function of E/q, integrated over incident angles, TOF, and Energy. Includes full counts of events subject to decimation. Sensor rates also include two coincidence rates, the number of events with a valid TOF and energy (triple coincidence), and a count of those with only a valid TOF (double coincidence). These rates are primarily used to evaluate the performance of the instrument, rather than for science. In particular, they can be used for calculation of ion detection efficiency inflight (von Steiger et al. 2000);

– Decimation Rates: Counts of ion event words in each of three decimation ranges as a function of E/q. In order to reduce the on-board processing load caused by light ions and low-TOF noise sources, only a fraction (1 in N) of those events are transmitted to the SWA-HIS C&DH board from the HV bubble. Separate decimation ranges in E/q and TOF are included for alpha particles, protons, and low-TOF events caused by accidental coincidences. The fraction transmitted is commandable, from typically one in four for alphas to zero for low-TOF noise events;

– Matrix Rates: Counts of ion event words within a specified Energy-TOF range, classified and counted onboard, for each E/q step. These are summed over incident angle. SWA-HIS has 32 such species boxes intended to roughly select counts of ion event words measured for particular ion species. Classification transforms E/q, TOF, and residual energy into the two dimensions of Energy and TOF. Classification is primarily used for other data products (below and in low-latency). This data product is not in telemetry for most instrument data rates. If resources allow, He^{2+}, C^{4-6+}, O^{6-7+}, and Fe^{10+} ions may be included. Additional ions and charge states may be produced according to science needs and as counting statistics allow;

– Rate-Based VDFs: Counts of ion event words for a set of ions subdivided by E/q, elevation, and azimuth. The selection of ions will include He^{2+}, C^{5+}, O^{6+}, and Fe^{10+}. Additional ions and charge states may be produced according to science needs and as counting statistics allow. Since these counts are not subject to the effect of the priority sampling algorithm, they represent the best possible statistics. However, because species are separated simply by boxes and no peak overlap removal is performed (see below), the counts are not as accurately assigned to a given species as they would be if formed on the ground, especially for lower abundance heavy ions;

– Engineering and calibration data.

4.4.3. SWA Level 2 data

We define SWA L2 data products as those that have been fully processed and calibrated such that parameters have physical units and are in a common, scientific frame of reference. These are intended as the primary science quality data sets from the SWA project, and the intention is to release these products to the open Solar Orbiter Mission Archive at 90 days after the receipt of the corresponding telemetry from the spacecraft, consistent with the requirements of the mission Science Management Plan. The validation of some L2 data products requires information from other instruments on the spacecraft (e.g. the spacecraft potential measure from RPW and the B-field unit vector from MAG) or extended periods of data taking to validate calibration parameters (e.g. for very low flux heavy ion populations) which may compromise science quality at 90 days and necessitate later updates to the data products.

All SWA L2 data products will be placed, with appropriate metadata, within CDF files according to the format specified in "SOL-SGS-TN-0009 Metadata Definition for Solar Orbiter Science Data". The L2 files from all three SWA sensors will be collected and stored in the SWA master repository at UCL MSSL, along with the auxiliary data generated from the mission. These data files will be submitted to the official ESA Solar Orbiter Archive, from where they will be shared with the NASA Space Science Data Coordinated (NSSDC) archive and the CDPP data archive in France. These files may also be converted by the UCL MSSL team to appropriate format (e.g. NetCDF format to fit the AMDA tool specification) as requested by the archives.

In the remainder of this subsection we provide an overview of the SWA L2 data products that we expect to be readily available from the archive and suitable for science purposes. Full details can be found in SWA technical documentation, particularly the SWA Data Product Definition Document (SO-SWA-MSSL-IF-006).

SWA-EAS L2 data. The Operations team at UCL MSSL is responsible for generating SWA-EAS L2 data. The generation of the full set of SWA-EAS L2 data products from the L0 data products depends a number of sources of auxiliary information including:

– SWA-EAS ground calibration files held at UCL MSSL;

– SWA-EAS flight calibration files, regularly updated during the mission from ESA L0 engineering and calibration data and held at UCL MSSL;

– Spacecraft orbit and attitude information files (e.g. SPICE kernels) available from the SOC;

– Spacecraft potential data associated with each set of SWA-EAS moment calculations (i.e. at 4 s cadence), provided by the RPW instrument;

– Magnetic field direction associated with each SWA-EAS burst mode sample (i.e. at 0.125 s cadence), provided by the MAG instrument.

The set of SWA-EAS L2 data products includes the following primary scientific outputs:

– Onboard moments: A complete set of 14 parameters comprising the best estimation of the moments of the electron velocity distribution (i.e. density, bulk velocity vector, components of the pressure tensor, heat flux vector, and including total counts in the distribution) available from the onboard-generated L1 moments data. This product is available for periods in which the SWA-EAS sensors are in normal mode, and will be provided in physical units and in a relevant heliospheric reference frame. This product will be produced by appropriately combining the L1 partial moments data from each sensor including reference to the spacecraft potential from RPW in order to minimise the effect of spacecraft charging and presence of photo- and secondary electrons of spacecraft origin. The data product will be available at 4 s time resolution;

– Full 3D electron distributions: Electron distributions expressed as a VDF, differential energy flux, and differential number flux provided with appropriate physical units and in a relevant heliospheric reference frame. These distributions are produced by appropriately combining spectra from the two sensors, taking into consideration those parts of the FoV which have an overlap between the two SWA-EAS sensors. In their fullest form these data products will cover the energy range 1 eV−5 keV in 64 energy steps, and with the two orthogonally-mounted sensors each covering ±45° and ±180° in elevation (in 16 steps) and azimuth (in 32 steps), the combined system is capable of covering more than the full 4π steradian FoV. Measurements at low energy steps contaminated by photo- and secondary electrons will be replaced by fill values, as well as angular bins which may have been affected by a blockage to arrival electrons by the spacecraft and its appendages. These products are available for periods in which the SWA-EAS sensors are in normal mode. The nominal time resolution for these data products is 100 s, although they can be made available with 10 s resolution when the spacecraft is relatively close to the Earth and higher than average telemetry rates can be made available. Conversely, these products may only be available at 400 s resolution during periods when the project needs to limit overall telemetry below the baseline allocation to instruments;

– Ground moments: A complete set of 14 parameters comprising the ground-calculated moments of the electron VDF (i.e. density, bulk velocity vector, components of the pressure tensor, heat flux vector, and including total counts used to derive the distribution). This product is generated from the normal mode combined 3D electron distributions following calibration and correction for the spacecraft potential derived from RPW data. These data products will have two variants, the moments resulting from both a direct moment summation across the corrected and validated full 3D VDF and, where appropriate, a fit to a model core, halo, and strahl distribution. This product is again available for periods in which the SWA-EAS sensors are in normal mode, and will be provided in physical units and in a relevant heliospheric reference frame. It will be generated on the same resolution as the available 3D VDF's (i.e. nominally at 100 s time resolution, but with variants at 10 s and 400 s depending on telemetry rates);

– Trigger Mode distributions: Full 3D electron distributions derived from L0 data captured and telemetered to ground in response to a freeze of the internal SWA rolling memory buffer following the receipt and acceptance by the SWA-DPU of an appropriate trigger flag via the S20 inter-instrument communications link from RPW. This "trigger mode" data product will be assembled in the same way as the normal mode full 3D distributions functions discussed above (i.e. combined data from both sensors) but will be available at 1 s cadence for a period of 5 min per triggered event. As for the normal mode distributions, these data will be available in appropriate physical units expressed as a VDF, a differential energy flux, and a differential number flux, each in a relevant reference heliospheric frame.

– Trigger Mode Moments: These moment parameters are calculated on the ground in the same way as the "Ground Moments" described above, but are derived from the combined trigger mode VDF's following calibration and correction for the spacecraft potential derived from RPW data. They will thus be available at 1 s time resolution over the trigger mode periods of 5 min per event accepted by the SWA-DPU;

– Burst mode electron pitch angle (2D) distributions: SWA-EAS data collected in burst mode, comprising two full azimuth scans from two elevations from one sensor, will be rebinned into pitch angle space on the ground with reference to the validated magnetic field unit vector. The resulting 2D electron pitch-angle distributions thus will be delivered in physical units (in distribution function, differential energy flux, and differential number flux formats), and in a frame defined by the magnetic field direction. The data product can contain up to 64 energy bins and 64 pitch angle bins, although these will likely be reduced in size by removing energy bins contaminated by photo-electron fluxes and combining the individual pitch angle measurements into a regular set of pitch angle bins. The time cadence of this product is 0.125 s, and it will generally be available for limited periods (average of less than 12 min per day) due to telemetry constraints. Longer periods may be available during enhanced telemetry periods or by reducing the duty cycle and combining available burst mode periods over a longer period of time;

– Single energy angle-angle electron distributions: This data product is equivalent to the ground validated and enhanced SWA-EAS low-latency data product (see Sect. 4.4.5). It is available for periods in which the sensor operates in normal mode, and contains a full angular distribution (i.e. combined data from both sensors) for a single energy bin, usually chosen in the range expected for the solar wind strahl population. The data product will be made available in physical units (in distribution function, differential energy flux, and differential number flux formats), and in a relevant heliospheric frame. The raw L0 data forming the corresponding low-latency product is only available at a time resolution 100 s. However, given the operation of the sensor to capture that product between measurements of the normal mode VDF's the ground produced L2 version of this product will usually be available at 50 s time resolution or better;

SWA-PAS L2 data. The SWA operations team at IRAP, Toulouse, is responsible for generating SWA-PAS L2 data. The generation of the full set of SWA-PAS L2 data products from the L0 data products depends a number of sources of auxiliary information including:

– L0 data products;

– SWA-PAS ground calibration files;

– SWA-PAS flight calibration files (Obtained from L0 data);

– Spacecraft orbit and attitude information files (e.g. SPICE kernels);

The set of SWA-PAS L2 data products includes the following primary scientific outputs from the SWA-PAS sensor:

– Full and reduced 3D ion distributions: Ion distributions expressed in scientific units (as differential fluxes and as VDFs), and in a relevant physical frame (e.g. the solar-ecliptic frame). These data are available from periods of normal mode operation, usually with 4 s time resolution;

–Snapshot mode fast 3D ion distributions: Ion distributions obtained during periods of snapshot operation expressed in scientific units (as differential fluxes and as VDFs), and in a relevant physical frame. Snapshot mode measurements are made at a cadence of one distribution per second over a period of 7 s, recurring every 300 s during normal mode operation;

– Burst Mode fast 3D ion distributions: Ion distributions obtained during periods of burst mode operation expressed in scientific units (as differential fluxes and as VDFs), and in a relevant physical frame. SWA-PAS burst mode measurements can be made at a variety of cadences (extending down into the sub-second range) depending on the trade-off between time and angular or energy resolution. The duration of the burst mode period is variable, depending on available telemetry, but will generally occur in 5 min periods. Details of the operation for a given burst mode interval will be included in the meta-data for the data product.

– Ground-calculated H^+ moments: The 3D ion distributions will be appropriately processed on the ground to produce moments (density, bulk velocity, pressure tensor) for the proton component of the solar wind captured by SWA-PAS. Data will be in scientific units in an appropriate physical reference frame, and will generally be available with 4 s cadence;

– Ground-calculated He^{2+} moments: As above for protons, but separating out the moments for the alpha particle component of the solar wind capture by SWA-PAS;

– Onboard-calculated Moments: This data product is essentially the ground-validated SWA-PAS low-latency data product (see Sect. 4.4.5). It is provided for reference, but essentially

Table 9. SWA-HIS Level 2 derived data products in physical units.

Data product	Time resolutions (1)
Ion event (PHA) words	30 s, 300 s, 4 s (2)
E/q (keV/e)	
Elevation and azimuth (deg)	
Time-of-flight (ns)	
Total energy (keV)	
Priority range	
Decimation range	
Sensor rates (flux)	30 s, 300 s, 4 s (2)
Start	
Stop	
SSD	
Double coincidence	
Triple coincidence	
Normalisation rates	30 s, 300 s, 4 s (2)
Decimation	
Priority	
Matrix rates (3)	30 s, 300 s, 4 s (2)
He^{2+}	
C^{4-6+}	
O^{6-7+}	
Fe^{10+}	
Rate-based velocity distributions (3)	
He^{2+}	30 s, 300 s, 4 s (2)
C^{5+}	30 s, 300 s, 4 s (2)
O^{6+}	30 s, 300 s, 4 s (2)
Fe^{10+}	30 s, 300 s, 4 s (2)

Notes. (1)These are the possible time resolutions. For some periods in the solar wind, the highest time-resolution will not provide data with sufficient statistical accuracy. The best, most scientifically useful averaging intervals will be determined ground analyses of the counting accuracy achievable. (2)Data at this resolution corresponds to SWA-HIS Burst mode, which can only be run on average 1% of the time due to telemetry constraints. (3)Data product not included for most telemetry rates.

is superceded in terms of quality by the ground-calculated moments described above.

SWA-HIS L2 data. The SWA operations team at UMich is responsible for generating SWA-HIS L2 data. The generation of the full set of SWA-HIS L2 data products from the L0 data products depends a number of sources of auxiliary information including:

– L0 data products;

– SWA-HIS ground calibration files;

– SWA-HIS flight calibration files (Obtained from L0 data);

– Spacecraft orbit and attitude information files (e.g. SPICE kernels);

The set of SWA-HIS L2 data products is summarised in Table 9 and includes the following primary scientific outputs from the SWA-HIS sensor:

– Ion event (PHA) words: Full information about measured ion events, including E/q, TOF, energy, and incident angles (elevation and azimuth) in physical units. These are the primary science data product from SWA-HIS, and make up the bulk of SWA-HIS telemetry volume in normal and low cadence modes;

– Priority rates: Total counts of ion event words in each priority range, divided by E/q and elevation angle bin. (Duplicate of L1 version). These rates are used to correct the weighting of telemetered ion event words for the effect of the sampling algorithm. For example, if the priority rate for a given E/q step and elevation bin is ten, but only five of these ion event words were included in telemetry, then each counts for two in further processing;

– Sensor rates: L1 sensor rates converted to differential number flux units, $(cm^2\,s\,sr\,keV)^{-1}$;

– Decimation rates: Duplicate of L1 version since conversion to flux units is not useful;

– Matrix rates: L1 Matrix Rates converted to number flux units, $(cm^2\,s)^{-1}$;

– Rate-based VDFs: L1 Rate-Base VDFs converted to differential number flux units, $(cm^2\,s\,sr\,keV)^{-1}$.

4.4.4. SWA Level 3 data

It is anticipated that during the course of the mission the primary science data products, as represented by the SWA L2 data products submitted to the archives and discussed above, will be supplemented by the creation of higher order, or Level 3, SWA data products. These products may arise either through further reduction of the L2 products or perhaps through further combinations of data products either within the SWA suite or with other instruments on Solar Orbiter. For SWA-EAS and SWA-PAS, possible examples of this might include SWA-EAS PADs generated from the Trigger Event 3D distributions with reference to the magnetic field direction (providing a cadence of 1 s for a 5 min period), or electron or ion moments calculated over narrower energy ranges, etc.

In the case of SWA-HIS, the most accurate and scientifically useful data products are formed via a peak overlap removal algorithm to assign counts to individual ion species in ground processing (von Steiger et al. 2000; Shearer et al. 2014). This algorithm uses a forward model to predict the peak centre location of each of the >75 analysed ions in TOF – energy space at each E/q step. This forward model, which includes estimated peak width as well as centre, is developed from ground calibration and in-flight accumulated data. A set of two-dimensional Gaussian curves is formed from these centres and widths and provides an initial estimate of count vectors assigned each species. A maximum-likelihood estimation (MLE) method then shuffles counts among these vectors to remove overlap in the statistically optimal way. Events at each pair of incident angle bins are processed independently to preserve distributions in these dimensions. Count vectors from all angle bins are then recombined and converted to phase-space density ($s^3\,km^{-6}$) to form 3D VDFs. Moments of density, velocity, and temperature are then computed from these VDFs and used to produce the following data products from SWA-HIS (see Table 10):

– Elemental abundances: This data product contains the sum of all ion densities for a particular element provided as a ratio to those of oxygen;

– Ionic charge states: Density ratios for specified ion pairs or average charge states, computed as density-weighted average;

– Charge state distributions: Normalised distribution of all charge states analysed for a specified element;

– Kinetic properties: Moments of VDFs for specified ions. This data product includes the density (cm^{-3}), bulk velocity ($km\,s^{-1}$), and temperature (K) for the specified ions;

– Velocity distributions: Phase space density ($s^3\,km^{-6}$) of the specified ions in instrument frame, binned according to speed and incident angles (elevation and azimuth).

Table 10. SWA-HIS Level 3 derived data products in physical units.

Data product	Time resolutions [1]
Elemental abundances	
Fe/O	30 s, 300 s, 4 s [2]
C/O	30 s, 300 s, 4 s [2]
He/O	30 s, 300 s, 4 s [2]
Mg/O	30 s, 300 s
Si/O	30 s, 300 s
Ne/O	30 s, 300 s
S/O	>300 s [2]
N/O	>300 s
Ionic charge states	
O^{7+}/O^{6+}	30 s, 300 s, 4 s [2]
C^{6+}/C^{4+}	30 s, 300 s, 4 s [2]
C^{5+}/C^{4+}	30 s, 300 s, 4 s [2]
$\langle Q_O \rangle$	30 s, 300 s, 4 s [2]
$\langle Q_C \rangle$	30 s, 300 s, 4 s [2]
$\langle Q_{Fe} \rangle$	30 s, 300 s, 4 s [2]
Ionic charge state distributions	
$Q_i(O)$, $i = 5, \ldots, 8$	30 s, 300 s
$Q_i(C)$, $i = 4, \ldots, 6$	30 s, 300 s
$Q_i(Fe)$, $i = 6, \ldots, 20$	30 s, 300 s
$Q_i(Si)$, $i = 6, \ldots, 12$	30 s, 300 s
$Q_i(Ne)$, $i = 8, \ldots, 10$	30 s, 300 s
$Q_i(Mg)$, $i = 5, \ldots, 12$	30 s, 300 s
$Q_i(N)$, $i = 5, 6$	30 s, 300 s [3]
$Q_i(S)$, $i = 6, \ldots, 14$	30 s, 300 s [3]
Bulk properties (n, v_{bulk}, T)	
He^{2+}	30 s, 300 s, 4 s [2]
C^{5+}	30 s, 300 s, 4 s [2]
O^{6+}	30 s, 300 s, 4 s [2]
Fe^{10+}	30 s, 300 s, 4 s [2]
Velocity distributions [4]	
He^{2+}	30 s, 300 s, 4 s [2]
C^{5+}	30 s, 300 s, 4 s [2]
O^{6+}	30 s, 300 s, 4 s [2]
Fe^{10+}	30 s, 300 s, 4 s [2]

Notes. [(1)]These are the possible time resolutions. For some periods in the solar wind, the highest time-resolution will not provide data with sufficient statistical accuracy. The best, most scientifically useful averaging intervals will be determined by ground analyses of the counting accuracy achievable. [(2)]Data at this resolution corresponds to SWA-HIS Burst mode, which can only be run on average 1% of the time due to telemetry constraints. [(3)]These elements are more difficult to resolve. Appropriate time resolutions will be determined in flight. [(4)]Additional charge states may be produced during periods of high counting statistics.

It is expected that some elements of the processing or analyses of the SWA sensor data will in time become routine. In such cases, the SWA operations teams will include these in the SWA processing pipelines and the results will be stored in the master SWA archive at UCL MSSL and submitted to the archives with the corresponding level 2 data.

4.4.5. SWA low-latency data

The Solar Orbiter project reserved a small amount of telemetry within the download budget for priority download of a subset of the data from each of the instruments on board the spacecraft. These data are downloaded from the instrument packet stores with priority second only to the house-keeping data. It is thus anticipated that these data would also normally be available immediately after the ground station pass following their acquisition, and thus with a latency which will generally be low in comparison to that of the full, regular instrument data set for the same observing period. For this reason, the volume of such low-latency data generated by each instrument is very limited ($\sim$1 Mbyte day^{-1}), corresponding to a maximum of $\sim$100 bits s^{-1} within each instruments telemetry stream.

The primary purpose of the low-latency data is to aid in the "last-minute" pointing of the remote sensing instruments on the platform, although there are also obvious benefits to instrument operation to have visibility of the science data production with short turn-around times. However, this also has potential uses as a "space weather beacon" data set, and indeed to provide some context for early identification and assessment of periods of potentially high scientific interest (e.g. for those instruments that may wish to use a selective data download capability). Given these "fast-turnaround" functions, the low-latency data from SWA will be produced immediately after receipt of the telemetry by an automated pipeline within a virtual machine which has been delivered to the ESA SOC. It will be made available immediately to the community through the Solar Orbiter archive.

The specific SWA low-latency data products that, at the time of writing, are intended to be made available are described below:

SWA-EAS. Following acquisition of a full 3D VDF from the two SWA-EAS sensor heads, the SWA-DPU will, with 100 s cadence, select a single (ground-commandable) energy level and extract all electron counts from all angular bins for both heads. The resulting data (2 heads × 32 azimuths × 16 elevations × 1 energy × 2 byte words compressed by factor 4 every 100 s ~ 43 bits s^{-1}) will be added to the SWA low-latency telemetry stream. In flight it is intended that the SWA-DPU will select an energy in the range which generally isolates the strahl population in the solar wind, and thus has been termed "single (strahl) energy distribution". Thus after processing by the SOC virtual machine, this low-latency data product should indicate the presence (or not) of narrow beams directed parallel or anti-parallel to the magnetic field direction, which provides key information indicating the nature of the connection of the magnetic field line passing through the spacecraft location to the Sun. We note also that this data product will be derived from a full 3D distribution measurement that otherwise would not fall in the downloaded normal mode data (see below). Thus this SWA-EAS single (strahl) energy distribution product will be offset by 50 s from the 100 s cadence full 3D data product. This is in order to avoid duplication of telemetered data and to allow subsequent on-ground data processing to generate an equivalent data product at twice the cadence (~50 s). The data product can only be generated while the SWA-EAS sensor is in normal mode.

SWA-PAS. From the SWA-PAS normal mode measurements, the SWA-DPU will calculate on board a set of proton and alpha particle moments every four seconds. These SWA-PAS moments will consist of a single density value, a 3-element velocity vector, and a 9-element pressure tensor, which will be added to the SWA low-latency telemetry stream, where they typically require ~46 bits s^{-1}. This data product will regularly provide the community with near-immediate (<1 day delay) context of the solar wind conditions (fast or slow stream, etc.) at the spacecraft.

SWA-HIS. SWA-HIS will contribute four items to the low-latency telemetry stream, one charge state ratio, one elemental abundance ratio, and two rate spectra. The charge state and elemental abundance ratios will be on-board computed versions of those described in the L3 data products (above). The rate spectra will be selected from one of the sensor or matrix rates. These data, normally containing a total of 131 8-bit words, will be sent every 300 s, contributing 4 kbps to the telemetry stream, including packet overhead (although an option for 30 s cadence is available). These can be used for payload-wide science planning and end-to-end instrument health monitoring. Charge state and elemental abundance ratios enable monitoring of solar wind type (slow, fast, shock) and baseline tracking of structures in the solar wind, while the rate spectra are a valuable measure of the plasma environment and the correct end-to-end operation of the SWA-HIS sensor.

5. Summary and conclusions

The SWA instrument is a suite of scientific sensors on-board Solar Orbiter that is designed and developed to measure the thermal and suprathermal charged particle populations in the inner heliosphere. SWA is comprised of three distinct sensor systems, plus a coordinating SWA-DPU, or electronics box, which together will make key measurements of electron, protons and alpha particle, and heavy ion populations arriving at the spacecraft location. Details of the sensor designs and characteristics have been summarised in this paper: SWA-EAS is located in the spacecraft shadow at the end of the boom, and is capable of detecting electrons arriving from all directions (except those blocked by the spacecraft or its appendages) across the energy range of 1 eV to ∼5 keV. The SWA-PAS samples protons and alpha particles with energies in the range 0.2−20 keV/e arriving from within a few tens of degrees of the solar direction. Given the ratio of the solar wind bulk flow speed to the proton thermal speed, this FoV through a cut-out in the spacecraft heat shield is sufficient to capture the full distribution of arriving particles under most expected circumstances. The SWA-HIS samples and categorises heavy ions (masses from He to Fe) with energies in the range <0.5−100 keV/e, also arriving from within a few tens of degrees of the solar direction. The sensor is also located behind the spacecraft heat shield with a FoV extending through a cut out in one corner. Finally, the SWA-DPU provides all sensor commanding and control functions, power supply, and data processing for SWA-EAS and SWA-PAS and data communications from all sensors to the spacecraft SSMM, as well as monitoring sensor operations and health.

The broad range of operating modes and data products expected from the suite of sensors have also been described in this paper. Normal mode data products, including electron on-board-calculated moments and proton and alpha particle velocity distributions, are expected to be available on a time cadence of 4 s. Electron velocity distributions and heavy ion composition and charge state information will generally be available at a lower cadence (normally ∼100 s and ∼300 s respectively, due to telemetry restrictions or expected count rates), but each of these data products is expected to make a key contribution to the scientific objectives of the mission. In particular, SWA has a critical role in establishing the links between measurements made by the in situ instruments on the spacecraft and those remote sensing instruments observing potential source regions of the solar wind, either through establishing solar wind speed by which to map solar wind streamlines back to the Sun, through comparison of ion composition and FIP information to verify connections, to the presence of electron strahl to establish magnetic connections to the Sun. Moreover, the SWA sensors will operate in several possible burst modes and triggered modes (at sub-second cadences for SWA-EAS and SWA-PAS and down to 4 s for SWA-HIS) which will provide unique inputs to mission goals that focus on solar wind kinetics, turbulence, and the nature of relatively small-scale structures.

In all cases, the SWA sensors, as delivered to the spacecraft, meet or exceed the performance requirements originally set out to achieve the mission science goals. The successful operation of the SWA sensors throughout the course of the Solar Orbiter mission will result in the provision to the solar and heliospheric science community of unique data products revealing the nature of the solar wind depending on both heliocentric distance and solar latitude. The SWA data will underpin efforts to link the in situ measurements of the solar wind made at the spacecraft with remote observations of the candidate source regions. This will lead to very significant advances in our understanding of the mechanisms accelerating and heating the solar wind, driving eruptions and other transient phenomena on the Sun, and controlling the injection, acceleration and transport of the energetic particles in the heliosphere.

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