Mars Atmosphere and Volatile Evolution (MAVEN) Mission

Imaging Ultraviolet Spectrograph

IUVS data user guide

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The IUVS Data Products Novice Users Guide

Preamble & other reference documents

This is intended to be a quick-start reference guide for someone who is new to the IUVS instrument and its data products. A more comprehensive description of the IUVS data products can be found in the IUVS Software Interface Specification (SIS) and the MAVEN instrument paper by McClintock *et al.*, both of which can be found on the Science Data Center (SDC) website, under /Datasets/IUVS. Further, the content of this file should not be considered to be sufficiently complete or correct to be used as a reference when preparing publications. If you intend to use IUVS data in publications, significant interaction with the IUVS team is the best way to ensure you are using the IUVS data correctly. Please also see the MAVEN Rules of the Road if you are thinking of publishing or presenting any results.

IUVS images & spectra

The IUVS instrument is a 1-dimensional imaging spectrometer. Put simply this means that its instantaneous field of view covers some region of the sky, which is resolved into an image in one dimension (see Figure 1). The light in each of these imaging pixels is dispersed in wavelength to form a 2D image on the detector. Thus, each exposure of IUVS can be thought of as a 1D image at each wavelength. By using a scan mirror, IUVS can move its the field of view around the sky. Using a combination of this and also the spacecraft motion, extended 1D and 2D images can be formed, although it is worth remembering that these are made up of individual smaller 1D slices, taken at slightly different times and slightly different spacecraft locations.
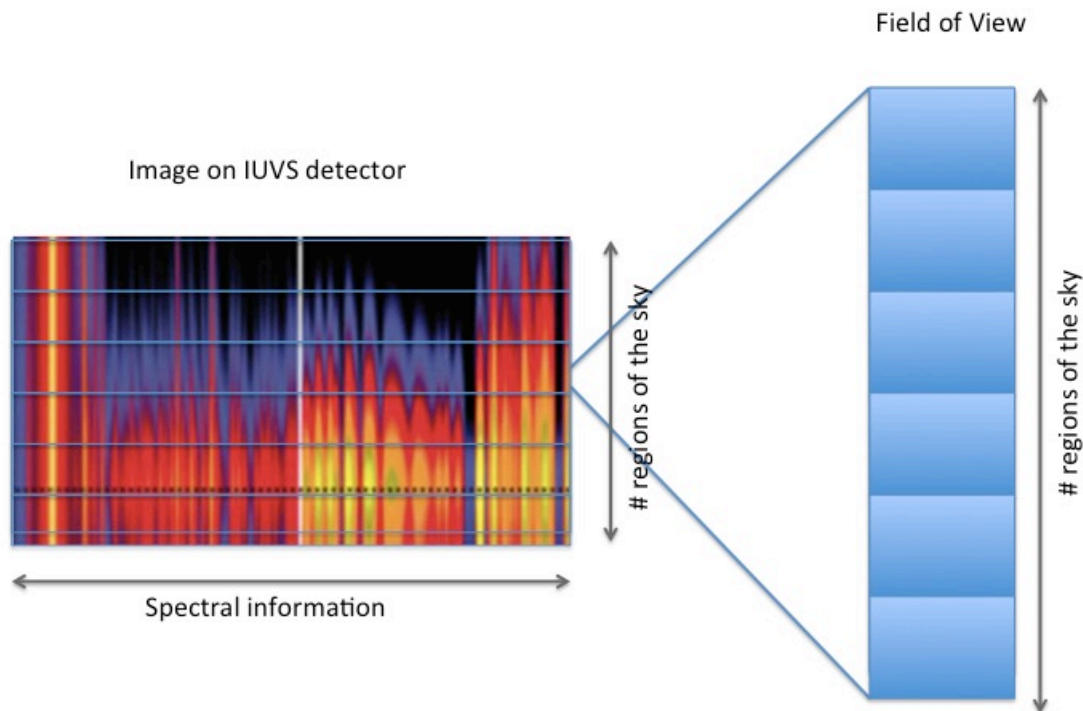
A quick guide to the basic observation modes

The IUVS instrument does not take observations continuously around MAVEN's orbit, but in 4 distinct portions. Given the highly elliptical orbit of MAVEN and the differences in the use of the instrument and scan mirror, it is easiest to think of these 4 sets of observations separately. Figure 2 shows these 4 regions – the apopase observations, periaspe observations, coronal scans and stellar occultations. It is worth noting that stellar occultations do no occur regularly.
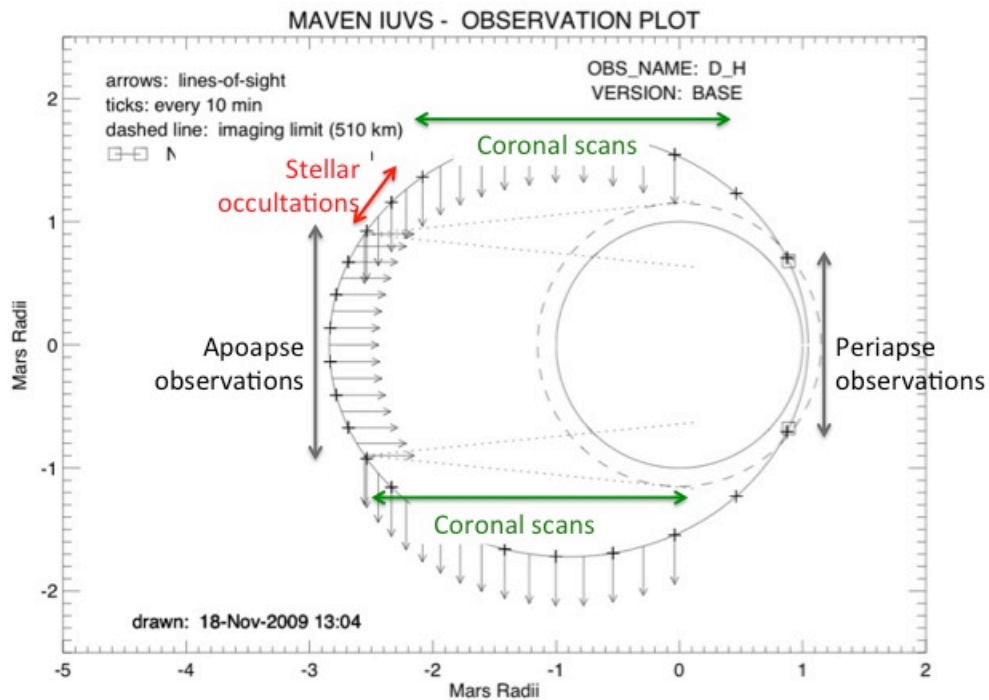
Figure 2 IUVS observations around the MAVEN orbit.

Periapse observations

These observations are made when the spacecraft is close to the planet (altitudes below ~500 km). Individual observations are made by pointing the field of view at the limb of the planet, close to parallel to the surface. The scan mirror then moves this field of view vertically, so samples at different altitudes are made. One complete scan vertically (a sequence of ~21 exposures) that covers all altitudes is referred to as a swath.

Figure 3 - Peripase observation geometry

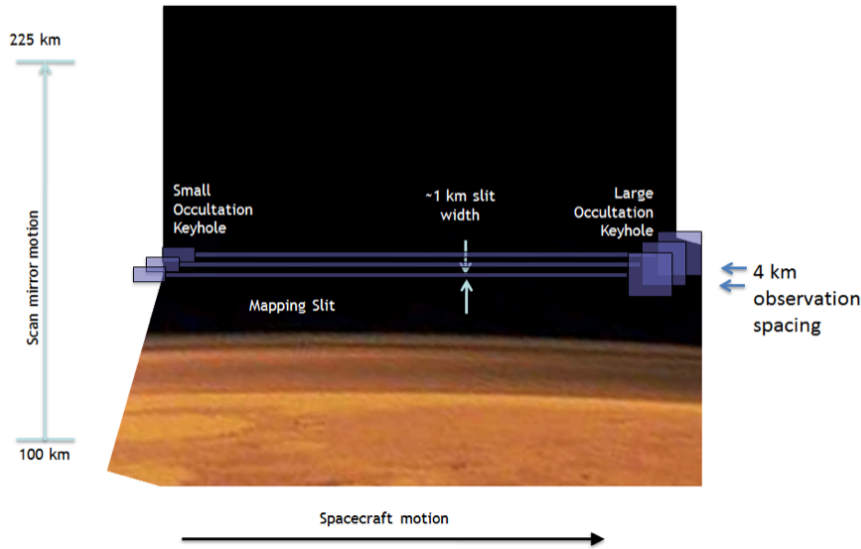Depending on the application, it is worth noting that the spacecraft moves both during and in-between each exposure. While motion within an exposure may be negligible, the spacecraft moves in both areocentric location and altitude between the first and last exposure within a swath. An example of this for one swath is shown in Figure 4. As can be seen, the spacecraft does not move far during the 21 exposures that make up this swath, but for certain applications, this may be important. The bottom right figure also shows that for certain spacecraft locations, the slit is not necessarily parallel to the surface.
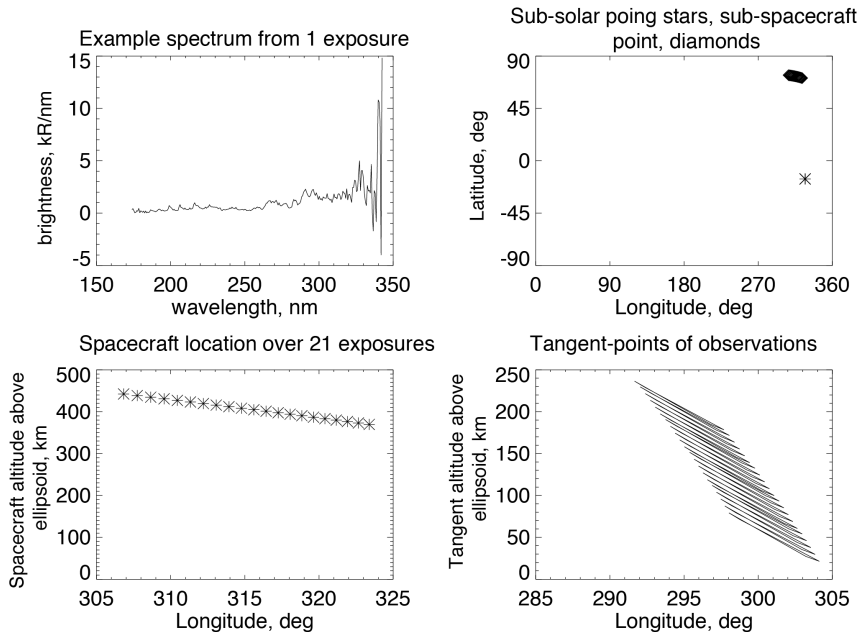

Figure 4 – Example geometry for one Periapse swath.

During a Periapse pass, IUVS takes several (typically 12) swaths of observations. While spacecraft motion within 1 swath may be small enough to be ignored, there is

considerably more motion of the spacecraft between each swath. This geometry can be seen for an example Periapse pass in Figure 5. The color-coding shows identifies each of the 12 swaths taken during this Periapse pass. The sub-solar point is marked in the upper left panel.
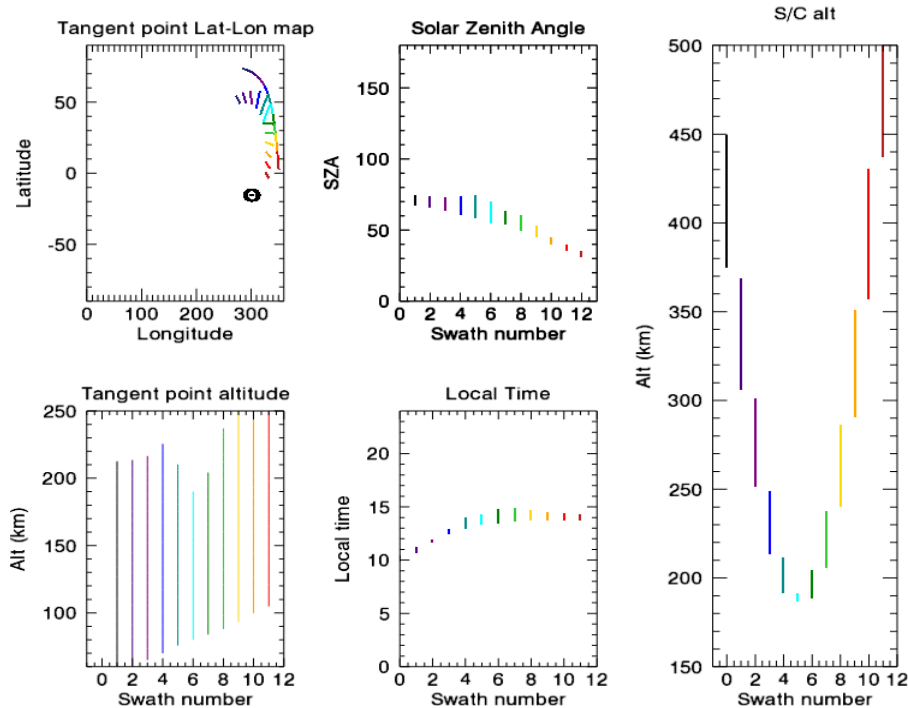

Figure 5 – Spacecraft and limb viewing geometry during a complete Periapse pass.

Figure 5 shows both the spacecraft and observation location. Observation locations refer to the tangent point, the point where the rays become parallel to the surface, which is shown schematically by the white stars in Figure 6. The tangent point is chosen as this the region of the atmosphere where the line-of-sight has the longest path-length and thus it is sometimes suitable to assume that this region has the largest contribution to the light being observed. For limb-viewing geometry, the tangent point is also the lowest altitude seen along a line-of-sight. As can be seen in this figure, at the highest altitude from which an emission is coming, the only contribution to a line-of-sight comes from the tangent point. At lower tangent altitude lines of sight, the observation is a sum over several emission altitudes, including the tangent altitude and all altitudes above that point, weighted by the path length through those regions. For an ideal case where the emission is optically thin and increases in brightness with decreasing altitude, and assuming local spherical symmetry of the emissions (no strong local horizontal gradients in the emission) a simple onion-peeling Abel inversion can easily convert a profile of observed tangent brightnesses into emission rates as a function of altitude, attributing this emission to the locations shown in Figure 5. For emissions that are optically thick, the majority of the light observed by IUVS may be coming from locations closer than the tangent point. Thus, caution should be used in using the tangent locations for attributing the location on Mars that an emission is coming from.
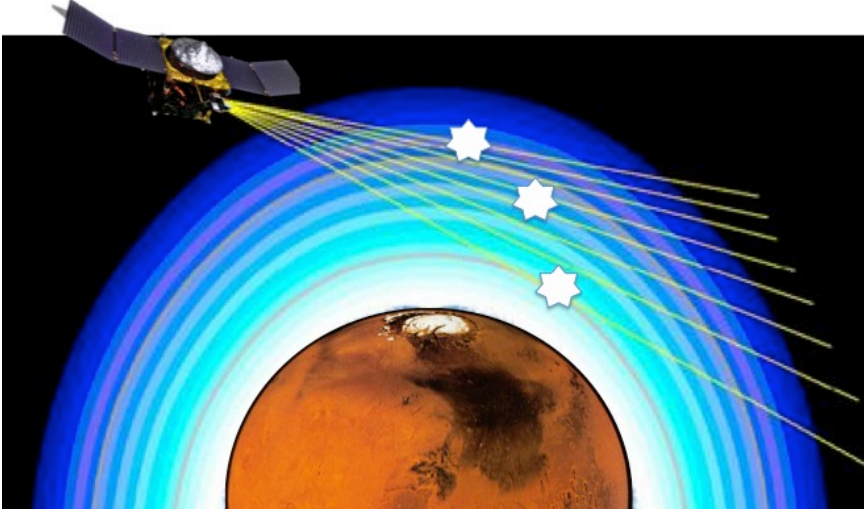
Figure 6 – MAVEN peripase limb viewing geometry

Apoapse Observations

From Apoapse, IUVS is able to build up 2D images of the whole of the Mars disk. This is done using a combination of both the motion of the scan mirror (which builds up a swath just like during the periaspe observations) and the motion of the spacecraft, which provides motion perpendicular to the swaths. Figure 7 shows the geometry of the swaths that make up an apoapse disk observation. Each individual observation is still a 1D image, with spectral information in the second dimension on the detector. Over a complete apoapse disk observation, this then produces a 3D cube of data, with 2 imaging dimensions and 1 spectral dimension. Just as with the Periapse observations, the spacecraft moves within a swath and between each swath. Also, there is some passage of time and thus some small rotation of the planet over the time taken to build up a 2D disk image, but this may be negligible for most applications.
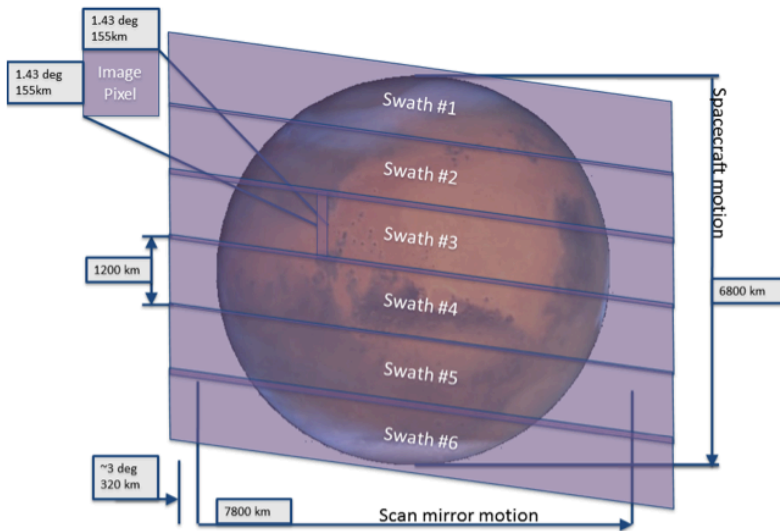

Figure 7 – Geometry of apoapse observations.

Just as with the Periapse observations, each observed spectrum is attributed to a location in an areographic reference frame. For lines of sight that intersect the planet, the reported location is at the surface. For lines of sight that do not intersect the surface of the planet, the tangent altitude, latitude, longitude etc is reported.

Stellar Occultations

Stellar occultation observations allow IUVS to determine the density of the middle atmosphere of Mars, by observing the absorption of stellar light as a function of tangent altitude. The motion of the MAVEN spacecraft changes the tangent altitude of the star as a function of time. Figure 8 shows the geometry of IUVS, Mars and the star during a stellar occultation. At present, no stellar occultations have been made. This document will be updated following the first stellar occultation campaign.

Coronal scans
SLE: I have not looked at these & can't say anything useful.

The regions of the orbit between apoapse and periapse are referred to as the orbit 'sides'. On the outbound side the slit is oriented perpendicular to the spacecraft orbit plane, and the field of view is directed perpendicular to the line of apsides. Here, with the slit perpendicular to the limb, IUVS observes emissions from both the Mars extended atmosphere and from the interplanetary space beyond it. In this orientation it uses both normal incidence and echelle modes to measure hydrogen, deuterium, and hot oxygen. On the inbound side IUVS maintains the same inertial point, which is now outward from the orbit, so that it measures emissions in the same direction observed on the outbound leg. Inbound and outbound are analyzed together during ground data processing to characterize the corona along the lines connecting the two sides of the orbit.
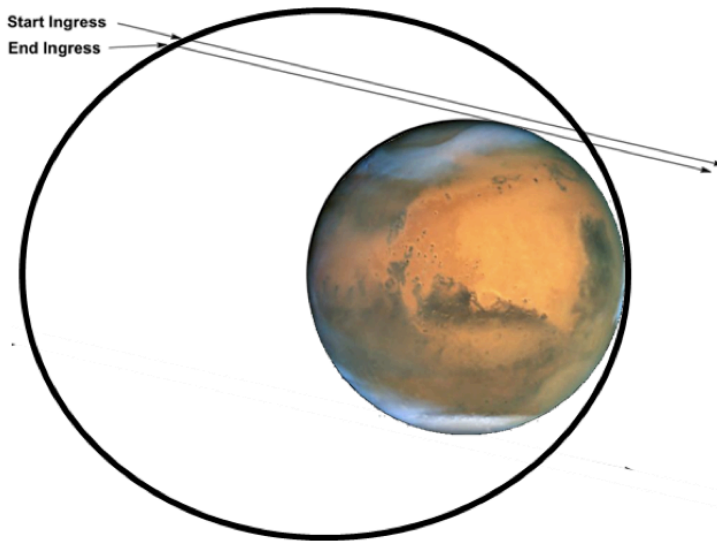
Figure 8 – Geometry of stellar occultation observations

Stars

Occasionally stars fall within the instrument FOV during an observation that is not a stellar occultation. There are a number of stars in the sky that are bright enough in FUV and MUV wavelengths to be seen by IUVS. These are sometimes relatively easy to see in the IUVS data as they are point sources & spectrally broad compared to the atmospheric features. Figure 9 shows an example FUV spectrum with a star present in the field of view. The atmospheric spectrum contains easily recognizable spectral line features such as Lyman alpha which is the bright feature towards the left of the plot, with other bright O lines and CO band features seen, which vary in brightness in the imaging direction. The star can be seen as a spatially narrow, spectrally wide feature. The IUVS data processing can identify stars from the pointing information of IUVS and MAVEN and remove these from the data products (*Make a note here when this has been done.*).
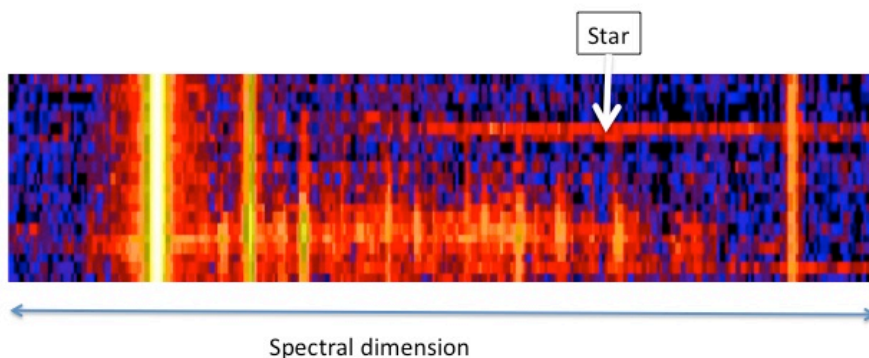

Figure 9 Example of an IUVS FUV spectrum with a star within the field-of-view.

Placeholder for other observational (instrument) features you should be aware of

Users of IUVS data should be aware of possibility of finding unwanted photon in the detectors along with good photons, e.g., splotches, measles, MUV light in the FUV channel during apoapse, solar continuum in the MUV channel. IUVS team tries to remove all the possible contamination before putting data into SDC, however, please contact IUVS team for more information about the instruments behavior.
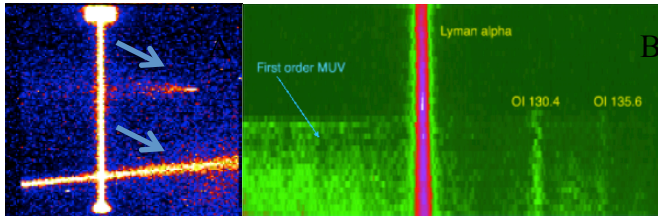

Figure 10: (a) A detectors image shows IUVS slit at Lyman-alpha wavelength. Arrow depicts intensifier events. (B) The FUV detector image shows the first order MUV contamination.

Level 1 B Peripase data

This file contains most of the information (detector data, calibrated spectral brightness data, observational geometry data and spacecraft location data) that any novice user would ever need. Files are arranged with 1 file per swath, so approximately 12 files make up a complete Periapse portion of the orbit. Files are named as

MAVEN – mvn
IUVS – iuv
Level –l1b
apoapse/periapse,
orbit number
instrument mode
wavelength channel - fuv/muv,
year,month,day, time
version number.

Within the Level 1 B FITS file, there are a number of structures, where similar parameters are grouped. Each of these also has a header, which contains plain text strings describing the contents. A novice use is likely interested in 4 structures – Primary, Observation, Spacecraft_geometry, and Pixelgeometry.

Primary:
This contains the calibrated brightness data for each spectrum. The primary_header describes the contents. For a single exposure, the data has 2 dimensions – angular / imaging information along the slit and spectral perpendicular to the slit. For a typical Level 1B periapse file, this means there are 7 bins in the imaging dimension, 256 spectral bins. For a complete swath, there are 21 mirror positions, so the dimension of the primary array is 256x7x21.

The calibrated brightness units are in kR/nm. To convert to brightness in kR, you also need to know the width of each spectral bin, in nm. This is contained within the array wavelength_width under the structure observation.

Observation
Along with version control information like the product creation date, software version etc, and this structure contains several parameters that a novice will find useful. The first of these is wavelength – which provides the wavelength scale to go along with the 256 bins in Primary. These, plus their intervals – in wavelength_width – completely define that dimension of each exposure.

Other useful parameters are the orbit number (which is also in the filename) and the solar longitude of Mars

Spacecraft Geometry
This structure contains all of the spacecraft geometric information that a novice user will need. These are the spacecraft altitude, sub-spacecraft latitude & longitude (defined east positive), angle from the instrument to the sun, sub-solar latitude and longitude, and all vectors for the spacecraft, instrument and sun in different coordinate systems. The top right and bottom left panels of Figure 4 were created from these spacecraft and solar parameters in the areographic coordinate system.

Pixelgeometry
This contains all of the geometric information relevant to the remote observation, for the tangent location etc discussed above. Each imaging pixel shown in Figure 1 subtends some region of the sky and thus a range of locations on the planet. To account for that, a number of parameters are given at the corners and center of each of these pixels. The parameters can be identified with the word _corners in their names. Each has 5x7x21 values – 7 imaging pixels, each of which has a parameter at each corner and the center, for each of the 21 mirror positions that make up a swath. The 5 elements in the 'corners' dimension are given as bottom left, top left, bottom right, top right, center. For any problem not requiring very precise pointing information, simply using the center is sufficient. In whole, Pixelgeometry contains the tangent locations (latitude, longitude, altitude) for each pixel, the emission angle in the atmosphere, zenith angle of that tangent point, angle to the sun. The data for the 4 outer corners was used to make the bottom right plot in of Figure 4.

Detector background subtracted:
The structure of this header is similar to the primary header. This header contains dark subtracted un-calibrated data.

Level 1C Periapse Data
The Level 1C files are made from the Level 1B files. While Level 1B has 1 file / swath (so ~12/orbit), and separate files for FUV and MUV, Level 1C has 1 file/orbit.

The processing from L1B to L1C involves combining separate exposures into single altitude profiles (1 profile per swath). To do this, regular 5km altitude bins are defined,

which cover the altitude range of the current swath. The range over which data exist varies from one swath to another as the spacecraft altitude changes between each swath. For many of these bins, more than 1 imaging pixel from the swath contributes to the binned L1C value. This is shown schematically in Figure 11. Close to the very top and bottom of the altitude range, fewer points contribute to each bin. The tangent geometry for this new combined altitude profile is given in the structure **Geometry_alt_specbin**. This contains the mean value of each of the sampled tangent points that go into each bin. For most swaths, changes in local time, longitude etc are relatively small, so this data reduction is a reasonable approximation. Looking at the corresponding Level 1B files provides a useful check.
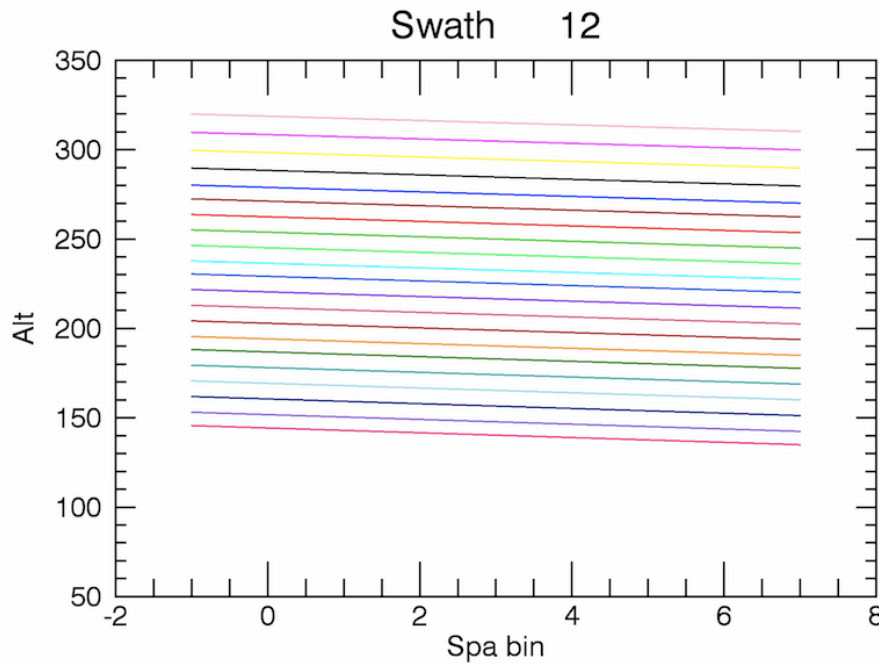

Figure 11 – Spatial binning of data for Level 1C

Radiance_alt_nospecbin
This contains the brightness profiles for each frequency for both the FUV and MUV channels, with 256 wavelengths for each. In addition, estimates of the random and systematic errors are included.

Radiance_alt_specbin
The spectral targets for IUVS are a mixture of atomic lines and spectral bands. These subtend different ranges of widths in the spectral dimension on the IUVS detector. The altitude profiles at each spectral feature are binned into the 38 main spectral features. These are stored in Radiance_alt_specbin. These are identified by name and frequency range in **Specbin_desc.** A sample of this is given here:

Bin_names	superbin	start	stop
0 First order MUV	First order MUV	107.458	114.291
1 CO B-X	CO B-X	114.291	116.243
2 NI 1200	NI 1200	119.171	120.798

3 LyA   LyA   120.798   122.750

The start and stop wavelengths give the center of the start & stop wavelength bin on the detector (not the outer limits).

An example of the data from Radiance_alt_specbin is shown in Figure 12. Here the color-coding distinguishes between swaths. Each swath is now binned into regular 5 km altitude steps and each emission line/band is summed up over the ranges described above.
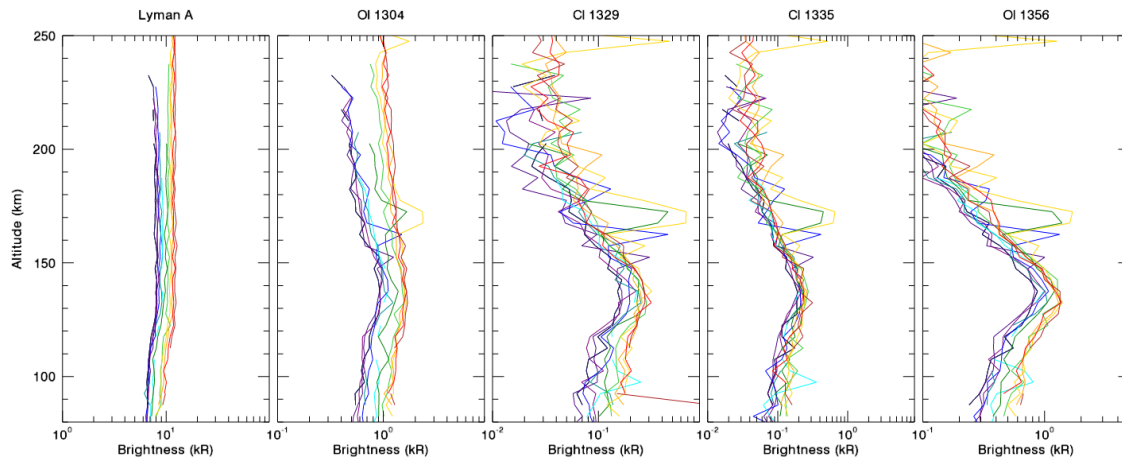

Figure 12 – Level 1C Periapse altitude profiles

Level 1B Apoapse data

The Level 1B Apoapse data is very similar to the Periapse data, so only the differences are discussed here. There are total 8 swaths in an apoapse segment of MAVEN orbit covering entire Martian disk (see Figure 7). However, as the Mars disk seen from MAVEN typically spans from day to night, the instrument changes between day and night mode during the creation of a single disk image, in this case there are 2 files / swath. These can be combined to make a single image at a single wavelength. Beware thought that the dominant atmospheric emission processes may differ between day and night. Further, for fields of view off the disk, the tangent location is reported, which can be below the emission altitude, and thus may not be representative of where the emission is coming from.

Level 1C Apoapse data

L1C file contains the information of an entire apoapse segment. All the information in the l1b apoapse files is binned into 2×2 longitude and latitude grid to provide cylindrical projection in the lat-lon coordinates. There is a single L1C apoapse file per orbit.

Reading IUVS files into IDL

IUVS files are available as gzipped FITS files. Fits is a special file format for storing and sending scientific data such as images, spectra, tables etc. For information about the fits format please visit following pages

http://www.digitalpreservation.gov/formats/fdd/fdd000317.shtml,
http://en.wikipedia.org/wiki/FITS).

There are many fits format viewer available to view the content of fits format such FV, DS9 (http://fits.gsfc.nasa.gov/fits_viewer.html). IUVS data users can get help of various libraries to read the fits format in different programming language (C++, IDL, FORTRAN etc, http://idlastro.gsfc.nasa.gov/fitsio.html).

Index	Extension	Type	Dimension	View				
☐ 0	Primary	Image	256 X 7 X 21	Header	Image			Table
☐ 1	Random_dn_unc	Image	256 X 7 X 21	Header	Image			Table
☐ 2	Random_phy_unc	Image	256 X 7 X 21	Header	Image			Table
☐ 3	Systematic_phy_unc	Image	256 X 7 X 21	Header	Image			Table
☐ 4	detector_raw	Image	256 X 7 X 21	Header	Image			Table
☐ 5	detector_dark_subtracted	Image	256 X 7 X 21	Header	Image			Table
☐ 6	quality_flag	Image	256 X 7 X 21	Header	Image			Table
☐ 7	background_dark	Image	256 X 7 X 21	Header	Image			Table
☐ 8	Dark_Integration	Binary	9 cols X 2 rows	Header	Hist	Plot	All	Select
☐ 9	Dark_Engineering	Binary	38 cols X 2 rows	Header	Hist	Plot	All	Select
☐ 10	Dark_Observation	Binary	22 cols X 2 rows	Header	Hist	Plot	All	Select
☐ 11	detector_dark	Image	256 X 7 X 2	Header	Image			Table
☐ 12	Integration	Binary	9 cols X 21 rows	Header	Hist	Plot	All	Select
☐ 13	Engineering	Binary	38 cols X 1 rows	Header	Hist	Plot	All	Select
☐ 14	Binning	Binary	9 cols X 1 rows	Header	Hist	Plot	All	Select
☐ 15	SpacecraftGeometry	Binary	36 cols X 21 rows	Header	Hist	Plot	All	Select
☐ 16	PixelGeometry	Binary	12 cols X 21 rows	Header	Hist	Plot	All	Select
☐ 17	Observation	Binary	27 cols X 1 rows	Header	Hist	Plot	All	Select

Figure 13: Structure of an l1b periapse fits file as seen by FV viewer.

IUVS level 1, 2, files contains information about the observation, integration, engineering, S/C, dark level, and IUVS field of regard (FOR) parameters in various structure array called HDU (Header and data unit). The structure of IUVS level1a and level1b data is same for all observation modes. A typical structure of HDUs in a level1b is given below. Figure 13 shows the structure of periapse level1b file as viewed by FV. Each HDU contains a data structure or table accompanied by a header, which has information about the content of that HDU.

Following paragraph will describe the use of IDL routine MRDFITS to read a fits file.

The MRDFITS utility in the IDL Astronomy Library is intended to be a general purpose function allowing users to quickly read FITS files in all standard formats. MRDFITS returns an array or structure containing the data from the specified FITS extension. Header information may optionally be returned as a string array. MRDFITS

can be downloaded from http://idlastro.gsfc.nasa.gov/ftp/pro/fits/mrdfits.pro. A detailed description of its usage is provided in the IDL code itself.

MRDFITS uses either an extension number or the name of the extension (HDU) to read the content of an HDU. Extension number 0 is used for primary header. A good way to get the information of extension number and name is to open the fits file using some viewer such FV, as shown in figure 13. First and second columns in Figure 13 show the extension number and name of different HDUs, respectively.

Following examples show how to read observation, spacecraft geometry, pixel geometry, and primary headers using extension number and name.

A) Primary header:

Filename=complete path of file location/ filename.fits.gz
Fits_data_primary=mrdfits(filename,0,header);
will save the content of primary HDU (The format of result depends upon the type of FITS data read) into Fits_data_priamry.

Note: If no extension number or name is provided then by default mrdfits read the content of primary header. Primary header can't be read using extension name.

B) IUVS FOR (pixelgeometry)

FITS_data_FOR=mrdfits(filename,16,header) ; see figure 13 for extension number
Or
FITS_data_FOR=mrdfits(filename,'pixelgeometry',header) ; see figure 13 for extension name
Note: Users can use different name for header, such as pixel_header for pixelgeometry header to distinguish it from other header information.

C) S/C information:

FITS_data_SC=mrdfits(filename,15,header) ; see figure 13 for extension number
Or
FITS_data_SC=mrdfits(filename,'spacecraftgeometry',header) ; see figure 13 for extension name

D) Observation information

FITS_data_OBS=mrdfits(filename,17,header) ; see figure 13 for extension number
Or
FITS_data_OBS=mrdfits(filename,observation,header) ; see figure 13 for extension name

Data availability & events
L1A, L1B, and L1C data are available at SDC. Work is in progress to produce Quicklooks, L2 files and KP for all observational modes.

A brief note on publications

As with all the MAVEN data, please consult the instrument PI prior to publishing any results from the IUVS instrument. Proper acknowledgement of the data is also required.

A brief note on systematics:

Random and systematic errors should never be combined. Systematic errors should not be applied to individual data points, but instead be applied when conclusions are drawn from using a set of data points.

For example, consider fitting a line to a set of points whose random errors are small compared to the systematic error (as for IUVS). If the errors were combined and applied to individual data points, the fit would be poorly constrained, and you might conclude there was no statistically significant trend in the data. Instead, one should fit the data only using the random errors, and decide if the trend is statistically significant. Assuming it is, the systematic error is then applied to the fit coefficient and to its error.

Reference:

McClintock, W. E., N. M. Schneider, G. M. Holsclaw, J. T. Clarke, A. C. Hoskins, I. Stewart, F. Montmessin, R. V. Yelle, and J. Deighan (2014), The Imaging Ultraviolet Spec- trograph (IUVS) for the MAVEN Mission, Space Sci. Rev., doi:10.1007/s11214-014- 0098- 7..

McClintock, W. E., N. M. Schneider, A.I.F. Stewart, G. M. Holsclaw, I. Stewart, F. Exploring the Mars atmosphere with ultraviolet spectroscopy (2013), SPIE, 10.1117/2.1201302.004733.

Schneider, N. M., et al. (2015), MAVEN IUVS Observations of the Aftermath of Comet Siding Spring's Meteor Shower, Geo- phys. Res. Lett., 42, doi:10.1002/2015GL063863