$

$$\frac{\Delta R_c}{R_c} = \sqrt{\frac{(\Delta t)^2}{t^2} + \frac{(\Delta C)^2}{C^2}} \quad (\text{Equation 5})$$

$$\Delta R_c = \left(\sqrt{\frac{(\Delta t)^2}{t^2} + \frac{(\Delta C)^2}{C^2}} \right) R_c \quad (\text{Equation 6})$$

14.5.5 Quality Flags

Flags assessing the quality of the data are based on operational housekeeping alarms, but in the future additional ones may need to be added which are based on orbit and attitude, and additional calculations. All current flags are stored in a table extension.

14.5.6 Thruster Firings

As mentioned earlier the calibrated (level 3) code reorganizes the thruster data into a table where each column refers to a given thruster name and each row is the start time of the thruster firing. The numbers under each thruster column indicate the duration of the thruster firings. Each thruster column has a title that looks like GC1_A2_FIRING where GC1 indicates it originated in a G&C packet, and FIRE indicates thruster firing. The thruster names are A1, A2, B1, B2, B3, C1, C2, C3, C4, D1, D2, D3, D4, F1, and F2.

The value for each thruster firing corresponds to the duration of the thruster firing (0=0msec,1=5msec,2=20msec,3=40msec). In the raw data each row is a major frame, and the columns are minor frames where each minor frame is 40msecs. Thus, there are 25 columns with numbers between 0 and 24. In the level 3 (calibrated) data we calculate the start time of the firings for a given minor frame which means we have already taken the major frame start time and added in the time to the start of the minor frame where the firing occurred ($\text{Start_time} = \text{major_frame_start_time} + 0.040 * (\text{minor_frame_number} + 1)$). The implication of this is that one row in the raw file may result in several rows in the calibrated file if there are multiple thruster firings.

14.5.7 SPICE Orbit and Attitude Calculations

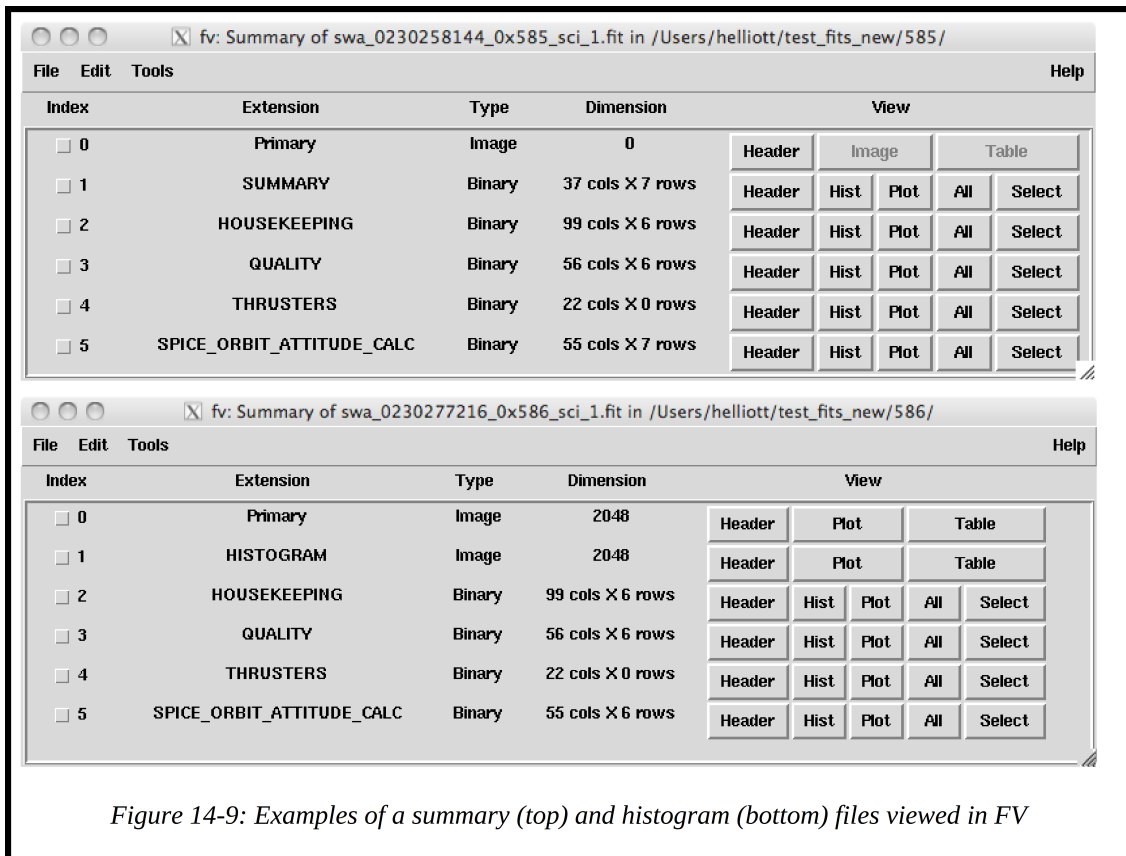
Our orbit and attitude calculations are contained in the SPICE_ORBIT_ATTITUDE_CALC extension. We calculate times for each SWAP measurement in the REAL_TIME extension. The MET for the packet is listed along with the UTC, and ET for the start and stop time of each measurement. There are two start times and two stop times one since each packet stores two measurements one in the first half second (labeled with a 0) and one in the second half second (labeled with a 1). In the tail the spacecraft is spinning so we have included the angle in the Xsc-Zsc plane between the Zsc axis and Jupiter's spin axis (north). This angle is 0 deg (90 deg) when Zsc (Xsc) is aligned with the North end of Jupiter's spin axis. These angles are named ANGLE_JSP_XZ in the files and calculations were done for the start, middle, and stop for each observation, since the spacecraft rotates quickly (5RPM). All other parameters are calculated at the middle of each observation. We also calculated the angle between the Ysc and the Sun, Jupiter, and Earth. The label for the angle between Ysc and the Sun for the 1st measurement is called Y_SUN_ANG0_MIDDLE. The distances from the spacecraft to Earth, Jupiter and the Sun are calculated (i.e., SUN_SC_0_MIDDLE). We calculate the angle to the Sun is in the X-Y plane (phi), and the latitude angle from the X-Y plane (theta). Positive phi values are toward the +Xsc axis and negative phi angles are towards the -Xsc axis. Negative theta values are towards the top of the instrument since the -Zsc axis is at the top of the instrument. Note this is the opposite convention used in the calibration chamber. However, the phi angle is analogous to the roll angle in calibration (see calibration Document). We also calculate the position and velocity of the spacecraft in IAU Jupiter Cartesian coordinates. The naming convention is such that the X component of position in IAU Jupiter for the 1st half second measurement is labeled as SC_IAU_JUP_X_0. Likewise the X component of the velocity is SC_IAU_JUP_VX_0. In addition to IAU Jupiter coordinates we calculate the spacecraft position in J2000 Jupiter coordinates the X component for the 1st measurement is labeled as SC_J2000_JUP_X_0. Column name descriptions are given in the header for the SPICE extension as well as the names of the SPICE kernel files used to perform the calculations.

As of January, 2014, these SWAP instrument attitude calculations are only made for the Jupiter reference frame. There is a task in its final stages to formalize similar calculations for the SWAP instrument attitude in heliocentric, heliographic and inertial reference frames, as well as future plans for a Pluto-based reference frame for Pluto Encounter observations. These products will be added to SWAP PDS data sets with future deliveries. In the meantime, the PDS user should note that a table containing spacecraft mission trajectory and PDS label keywords describing the attitude of the spacecraft, both in the J2000 inertial reference frame, are provided.

14.5.8 Summary and Histogram Files

Both the summary (Figure 14-9 top) and histogram (Figure 14-9 bottom) files also have the primary header, and housekeeping, quality, thruster and SPICE orbit attitude extensions the same as in the real-

time files. In summary files, the Primary Data Unit (PDU; 0th extension) is empty, and extension 1 contains the summary data table converted to engineering units. In histogram files, the histogram data are stored as images in the 0th and 1st extensions. The 0th extension contains the number of times data were added to each bin, and the 1st extension contains the histogram count rates.



14.5.9 Calibration

Analysis of ground calibration data provides critical information used to process the SWAP data, and is consequently a crucial input to our software; therefore, the use of calibration information in the pipeline is described in a section of the calibration document. The SWAP lab calibration consists of an effective area; an angular response function for the ESA (function of α and ϕ); an energy response curve for the RPA that depends on the RPA and deflector voltages; a function representing how the RPA changes the energy of ions prior to enter the ESA; an energy response function for the ESA; the functions for how the width and center of the ESA passband varies with α ; and a function for how the conversion factor for converting ESA voltage to energy depends on ϕ . Our pipeline incorporates ESA and RPA response curves by precalculating the energy passband for each RPA and ESA voltage pair stored in the onboard tables. This information is used as a lookup table in the pipeline code so that each RPA and ESA voltage step can be assigned a energy per charge value. The code determines which set of tables to use by examining the time range since we have had different sets of RPA and ESA tables loaded at different times in the mission. To determine which of the 4 RPA tables to use the code compares the sweep and

plan number in the data to the sweep and plan number in the precalculated tables. The results of the pipeline energy determination are stored in the energy axis label extension and can be used directly to label the y-axis of the spectrogram.

14.5.10 Background Subtraction

There is a background signal (count rate) in our data when the RPA is on. This background decreases as the distance from the Sun increases and will most likely not be a problem for the Pluto encounter. We can

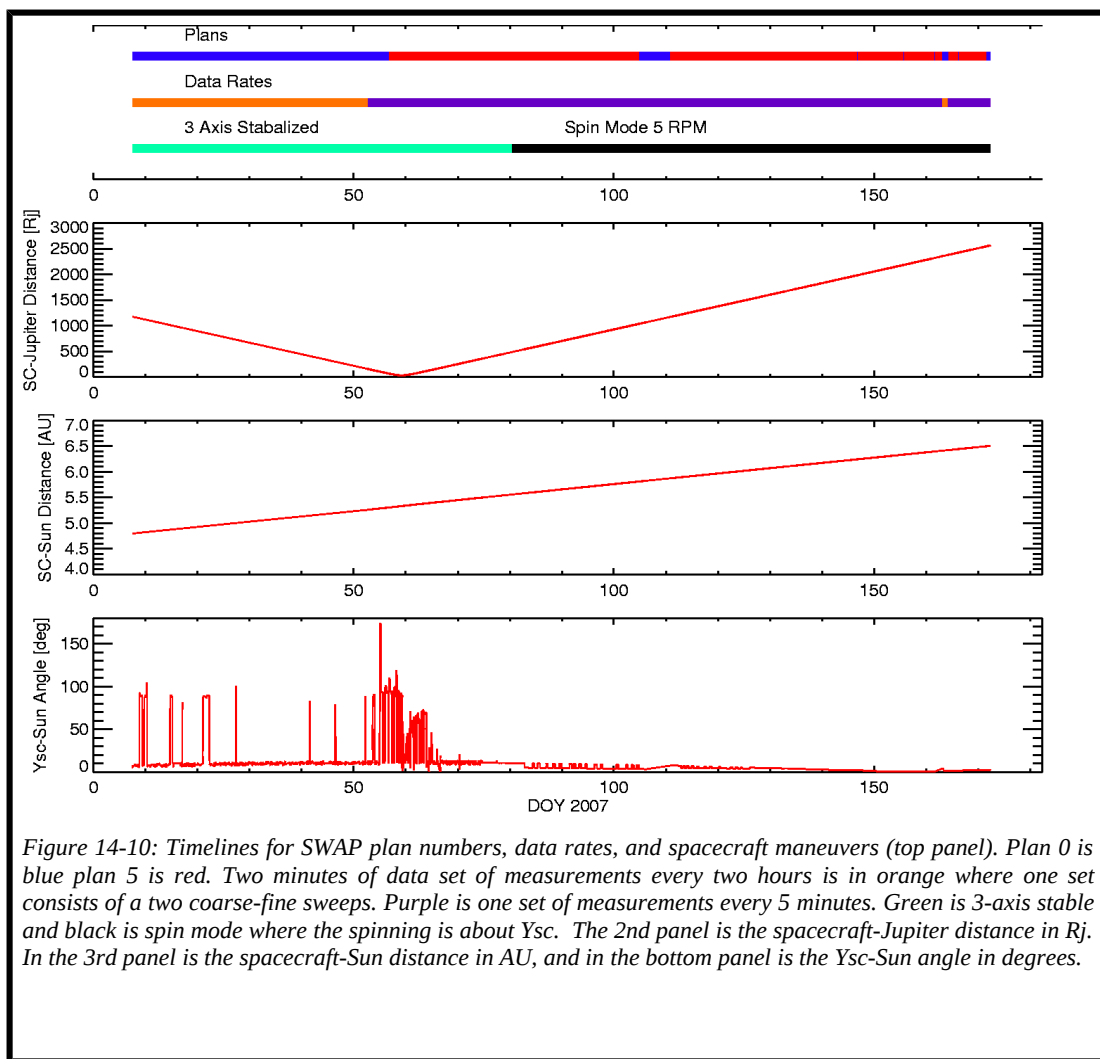


Figure 14-10: Timelines for SWAP plan numbers, data rates, and spacecraft maneuvers (top panel). Plan 0 is blue plan 5 is red. Two minutes of data set of measurements every two hours is in orange where one set consists of a two coarse-fine sweeps. Purple is one set of measurements every 5 minutes. Green is 3-axis stable and black is spin mode where the spinning is about Ysc. The 2nd panel is the spacecraft-Jupiter distance in Rj. In the 3rd panel is the spacecraft-Sun distance in AU, and in the bottom panel is the Ysc-Sun angle in degrees.

operate using only the ESA and have done so for the Jupiter encounter (plan 5). For the solar wind measurements inbound we needed to use the RPA (plan 0) to shield the instrument from high solar wind fluxes. Background subtraction information is processed in a way similar to the energy bin information. A given background subtraction, provided in a calibration file, is only valid for a given time range; therefore, a list of background files with valid application times for each are read in and used to select and read the applicable background, and then the background is subtracted. The background files are stored in the calibration directory and the names of the files used are stored in the list file. The instrument detector

gain will evolve with time and this information will be incorporated in fashion similar to the background subtraction. Gain calibrations occur during annual checkouts. The background subtraction is described in more detail in the calibration document.

14.6 Operations

14.6.1 Commissioning

Plan 3 was used to take the first complete sweeps of the solar wind in sequence SWAP-009-6 during commissioning.

14.6.2 Jupiter

The voltage tables were updated before the Jupiter mission phase to improve the voltage sweeps for the Jupiter encounter. There were only two plans used in the Jupiter phase: plan 0 and plan 5. Plan 0 is designed for solar wind and plan 5 is designed for magnetosphere. The voltage settings in plan 0 protect the instrument from high solar wind proton fluxes. Early on the data rate was two coarse-fine scans taken approximatedly every two hours; the exact timing was adjusted so as not to interfere with other instruments. At 2/21/2007 17:27:31 we kept the plan number set at 0 and changed the sampling rate to 1 coarse and 1 fine scan every 5 minutes. Then at 02/25/2007 19:22:43 we switched to plan 5, which consists of two coarse scans in 64 seconds every 5 minutes. In plan 5 the RPA is off and only the ESA voltage is swept. If the instrument encountered high proton fluxes in the solar wind with the RPA off, the energy passband is large enough that high count rates could cause the instrument to shut down via autonomy rules. Therefore, we took some plan 0 measurement in the magnetosphere to ensure that some measurements would be obtained even if the spacecraft did encounter solar wind. We show timelines for operations in Figure 14-10 along with the distance to Jupiter and the Sun. And in the bottom panel we show the angle between Ysc and the Sun. In spin mode the spacecraft spins about Ysc. The spacecraft entered the magnetosphere on day 056(02/25) in 2007 and the first time it exited in the tail was approximately on day 132 (05/12) of 2007. There were many tail crossing and there appears to be a boundary layer inside the sheath; therefore, definitive boundary crossing times are difficult to determine. When SWAP turned off on day168 (06/17) of 2007 for hibernation, New Horizons was once again in the magnetosphere.

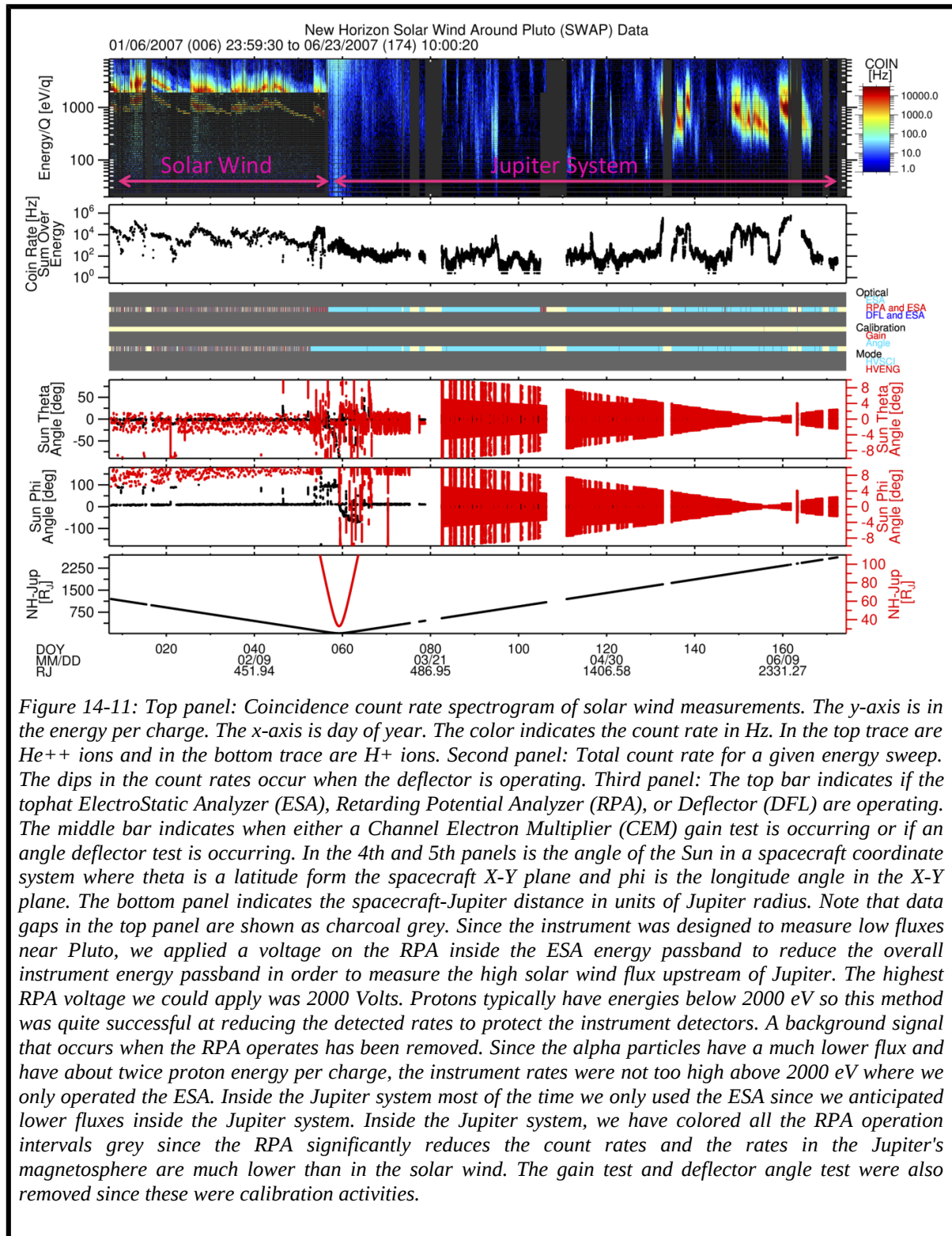
14.6.3 Pluto Cruise

Per the original mission plan for cruise operations, the SWAP instrument was off for the first 460+ days of Pluto Cruise. After that the operations were sporadic (just a few days in 2009) and mostly Science, alternating with Channel Electron Multiplier gain tests during Annual CheckOuts. After extensive testing in early 2012, in July of that year the project approved daily science operations for the SWAP and PEPSSI instruments throughout the rest of the cruise to Pluto.

14.7 Observation Examples

In this section we show several examples of SWAP data. Figure 14-11 shows the solar wind measurements on approach to Jupiter, and all of the Jupiter magnetosphere and sheath observations. The format is that of a color-coded spectrogram of the background-subtracted coincidence count rates in Hz of solar wind ions as a function energy per charge (E/q) as measured by the Solar Wind Around Pluto (SWAP) instrument on New Horizons at ~ 4.9 AU from the Sun (~ 0.4 AU upstream from Jupiter). We used plan 0 for these measurements since this plan helps protect the instrument from high fluxes by

reducing the overall energy passband. In plan 0 the RPA is on at energies below 2000 eV/q. The RPA creates a background and this background has been removed (see calibration document). The lower trace shows the solar wind protons, while the upper trace shows the alpha particles (He^{++}), with enhanced sensitivity ($\sim 100\times$ larger) above 2 keV/q. Solar wind speed is a function E/q , with 1 keV protons corresponding to typical, ~ 440 km/s solar wind and larger (smaller) E/q representing faster (slower) wind speeds. Interplanetary shocks passed over the New Horizons spacecraft at $\sim 18:00$ on Day-of-Year (DOY) 11 and at ~ 1300 on DOY 14 causing the abrupt jumps in solar wind speed; the speed immediately following the latter shock was in excess of 600 km/s. The slowly decreasing speed after the second shock (falling E/q of the proton and alpha beams) is a rarefaction region, which forms as faster solar wind outruns the slower solar wind behind. In all, these SWAP observations show a clear solar wind stream structure.



Most of the magnetospheric observations were taken using plan 5 since the plan 5 energy passband is wider and the flux rates are lower in the magnetosphere than in the solar wind (Figure 14-11). The only time the plan 5 data has any background is when there is penetrating radiation, and we do not remove background due to penetrating radiation. The penetrating radiation occurs close to Jupiter and usually is greatest in the secondary and primary signals. When it occurs, the count rates are usually elevated at all energy steps; therefore, in spectrograms the penetrating radiation usually shows up as vertical stripes. The penetrating radiation is significantly reduced in the coincidence signal. The plan 5 data consists of one measurement set every 5th SWAP minute, and one set consists of 2 coarse scans performed in 64 seconds.

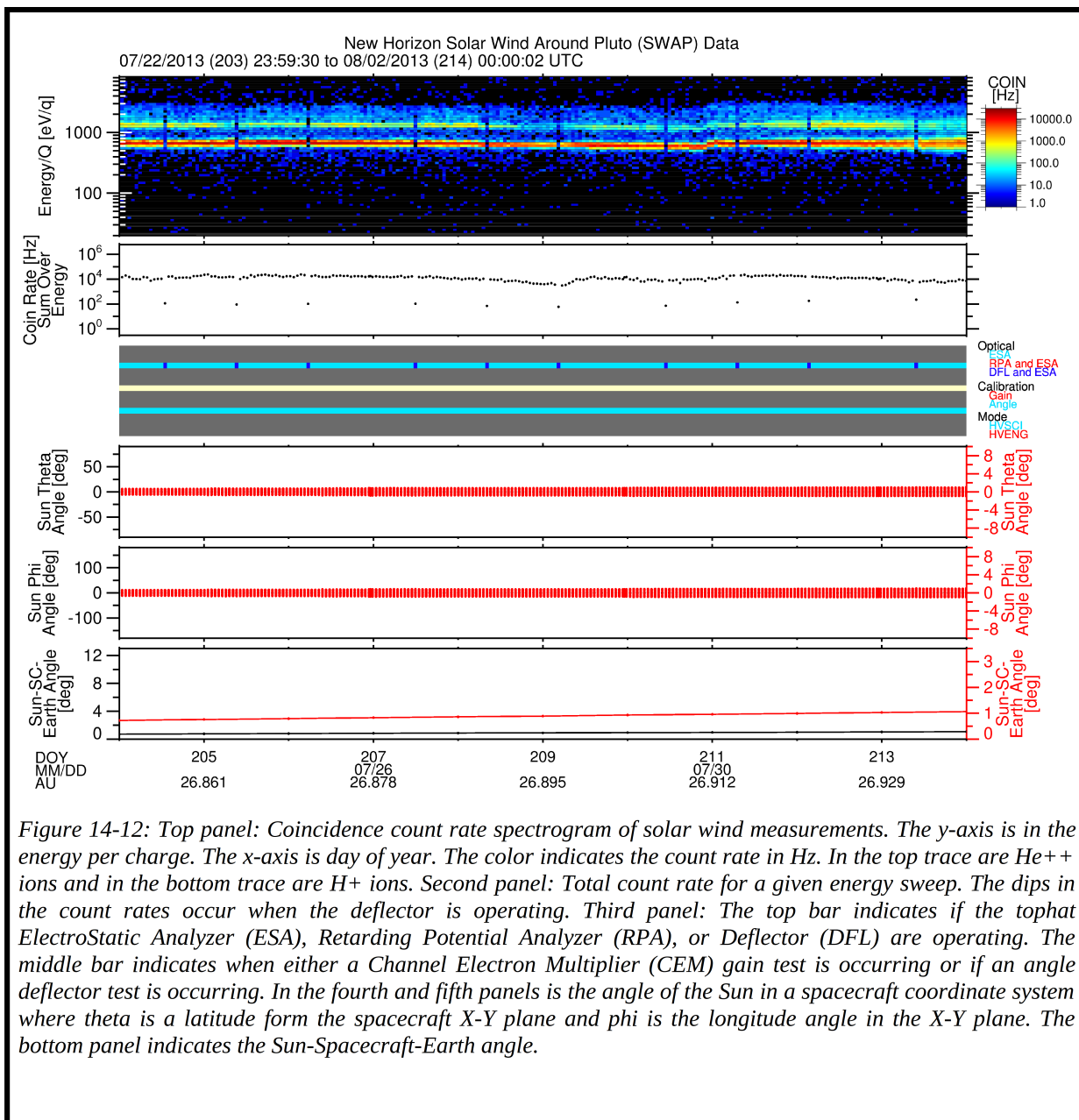
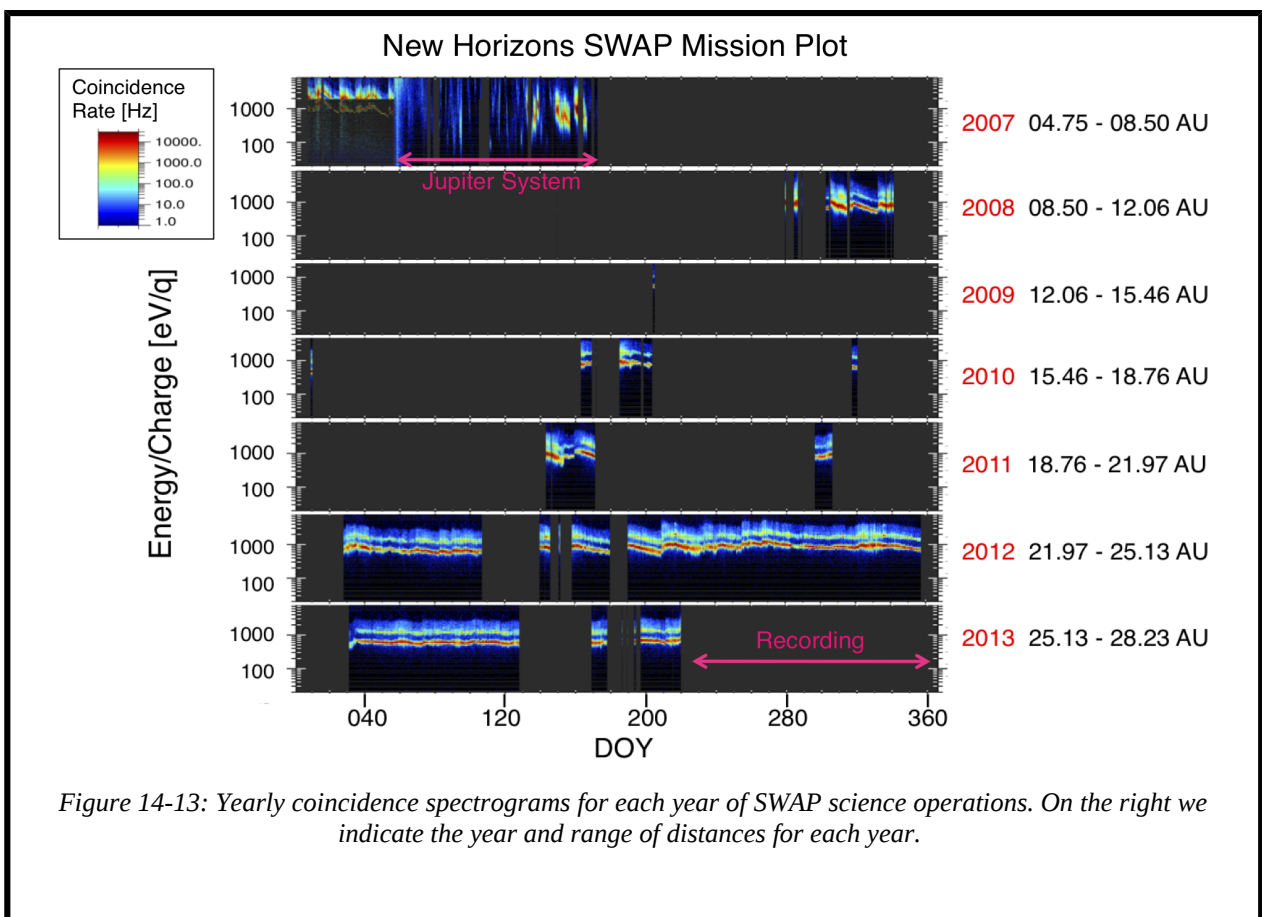


Figure 14-12: Top panel: Coincidence count rate spectrogram of solar wind measurements. The y-axis is in the energy per charge. The x-axis is day of year. The color indicates the count rate in Hz. In the top trace are He++ ions and in the bottom trace are H+ ions. Second panel: Total count rate for a given energy sweep. The dips in the count rates occur when the deflector is operating. Third panel: The top bar indicates if the tophat ElectroStatic Analyzer (ESA), Retarding Potential Analyzer (RPA), or Deflector (DFL) are operating. The middle bar indicates when either a Channel Electron Multiplier (CEM) gain test is occurring or if an angle deflector test is occurring. In the fourth and fifth panels is the angle of the Sun in a spacecraft coordinate system where theta is a latitude form the spacecraft X-Y plane and phi is the longitude angle in the X-Y plane. The bottom panel indicates the Sun-Spacecraft-Earth angle.

In Figure 14-12 we show a recent example of solar wind measurements taken during the 2013 Annual Checkout (ACO). The data format is similar to the previous figure expect now the Sun-spacecraft-Earth angle is in the bottom panel. Dips in the count rate occur when the SWAP instrument deflector (DFL) is turned on. The deflector intervals are denoted by dark blue in the top bar of the 3rd panel. The main species in the solar wind are protons (H^+) and alpha particles (He^{++}). In the spectrogram (top panel), the peak with the highest count rate is the solar wind proton (H^+) peak, and the alpha particle peak (He^{++}) has energy per charge twice that of the proton peak. Therefore, the 2nd brightest peak in yellow and green is the alpha particle (He^{++}) peak. The blue band above alphas is the interstellar proton pickup ions. The cutoff for these ions occurs at 4 time the energy per charge of the proton peak.



To help users know when SWAP was collecting observations, in Figure 14-13 we show an overview of all the SWAP science measurements for the entire New Horizons mission to date. Note that starting in 2012 the coverage increases since we began taking measurements during hibernation. In the heliospheric measurements there are times when the solar wind is outside the SWAP FOV. Since the solar wind is quite radial, the Sun location can be used to find the approximate solar wind direction. The Sun direction is given in spacecraft coordinates in the SPICE extension. The Sun location is given as a latitude (theta) and longitude (phi). The names of the parameters THETA_SUN_SC_0, THETA_SUN_SC_1, PHI_SUN_SC_0, PHI_SUN_SC_1 where the "0" and "1" refer to the first and second measurement in a given packet. There for each count rate measurement in the REAL_TIME extension there is a

corresponding set of theta and phi angle values in the SPICE extension. The SWAP FOV spans from -10 to +10 degrees in theta and from -138 to +138 degrees in phi.

14.8 Updates to the Level 3 Calibrated SWAP Data Pipeline

In 2007 we added the center energy for given RPA and ESA voltages to the REAL_TIME data extension. The column names are ENERGY_0 and ENERGY_1 in eV and correspond to the 1st and 2nd measurement in a given packet (row). We corrected the background subtraction. We corrected a rounding error in the time used to calculate the spin angles in the SPICE extension and fixed a small offset in the times for the spectrogram in the TIME_LABEL_SPECT extension.

In 2012 and 2013 the SWAP level 3 calibrated data pipeline was rewritten in IDL. The original code was written in C and had some memory overwrite issues that proved difficult to solve. The code was rewritten into IDL since it is easier to avoid memory overwrite issues in IDL. The old files were compared against the new files by examining differences between the old and new values for all the quantities in all the extensions. All the differences were flagged and each difference was addressed. When a problem was found with the new files, the problems were resolved. We found many issues with old files and have made many corrections. We documented the differences that remain which are corrections. The some small errors in the time calculations were fixed and this also affected some of the angle calculations. Many of the comment fields were updated. A few typos in parameter names were fixed. We provide a pdf file of a power point presentation with a summary of the changes and corrections (SWAP_level2_C_IDL_10152012.pdf).

14.9 Gain and Deflector Angle Sweep Tests

After October 28, 2008 the Channel Electron Multiplier (CEM)_detector gain tests are performed using plan 2 and the only plan 2 data after that date occurs during a gain test. Error: Reference source not found shows the start and stop times for the gain tests and the angle test prior to this date.

Type of Test	Start Date and Time	Stop Date and Time
CEM Gain Test	2007-06-04T17:12:34.41	2007-06-04T18:54:58.41
Deflector Angle Sweep Test	2007-06-12T05:30:42.51	2007-06-12T10:23:18.41
CEM Gain Test	2008-09-28T10:06:58.62	2008-09-28T11:36:34.62
CEM Gain Test	2008-10-27T04:07:30.63	2008-10-27T05:38:09.63

Table 14-1: Start and stop times for gain tests and angle test prior to 2008-10-28.

14.10 SWAP Science Goals

These level 3 (calibrated) data products described above will allow us to meet two key science goals as outlined in section 6.3.1.1 of the SWAP Specification document (Document No. 05310-03-SWAPSPEC-01). Below we quote this section.

The Mission Science Requirements document specifies that SWAP should make the following measurements.

- Measure solar wind standoff to ~ 3000 km.
- Determine nature of solar wind interaction at Pluto. Distinguish between magnetic, cometary, & ionospheric interactions.

14.10.1 Dataflow Block Diagram

Figure 14-14 provides a summary of the inputs (in gold and violet) and steps (in blue) in the calibration pipeline which convert the raw data to scientific units.

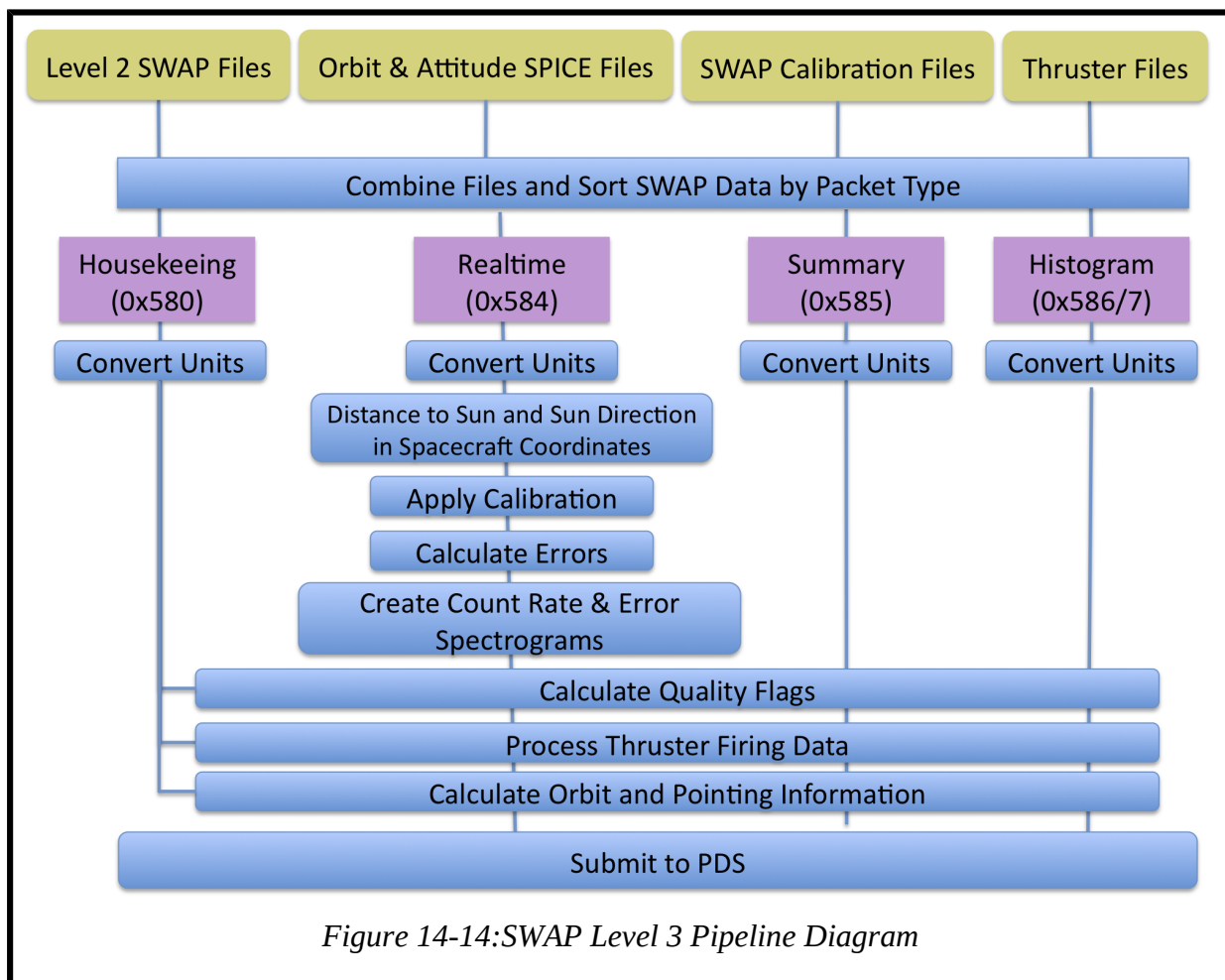


Figure 14-14:SWAP Level 3 Pipeline Diagram

14.10.2 *Extra FITS Extensions and Their Definitions*

We have binary tables for both real-time, and summary data. Likewise, we have binary table extensions for housekeeping data, flags, errors, and thruster packet spacecraft data. We have image extensions for both count rate spectrograms and error spectrograms image. For histogram data we have two image extensions: one for counts and one for accumulations (number of samples).

14.10.3 *Scientific Units*

14.10.4 *Additional FITS and PDS Keywords Added*

The level 3 calibrated code has rate spectrogram in Hz, and all the engineering data converted to engineering units.

14.10.5 *Hardware/OS Development Platform*

Intel, Linux

14.10.6 *Language(s) Used*

IDL

14.10.7 *Third Party Libraries Required*

SPICE and FITS.

14.10.8 *Memory Required*

14.10.9 *Temporary File System Space Needed*

None

14.10.10 *Predicted Size of Output File(s)*

14.10.11 *Predicted Execution time*

On the order of seconds

14.10.12 *Contact/Support Person(s)*

PI: Dave McComas

Lead Engineer and Project Manager: Scott Weidner

Onboard Software and Commanding: John Hanley

Pipeline and Science Operations: Heather Elliott

Sequencing: Helen Hart

14.10.13 Maintenance Schedule (Code/Data Updates, Documentation)

14.11 SWAP Publications To Date

- Ebert, R. W., D. J. McComas, B. Rodriguez, P. Valek, and S. Weidner, A composition analysis tool for the Solar Wind Around Pluto (SWAP) instrument on New Horizons, *Space Sci. Rev.*, doi:10.1007/s11214-010-9683-6, 156, 1-12, 2010.
- Ebert, R. W., D. J. McComas, F. Bagenal, and H. A. Elliott, Location, structure, and motion of Jupiter's dusk magnetospheric boundary from ~1625 to 2550 RJ, *J. Geophys. Res.*, 115, A12223, doi:10.1029/2010JA015938, 2010.
- McComas, D. J. and F. Bagenal, Jupiter: A fundamentally different magnetospheric interaction with the solar wind, *Geophys. Res. Lett.*, 34, L20106, doi:10.1029/2007GL031078, 2007.
- McComas, D.J., F. Allegrini, F. Bagenal, F. Crary, R. W. Ebert, H. Elliott, A. Stern, and P. Valek, Diverse Plasma Populations and Structures in Jupiter's Magnetotail, *Science*, 318, doi:10.1126/science.1147393, 217-220, 2007.
- McComas, D. J., F. Allegrini, F. Bagenal, P. Casey, P. Delamere, D. Demkee, G. Dunn, H. Elliott, J. Hanley, K. Johnson, J. Langle, G. Miller, S. Pope, M. Reno, B. Rodriguez, N. Schwadron, P. Valek, and S. Weidner, The Solar Wind Around Pluto (SWAP) instrument aboard New Horizons, *Space Sci. Rev.*, doi:10.1007/s11214-007-9205-3, 140, 261-313, 2008.
- McComas, D. J. and F. Bagenal, Re: Jupiter: A fundamentally different magnetospheric interaction with the solar wind, Response to Comment, *Geophys. Res. Lett.*, 35, L10103, doi:10.1029/2008GL034351, 2008.
- McComas, D. J., H. A. Elliott, and N. A. Schwadron, Pickup hydrogen distributions in the solar wind at ~11 AU: Do we understand pickup ions in the outer heliosphere?, *J. Geophys. Res.*, 115, A03102, doi:10.1029/2009JA014604, 2010.
- Nicolaou, G., D. J. McComas, F. Bagenal, and H.A. Elliott, Fluid properties of plasma ions in the distant Jovian magnetosheath using Solar Wind Around Pluto (SWAP) data on New Horizons, submitted to *J. Geophys. Res.*, SUBMITTED, 2013.
- Randol, B. M., R. W. Ebert, F. Allegrini, D. J. McComas, and N. A. Schwadron, Reflections of ions in electrostatic analyzers: A case study with New Horizons/Solar Wind Around Pluto, *Rev. Sci. Instrum.*, 81, 114501, 2010.
- Randol, B. M. and D. J. McComas, Density correlations between solar wind and pick-up ions, Pickup Ions throughout the Heliosphere and Beyond: Proceedings of the 9th Annual International Astrophysics Conference, AIP CP1302, pp. 64-69, 2010.
- Randol, B. M., H. A. Elliott, J. T. Gosling, D. J. McComas, and N. A. Schwadron, Observations of isotropic interstellar pick-up ions at 11 and 17 AU from New Horizons, *Astrophys. J.*, 755:75, doi:10.1088/0004-637X/755/1/75, 2012.
- Randol, B. M., D. J. McComas, and N. A. Schwadron, Interstellar pick-up ions observed between 11 and 22 AU by New Horizons, *Astrophys. J.*, 768:120, doi:10.1088/0004-637X/768/2/120, 2013.
- Young, L. A., S. A. Stern, H. A. Weaver, F. Bagenal, R. P. Binzel, B. Buratti, A. F. Cheng, D. Cruikshank, G. R. Gladstone, W. M. Grundy, D. P. Hinson, M. Horanyi, D. E. Jennings, I. R. Linscott, D. J. McComas, W. B. McKinnon, R. McNutt, J. M. Moore, S. Murchie, C. B. Olkin, C. C. Porco, H. Reitsema, D. C. Reuter, J. R. Spencer, D. C. Slater, D. Strobel, M. E. Summers, and G. L.

Tyler, New Horizons: Anticipated scientific investigations at the Pluto system, Space Sci. Rev., doi: 10.1007/s11214-008-9462-9, 140, 93-127, 2008.

14.12 Packet Description

This section gives the parameters found in SWAP science packets. The names are as given in the APL spreadsheets used to view the data in real-time and playback modes. The level 1 names are shortened versions of these names.

REAL_TIME

SWAP_RT.CC_PID_VER	Primary Header - Version Number
SWAP_RT.CC_PID_TYPE	Primary Header - Packet Type
SWAP_RT.CC_PID_SEC_FLAG	Primary Header - Secondary Header Flag
SWAP_RT.CC_PID_APID	Primary Header - Application ID; type of data i.e. real-time, housekeeping, etc
SWAP_RT.CC_PSC_GRP_FLAG	Primary Header - Grouping Flag; set to a constant value, not used
SWAP_RT.CC_PSC_SSC	Primary Header - Sequence Count
SWAP_RT.CC_PKT_DATA_LN	Primary Header - Packet Length; this is used to
SWAP_RT.CC_MET_TIME	Secondary Header - Time
SWAP_RT.SEC64_ST	A bit indicating the beginning of a 64-second cycle
SWAP_RT.PLAN_ID	Plan ID
SWAP_RT.SWEEP_ID	Sweep ID
SWAP_RT.ANGLE	Commanded angle for deflection compensation
SWAP_RT.RPA_LVL0	RPA level during first half-second
SWAP_RT.DFL_LVL0	DFL level during first half-second
SWAP_RT.ESA_LVL0	ESA level during first half-second
SWAP_RT.RPA_LVL1	RPA level during first half-second
SWAP_RT.DFL_LVL1	DFL level during first half-second
SWAP_RT.ESA_LVL1	ESA level during first half-second
SWAP_RT.MODE	Enumerated type representing each of the modes
SWAP_RT.PCEM_RNG_ST0	PCEM counts are compressed or raw during first half-second; this is a flag that determines if the data in SWAP_RT.PCEM_CNT0 is compressed or not. If this flag is set to zero the data are not compressed. If the flag is set to 1 then the data in SWAP_RT.PCEM_CNT0 is 1/16 of the actual count rate.
SWAP_RT.SCEM_RNG_ST0	SCEM counts are compressed or raw during first half-second
SWAP_RT.COIN_RNG_ST0	Coincidence counts are compressed or raw during first half-second
SWAP_RT.PCEM_RNG_ST1	PCEM counts are compressed or raw during second half-second
SWAP_RT.SCEM_RNG_ST1	SCEM counts are compressed or raw during second half-second
SWAP_RT.COIN_RNG_ST1	Coincidence counts are compressed or raw during second half-second
SWAP_RT.PCEM_CNT0	PCEM count value during first half-second

SWAP_RT.SCEM_CNT0	SCEM count value during first half-second
SWAP_RT.COIN_CNT0	Coincidence count value during first half-second
SWAP_RT.PCEM_CNT1	PCEM count value during second half-second
SWAP_RT.SCEM_CNT1	SCEM count value during second half-second
SWAP_RT.COIN_CNT1	Coincidence count value during second half-second
SWAP_RT.CHKSUM	XOR checksum; this value is based on all the other real-time quantities listed above. It is used to determine if a bit was flipped in one of the real-time quantities. If check sum is not what is predicted based on the other real-time quantities then the data need to be thrown away.

SUMMARY

SWAP_SM.CC_PID_VER	Primary Header - Version Number
SWAP_SM.CC_PID_TYPE	Primary Header - Packet Type
SWAP_SM.CC_PID_SEC_FLAG	Primary Header - Secondary Header Flag
SWAP_SM.CC_PID_APID	Primary Header - Application ID
SWAP_SM.CC_PSC_GRP_FLAG	Primary Header - Grouping Flag
SWAP_SM.CC_PSC_SSC	Primary Header - Sequence Count
SWAP_SM.CC_PKT_DATA_LN	Primary Header - Packet Length
SWAP_SM.CC_MET_TIME	Secondary Header - Time
SWAP_SM.BEG_TIME	Time stamp at the beginning of this summary period
SWAP_SM.END_TIME	The time stamp at the end of this summary period
SWAP_SM.N64_CNT	Number of 64-second sample sets used
SWAP_SM.NDFL	DFL
SWAP_SM.ANGLE_SUM	Angle
SWAP_SM.DENSITY_SUM	An estimate of the pseudo density
SWAP_SM.VELOCITY_SUM	An estimate of the pseudo speed using energy
SWAP_SM.TEMP_SUM	Estimate of the pseudo temperature
SWAP_SM.ANGLE_SSQ_HI	The variance of the angles
SWAP_SM.ANGLE_SSQ_LO	The variance of the angles
SWAP_SM.DENSITY_SSQ_HI	The variance of the pseudo n-values
SWAP_SM.DENSITY_SSQ_LO	The variance of the pseudo n-values
SWAP_SM.VELOCITY_SSQ_HI	The variance of the pseudo V-values
SWAP_SM.VELOCITY_SSQ_LO	The variance of the pseudo V-values
SWAP_SM.TEMP_SSQ_HI	The variance of the pseudo T-values
SWAP_SM.TEMP_SSQ_LO	The variance of the pseudo T-values
SWAP_SM.ANGLE_MIN	Minimum Angle
SWAP_SM.DENSITY_MIN	Minimum pseudo density
SWAP_SM.VELOCITY_MIN	Minimum pseudo speed
SWAP_SM.TEMP_MIN	Minimum pseudo Temperature
SWAP_SM.ANGLE_MAX	Maximum Angle
SWAP_SM.DENSITY_MAX	Maximum pseudo density
SWAP_SM.VELOCITY_MAX	Maximum pseudo speed
SWAP_SM.TEMP_MAX	Maximum pseudo temperature
SWAP_SM.CHKSUM	XOR checksum

HISTOGRAM Type 1

SWAP_H0.CC_PKT_DATA_LN	Primary Header - Packet Length
SWAP_H0.CC_MET_TIME	Secondary Header - Time
SWAP_H0.BEG_TIME	Time stamp at the beginning of this histogram period
SWAP_H0.END_TIME	The time stamp at the end of this histogram period
SWAP_H0.SMPLS_CNT	Number of 64-second samples used
SWAP_H0.PLAN_ID	The Plan ID used for the current science sweeping mode
SWAP_H0.TABLE_ID	Table ID within the Plan ID that is being used
SWAP_H0.SEQNUM_CNT	Sequence number starting at 0 for header
SWAP_H0.DATA	Histogram data
SWAP_H0.CHKSUM	XOR checksum

HISTOGRAM Type 2

SWAP_H1.CC_PID_VER	Primary Header - Version Number
SWAP_H1.CC_PID_TYPE	Primary Header - Packet Type
SWAP_H1.CC_PID_SEC_FLAG	Primary Header - Secondary Header Flag
SWAP_H1.CC_PID_APID	Primary Header - Application ID
SWAP_H1.CC_PSC_GRP_FLAG	Primary Header - Grouping Flag
SWAP_H1.CC_PSC_SSC	Primary Header - Sequence Count
SWAP_H1.CC_PKT_DATA_LN	Primary Header - Packet Length
SWAP_H1.CC_MET_TIME	Secondary Header - Time
SWAP_H1.SEQNUM_CNT	Sequence number
SWAP_H1.DATA	Histogram data
SWAP_H1.CHKSUM	XOR checksum starting with beginning of CCSDS header

HOUSEKEEPING

SWAP_HK.CC_PID_VER	Primary Header - Version Number
SWAP_HK.CC_PID_TYPE	Primary Header - Packet Type
SWAP_HK.CC_PID_SEC_FLAG	Primary Header - Secondary Header Flag
SWAP_HK.CC_PID_APID	Primary Header - Application ID
SWAP_HK.CC_PSC_GRP_FLAG	Primary Header - Grouping Flag
SWAP_HK.CC_PSC_SSC	Primary Header - Sequence Count
SWAP_HK.CC_PKT_DATA_LN	Primary Header - Packet Length
SWAP_HK.CC_MET_TIME	Secondary Header - Time
SWAP_HK.CMD_EXE_CNT	Cumulative mod-256 count of successfully executed commands
SWAP_HK.CMD_REJ_CNT	Cumulative mod-256 count of rejected commands
SWAP_HK.LUT_CHOICE	Which LUT is in use
SWAP_HK.PCEM_SAFE	PCEM was safed due to CEM interrupts
SWAP_HK.SCEM_SAFE	SCEM was safed due to CEM interrupts
SWAP_HK.WDT_ST	SWAP has rebooted due to a watchdog expiration.
SWAP_HK.RCV_SAFE_ST	SWAP has received safe command from S/C
SWAP_HK.SAFE_ST	SWAP has safed itself.
SWAP_HK.PCEM_RATE_ST	Count rate threshold for PCEM counter has been exceeded
SWAP_HK.SCEM_RATE_ST	Count rate threshold for the SCEM counter has been exceeded

SWAP_HK.PCEM_CURR_ST	Current threshold for the PCEM has been exceeded
SWAP_HK.SCEM_CURR_ST	Current threshold for the SCEM has been exceeded
SWAP_HK.PCEM_VOLT_ST	Voltage tolerance for the PCEM has been exceeded.
SWAP_HK.SCEM_VOLT_ST	Voltage tolerance for the SCEM has been exceeded.
SWAP_HK.LVPS_VOLT_ST	Voltage tolerance for +5 V or -5V supply has been exceeded.
SWAP_HK.LVPS_CURR_ST	Current tolerance for +5 V or -5V supply has been exceeded.
SWAP_HK.OVR_TEMP_ST	Upper temperature limit exceeded.
SWAP_HK.UND_TEMP_ST	Lower temperature limit exceeded.
SWAP_HK.MODE	Enumerated type representing each of the modes
SWAP_HK.MEMDP_ST	MEMDUMP State
SWAP_HK.SENSOR_TEMP	Temperature of sensor detector. AD mux = 0x10
SWAP_HK.HVSUPP_TEMP	Temperature of HVPS. AD mux = 0x11
SWAP_HK.CNTRLR_TEMP	Temperature of controller. AD mux = 0x12
SWAP_HK.PCEM_VOLT	Voltage monitor of PCEM high-voltage power supply. AD mux = 0x02
SWAP_HK.SCEM_VOLT	Voltage monitor of SCEM high-voltage power supply. AD mux = 0x03
SWAP_HK.PCEM_CURR	Strip current monitor of PCEM high-voltage power supply. AD mux = 0x04
SWAP_HK.SCEM_CURR	Strip current monitor of SCEM high-voltage power supply. AD mux = 0x05
SWAP_HK.P5_VOLT	Voltage monitor of +5V power supply. AD mux = 0x0c
SWAP_HK.N5_VOLT	Voltage monitor of -5V power supply. AD mux = 0x0d
SWAP_HK.P5_CURR	Current monitor of +5V power supply. AD mux = 0x0e
SWAP_HK.N5_CURR	Current monitor of -5V power supply. AD mux = 0x0f
SWAP_HK.SWAP_REV	Revision number for the SWAP software
SWAP_HK.LAST_OPCODE	Opcode of last executed command
SWAP_HK.PHD_LLD_LVL	DAC Level of PHD LLD
SWAP_HK.MEMLD_ST	MEMLOAD state
SWAP_HK.OPT1_ST	State of primary optics
SWAP_HK.OPT2_ST	State of backup optics
SWAP_HK.PCEM_ST	State of Primary Channel Electron Multiplier disable/enable
SWAP_HK.SCEM_ST	State of Secondary Channel Electron disable/enable
SWAP_HK.SPARE1	SPARE
SWAP_HK.PCEM_CNT_ST	The PCEM count rate was tripped but handled by SWAPFW
SWAP_HK.SCEM_CNT_ST	The SCEM count rate was tripped but handled by SWAPFW
SWAP_HK.PCEM_CURRTHR	Current level when PCEM safety algos are tripped
SWAP_HK.SCEM_CURRTHR	Current level when SCEM safety algos are tripped
SWAP_HK.PCEM_LVL	PCEM DAC level
SWAP_HK.SCEM_LVL	SCEM DAC level
SWAP_HK.AGND_VOLT	Voltage monitor of Analog ground. A/D mux = 0x00
SWAP_HK.CEM_CURR	Current level when SCEM safety interrupt is tripped
SWAP_HK.ESA1_VOLT	Voltage monitor of ESA high-voltage power supply. AD mux = 0x06
SWAP_HK.ESA2_VOLT	Voltage monitor of ESA high-voltage power supply. AD mux = 0x07

SWAP_HK.DFL1_VOLT	Voltage monitor of DFL high-voltage power supply. AD mux = 0x08
SWAP_HK.DFL2_VOLT	Voltage monitor of DFL high-voltage power supply. AD mux = 0x09
SWAP_HK.RPA1_VOLT	Voltage monitor of RPA high-voltage power supply. AD mux = 0x0a
SWAP_HK.RPA2_VOLT	Voltage monitor of RPA high-voltage power supply. AD mux = 0x0b
SWAP_HK.P2_5_VOLT	Voltage monitor of +2.5V reference. AD mux = 0x13
SWAP_HK.PHD_LLD_VOLT	Voltage monitor of PHD_LLD. Ad mux = 0x14
SWAP_HK.PCEM_RATELIM	The count value at which the primary CEM safety limit is set.
SWAP_HK.SCEM_RATELIM	The count value at which the secondary CEM safety limit is set.
SWAP_HK.STIM_ENA	State of whether the stimulator pulsers are enabled or disabled.
SWAP_HK.PPS_SEL_ST	State of which side of the IEM interface is being used.
SWAP_HK.PPS_DET_ST	1 PPS detected state
SWAP_HK.CEM_INT_LIM	Current limit at which the CEM triggers an interrupt.
SWAP_HK.CMD_ECHO_ST	Whether command echo is enabled or disabled
SWAP_HK.HV_PGSAFE_ST	State of safe / arm plug
SWAP_HK.HV_PGENA_ST	State of high-voltage disable/enable plug
SWAP_HK.HV_ARM_ST	State of high-voltage software disable/enable
SWAP_HK.CEM_INT_DIP	Counts to dip the CEM supplies
SWAP_HK.PLAN_ID	The Plan ID used for the current science sweeping mode if any.
SWAP_HK.SWEEP_ID	Current Sweep table ID
SWAP_HK.ANGLE	The commanded angle for deflection compensation
SWAP_HK.PCEM_VLT1_ST	PCEM voltage is out of tolerance for only one 0.5 second sample
SWAP_HK.PCEM_CUR1_ST	PCEM current is out of tolerance for only one 0.5 second sample
SWAP_HK.SCEM_VLT1_ST	SCEM voltage is out of tolerance for only one 0.5 second sample
SWAP_HK.SCEM_CUR1_ST	SCEM current is out of tolerance for only one 0.5 second sample
SWAP_HK.PCEM_INT_ST	The CEM current interrupt was tripped, but handled by SWAPFW
SWAP_HK.SCEM_INT_ST	The CEM current interrupt was tripped, but handled by SWAPFW
SWAP_HK.EEP2_RDY	EEPROM 2 is ready to be written
SWAP_HK.EEP1_RDY	EEPROM 1 is ready to be written
SWAP_HK.FPGA_TYPE	Type number of the FPGA
SWAP_HK.FPGA_REV	Revision number of the FPGA
SWAP_HK.SM_TLM	How often the science summary packet is output.
SWAP_HK.HX_TLM	How often the histogram telemetry packet is output.
SWAP_HK.RT_TLM	How often all of the 64-second real-time packets are output
SWAP_HK.HK_TLM	How often the housekeeping packet is output.
SWAP_HK.FPGA_PUP_ST	A status of the power on check of the FPGA initialization check
SWAP_HK.EEPL2_CKS_ST	Status of the power on check of the EEP_L2 checksum
SWAP_HK.EEPL1_CKS_ST	Status of the power on check of EEP_L1 checksum
SWAP_HK.RAM_D_ST	Status of the power on check of the RAM_D memory test
SWAP_HK.EEPC2_CKS_ST	Status of the power on check of the EEP_C2 checksum
SWAP_HK.EEPC1_CKS_ST	Status of the power on check of the EEP_C1 checksum

SWAP_HK.RAM_C_ST	Status of the power on check of the RAM_C memory test
SWAP_HK.PROM_CKS_ST	Status of the power on check of the PROM checksum
SWAP_HK.CHSUM	XOR checksum