# 13. SDC INSTRUMENT DESCRIPTION

## 13.1 Overview

The mission of the Venetia Burney Student Dust Counter (VSDC, but typically just SDC in project documentation) is to analyze the size and distribution of dust particles along the New Horizon's trajectory to the Kuiper Belt. The SDC instrument consists of the front end analog electronics, the digital interface electronics, the detector panel, and the intraharness.

Each particle impact on one of the 12 active SDC detectors (see 13.1.1 below) will be a candidate for a science event This impact causes a depolarization signal in the Polyvinylidene Fluoride (PVDF) detector film dependent on the size and speed of the particle. This signal gets converted to a digital number via the electronics. If the amplitude is above the value at which the threshold is currently set, then the signal is stored in memory as a science event along with other relevant housekeeping data.

These depolarization signals are measured in charge (Q) produced (Note that SDC reports charge in number of electrons. Even though this is not strictly charge, the number of electrons will from here on be referred to as the charge.) The charge from an impacting particle depends on the particles mass and velocity. Because the unit of the raw data is data number (DN), a calibration curve from data number to charge (DN=>Q) is needed. This curve is a function of box temperature and detector channel. For SDC, this curve was produced pre-flight and is checked during the mission with internal calibration procedures. The DN=>Q calibration curves are shown in Figure 13-2. The calibrated files are derived from the raw files through these curves.

### *13.1.1 Notes*

Each detector has an independent set of electronics called a channel.

There are a total of 14 channels; there are also two inactive detectors mounted on the back of the panel, out of the path of any dust, for estimating the rate of detectable non-dust events such as spacecraft thruster firings.

Channel 11 failed before launch; it can still generate spurious data, which are processed by the pipeline, but they should be ignored.

## 13.2 Raw Data Specifics

The raw data are unprocessed telemetry. At the SOC and PDS, all levels of data are recorded in FITS format. The SDC team uses IDL for our data processing and hence would like to be able to load these FITS files into IDL as structures/arrays, etc. To do this we typically use an IDL fits reader which can be found in the Goddard IDL library. Specifically we use mrdfits.pro. If this is used, please note that a "/unsigned" flag must be given as the data are all unsigned integers.

The raw data FITS file consists of housekeeping and science data. Some of these data are not used in the calibration process to produce the calibrated data. It stated in the PDS label files which telemetry points are and are not used by the calibration process.

In addition to the IDL functions for FITS files, generic programs such as fv can also be found. If opened in this program, the raw data tables are displayed in Figure 13-1 below.

File Edit Tools Help

| Index | Extension | Type | Dimension | View |
|---|---|---|---|---|
| 0 | Primary | Image | 0 | Header Image Table |
| 1 | DATA | Binary | 6 cols X 3 rows | Header Hist Plot All Select |
| 2 | HOUSEKEEPING_SDC | Binary | 9 cols X 1 rows | Header Hist Plot All Select |
| 3 | HOUSEKEEPING_0X004 | Binary | 37 cols X 1 rows | Header Hist Plot All Select |
| 4 | HOUSEKEEPING_0X00D | Binary | 8 cols X 1 rows | Header Hist Plot All Select |
| 5 | HOUSEKEEPING_0X00A | Binary | 5 cols X 1 rows | Header Hist Plot All Select |
| 6 | THRUSTERS | Binary | 28 cols X 268 rows | Header Hist Plot All Select |

*Figure 13-1: Primary Data Unit (PDU) and Extension Data Unit layout in FITS file*

### *13.2.1 Data Format*

The data in the FITS file are stored as a binary table extension. There are five tables in the raw file. These tables and their columns are :

DATA –

1) Copy Number – Not used in calibration
2) Channel ID – Detector number (0-13) [Channel 10 has a electrical issue and is not used for science. Channels 6 and 13 are reference detectors. These detectors cannot detect real dust as they are covered. For all higher level data products the channel IDs are incremented by one and become 1-14.]
3) Zero Fill – Not used in calibration
4) Threshold – First note that this DN scale is reversed. This means 65535 is a small event while 0 is a very large event. This reverse scale is also true for the Magnitude described below. The threshold value is the maximum (highest DN but smallest signal) magnitude (see next item) for accepted hits. Hits above (smaller amplitude) the threshold are rejected at the instrument level. These thresholds are adjustable and vary from channel to channel.

   Note that it is SOMETIMES possible for a slightly smaller amplitude hit to come in just above this value; this is a timing effect due to the way the instrument software work. An event that triggers a measurement occurs before that measurement. The peak of the pulse from a dust event that is *below* (larger amplitude) threshold triggers a measurement, but that measurement occurs with a slight delay after its trigger event. For some events, between the time of the trigger and the time of the measurement the pulse may have decayed to very slightly *above* (smaller amplitude) the threshold, with the result that the measured and recorded Magnitude (next item) is *above* (smaller amplitude) the threshold.
5) Magnitude – The size of the hit in DN [Note that this scale is also reversed. This means that 65535 is a small event while 0 is a very large event.]
6) Time Stamp – The time the hit was recorded in Mission Elapsed Time (MET)

HOUSEKEEPING_SDC –

1) MET – Mission Elapsed Time
2) PanTemp A-D – Temperature recorded on the panel of SDC
3) BoxTemp 1-4 – Temperatures recorded on the electronics box of SDC

HOUSEKEEPING_0X004 – Values used in Calibration from this table:

1) CDH_PNL_A-D_TEMP – Temperature recorded on the panel of SDC (Note these are the same as above)
2) CDH_ANA_A-B_TEMP – Temperature recorded on analog side of the electronics box of SDC
3) CDH_ANA_DCDC_TEMP – Temperature recorded on DCDC
4) CDH_ANA_DCDC_TEMP – Temperature recorded on the FPGA

HOUSEKEEPING_0X00D – Values used in Calibration from this table:

a. MET – Mission Elapsed Time for the columns in this table
b. CDH_TEMP_SDC_ELEC – Electronics box temperature as recorded by the spacecraft
c. CDH_TEMP_SDC_DET – Detector temperature as recorded by the spacecraft

HOUSEKEEPING_0X00A

1) MET - Mission Elapsed Time for the columns in this table
2) SDC_LVPS_VOLT – Voltage of SDC recorded by the spacecraft
3) SDC_LVPS_CURR – Current of SDC recorded by the spacecraft

THRUSTERS – Values used in this Table

- GC1_DATA_VALID_MET – MET of Thruster Fire

### *13.2.2 Data Sources (High/Low Speed, CCSDS, ITF)*

- GC1_RCS_FIRE_MINOR_1-24 – Tells whether one of the thrusters fired

SDC data are low-speed CCSDS (Consultative Committee for Space Data Systems) packets only.

### *13.2.3 Definition of an "Observation"*

One observation is one collection of events in one CCSDS packet.

### *13.2.4 Housekeeping Needed in Level 1 Files (for Calibration)*

See Section 13.2.1

### *13.2.5 Raw Science Data and/or Housekeeping Requirements*

From launch to the end of the first month, HK packet METs should be within 1 minute of a dust observation

From the end of the first month until Jupiter, HK packet METs should be within 1 hour

From Jupiter until the end of the mission HK packet METs should be within 1 day

For the redundant points, such as temperatures, only one of these needs to satisfy this requirement.

### *13.2.6 Notes about Raw Data*

1) The scale in DN is "backwards" on a 0-65535 scale. In other words, a very large hit represent a number near 0. A small hit registers as a number close to 65535
2) The threshold can be tuned and represents the minimum DN of a detectable hit. HOWEVER, it is possible due to the way the electronics work, that you might get a hit with a slightly higher DN (smaller hit) than the threshold. Usually this is no more than a few tens of DN higher than the threshold.
3) SDC has on-board flight rules for autonomously turning a channel off. The user will then need to know when the channel was on/off. This information is in a separate file named sdc_on_off_times.dat.
4) The maximum number of recorded hits in one second on a given channel for SDC is in general 3. The way the timing works it is possible to get up to 5 hits/second. However, if more than one hit is recorded in one second (instrument wide) this is considered a coincident event and will be flagged. The science processing interprets such an event as s/c noise and removes it.

## 13.3 Calibration

The data calibration is a three-step process:

1. the telemetry is stored as raw DN (Section 13.2, above);
2. each DN value representing the size of a hit is converted into charge (Section 13.3.1, below);
3. each charge is converted into mass via the ground calibration results and an assumed particle velocity (Section 13.3.2, below).

Note that each event (hit) is converted to mass regardless of whether or not it is believed to be noise.

### *13.3.1 Pre-Flight Calibration Procedure- Charge*

In a temperature controlled environment, the electronics from the end of the PVDF to the DN in the raw data were calibrated, at each of 4 calibration box temperatures and for each of the 14 channels. This was done by injecting 19 (actually 21; see below) fixed-amplitude charge pulses 100 times into a channel and recording the DN value each time. From those recorded values, the average DN (DNavg) and its standard deviation (SIG) at each charge pulse amplitude, box temperature and channel were calculated. Then, for each box temperature and channel, a 9th order polynomial fit of Q(DNavg) was derived. Finally, these 3 sets of values (the polynomial coefficients, DNavg, and SIG) were stored in a matrix. This matrix contains all information required to calculate the charge equivalent to a DN as a function of box temperature and channel (detector), as well as the uncertainty in that calculated charge value.

#### 13.3.1.1 Charge Calbration File

In a temperature controlled environment, the electronics from the end of the PVDF to the DN in the raw data were calibrated, at each of 4 calibration box temperatures and for each of the 14 channels. This was done by injecting 19 (actually 21; see below) fixed-amplitude charge pulses 100 times into a channel and recording the DN value each time. From those recorded values, the average DN (DNavg) and its standard deviation (SIG) at each charge pulse amplitude, box temperature and channel were calculated. Then, for each box temperature and channel, a 9th order polynomial fit of Q(DNavg) was derived. Finally, these 3 sets of values (the polynomial coefficients, DNavg, and SIG) were stored in a matrix. This matrix contains all information required to calculate the charge equivalent to a DN as a function of box temperature and channel (detector), as well as the uncertainty in that calculated charge value.

**Pre-Flight Calibration Procedure- Charge ChargeCharge Calibration File**

The calibration file contains the calibration values described above as a matrix of floating point values with dimension (4 X 14 X 3 X 19) representing values for the 4 box temperatures (Tbox), the 14 channels, and the 3 types of calibration values (coefficients, DNavg & SIG). The the zero-based indices have the following meanings:

First Index – 4 Box Temperatures:
 0) 49.9deg
 1) 40deg
 2) 34.25deg
 3) -7.1deg

Second Index – 14 Channels
 0) First channel
 1) Second channel
 ...
 13) Last (fourteenth) channel

Third Index – 3 types of data.
– By setting this index you select which array of values are retrieved via the last index:
 0 – Coeffs - Polynomial fit coefficients (in practice only the first 10 are used)
 1 – DNavg - Average DN recorded during Calibration at this Tbox & Channel
 2 – SIG - Standard deviation of the corresponding average DN value (index = 1)

Fourth Index – Dependent on Third index; see also Note 1 below

- For the coefficients of the polynomial (third index = 0)
  $\log_{10}(Q(DN)) = C_0 + C_1*DN + C_2*DN^2 + C_3*DN^3 + ... + C_9*DN^9$
  - 0) Zeroth order coefficient, $C_0$
  - 1) First-order coefficient, $C_1$
  - N) Nth-order coefficient, $C_n$
- For DNavg & SIG data types (third index = 1 & 2)
  - the index of each charge pulse tests arranged in order of increasing charge (decreasing DN)

Note 1: We injected charge pulses at 21 different values, but some of these were too small to record, and no channel had more than 19 recordable values at any box temperature. Also, there are only 10 coefficients in the 9th-order polynomial. So, although the matrix can hold up to 19 coefficients, average DNs or standard deviations per box temperature and channel, only the derived/recorded values are stored in the matrix, and the any unused matrix values are set to zero. This does not affect the polynomial evaluation, but when using the DNavg and SIG values one should ignore zero values.

Thus from this matrix you can get 3 things: Fit coefficients, Average DNs, and standard deviations.
So, for example, to get the fit coefficients for a box temperature of -7.1 degrees on the first channel you

want (-7.1, first channel, Coeff, *) => CALARRAY[3, 0, 0, *] (IDL notation). See Figure 13-2 for a plot of Charge vs DN represented by the Fit Coefficients.

For detailed information about this calibration procedure see Horanyi, et. al., "The Student Dust Counter on the New Horizons Mission", Space Sci. Rev., in pub., 2007..

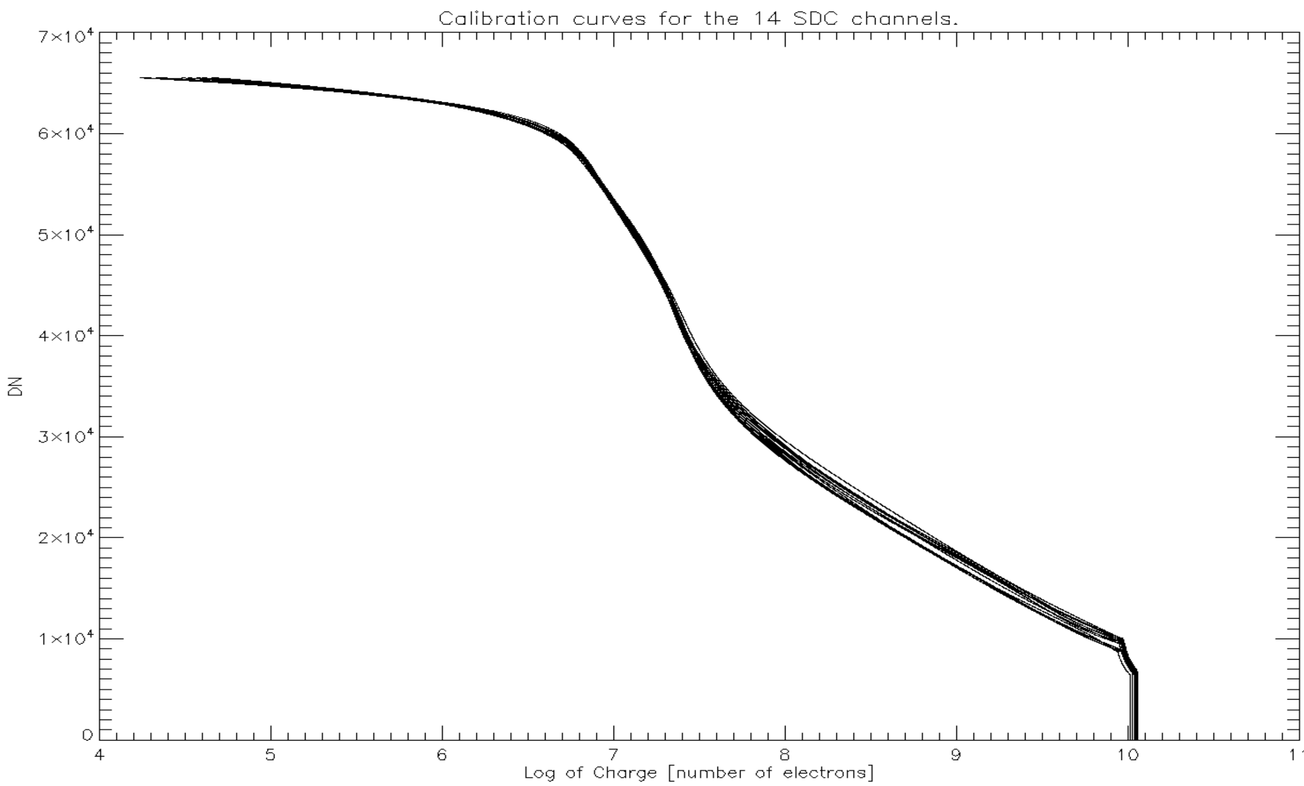



**Figure 13-2: Calibration curves for SDC. All 14 channels are shown for reference.**

### *13.3.2 Calibration – Mass*

#### 13.3.2.1 Pre-Flight and other ground-based calibrations

The mass can be derived from the charge. It was discovered by J.A. Simpson and A.J. Tuzzolino (1985) [S-T] that a particle impacting a 28 μm PVDF film (such as those on SDC) will produce a charge given by the equation:

$$N[e^-] = c \times (m[g])^a \times (v[km/s])^b$$

In this equation N is the charge in equivalent number of electrons, m is the mass in grams, v is the detector-relative particle speed in km/s; see Table 13-1 for constants a, b, and c.

Additional data were considered from tests on flight spare detectors built at the Laboratory for Atmospheric and Space Physics (LASP). Initial ground calibration results updated the constant **c** for the three-parameter model above; James et al., 2010 [JAMESETAL2010] updated all of the constants for the three-parameter model, and also proposed a four-parameter model that includes temperature dependency (T in Celcius; d is another constant in Table 13-1):

$$N[e^-] = (c + d \times T[Celsius]) \times (m[g])^a \times (v[km/s])^b$$

The New Horizons pipeline code switched to using this four-parameter model in 2013, and redelivered past PDS data (Launch and Jupiter mission phases) based on the four-parameter model in 2014.

As of March, 2014, James et al., 2010 [JAMESETAL2010] is available online at ResearchGate.net.

#### 13.3.2.2 Mass Production

On the NH SDC instrument we have two measurements per event: the charge, N[e-]; the temperature of the detector, T[Celsius]. Thus to find either mass or velocity we must assume the other. In the pipeline we assume a Keplerian velocity for the hypothetical dust particle that produced each event, and use that to determine a mass for the event.

Note that each event is converted to mass regardless of whether or not it is believed to be noise.

Thus one can simply use the number of electrons produced and the assumed spacecraft-relative speed of the dust particle calculated through SPICE to determine the mass of the impacting particle.

Rearranging the equation for the four-parameter model above yields

$$m[g] = \{N[e^-] \ / \ ((c + d \times T[Celsius]) \times (v[km/s])^b)\}^{1/a}$$

The New Horizons pipeline code started using this equation in 2013. In 2014 the project redelivered past Launch and Jupiter mission phase SDC data to PDS based on this four-parameter model; see Table 13-1 for constants a, b, c, and d.

#### 13.3.2.3 Constants

| | **Simpson and Tuzzolino three-parameter** | **Initial ground calbrations three-parameter** | **James et al., 2010 three-parameter** | **James et al., 2010 four-parameter** |
|---|---|---|---|---|
| **a** | 1.3 ± 0.1 | 1.3 ± 0.1 | 0.9343 ± 0.0009 | 1.052 ± 0.004 |
| **b** | 3.0 ± 0.1 | 3.0 ± 0.1 | 2.4 ± 0.1 | 2.88 ± 0.06 |
| **c** | $3.8 \times 10^{17}$ | $5.63 \times 10^{17}$ | $(6.7 \pm 0.3.2) \times 10^{12}$ | $(1.2 \pm 0.1) \times 10^{15}$ |
| **d** | 0 | 0 | 0 | $(6.7 \pm 0.3.2) \times 10^{12}$ |

*Table 13-1: Constants for the mass-charge-velocity relationships; Simpson and Tuzzolino, 1985, and James et al., 2010.*

## 13.4 Calibrated Data Specifics

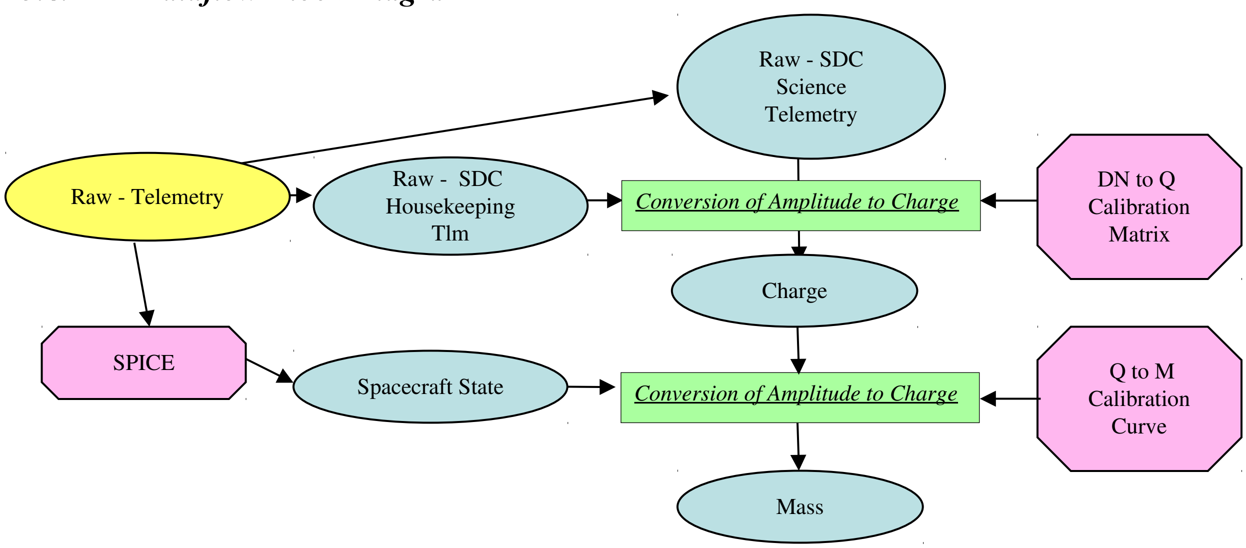
### *13.4.1 Algorithm for Pipeline*

Pre-flight calibration of the electronics box was performed to find the relationship between charge in and

DN out. This was done at 4 electronics box temperatures for all 14 channels. Fits were established from this data and the coefficients were stored in a matrix (see Figure 7 and section 13.3.1 above).

The code for Level 2 data uses the channel number and electronics box temperature to find the correct coefficients in the matrix. These coefficients are then used in a polynomial function, with the raw DN as the independent value, to calculate the corresponding charge, and then converted to mass using the equation the Mass Production equation above. For in-flight box temperatures other than the calibration temperatures represented by the first index of the calibration matrix, the in-flight charge is interpolated (or extrapolated) from the calculated charges using the two nearest calibration temperatures. Finally, in like manner using the standard deviations calibration matrix (SIG), for the nearest DN calibration measurements (DNavg) and nearest two calibration temperatures, as an analog for the 1-sigma combined uncertainty of the calibration charge pulse measurement and of the calibration and in-flight DN measurement, the +/- 1-sigma masses (M_sigplus & M_sigminus) are calculated.

### *13.4.2 Dataflow Block Diagram*




### *13.4.3 Data Format*

The calibrated FITS file consists of science data expressed in units of number of electrons and quality flags for the PVDF detectors. The quality flags signal whether or not any of the housekeeping values were out of the standard operating range when the hit occurred. The quality flags also tell whether or not the data was extrapolated or interpolated from our pre-flight calibration curve.
Note that for scientific convenience in calibrated data, the channels are labeled 1-14 instead of 0-13.

### *13.4.4 Extra FITS Extensions (planes) and Their Definitions*

The two tables in the calibrated FITS file are

1) CALIBRATED_DATA –

   a. UTC Time

b. MET - Time in Mission Elapsed Time (MET)
c. Channel – [1-14]
d. Charge [Number of Electrons]
e. Mass [grams]
f. Mass_Thrsh - The threshold in mass [grams]
g. M_sigplus - Mass Plus sigma [grams]
h. M_sigminus - Mass Minus sigma [grams]
i. Quality_flag - Because we are susceptible to thruster firings (i.e. a thruster fire can cause false hits) a flag has been created to flag events we believe were caused by a thruster..
    i. "OK" – No thruster firings occurred near this event
    ii. "TF" – A thruster firing occurred within 1 second of this event and thus we believe the event was possibly caused by a thruster firing

#### *13.4.5 Scientific Units*

Charge - Number of electrons produced from impact.

Mass – Grams of impacting particle.

#### *13.4.6 Additional FITS and PDS Keywords Added*

#### *13.4.7 Hardware/OS Development Platform*

Intel, Linux or Windows

#### *13.4.8 Language(s) Used*

IDL

#### *13.4.9 Third Party Libraries Required*

JPL Astro Library downloaded from NASA at Goddard.

#### *13.4.10 Calibration Files Needed (with Quantities)*

IDL .sav file consisting of a table for fit coefficients. ( TBD, <1MB )

#### *13.4.11 Memory Required*

TBD

#### *13.4.12 Temporary File System Space Needed*

TBD

#### *13.4.13 Predicted Size of Output File(s)*

Less than 1KB

#### *13.4.14 Predicted Execution time*

A few seconds

### *13.4.15 Contact/Support Person(s)*

Level 1: Andrew Poppe, David James

Level 2: Mihaly Horanyi, David James

### *13.4.16 Maintenance Schedule (Code/Data Updates, Documentation)*

We do have on-board calibration capabilities for the instrument and a place to insert these changes built into the code. Currently this simply multiplies by 1, but it the capability to adjust the values by some specified function remains.