Parker Solar Probe SWEAP SPAN-Ion

Data Release Notes

Roberto Livi	rlivi@berkeley.edu	SPAN-Ion Lead
Ali Rahmati	rahmati@berkeley.edu	SPAN-Ion Data Processing
Davin Larson	davin@berkeley.edu	SWEAP Institutional PI
Justin C. Kasper	jckasper@umich.edu	SWEAP PI

Overview of Measurements

The SWEAP team is pleased to release the Level 3 data from Encounter 1 and Encounter 2, in addition to previously released Level 2 data released from Encounter 1,2, and 3. The Level 3 files contain data from the time range October 31, 2018 - June 18, 2019.

The prime mission of Parker Solar Probe is to take data within 0.25AU of the Sun during its orbit. However, there have been some extended campaign measurements outside of this distance. The data are available for those days that are within 0.25AU as well as those days when the instruments were operational outside of 0.25AU.

Each SWEAP data file includes a set of a particular type of measurements over a single observing day. Measurements are provided in Common Data Format (CDF), a self-documenting data framework for which convenient open source tools exist across most scientific computing platforms. Users are strongly encouraged to consult the global metadata in each file, and the metadata that are linked to each variable. The metadata includes comprehensive listings of relevant information, including units, coordinate systems, qualitative descriptions, measurement uncertainties, methodologies, links to further documentation, and so forth.

SPAN-I Level 2 Release Notes

Version 01

The SPAN-I sensor is mounted behind the Thermal Protection Shield and oriented to maximize the field-of-view from the sun line and spacecraft ram direction. The azimuthal plane (anodes) spans 247.5°in segmented anodes while the deflectors scan +- 60° in elevation. The rotation matrix converts instrument coordinates into the spacecraft frame and can be found in the individual CDF file. This data set covers all periods for which the instrument is turned on and collects data in the solar wind. This includes maneuvers affecting the spacecraft attitude and orientation.

General Remarks for v01

SPAN-I is located behind PSP's Thermal Protection Shield (TPS) and can only observe the partial distribution function of the solar wind. The first 8° closest to the spacecraft z-axis are completely obstructed, meaning that anode 0, which has a 11.25° azimuthal size, is ~70% covered. For encounters 1 and 2 the instrument mostly measured the wings of the solar wind distribution function, with occasional intervals when the full distribution was visible.

When ions travel through the TOF they initially collide with the first set of carbon foils that generate the START signal. The interaction with the carbon foil causes a slight loss in kinetic energy; therefore, ions are measured to travel slower than their expected velocity. This straggling effect is especially noticeable in high flux beams such as Protons, to the point that enough energy is lost to appear within the Alpha product. This issue is addressed for the Alpha channel by subtracting a percentage of the proton channel, since straggling protons appear at the same energy per charge in both channels.

Deviations from the nominal mass peak can occur due to the interactions between ions and the carbon foils. Ghost peaks are generally caused by a delay of a START or STOP signal due to the finite probability of particles penetrating the carbon foil of < 30%. Ions can reflect and generate a delayed secondary electron, and therefore a delayed time-of-flight measurement.

The high voltage sweeps are arranged such that the hemisphere (energy per charge) is held at a constant voltage value (starting with the highest within the series) while the deflectors are swept in one direction. When plotting individual energy spectra a clear hysteresis is observed, where the sweeping of the deflector voltages lags and differs in direction in which it sweeps. This effect will be addressed in future in-flight calibrations.

SPAN-I Level 2 Ion Proton Data Product ("psp_swp_spi_sf00_L2_8Dx32Ex8A_yyyymmdd_v01.cdf")

This data product contains measurements of differential energy flux of protons as a function of elevation, energy, and azimuth and organized into spectra. The SPAN-I instrument measures 3D (partial) distributions with a wide field of view. Please refer to the instrument paper for details.

This data set covers all periods for which the instrument is turned on and collects data in the solar wind in "Full Sweep", normal cadence survey mode. This includes maneuvers affecting the spacecraft attitude and orientation.

SPAN-I Level 2 Ion Alpha Data Product ("psp_swp_spi_sf01_L2_8Dx32Ex8A_yyyymmdd_v01.cdf")

This data product contains measurements of differential energy flux of alphas with proton contamination as a function of elevation, energy, and azimuth and organized into spectra. The SPAN-I instrument measures 3D (partial) distributions with a wide field of view. Please refer to the instrument paper for details.

This data set covers all periods for which the instrument is turned on and collects data in the solar wind in "Full Sweep", normal cadence survey mode. This includes maneuvers affecting the spacecraft attitude and orientation.

CAUTION: The sf01 data product contains contamination from the neighbouring sf00 data product. The contamination is the result of slightly overlapping distributions between the protons and alphas in the time-of-flight measurement. Quantitatively, due to the much higher presence of protons, ~1% of its distribution is present in the sf01 data product along with the alpha population. Data product sf0a contains the sf01 with a 0th order proton removal.

SPAN-I Level 2 Ion Alpha Data Product for Moments ("psp_swp_spi_sf0a_L2_8Dx32Ex8A_yyyymmdd_v01.cdf")

This data product contains measurements of differential energy flux of alphas with the proton contamination subtracted as a function of elevation, energy, and azimuth and organized into spectra. The SPAN-I instrument measures 3D (partial) distributions with a wide field of view. Please refer to the instrument paper for details.

This data set covers all periods for which the instrument was turned on and taking data in the solar wind in "Full Sweep", normal cadence survey mode. This includes maneuvers affecting the spacecraft attitude and orientation.

The sf0a product is derived from the sf01 product, where the proton background has been subtracted. This correction is accomplished by selecting the sf00 data, scaling it by a percentage that is close to the expected leakage (~1%), and then removing it from sf01.

Version 02

The metadata attribute was changed to include the global attribute ‘sw_runtime’. Otherwise there have been no changes relative to version 01.

Version 03

Corrections to the transformation matrix, specifically going from spacecraft to instrument coordinates, are included in the new version.

SPAN-I Level 3 Release Notes

Version 01

The TEMP variable is defined to be the trace of the temperature tensor. Due to the obstruction of the FOV and consequently the partial measurement of the distribution, the TEMP parameter is not ideal and should be used with caution. The Txx and Tzz temperatures are within the FOV of the instrument and are thus reliable quantities. The Tyy temperature suffers from the limited FOV.

SPAN-I Level 3 Ion Proton Moments (“psp_swp_spi_sf00_L3_mom_INST_yyyymmdd_v01.cdf”)

This data product contains the partial moments as derived from the SF00 proton data product. It includes the solar wind parameters of density, perpendicular and parallel temperatures, and the velocity vector. As stated, the solar wind is not fully in the field of view of the instrument, thus the calculated densities are partial and therefore smaller.

SPAN-I Level 3 Ion Alpha Moments (“psp_swp_spi_sf01_L3_mom_INST_yyyymmdd_v01.cdf”)

This data product contains the partial moments as derived from the SF01 alpha data product. It includes the solar wind parameters of density, perpendicular and parallel temperatures, and the velocity vector. As stated, the solar wind is not fully in the field of view of the instrument, thus the calculated densities are partial and therefore smaller.

SPAN-I Level 3 Ion Alpha Moments with subtracted background (“psp_swp_spi_sf0a_L3_mom_INST_yyyymmdd_v01.cdf”)

This data product contains the partial moments as derived from the SF0A alpha data product. It includes the solar wind parameters of density, perpendicular and parallel temperatures, and the velocity vector. As stated, the solar wind is not fully in the field of view of the instrument, thus the calculated densities are partial and therefore smaller.

Version 02

The TEMP variable is now the trace of the temperature tensor **divided by 3**. The temperature tensor itself is unchanged. Additionally, the metadata content was changed to fix the global attribute: "sw_runtime", which now accurately reflects true runtime.

Version 03

Corrections to the transformation matrix, specifically going from spacecraft to instrument coordinates, are included in the new version.

Timeline Remarks By Encounter:

SPAN-I Commissioning

At first turn on, it was discovered that the primary sweep table was corrupted. This was evidenced by the fast housekeeping, which monitors the HV supply, and the resulting failed checksum. This issue was immediately addressed by selecting a backup table to avoid a total loss of data for the first encounter. The backup table has an energy range from 1 keV - 4 keV, resulting in the solar wind beam flowing in and out of the instrument energy scan.

Commissioning of SPAN-I, including its configuration and HV ramping, was limited in time due to spacecraft maneuvers that placed the sun behind the heat shield closely after launch and therefore out of the FOV. The spacecraft did perform a transient slew in order to obtain the solar wind into the FOV of SPAN-I, which lasted ~20 minutes. The test was used to confirm full functionality of the instrument.

SPAN-I Encounter 1

The product spectra SF01, SF02, and SF0A have zeroed out counts for anode 0 during encounter 1. Anode 0 partially faces the TPS and its efficiency is not yet understood.

Subsequent encounters include anode 0 in the full spectra and the user should be aware of this obstruction before computing scientific parameters.

Since the primary sweep table was found to be corrupt during commissioning, the backup table was still employed for encounter as well. This change to the backup table was not recorded by flight software, therefore the MODE_ID has to be corrected on ground retroactively.

SPAN-I Encounter 1 - Cruise Phase

In order to account for the corrupted table, a new energy sweep was uplinked with an energy range from 125eV - 20keV. This allowed the instrument to properly scan the solar wind proton and alpha distributions in energy.

A new product table 08Dx32Ex08A was uplinked that now includes anode 0 (168.5 - 180) within the accumulations. Since anode 0 is partially obstructed by the TPS the energy flux is not yet fully understood within this sector and is approximately a factor of 3 lower. The user is advised to be cautious about computing plasma parameters with products SF00, SF01, and SF0A.

SPAN-I Encounter 2

The telemetry rate was changed for the following products:

SF00 - 27.96 [s] to 6.99 [s]
SF01 - 55.92 [s] to 13.98 [s]
SF0A - 55.92 [s] to 13.98 [s]

AF00 - 1.748 [s] to 0.874 [s]
AF01 - 1.748 [s] to 0.874 [s]
AF0A - 1.748 [s] to 0.874 [s]

SPAN-I Encounter 3

The particle correlator configuration was enabled during this encounter but did not send any counts. A mask bit that determines the origin of the pulse was not set correctly.

SPAN-I Encounter 4

The solar wind distribution was observed to be very slow during this encounter. This is especially helpful with regards to SPAN-Ai's field-of-view, where a slow solar wind has a larger probability of entering the instrument aperture due to the fast spacecraft velocity and their respective aberration.

SPAN-I Encounter 5

No operational changes.

SPAN-I Venus Gravity Assist #3

Implemented a new energy table, emode=8, that increases the energy sweep from 60ev-20keV to 5eV-20keV. This allows for measuring low energy ions in the venusian ionosphere.

SPAN-I Encounter 6

No operational changes.

SPAN-I Encounter 7

No operational changes.

SPAN-I Encounter 8

Implemented a new Mass-Energy table. The boundaries between the 4 different mass products have been adjusted to improve individual ion measurements, specifically for He++ and for higher mass products such as O+ and O2+. The calibration of the new mass-energy table is a combination of solar wind data and venusian ionospheric measurements.

SPAN-I Encounter 9

No operational changes.

SPAN-I Encounter 10

No operational changes.

SPAN-I Encounter 11

Implemented a higher telemetry rate (cadence = 3.5s) for products that contain the backward looking anodes: SF10, SF11, ST10, and ST11. This now matches the telemetry rate of the forward looking anode products (SF00, SF01, ST00, ST01). The Solar Probe spacecraft is now traveling fast enough such that the aberration angle allows for the ion population to be observed

almost entirely in the SPAN-I field-of-view. This results in fluxes (mostly the edge of the distribution function) reaching the backward positioned anodes during passes near perihelion. Originally, the backwards anodes were at a lower cadence since they were mostly filled with 0 counts.

SPAN-I v01 Data Products Remarks

The data quality flags for the SPAN data can be found in the CDF files in the variable named QUALITY_FLAG, which is a byte-type variable with each bit indicating:
Bit 1: Counter Overflow
Bit 2: Snapshot On
Bit 3: Alternate Energy Table
Bit 4: Spoiler Test
Bit 5: Attenuator Engaged
Bits 6-8: Reserved
Apart from Bit 5 (instrument mechanical attenuator engaged), when any of the other bits are set, the data quality may be reduced.

SPAN Level 2 Ion Data

psp_swp_spi_sf00_L2_8Dx32Ex8A_YYYYMMDD_v01.cdf (SPI Proton 3D spectra)
psp_swp_spi_sf01_L2_8Dx32Ex8A_YYYYMMDD_v01.cdf (SPI Alpha 3D spectra)
psp_swp_spa_s0a_L2_8Dx32Ex8A_YYYYMMDD_v01.cdf (SPI Alpha Moments 3D spectra)

SPAN Level 3 Ion Data

psp_swp_spi_sf00_L3_mom_INST_YYYYMMDD_v01.cdf (proton moment)
psp_swp_spi_sf01_L3_mom_INST_YYYYMMDD_v01.cdf (alpha moment)
psp_swp_spi_sf0a_L3_mom_INST_YYYYMMDD_v01.cdf (background subtraction)

SPAN-I v02 Data Products Remarks

ROTMAT_SC_INST matrix is included in order to rotate spacecraft coordinates into instrument coordinates.

SPAN-I v03 Data Products Remarks

The transformation matrix, ROTMAT_SC_INST, which transforms spacecraft coordinates to instrument coordinates was changed from row-major to column-major, effectively transposing the matrix.

The QUALITY_FLAG is changed to a two-byte unsigned integer with the following updated contents:
Bit 0: Counter Overflow
Bit 1: Survey Snapshot ON (not applicable to archive products)
Bit 2: Alternate Energy Table
Bit 3: Spoiler Test
Bit 4: Attenuator Engaged
Bit 5: Highest Archive Rate
Bit 6: No Targeted Sweep
Bit 7: SPAN-Ion New Mass Table (not applicable to electrons)
Bit 8: Over-deflection
Bit 9: Archive Snapshot ON
Bits 10-15: Reserved.

SPAN-I v04 Data Product Remarks

The time variable within the packet has been changed and now refers to the middle of the accumulation period. In prior versions (v03 and below) it referred to the beginning of the measurement.

We are now including ion and spacecraft velocities in RTN coordinates. The ion velocities can now be adjusted by subtracting the spacecraft velocity from them. The list below outlines all the new variables that are now included in the CDF v04 files. There are also a few variables that changed their name:

Variables were added to the CDF file:
VEL_SC - Spacecraft Velocity.
VEL_RTN_SUN - Ion Velocity in RTN coordinates.
SUN-DISTANCE - Distance from the Sun.
VENUS-DISTANCE - Distance from Venus.
SC_VEL_RTN - Spacecraft Velocity in RTN coordinates.
QUAT_SC_TO_RTN - Quaternion rotation of spacecraft in RTN coordinates.

Renamed the following variables:
vel - vel_inst
t_Tensor - t_Tensor_inst

The QUALITY_FLAG has 4 additional bits (Bits 10-14):
Bit 0: Counter Overflow
Bit 1: Survey Snapshot ON (not applicable to archive products)
Bit 2: Alternate Energy Table
Bit 3: Spoiler Test
Bit 4: Attenuator Engaged

Bit 5: Highest Archive Rate
Bit 6: No Targeted Sweep
Bit 7: SPAN-Ion New Mass Table (not applicable to electrons)
Bit 8: Over-deflection
Bit 9: Archive Snapshot ON
Bits 10-15: Reserved.
Bit 10: Bad energy table
Bit 11: MCP Test
Bit 12: Survey available
Bit 13: Archive Available

SPAN-I Uncertainty Statement

The SWEAP team recognizes that the SPAN-I data products were calibrated based on a simulated geometric factor. Further ground-based and in-flight calibration efforts are in progress, and we thank you for your patience as we resolve more accurate uncertainties in the data set. Assuming the instrument has sufficient field-of-view (FOV), our current estimates of the systematic[2] uncertainties are:

L3 sf00 data products (moments)
Density: 25-30 %
Temperature: 10-15 %
Velocity: 3 %

L2 sf00 data products (counts/fits)
Energy: 3 %
Phi: 10 Degrees
Theta: 6 Degrees

Velocity distribution function (VDF) fits obtained from L2 sf00 products should be treated with caution, and we recommend informing a member of the SPAN-I instrument team[3] of your study before use. In general, a qualitative assessment of the macroscopic trends of the VDF may be valid on a case-by-case basis to support your science questions, whereas more quantitative analysis that relies on kinetic-scale assumptions must be treated with extra caution.

A quality flag for indicating adequate SPAN-I FOV coverage is in progress. Note that measurements made outside of sufficient SPAN-I FOV periods could have uncertainties in the moments by up to 50%.

Other uncertainties based on both random (counting statistics, etc) and systematic error (MCP

efficiencies, etc) relies on a significant calibration effort, which is ongoing work.

SWEAP Science Working Group

For a further discussion of the scientific uses of the data please join the Parker Solar Probe Working Group which will meet Tuesdays and run for 2 hours starting November 19. Call in information and times will be posted on the SWEAP and FIELDS website prior to the meeting. Announcements will also be made in SPA and Solar newsletters.

Contacts

For science questions related to the SPAN-Ion measurements, contact the Instrument Lead, Roberto Livi (rlivi@berkeley.edu), or Davin Larson (davin@berkeley.edu).