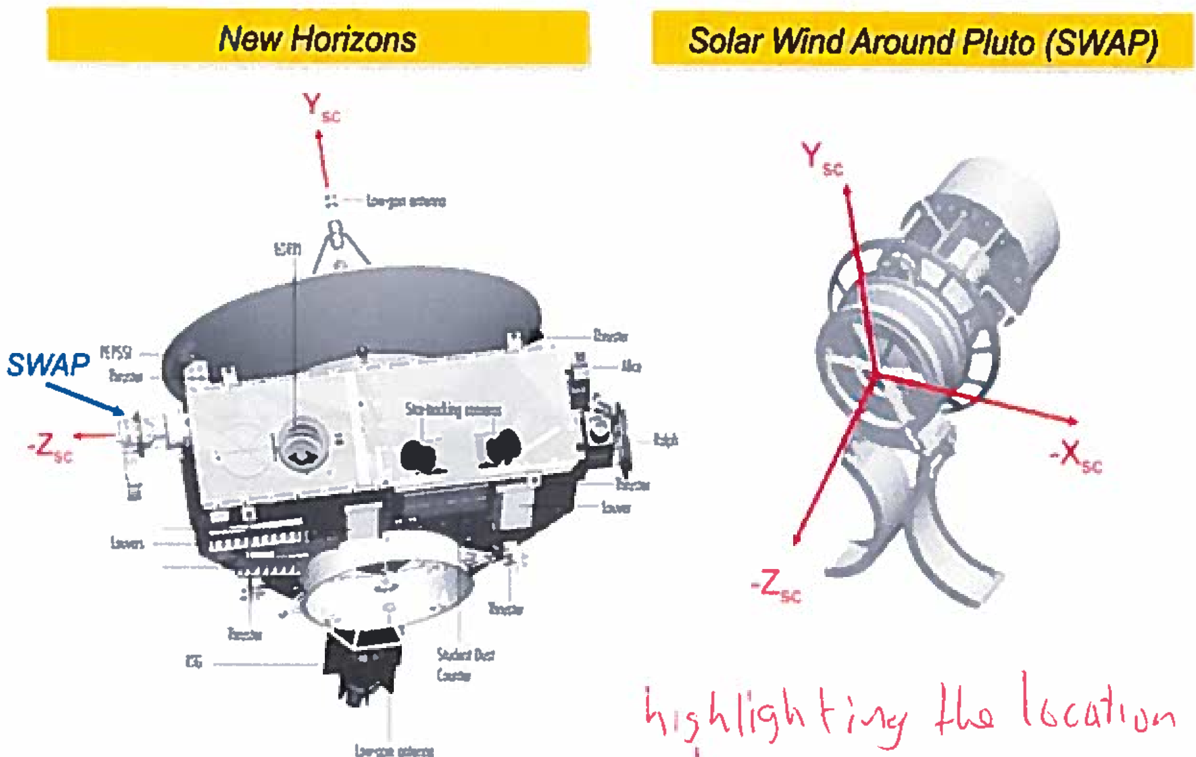

Figure 14-2: Diagram of New Horizons spacecraft SWAP instrument on the left. On the right diagram of the SWAP instrument with the spacecraft axes labeled.

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 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.

14.5.4 Errors

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 converted 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.

$$R_c = \frac{C}{t}$$

(Equation 1)

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

(Equation 2)

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

(Equation 3)

$$\frac{(\Delta R_c)^2}{R_c^{\ 2}} = \frac{(\Delta t)^2}{t^2} + \frac{(\Delta C)^2}{C^2}$$

(Equation 4)

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

(Equation 5)

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

(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 GN&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 (Start_time=major_frame_start_time + 0.040*(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

of the Jupiter encounter,

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 for solar wind observations, 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

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 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

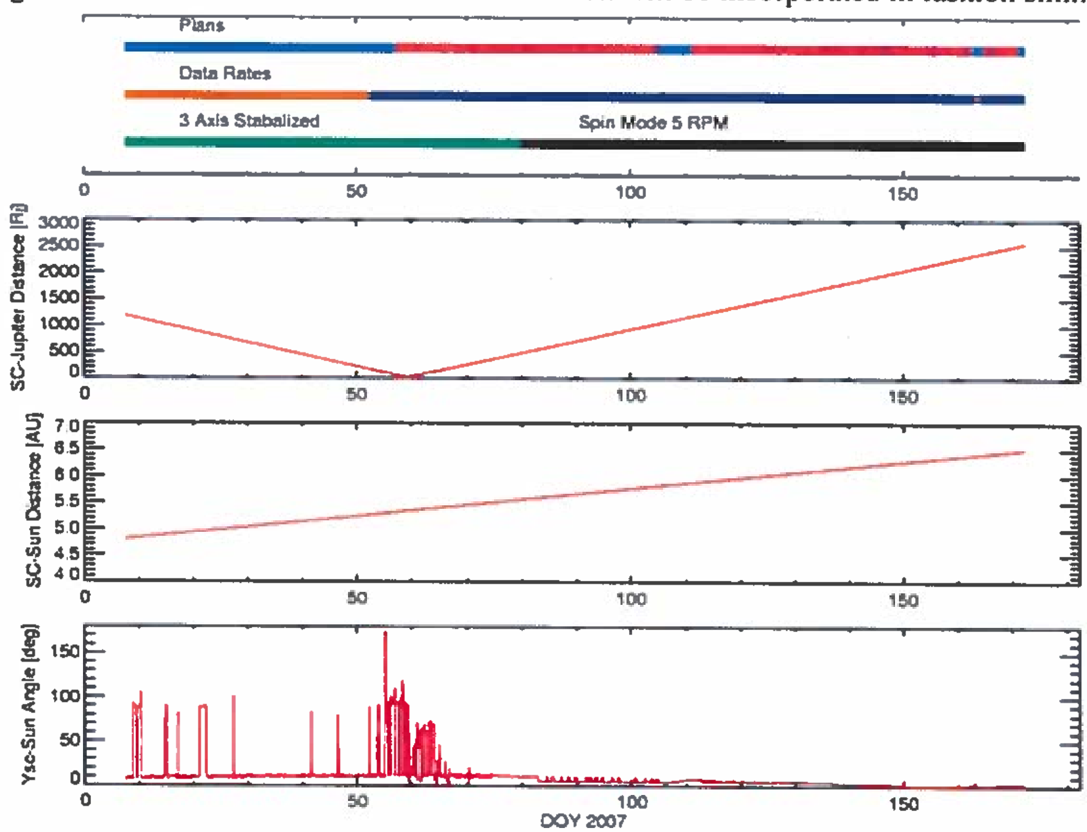

Figure 14-10: Timelines for SWAP plan numbers, data rates, and spacecraft maneuvers (top panel). Plan 0 is blue plan 5 is red. Two minutes of data set of measurements every two hours is in orange where one set consists of a two coarse-fine sweeps. Purple is one set of measurements every 5 minutes. Green 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.

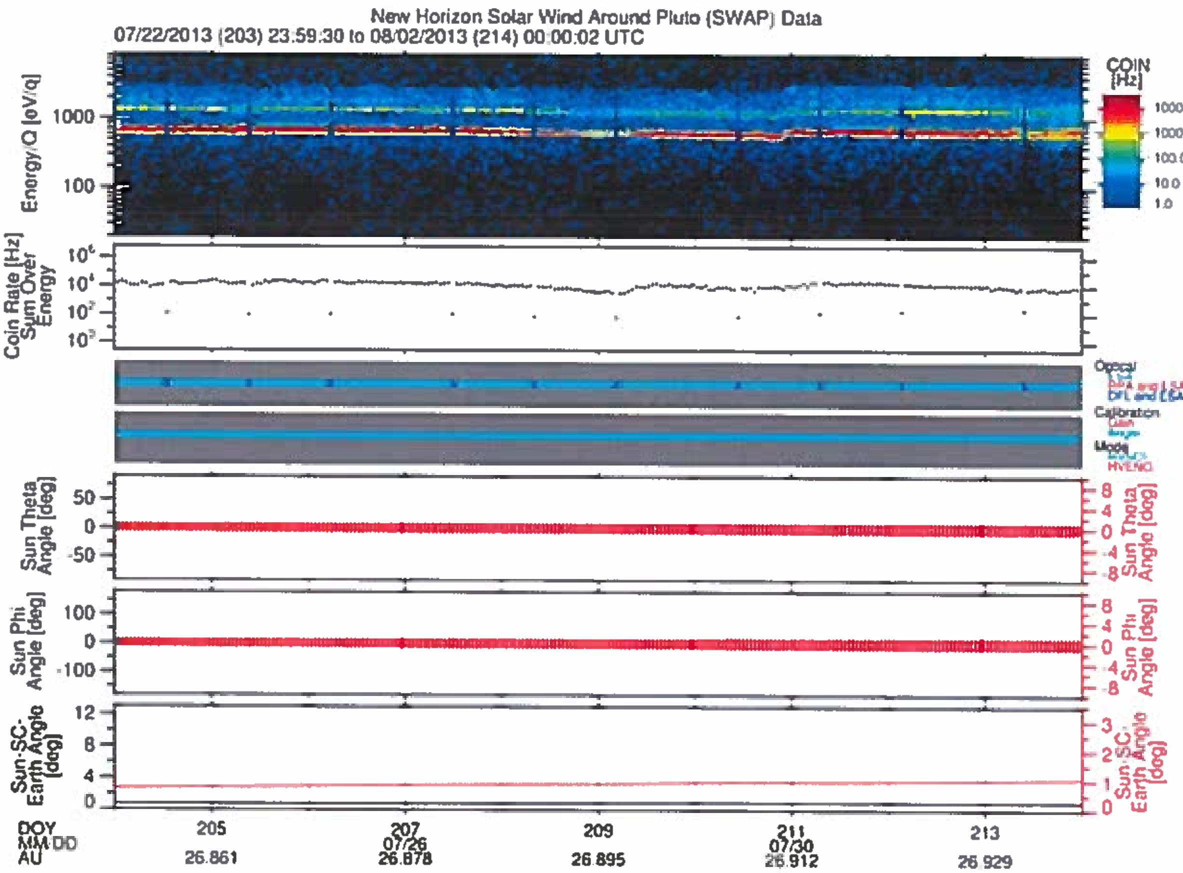

Figure 14-12: Top panel: Coincidence count rate spectrogram of solar wind measurements. The y-axis is ~~in the~~ energy per charge. The x-axis is day of year. The color indicates the count rate in Hz. In the top trace are He++ ions and in the bottom trace are H+ ions. Second panel: Total count rate for 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.

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 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 provided a PDF file of a PowerPoint(tm) presentation to the SOC with a summary of the changes and corrections (SWAP_level2_C_IDL_10152012.pdf; N.B. this is a project-internal presentation and it is not delivered with SWAP PDS data sets).

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. Table 14-1 shows the start and stop times for the gain tests and the angle test prior to this date.

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

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

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.*