UVIT Pipeline Cookbook

(version 'v4' : 02-Nov-2017);

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This write up provides the most crucial information for any user of UVIT to run the UVIT Pipeline, while more details are available in a separate Manual. An additional document provides details for installing the entire software package (& two related databases - calibration & star_catalogue).
[All these can be downloaded from : ftp://wm.ncra.tifr.res.in/swarna/]

The purpose of the UVIT Pipeline is to generate sky images in UltraViolet (NUV & FUV) after correcting for known systematic effects (instrument effects, spacecraft drifts, jitters, thermal effects, etc). This needs to be achieved with best recoverable angular resolution and aspect. The instrument effects include : variations of response over half-degree field of view, distortions introduced by the detectors & optic assembly of the telescopes. The spacecraft drift is extracted from sky images taken every 1 second by the optical channel (VIS). In case VIS images are not available, then accumulated photons detected in the NUV channel (every 2-3 seconds) are used to generate instantaneous sky images. These successive NUV images are used to extract the spacecraft drift - albeit success critically depends on availability of bright NUV stars in the field.

The pipeline can also discard frames which have abnormally large counts of events due to Cosmic ray showers. As the spacecraft pointing drifts with time, edges of the UVIT field get lesser exposure and this has been be corrected for in the final images giving Counts/Sec.

The activities described above, are implemented via 3 data processing chains [viz., Relative Aspect Series (Integration Mode) “RA_IM”; Relative Aspect Series (Photon Counting Mode)“RA_PC”; & Sky Imaging (Photon Counting Mode) “L2_PC”]. A top level driver module ("UVIT_DriverModule") calls these chains sequentially to process each observation (sub/orbit) one at a time. Typical operations on a single dataset involve a combination of RA_IM (using VIS, to extract drift), followed by 2 independent runs of L2_PC (once each for NUV & FUV). In case, VIS is not available at all for a specific sub/orbit data, the sequence changes to : RA_PC, L2_PC (NUV) & L2_PC (FUV). Please note that in case partial time overlap exists between VIS & UV data, then only that overlap part of the data are used to generate the final UV sky image products. In situations when the VIS overlap is a very small fraction of the UV exposure, then the user has the choice to “force” the drift extraction using NUV data only.

The automated driver module ("UVIT_DriverModule") takes input data for many orbits for a target and in addition to generating products for each individual datasets (sub/orbit), also combines images from different datasets corresponding to identical Filter & Window size (since this step involves aligning bright point sources detected in the UV images from individual orbit – sometimes not all orbits / datasets can contribute to the final combined sky image). The products from combined (multi-orbit) data provide information about contributing datasets (making them easily traceable). The components are aligned using a few brightest stars detected. Only those components which could be successfully aligned with the image with largest exposure time are included.

Sky images from individual datasets (sub-orbit) in both coordinate systems (Detector X-Y; Equatorial RA-Dec) are directly generated by populating individual photons using their final centroids corrected for all effects. Details of treatments of photon events or frames relevant for astronomical photometry are presented in Appendix-1 (at the end).

For each of the 3 chains and the driver module, a number of selectable parameters are chosen by the user either interactively or by editing the text file named "UVIT_DriverModule.par" and submitting as a batch job. The XLSX file "UL2P_selectable_parameters_30Oct2017.xlsx" provides the list of parameters and their definitions based on which, users may like to experiment with (driven by specific science needs). ***It is highly recommended that only these parameters could be tweaked (& not any of the other parameters, unless in consultation with the UVIT team)***. For completeness, another XLSX file ("UVIT_DriverModule_Parameters_v1.6_30Oct2017.xlsx") has also been provided which contains a complete list of ALL parameters that are read in by the Driver Module.

The UVIT Pipeline is run at the Payload Operation Centre (POC; IIA) using 'DEFAULT' settings of all the selectable parameters. Below, the parameters that could be 'tweak'-ed by general users, are presented :

Drift computation strategy : ["NUVonNUVflag"]

DEFAULT: 'NUVonNUV = n' (NO); which means try VIS tracking first, if not available, use NUV;
Alternate choice: 'NUVonNUV = y' (YES); force the use of NUV tracking only for all datasets (i.e. ignore all VIS data; usually this choice is useful when VIS data has << 100% time-overlap with the UV observation)

Drift generation using VIS data (RA_IM chain) :

Brightness threshold of VIS stars used for tracking ["threshold"]

DEFAULT: 'threshold = 10'; "N" in expression 'X = AVERAGE + N * SIGMA'; only pixels brighter than 'X' (& its nearest neighbours) are considered as potential star candidates;
Alternate choice: a higher value (> 10) may be useful for sky fields (VIS) with too many bright stars & a lower value (< 10) may be useful in sky fields comprising of only fainter (in VIS) stars;

Drift generation using NUV data (RA_PC chain using NUV) :

Brightness threshold of NUV stars used for tracking : ["thresholdrapc"]

DEFAULT: 'thresholdrapc = 10'; "N" in expression 'X = AVERAGE + N * SIGMA'; only pixels brighter than 'X' (& its nearest neighbours) are considered as potential star candidates;
Alternate choice: a higher value (> 10) may be useful for sky fields (NUV) with too many bright stars & a lower value (< 10) may be useful in sky fields comprising of only fainter (in NUV) stars;

Number of successive frames to be accumulated : ["framesComputerapc"]

DEFAULT: 'framesComputerapc = 90'; Number of successive frames (in Photon Counting mode) to be accumulated for generating each image to be used for extracting drift (after detecting starts). This selection depends critically on the NUV brightness of field stars. The value of '90' corresponds to about 3 seconds for full window (512x512) read-out of NUV. The parameters 'framesComputerapc' & 'thresholdrapc' are inter-related. Please note, this parameter ('90' for full window mode) need to be scaled up for small window mode operations [corresponding values are : ~180 (350x350); 240 (300x300); 345 (250x250); 540 (200x200), 900 (150x150), 1900 (100x100)]. The following para assumes full window (512x512) mode operation, but this parameter can be scaled up for smaller window sizes using the above scheme.
Alternate choice: The value may be increased (> 90) if generation of drift series fails with DEFAULT value of '90'. On the other hand, if there are some bright stars in the NUV field, then value of this parameter can be decreased to a lower value – but NOT below 30, which may lead to better tracking. There is no gain by going below 30.

Sky image generation in UV (L2_PC chain; identical set for NUV & FUV) :

Rejection of frames affected by Cosmic Rays showers :

Two parameters (**'N' & 'ST'**) decide the threshold for identifying frames affected by Cosmic Ray showers :

*Cosmic_Ray_threshold = AVERAGE + **N** * SQRT(AVERAGE) + (**ST** / (SQRT(AVERAGE)));* where AVERAGE = average number of photon events per frame; all frames with number of events larger than 'Cosmic_Ray_threshold' are rejected;

Parameter-1 : **N = [“thr_One_crpc” (NUV) / “thr_One_crpcfuv” (FUV)]**

DEFAULT : 'thr_One_crpc = 9999' / 'thr_One_crpcfuv = 9999'; This high value turns OFF the rejection of frames affected by Cosmic Ray shower (and hence all the frames are included for generating UV image);

Alternate choice: By careful study of average number of photon events per frame 'AVERAGE';

Parameter-2 : **ST = [“thr_Two_crpc” (NUV) / “thr_Two_crpcfuv” (FUV)]**

DEFAULT : 'thr_Two_crpc = 9999' / 'thr_Two_crpcfuv = 9999'; This high value turns OFF the rejection of frames affected by Cosmic Ray shower (and hence all the frames are included for generating UV image);

Alternate choice: By careful study of average number of photon events per frame 'AVERAGE';

[The cosmic rays contribute a background of ~ 150 c/s for any filter of NUV / FUV, and all of this contribution occurs in ~ 3 frames/s. In case the observed field has a background which is NOT >> 150, the background noise can be reduced by selecting lower values of these parameters at the cost of losing ~ 3 frames every second.]

The selectable parameters described above are listed in the XLSX table :
“UL2P_selectable_parameters_30Oct2017.xlsx”

For details about ALL the parameters required by the UVIT Level-2 Pipeline, see the XLSX table :
“Master_list_of_UVIT_DriverModule_Parameters_v1.6_30Oct2017.xlsx”

The document for quick installation and resulting product help provides complementary details (see : **“UL2P_quick_installation_and_output_product_help_v7.pdf”**)

Please note that the current version of the pipeline V5.6 can be run on any shell of UNIX (earlier there was a restriction of C-Shell 'csh', which is now relaxed). Also, input datasets can be either 'tar' (like those obtained from POC) or 'zip' (like downloadable from ISSDC).

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Appendix-1

The Level-1 (L1) science data which is the primary input for the UL2P consists of time ordered exposures (frames) in a well defined format. Each individual frame consists of two or more packets. The very first packet of each frame comprises of DETECTOR_SETTING and the remaining packet/(s) consist of the DETECTOR_DATA. The very first processing block of UL2P, viz., DataIngest reads the DETECTOR_DATA only. Detectors of UVIT can be operated in either Integration Mode (IM) or Photon Counting (PC) mode. For the IM, ADUs from successive pixels are packed in the DETECTOR_DATA along with other details like Spacecraft Time, UVIT Frame Time, Frame Number, etc & CRC. For the case of PC mode, centroid location for each detected photon event in Detector coordinate system are listed (along with other parameters exactly like the IM case). One bit parity is included in each of the 2 coordinates for the photon centroid.

While the DataIngest block is primarily designed to read-in the Detector data, several unexpected issues have been observed in the L1 datasets, which are also adequately handled by this block. A few examples of such abnormal issues are : missing frames, inserts of random frames (positive or negative 'spike' in frame number), positive or negative large jumps in frame number, 'spike' in frame time, etc. In the process, some part/(s) of the L1 data get discarded from further consideration. In addition to possible data loss in the DataIngest block, there are other selection effects which may also lead to effectively removal of some data. All these effects need to be considered while calculating measured physical quantities like photon arrival rate (counts/second) from a specific direction on the sky. The description below provides an insight into these aspects.

Details of data / event selection / rejection in the UVIT Level-2 Pipeline (UL2P)

A) DataIngest block :

A.1) Selections regarding CRC check [each 'packet' contains a CRC]
– there are two stages of selectable switches :
A.1.1) should a check be done if CRC is CORRECT or INCORRECT ? (Yes/No)
A.1.2) if selection of A.1.1 is 'Yes', then – for INCORRECT cases, should the only affected packets be discarded [DROP_PACKET] or all packets corresponding to the affected (full) frame be dropped [DROP_FRAME]?
DEFAULT selection is to ignore CRC [A.1.1 = 'No'; A.1.2 = 'Don't care'];

A.2) Removal of initial (~ 20 second) data during detector safety check (Bright Object Detect=BOD) check – during this time the High Voltages (HV) are ramping up; (There is no selection possible here, HV ramp-up data is ALWAYS REMOVED);

A.3) Effect of frames with NO PHOTON EVENT :
The UV detectors are operated in Photon Counting (PC) mode, where list of photon events are used. There are situations (e.g. fast read-out with small Window in FUV) when some particular frames may not have any photon event. Since the logic for generating the Exposure Map (& hence Exposure Time) uses the number of frames that contributed at least one photon, a correction needs to be applied for the “missing” fraction of frames with ZERO photon event.

This correction “CORR_FACTOR_ZEROCENTROID”, is related to the total number of frames with no photon event “N_ZERO_CENTROID”, and total number of all frames (with ZERO or non-zero photon events) “N_TOTAL”, as :

CORR_FACTOR_ZEROCENTROID =
[(N_TOTAL) / (N_TOTAL - N_ZERO_CENTROID)];

This correction factor is multiplied to each element of the Exposure Map.

A.4) Selections regarding Parity check on photon event centroid words :

Data for each photon event contain total three words, of which two words contain the centroid coordinates along 'X' & 'Y' axes of the detector sensor; The third word contains other details from the event foot-print; Each word contains one-bit parity;

Selection available for the Parity check :

A.4.1) check parity bits of the two centroid words only (i.e. ignore parity of the third word); if any one (or both) of these 2 parity bits is (are) wrong, then discard that photon event from further analysis;

A.4.2) check parity bits of all the three words; if any one of these 3 parity bits is wrong, then discard that photon event from further analysis;

DEFAULT selection is to check Parity for the two centroid words only [A.4.1];

Since a fraction of photons are rejected due to parity failure, a correction factor needs to be applied;

This correction “PARITY_CORRECTION_FACTOR” is related to the total number of photon events “Total_Events_Used”, and the total number of photon events rejected due to failed parity check “PARITY_TotalEvents_Failed”, as :

PARITY_CORRECTION_FACTOR =

[(Total_Events_Used) / (Total_Events_Used - PARITY_TotalEvents_Failed)]

This correction factor is multiplied to each element of the final UV sky image array (which has the unit of “counts/second”);

B) Masking of Bad pixel & Flagging of Multi-Photon Events block :

B.1) Bad Pixel masking :

Any photon event with centroid located at a pixel flagged as 'bad' (as per the BAD_PIXEL array in CALDB), is ignored from further consideration;

Currently, there is no pixel in the central circular region where the detector is sensitive for photon detection; only 4 corners (square minus circle regions) for full Window) are masked as 'bad'; For smaller Window case the masked 'bad' region becomes full square minus the selected central small square;

B.2) Multi-Photon Event Flagging :

The asymmetry among the 4 corner values (corners of 5x5 event foot-print) is an indicator of possible multi-photon event; A logic based on the measured asymmetry and a selectable threshold identifies multi-photon events and flags them from further consideration;

Currently, the DEFAULT for the Multi-Photon Threshold is set to such a large value that no event is discarded at all;

C) Detection of Cosmic Ray affected frames :

C.1) Depending on the selected parameters for detecting frames affected by Cosmic Ray generated showers, a 'threshold' (number of detected events) is computed;

All frames with number of events higher than this 'threshold' are discarded from further considerations;

Current DEFAULT : the selectable parameters defining the 'threshold' is set to such high values that NO FRAMES are removed;

D) Drift correction to the Event Centroids - Shift & Rotation block :

D.1) Depending on time overlap between UV data and available drift series (Relative Aspect Series= RAS), some UV data can get ignored if the drift correction for the corresponding time range is not available - e.g. if VIS data covered only a part of the NUV/FUV data (in default runs);
N.B. if NUV tracking is forced (by setting 'NUVonNUVflag' parameter to be YES), then this cannot happen for NUV channel [but depending on time overlap between NUV (used to generate RAS) & FUV, some FUV data can still be lost];

D.2) In case the spacecraft drift for some duration was unusually large (larger than the symmetric padding incorporated in the pipeline to allow for nominal drift), a segment of the data will be rejected since the pixel-coordinate/(s) fall outside the array range;

Comment on arriving at the UV intensity values (counts /second)

After applying all selections described above, a final table with : frame number, time stamp for the frame and details of each valid photon event (effective_photon_number as arrived at using flat field correction; centroids corrected for spacecraft drift, distortions due to detector & optics, etc) in that frame, is generated. All events from this final table are gridded to make sky maps – first in detector coordinates (X-Y) as well as astronomical coordinates (RA-Dec; J2000) by applying relevant transformation based on spacecraft attitude. The Exposure Array is generated by applying drift correction to a template exposure array, one for every photon event frame that contributed to the UV sky image. The pixel-by-pixel division of total effective number of photons and the exposure leads to the intensity map in the unit of "counts /second".

An Astrometry block finally applies finer corrections by comparing bright stars in the UVIT image to those listed in the optical catalogue USNO A2. In case the matching of detected stars with catalogue fails then the sky images using spacecraft attitude alone will be the final product.

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