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Page 2/126

NOMAD Experiment to Archive Interface Control Document

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Table of contents:

1 Introduction 11

1.1 Purpose and Scope11

1.2 Applicable Documents11

1.3 Reference Documents11

1.4 Abbreviations and Acronyms 12

2 NOMAD Instrument Description..... 13

2.1 The SO channel 14

2.2 The LNO channel 15

2.3 The UVIS channel 17

2.4 Observation Types.....18

2.5 Science Objectives 21

2.6 Operational Modes.....23

2.6.1 Infrared (SO and LNO) Channels25

2.6.2 UVIS Channel..... 28

2.6.3 Housekeeping and Telemetry.....29

2.6.3.1 *Packet Type Numbers* 30

2.6.4 NOMAD TC20 Parameters..... 31

2.7 Calibration.....34

2.7.1 Expected Performance.....34

2.7.1.1 Infrared Channels.....34

2.7.2 On-ground Calibration Measurements.....36

2.7.3 In-flight Calibration Measurements36

2.7.3.1 LoS Misalignment.....37

2.7.3.2 Dark Sky Calibration.....37

2.7.3.3 'Light Sky' Calibration37

2.7.3.4 Spectral Calibration37

2.7.3.5 Straylight Calibration37

2.7.3.6 Earth/Mars/Phobos Pointing Calibration..... 38

2.7.3.7 UVIS CCD and selector mechanism calibration..... 38

2.8 Observation Types.....39

2.8.1 Observation types for raw and partially processed products..... 41

2.9 NOMAD Observation Strategy42

2.9.1.1 Possible Observation and Measurement Types.....42

2.9.1.2 Nominal Observation Modes and Measurement Types.....44

3 Data Generation and Analysis Process 45

3.1 Data Flow Overview45

3.1.1 Data levels45

3.2 Data Processing Pipeline Outline.....47

3.3 Data Processing Pipeline Conversion Steps..... 51

3.3.1 Level 0.ob - SO/LNO Binary Data Correction..... 51

3.3.1.1 Creation of TM122 and TM125 packets 51

3.3.2 Level 0.1E - LNO straylight52

3.3.3 Level 0.1E - SO/LNO bad pixel53

3.3.4 Level 0.1E - LNO detector offsets.....54

3.3.5 Level 0.1E - LNO nadir data vertically binned56

3.3.6 Level 0.1E - SO/LNO detector bins flattened57

3.3.7 Level 0.2A – Geometry overview58



3.3.7.1 SO/LNO Occultation (50km switch)..... 61

3.3.7.2 SO/LNO Occultation (0-250km) 63

3.3.7.3 LNO nadir 64

3.3.7.4 UVIS Nadir and Occultation 64

3.3.7.5 LNO Limb..... 65

3.3.8 Level 0.3A - SO/LNO spectral calibration 66

3.3.8.1 Grating Calibration..... 66

3.3.8.2 AOTF Calibration..... 67

3.3.9 Level 0.2B - UVIS reshape dataset..... 68

3.3.10 Level 0.2B - UVIS dynamic range correction 68

3.3.11 Level 0.2B - UVIS detector saturation detection..... 70

3.3.12 Level 0.2C - UVIS anomaly detection in dark measurements 70

3.3.13 Level 0.2C - UVIS dark current removal 70

3.3.14 Level 0.2C - UVIS anomaly detection 70

3.3.15 Level 0.3B - UVIS spectral calibration..... 71

3.3.16 Level 0.3C - UVIS straylight removal 71

3.3.17 Level 0.3I – SO/LNO occultation dark frame subtraction 71

3.3.18 Level 0.3J – SO/LNO occultation merge high and low altitude orders 72

3.3.19 Level 0.3K – SO/LNO/UVIS split merged occultations into ingress and egress..... 72

3.3.20 Level 1.0A – SO/LNO/UVIS occultation transmittance calibration 72

3.3.21 Level 1.0A - LNO nadir/limb radiance calibration..... 73

3.3.22 Level 1.0A - UVIS nadir radiance calibration 75

3.4 Validation 76

3.4.1 Instrument Team Validation 76

3.4.1.1 Consistency Check 1..... 76

3.4.1.2 Consistency Check 2 76

3.4.2 Peer Review..... 76

3.5 Data Delivery Schedule..... 77

4 Data Organisation and Contents 78

4.1 Format and Conventions 78

4.2 Bundle Content and Structure..... 78

4.3 Logical Identifier Formation 78

4.4 Data Directory Naming Convention..... 79

4.5 File Naming Convention..... 80

4.5.1 Raw and Partially Processed Products..... 80

4.5.2 Calibrated Products 81

4.6 Data volume estimation..... 82

4.7 NOMAD Science Data Organisation 83

4.7.1 NOMAD Bundle 1 83

5 Data product formats 84

5.1 Primary Products Formats 84

5.2 Raw Data Products..... 85

5.2.1 NOMAD Housekeeping 1 Product..... 85

5.2.2 NOMAD Housekeeping 2 Product..... 88

5.2.3 NOMAD SO 22 and 122 Science Product..... 88

5.2.4 NOMAD LNO 25 and 125 Science Product..... 89

5.2.5 NOMAD UVIS 27 Science Product..... 91

5.2.6 NOMAD UVIS 28 Science Product 93

5.2.7 NOMAD UVIS 29 Science Product 96



5.2.7.1 SO/LNO Last Telecommand Parameters97

5.2.7.2 SO/LNO Science Data99

5.2.7.3 UVIS Science Data102

5.3 Partially Processed Data Products.....102

5.4 Calibrated Data Products.....102

5.4.1 Data Collections102

5.4.1.1 XML telecommand information103

5.4.1.2 XML instrument details104

5.4.1.3 XML quality flags.....104

5.4.1.4 XML SO/LNO measurement parameters.....105

5.4.1.5 XML UVIS measurement parameters.....106

5.4.1.6 XML nadir geometry parameters.....108

5.4.1.7 XML solar occultation geometry parameters109

5.4.1.8 XML Additional Information111

5.4.1.9 TAB SO/LNO nadir measurement parameters111

5.4.1.10 TAB UVIS nadir measurement parameters..... 112

5.4.1.11 TAB nadir geometry parameters 112

5.4.1.12 TAB solar occultation geometry parameters 113

5.4.1.13 TAB Science Data..... 114

5.4.2 Calibration Collection..... 114

5.4.2.1 SO and LNO 114

5.4.2.2 UVIS115

5.4.3 Browse Collection 116

5.4.3.1 SO Nominal Science Occultation 116

5.4.3.2 LNO Nominal Science Nadir Observation..... 116

5.4.3.3 UVIS Nadir Observation.....117

5.4.3.4 UVIS Occultation Observation..... 118

5.5 Derived Data Products..... 118

5.6 Supplementary Products Formats..... 119

6 Appendix.....120

6.1 Temperature Sensors on NOMAD120

6.2 Conversion of Housekeeping Raw Data to Physical Units 121

6.2.1 TC20 Parameters 126



List of Figures

Figure 1: The NOMAD instrument, with the SO (1), LNO (2) and UVIS (3) channels, and the electronics (4). Lines of sight towards the Sun (yellow cylinders) and the nadir direction (orange cylinders) are also indicated.....13

Figure 2: Schematics of the SO and LNO channels: (1) the entrance optics, (2) the AOTF filter, (3) the spectrometer entrance slit, (4 & 6) folding mirrors, (5) the echelle grating, (7) the detector.....15

Figure 3: View of the LNO channel and its components: (1) the entrance optics, (2) the solar occultation periscope, (3) the flip-mirror mechanism, (4) the AOTF filter, (5) the spectrometer entrance slit, (6) the folding mirror, (7) the echelle grating, (8) the detector. The SO channel has a very similar layout16

Figure 4: Schematics of the UVIS instrument: the entrance slit (Slit), the aperture (A), the collimating mirror (M1), the diffraction grating (G), the focusing mirror (M2), the 2nd order filter (F) and the detector (CCD).17

Figure 5: UVIS channel with the 2 entrance telescopes (1: Solar occultation ; 2: nadir), the fibers (3), the selector mechanism (4), the main spectrometer (5), and the proximity electronics (6). 18

Figure 6: Solar occultation geometry parameters.19

Figure 7: Definitions of the nadir geometry parameters.....20

Figure 8: Examples of simulated transmittances obtained during a typical solar occultation in the UV-visible (Left Panel) and the IR (Right Panel) recorded by the UVIS and SO channels respectively. These spectra contain the absorption of CO₂, H₂O, O₃ and CH₄ for a typical clear Mars atmosphere, considering the Rayleigh scattering and a dust loading of tau=0.2. The color code indicates the altitudes to which they correspond. For the IR spectra: The limits of the different diffraction orders covered are shown at the top of the figure and spectra have been artificially shifted by 0.45 for clarity..... 22

Figure 9: A NOMAD observation sequence with onboard background subtraction. PC = precooling; OBS = observation (nadir or solar occultation); MEAS = measurement; SUB = subdomain; ACC = accumulation; INT = integration time; PROC = process time (including detector read-out, AOTF settling, etc.). Left (blue): nadir observation with 1 subdomain, two accumulations, spectra with 3.7 s integration time. Right (red): solar occultation observation with 6 subdomains, 2 accumulations in subdomain 4, spectra with 27.5 ms integration time. Dark frames are automatically subtracted; the result of which is transmitted back to Earth. 24

Figure 10: A NOMAD observation sequence with manual background subtraction. PC = precooling; OBS = observation (nadir or solar occultation); MEAS = measurement; SUB = subdomain; ACC = accumulation; INT = integration time; PROC = process time (including detector read-out, AOTF settling, etc.). Left (blue): nadir observation with 2 subdomains, 2 accumulations, spectra with 2.95 s integration time. The dark measurement has only 1 accumulation, so must be multiplied by 2 during processing. Right (red): solar occultation observation with 5 subdomains, 3 accumulations in subdomain 2, spectra with 40 ms integration time. The dark measurement also has 3 accumulations. 25

Figure 11: Typical SO occultation (A) and UVIS nadir (C) detector frames. In SO, the horizontal direction is the spectral dimension and the vertical is the spatial dimension corresponding to the long edge of the slit centred on the solar disk (B). In UVIS, the horizontal direction is the spectral dimension, however no spatial information is retained in the vertical dimension – the illumination pattern follows the layout of the optical fibres. 28

Figure 12: TC20 timing parameters and how they relate to observation start and end times. Note that all references to SO also apply to LNO, however a nadir observation generally uses no reference periods and a single science period only. In these cases, LNOSTartTime, the precooling time (10 minutes) and the LNODurationTime parameters are sufficient to calculate the observation timing. 32

Figure 13: Flowchart outlining the expected data pipeline, including internal data levels and calibration inputs/outputs 50



Figure 14: Solar straylight entering LNO has a huge impact on the signal. As LNO is background-subtracted, the straylight manifests itself as positive or negative values depending on whether it hits the detector during the dark or measurement frame. 52

Figure 16: SO bad pixel map. White dots indicate bad pixels. Two observations were required to cover all the pixels required, hence the small difference between the top and bottom rows is likely due to slightly different instrument temperature..... 54

Figure 17: LNO detector spectra before offset correction 54

Figure 18: LNO nadir spectra after subtraction of the offset. A second offset is added to shift the curve upwards, removing the negative counts in the first pixels. 55

Figure 19: Ratio of mean value of first 50 pixels to mean value of pixels in centre of detector, calculated from viewing the sun for each diffraction order. This ratio is then applied to the data, shifting the nadir curves upwards so that the same ratio is observed in the spectra. 56

Figure 20: Vertical binning of one LNO nadir detector frame (red). Here 3 diffraction orders are measured, generating 8 individual spectra for a given measurement..... 57

Figure 21: Pictorial representation of the difference between ellipsoid, surface and areoid geometries..... 58

Figure 22: SO and UVIS solar occultation geometry, showing the 5 points per bin for SO and 9 points for UVIS..... 59

Figure 23: LNO and UVIS nadir geometry, showing the 5 points per bin for SO and 9 points for UVIS 59

Figure 24: Geometry points as defined in relation to the channels' fields of view. 60

Figure 25: Diagram showing the SO data acquired during a solar occultation where the set of diffraction orders is changed 50km above the surface. 62

Figure 26: An SO occultation where the same diffraction orders are measured throughout. 63

Figure 27: An LNO limb observation using two diffraction orders. The FOV generally sweeps across the limb as the spacecraft moves, in the direction of the short edge of the slit. 65

Figure 28: Raw spectra before (top) and after (bottom) dynamic range correction. 69

Figure 29: Example of jump corrected after the second loop of the dynamic range correction routine. Top: spectra after first loop. Bottom: spectra corrected after second loop. 69

Figure 30: Each solar occultation spectrum is split into 5 regions, S, R, E, U and T, corresponding to a given tangent altitude range..... 73

Figure 31: Draft LNO radiance to pixel counts for different diffraction orders, as calculated during ground calibration. For low orders (blue), the blackbody signal is relatively strong and therefore the noise is low. For higher orders (yellow and red), the signal is low and therefore noise is present. A sixth order polynomial is plotted through the data to extract the shape of the curve from the noise. The first 50 pixels are not included in the fit as these are very noisy due to the low signal at the edge of the detector. 74

Figure 32: Radiance to counts conversion for different diffraction orders, measured at the centre of the detector. This corresponds to the sensitivity curve of the LNO channel. The lines correspond to the minimum and maximum values measured during multiple blackbody measurements. 75

Figure 33: Instrument bundle structure in the PSA. Note that lowest level is subject to further subdivisions not shown here. 78

Figure 34: Separation of the data directories into further subdivisions. The number and type of separation depends on the mission phase..... 79

Figure 35: PSA product tree, showing how one nominal science observation is split by channel, observation type and diffraction order (if applicable) into multiple PDS4 products. SO and LNO can measure up to 6 diffraction orders, plus the 6 orders can be changed during a single observation – hence there could be 12 XML and TAB products generated from a single SO/LNO observation..... 80

Figure 36: An example of an SO browse product, showing the signal versus altitude for the accepted bins of one diffraction order. The colour denotes the transmittance. 116

Figure 37: An example of an LNO browse product, showing how the signal varies throughout the given observation for every pixel. The faint vertical bands are atmospheric absorption lines present in the data 117



Figure 38 : Example of an UVIS Nadir browse product, showing the radiance evolution during one observation.....118

List of Tables

Table 1: NOMAD characteristics and performances	14
Table 2: Science objectives of the NOMAD experiment.....	21
Table 3: Examples of binning factors required for various observations. Note that the number of lines per rhythm is a data rate limitation imposed by the central processor, and cannot be exceeded. The observation time includes detector readout time, data processing time, and any dark measurements – hence in reality the time spent observing mars can be significantly less than this.....	27
Table 4: Packet types and their associated numbers. Packet types 122 and 125 are explained in section 0	31
Table 5: COP tables in NOMAD.....	33
Table 6: Theoretical values for λ_c , $\Delta\lambda_o$ and $\Delta\lambda_e$ for SO.....	35
Table 7: Theoretical values for λ_c , $\Delta\lambda_o$ and $\Delta\lambda_e$ for LNO.....	35
Table 8: Calibration measurement types and how the results are used to calibrate NOMAD.	39
Table 9: All possible observation types currently envisaged by the NOMAD team	42
Table 10: All possible measurement types currently envisaged by the NOMAD team.	43
Table 11: Nominal science modes that will be converted to PDS4 format and delivered to the PSA.	44
Table 12: ESA PSA data levels for NOMAD as defined in the Science Data Generation, Validation and Archiving Plan.....	47
Table 13: Radiance values in the tab file, showing how the data is modified if straylight is detected in measurement 4.	53
Table 14: SO transmittance and binning data.	64
Table 15: LNO radiance and corresponding binning data	64
Table 16: UVIS transmittance data for a full spectrum (1048 pixels)	65
Table 17: List of deliverables with corresponding delivery schedule (to the ESA DataStore). * When fully operational, the interface between NOMAD and SOC will operate in near real time. Once all the required data for a given observation has arrived from the ESA DataStore, a product is made by NOMAD rapidly (<24 hours) and will be immediately transferred to the ESA DataStore where it is then prepared for delivery to the PSA. Delays will be incurred only if suspect or corrupted data is discovered.....	77
Table 18: Data volume estimates for NOMAD.....	82
Table 19: NOMAD data bundle.....	83
Table 20: NOMAD Bundle 1 Content	83
Table 21: NOMAD HSK 1 raw and partially processed (pp) PDS4 product fields.....	88
Table 22: NOMAD SO raw and partially processed (pp) PDS4 product fields.....	89
Table 23: NOMAD LNO raw and partially processed (pp) PDS4 product fields.....	91
Table 24: NOMAD UVIS TM(27) raw and partially processed (pp) PDS4 product fields.....	93
Table 25: NOMAD UVIS TM(28) raw and partially processed (pp) PDS4 product fields.....	96
Table 26: NOMAD UVIS TM(29) raw and partially processed (pp) PDS4 product fields.....	97
Table 27: SO or LNO last telecommand parameters in the raw and partial processed PDS4 products.....	99
Table 28: SO or LNO detector data in the raw and partial processed PDS4 products.....	101
Table 29: TC20 telecommand parameters.....	104
Table 30: Instrument description metadata.....	104
Table 31: List of quality flags present in the metadata.....	105



Table 32: Infrared metadata measurement parameters 106

Table 33: UVIS metadata measurement parameters. 108

Table 34: Nadir geometry metadata..... 109

Table 35: Occultation geometry metadata 110

Table 36: Addition metadata in the XML products..... 111

Table 37: Infrared calibrated nadir science parameters. 111

Table 38: UVIS calibrated nadir science parameters 112

Table 39: Calibrated nadir geometry parameters..... 113

Table 40: Calibrated solar occultation geometry parameters..... 114

Table 41: Calibrated science data. 114

Table 42: A list of temperature sensors embedded in NOMAD. NOMAD ANC temperature sensors will be monitored and read out continuously by spacecraft. SINBAD temperatures are recorded by the central processor when switched on. SO/LNO/UVIS temperatures are read out only while that channel is operating..... 121

Table 43: SINBAD housekeeping conversion formulae..... 122

Table 44: SO housekeeping conversion formulae 123

Table 45: LNO housekeeping conversion formulae 124

Table 46: UVIS housekeeping conversion formulae 125

1 INTRODUCTION

1.1 Purpose and Scope

This Experiment-to-Archive Interface Control Document (EAICD) describes the format and content of the NOMAD (Nadir and Occultation for Mars' Discovery) archived data. It includes descriptions of the data products and associated metadata, including the data format, content, and generation pipeline.

The specifications described in this EAICD apply to all NOMAD products submitted for archive to ESA's ExoMars 2016 Science Ground Segment (SGS), for all phases of the ExoMars 2016 mission. This document includes descriptions of archive products that are produced by both the NOMAD team and by the SGS.

1.2 Applicable Documents

The following documents, of the issue given hereunder, are pertinent to the extent specified herein and impose requirements to the SGS or the SGS schedule. They are referenced in the form [AD XX]:

- [AD.01] EM16-SGS-PL-002, ExoMars 2016 Science Data Generation, Validation and Archiving Plan
- [AD.02] EM16-SGS-TN-001, ExoMars 2016 Archiving Guide
- [AD.03] [PDS4 Standards Reference](#) (SR)
- [AD.04] [PDS4 Data Dictionary](#) (DDDB)
- [AD.05] [PDS4 Information Model Specification](#) (IM)

1.3 Reference Documents

The following documents, of the issue given hereunder, although not part of this document, amplify or clarify its contents. If no issue given, the most recent issue should be used. They are referenced in the form [RD.XX]:

- [RD.01] [PDS4 Data Providers Handbook](#) (DPH)
- [RD.02] [PDS4 Concepts](#)
- [RD.03] [PSA User Guide](#)
- [RD.04] Neefs E., et al. (2015), NOMAD spectrometers on the ExoMars Trace Gas Orbiter Mission: part 1 - design, manufacturing and testing of the infrared channels.
- [RD.05] Patel, M. R., et al., NOMAD spectrometers on the ExoMars Trace Gas Orbiter Mission: part 2 – the UVIS channel. (2017)
- [RD.06] Vandaele, A. C., (2015), Science objectives and performances of NOMAD, a spectrometer suite for the ExoMars TGO mission.
- [RD.07] Vandaele, A. C., (2015), Optical and radiometric models of the NOMAD instrument part I: the UVIS channel.



- [RD.08] Thomas, I. R., et al., (2016), Optical and Radiometric Models of the NOMAD Instrument Part II: The Infrared Channels – SO and LNO
- [RD.09] NOMAD User Manual: EXM-NO-UMA-OIP-00001-iss2-rev2 NOMAD User Manual_FMMmodif .docx
- [RD.10] EXM-NO-TNO-AER-00048-iss2rev5-DataOperationsHandbook-150505.xlsx
- [RD.11] Liuzzi, G., et al., (2019), Methane on Mars: new insights into the sensitivity of CH₄ with the NOMAD/ExoMars spectrometer through its first in-flight calibration, Icarus doi: 10.1016/j.icarus.2018.09.021

1.4 Abbreviations and Acronyms

See ExoMars online acronyms [RD.03].

2 NOMAD INSTRUMENT DESCRIPTION

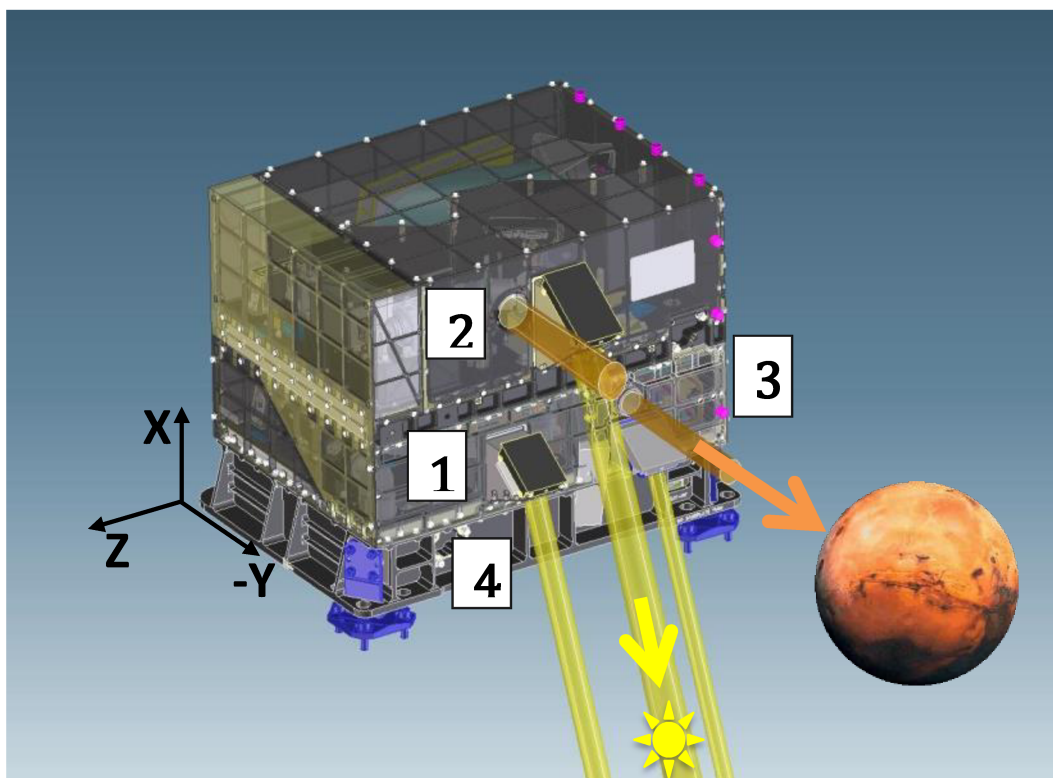


Figure 1: The NOMAD instrument, with the SO (1), LNO (2) and UVIS (3) channels, and the electronics (4). Lines of sight towards the Sun (yellow cylinders) and the nadir direction (orange cylinders) are also indicated.

The Nadir and Occultation for Mars Discovery instrument (NOMAD) is a spectrometer suite led by the Belgian Institute for Space Aeronomy (BIRA-IASB), being flown on the ESA/Roscosmos ExoMars Trace Gas Orbiter mission. NOMAD is predominantly based upon the SOIR-channel (Solar Occultations in the Infrared) in the SPectroscopy for the Investigation of the Composition of the Atmosphere of Venus instrument (SPICAV) from the highly successful Venus Express mission, a compact high-resolution echelle grating spectrometer with acousto-optical tunable filter for the infrared domain between 2.3 and 4.3 μm [1-4].

NOMAD consists of three separate channels, Solar Occultation (SO), Limb Nadir and Occultation (LNO) and Ultraviolet and Visible Spectrometer (UVIS), all controlled via a single main electronics unit (SINBAD)

	SO Channel	LNO Channel	UVIS Channel
Detector	2D HgCdTe	2D HgCdTe 320x256	2D 1024x256 pixel

	320x256 pixel FPA	pixel FPA	CCD
Detector temperature	88 K	88 K	N/A
Line of Sight	periscope lining up with Sun direction	Periscope for lining up with Sun direction – Nadir viewing entrance	2 telescopes lining up with Sun and nadir directions
Spectral range	2.3 – 4.3 μm	2.3 – 3.8 μm	200-650 nm
Resolving power	20000	10000	
Resolution	0.15-0.22 cm^{-1}	0.3-0.5 cm^{-1}	1-2 nm
FOV (spectral x spatial)	2 arcmin x 30 arcmin	4 arcmin x 150 arcmin	2 arcmin (solar occ) 43 arcmin (nadir)
Spatial resolution	1 km (Δz at limb)	1 km (Δz at limb)	1 km (Δz at limb)
Instantaneous footprint		0.5 km x 17 km	5 km x 5 km (Nadir)
Vertical sampling	180 m to 1 km	180 m to 1 km	< 300 m

Table 1: NOMAD characteristics and performances

2.1 The SO channel

The design of the SO channel has been inspired by the existing SOIR instrument (Nevejans et al., 2006b), which is part of the SPICAV/SOIR spectrometers' suite (Bertaux et al., 2007) on board Venus Express (Svedhem et al., 2007). The SO channel has been optimized for solar occultation observations, i.e. looking at the Sun during sunset and sunrise. It operates at wavelengths between 2.3 and 4.3 μm (2320 to 4550 cm^{-1}), using an echelle grating with a groove density of 4 lines/mm in a near Littrow configuration in combination with an Acousto-Optical Tunable Filter (AOTF) for spectral window selection. Figure 2 illustrates the schematics of the SO channel. The width of the selected spectral windows varies from 20 to 35 cm^{-1} depending on the selected diffraction order. The detector is an actively cooled HgCdTe Focal Plane Array and is made up of 320 pixels along the spectral axis and 256 rows. During the ten minutes before an occultation starts, the detector is cooled down to a temperature of $\sim 85\text{K}$. SO achieves an instrument line profile resolution of 0.15 cm^{-1} , corresponding to a resolving power $\lambda/\Delta\lambda$ of approximately 20000. The slit of the spectrometer is a 2' (spectral direction) by 30' (spatial direction) rectangle. The spectral range is divided into several diffraction orders, one of which can be selected by the AOTF. To do this, a radio-frequency signal is applied to the AOTF crystal so that the central wavelength of the AOTF bandpass corresponds to the centre of the desired diffraction order.

The instrument entrance slit is projected on 30 detector rows, from row 113 to 143 when the top line is designated as row 0. Different binning options can be selected depending directly on the number of different AOTF settings that will be used, knowing that at maximum the equivalent of 24 spectra can be downloaded per second. This will be further discussed in the next section. In most of the observations 6 different values of the AOTF frequency are chosen

to record spectra in different spectral intervals per second, hence increasing the number of species potentially detectable quasi-simultaneously. The duration of 1s has been chosen as the default cycle of observation performed by SO. It can be changed by telecommand if needed. All 320 pixels in the spectral direction are measured.

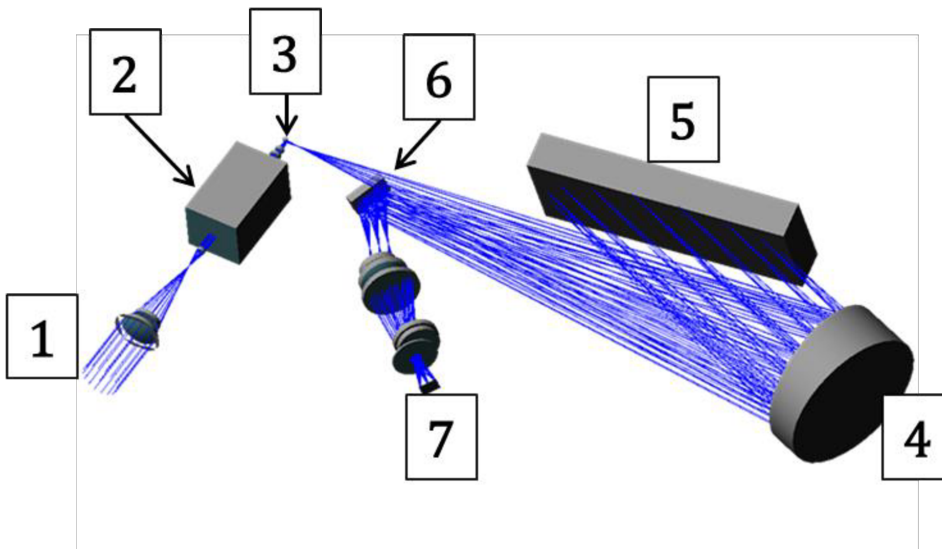


Figure 2: Schematics of the SO and LNO channels: (1) the entrance optics, (2) the AOTF filter, (3) the spectrometer entrance slit, (4 & 6) folding mirrors, (5) the echelle grating, (7) the detector.

2.2 The LNO channel

The optical layout of LNO is identical to that of SO (AOTF - echelle spectrometer- cooled detector, see Figure 2). LNO will be measuring in the wavelength range between 2.3 and 3.8 μm (2630-4550 cm^{-1}). To fulfil the Signal to Noise Ratio (SNR) requirement, a number of low risk and easy-to-implement measures were considered to increase the signal throughput as well as to reduce the thermal background of the instrument, e.g. decreasing the highest wavelength limit of the sensitivity of the detector to reduce the impact of thermal noise (from 4.3 μm for SO to 3.8 μm for LNO); increasing the length of the slit from 30' to 150'; using a larger AOTF crystal, and using longer integration times, appropriate pixel binning, and accumulating repeat spectra. For the LNO channel, the width of the slit has been increased to 4', leading to a higher throughput and therefore SNR, but a reduction in resolution to 0.3-0.5 cm^{-1} and a resolving power of $\lambda/\Delta\lambda \sim 10000$.

The detector of LNO is similar to the one chosen for the SO channel (320 x 256 pixels). Since the slit is larger, more rows will be illuminated, from row 77 to row 227. For the sake of compatibility in data processing between SO and LNO, also in LNO the equivalent of 24 detector rows x 320 pixels can be acquired per measurement cycle. This has a direct impact on the binning possibilities that LNO can access. In fact, binning is always requested for the

LNO channel. The different possible combinations for LNO will be further discussed in the next Section. As for SO, up to 6 different AOTF frequencies can be selected per measurement cycle. Since the light level will be far more reduced when using LNO in nadir mode compared to solar occultation viewing, the integration time is increased. The cycle of LNO has therefore been defined on a 15 s basis for nadir observations. As for SO, the duration of this cycle can be changed by telecommand.

The LNO channel is equipped with a movable mirror that can be flipped in and out of the optical path. When the mirror is ‘in’ the optical path, it is pointed towards nadir (-Y). When the mirror is ‘out’ of the optical path, it is pointed towards the limb and can perform measurements during solar occultations. The flip mirror, that is normally driven by a motor, has a fail-safe system that puts it permanently ‘in’ the optical path (nadir setting) in case of motor failure.

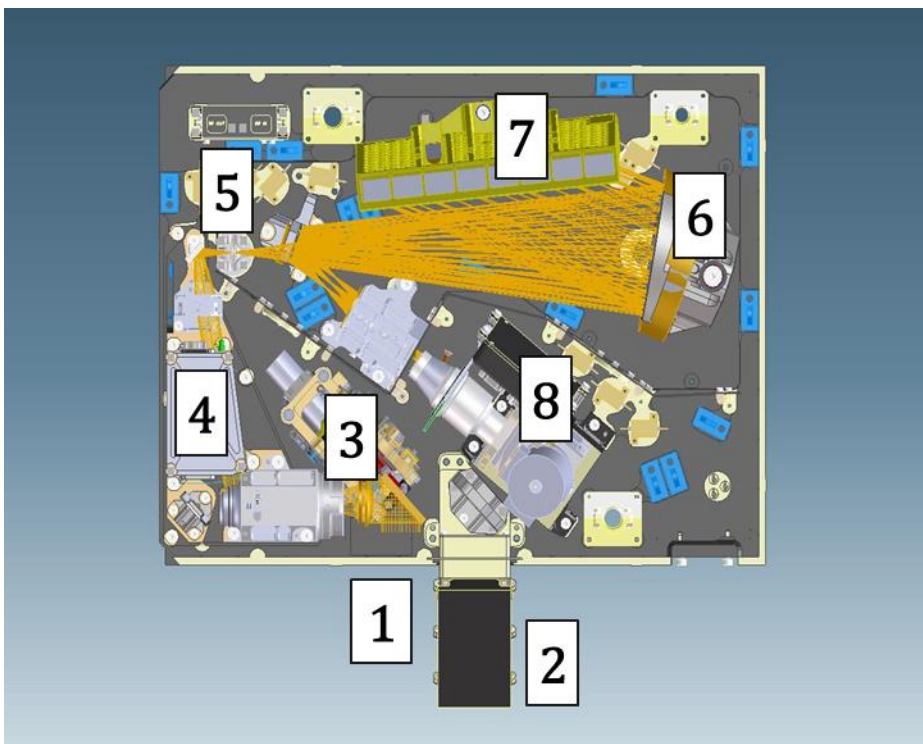


Figure 3: View of the LNO channel and its components: (1) the entrance optics, (2) the solar occultation periscope, (3) the flip-mirror mechanism, (4) the AOTF filter, (5) the spectrometer entrance slit, (6) the folding mirror, (7) the echelle grating, (8) the detector. The SO channel has a very similar layout

2.3 The UVIS channel

The UVIS channel operates in the wavelength domain between 200 and 650 nm. It is a full copy of the instrument designed for the ExoMars lander, with additional telescopic entrance optics for application in orbit. The spectrometer is based on the conventional Czerny-Turner configuration. The main components of the UVIS channel (see Figure 4), are the entrance slit, the aperture (A), the collimating mirror (M1), the diffraction grating (G), the focusing mirror (M2), the 2nd order filter (F) and the detector (CCD). The light is delivered by an optical fibre. The spectrometer is an imaging system with a magnification equal to 1. More details on the instrument can be found in Patel et al. (2015). The spectrometer configuration combines simplicity and high-performance. In particular, the spectral range is very broad (200-650nm) with optimized performance in the UV range. Blaze angle and incidence angle achieve the highest reflectance of the first diffraction order at 220 nm. The 2nd order filter solves the issue of the overlap between the 1st diffraction order and the 2nd diffraction order of the grating. Indeed, due to the wide spectral range of the observed signal (200-650nm), first diffraction order rays and second diffraction order rays overlap on the detector. Hence a high-pass filter has been placed in front of the detector to block the second order rays. The slit width is 65 μm which corresponds to a spectral resolution better than 1.5 nm. This width results from an optimisation of the resolution and the SNR.

UVIS has one periscope for the solar (narrow field) telescope and a cut out hole in the NOMAD cover for the nadir viewing telescope, see Figure 5. UVIS switches between nadir and solar viewing angles by alternating which optic fibre cable is placed at the input of the spectrometer – the one coming from the solar telescope (narrow field) or from the nadir telescope (wider angle). The selector mechanism is a rotating motor mechanism qualified on several space missions that drives to two hard stops and a central position: one hard stop is the solar fibre and the other the nadir fibre; whilst in the central position is used for acquiring dark frames, where neither fibre is in position.

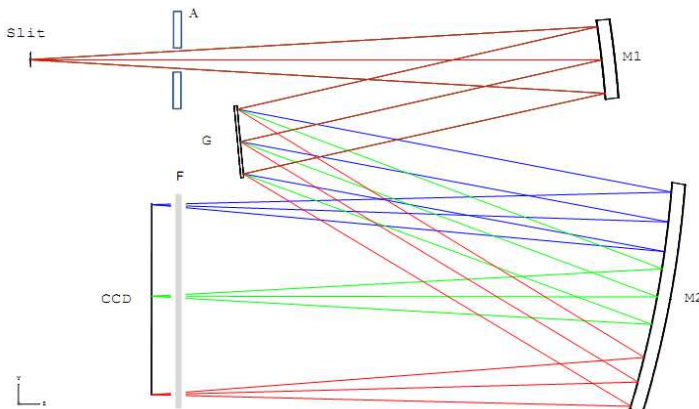


Figure 4: Schematics of the UVIS instrument: the entrance slit (Slit), the aperture (A), the collimating mirror (M1), the diffraction grating (G), the focusing mirror (M2), the 2nd order filter (F) and the detector (CCD).

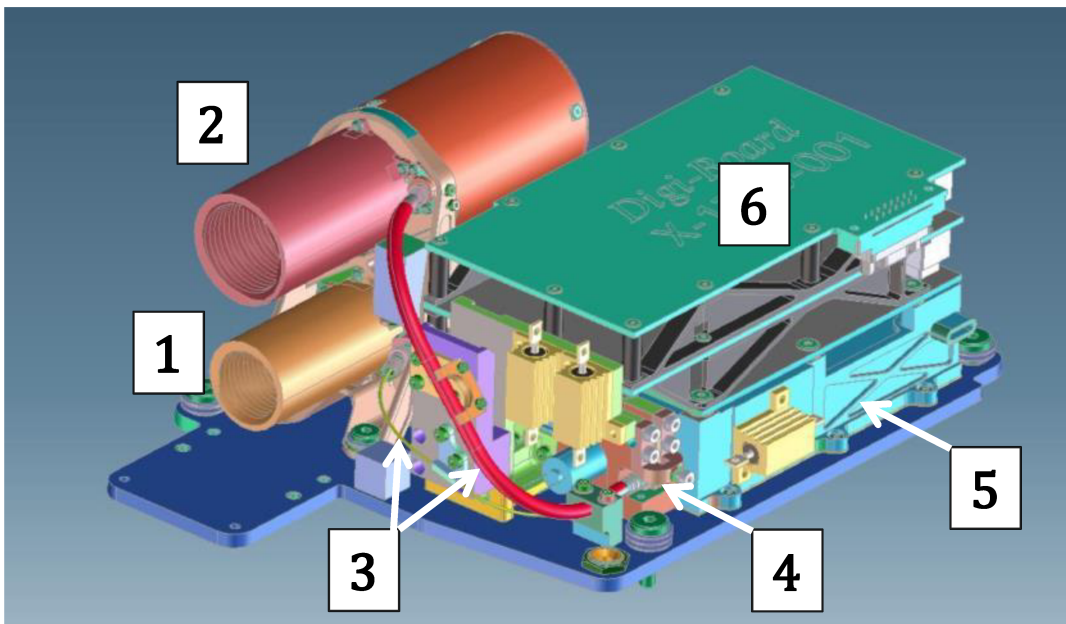


Figure 5: UVIS channel with the 2 entrance telescopes (1: Solar occultation ; 2: nadir), the fibers (3), the selector mechanism (4), the main spectrometer (5), and the proximity electronics (6).

Therefore in total there are 5 fields of view. In the spacecraft reference frame, nadir is defined as the $-Y$ direction, and the occultation channels point at $\sim 67^\circ$ from this, so that they always point towards the limb of Mars when in a 400km circular orbit. The spacecraft directions are shown in Figure 1. In summary:

- SO, which points towards the sun/limb of Mars only ($\sim 67^\circ$ from $-Y$; $\sim 33^\circ$ from $-X$);
- LNO, which nominally points nadir towards the centre of Mars ($-Y$), but can also point towards the Sun/planet limb ($\sim 67^\circ$ from $-Y$; $\sim 33^\circ$ from $-X$) by moving the flip mirror;
- UVIS, which points towards both nadir ($-Y$) and the sun/limb (also $\sim 67^\circ$ from $-Y$; $\sim 33^\circ$ from $-X$).

More information can be found in "The NOMAD Spectrometer on the ExoMars Trace Gas Orbiter Mission: Part 1 - Design, Manufacturing and Testing of the Infrared Channels" by Neefs et al. (2015) and "The NOMAD Spectrometer on the ExoMars Trace Gas Orbiter Mission: Part 2 – The UVIS Channel" by Patel et al. (2016).

2.4 Observation Types

NOMAD operates primarily in dayside nadir and solar occultation modes, which are shown in Figure 6 and Figure 7 with some of the geometric parameters required to analyse the data. Typically, SO and UVIS operate in solar occultation mode, and LNO and UVIS operate in

nadir mode. Limb and nightside nadir observations can be made, though these are not in the baseline plan.

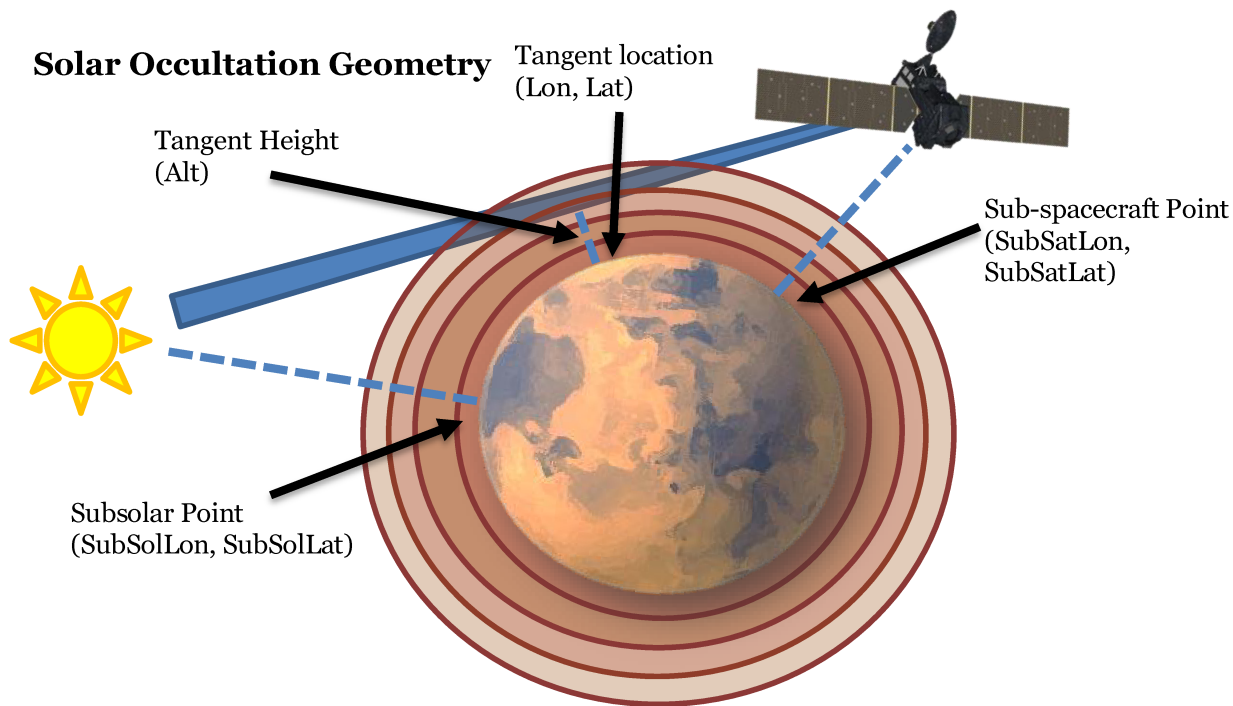


Figure 6: Solar occultation geometry parameters.

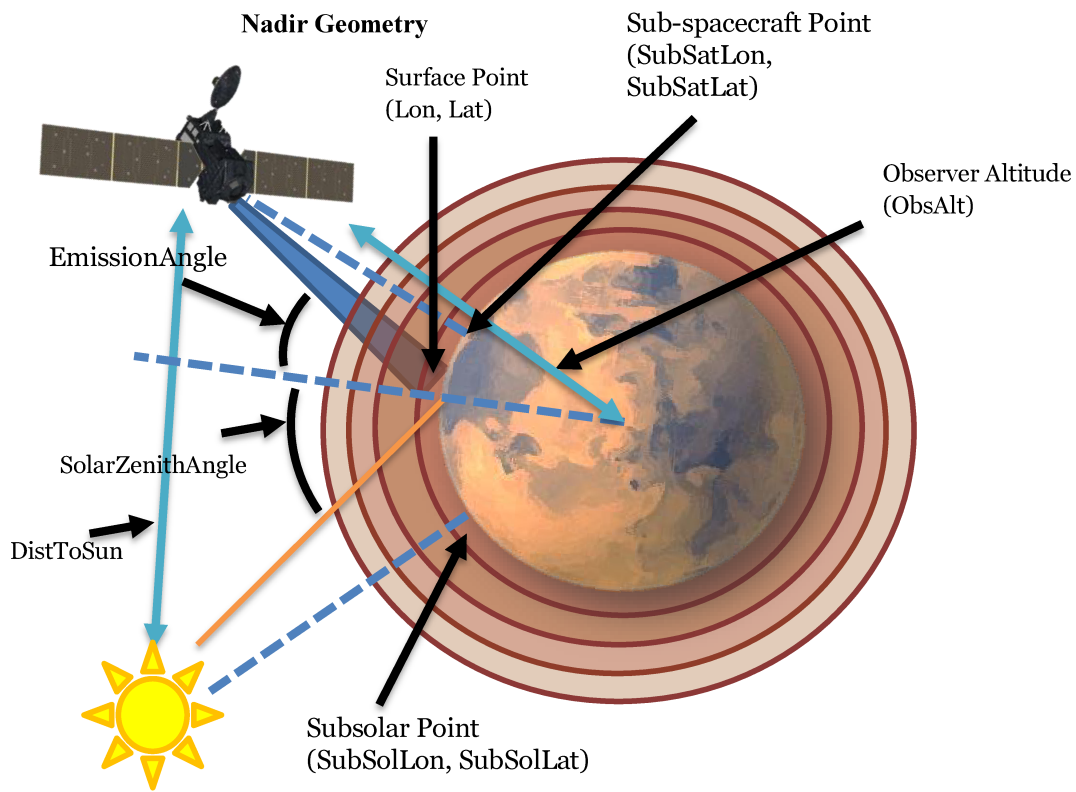


Figure 7: Definitions of the nadir geometry parameters.

2.5 Science Objectives

NOMAD science objectives are summarized in Table 2. Simulations of expected solar occultation spectra are given in Figure 8.

Science Objective	Description
Chemical Composition	Analyse the present-day chemical composition of the Martian atmosphere through detection of a broad suite of trace gases and key isotopes. Extend the detection to the upper atmosphere in order to constrain atmospheric escape processes relating the present-day atmosphere to its past and future evolution. Understand the chemistry in order to constrain the methane origin (i.e. geophysical, exogenous or biological) and destruction processes, and study gases related to possible ongoing geophysical and volcanic activity on Mars.
Climatology and Seasonal Cycles	Characterize the spatial (3D) and temporal variability of trace gases and dust/clouds. Provide an extension and refinement of current climatologies for CO ₂ , H ₂ O, CO, CH ₄ and other species including dust/clouds, O ₃ , and UV radiation levels at the surface in 3D+time. Contribute to the understanding of fine-scale processes and annual variability, and to the constraint of atmospheric dynamics.
Sources and Sinks	Characterize the production and loss mechanisms of trace gases, including the localization of trace gas sources related to outgassing as well as atmospheric production. Refine processes in the water, carbon, ozone and dust cycles. Relate this to surface mineralogy/ ices and characterize sites of interest.

Table 2: Science objectives of the NOMAD experiment.

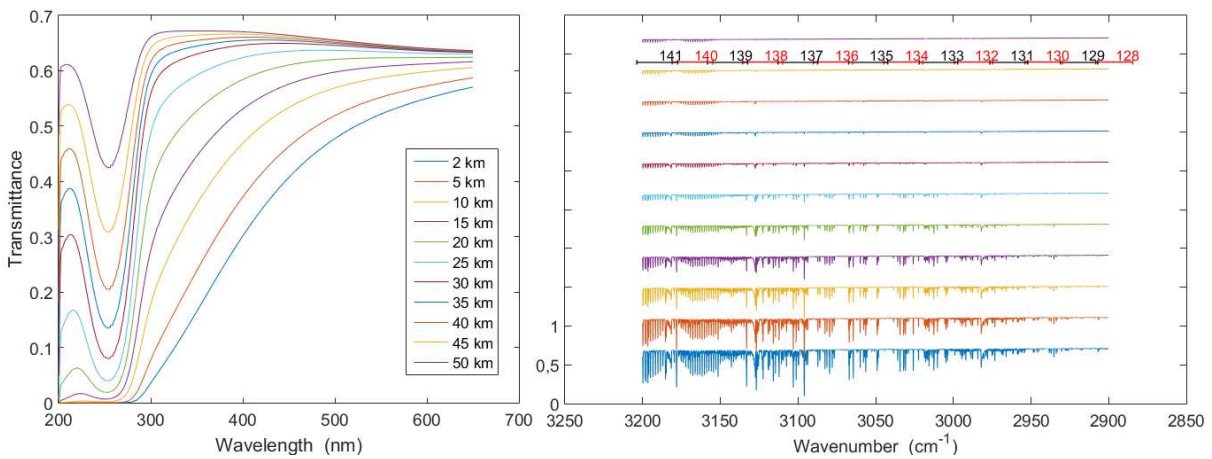


Figure 8: Examples of simulated transmittances obtained during a typical solar occultation in the UV-visible (Left Panel) and the IR (Right Panel) recorded by the UVIS and SO channels respectively. These spectra contain the absorption of CO₂, H₂O, O₃ and CH₄ for a typical clear Mars atmosphere, considering the Rayleigh scattering and a dust loading of tau=0.2. The color code indicates the altitudes to which they correspond. For the IR spectra: The limits of the different diffraction orders covered are shown at the top of the figure and spectra have been artificially shifted by 0.45 for clarity.

More information can be found in "NOMAD, a spectrometer suite for the ExoMars mission" by Vandaele et al. (2015).

2.6 Operational Modes

During flight NOMAD is always in one of three modes: two operational modes (safe mode and observing mode) and one non-operational mode (power off mode)

The three modes are:

- **Safe Mode.** This is the default mode at NOMAD power on. SO, LNO and UVIS are powered off. In this mode only the central electronics unit (SINBAD) is powered on. The power consumption is constant. It is suggested to keep SINBAD (and hence NOMAD) on permanently during the science phase of the mission, but switching it on/off as a function of science activity is possible.
- **Observing Mode.** In this mode one or several of the three NOMAD channels (SO, LNO, UVIS) can be powered on, depending on the selected observation sequence. Possible combinations are SO only, LNO only, UVIS only, SO+UVIS and LNO+UVIS. The power consumption depends on the specific configuration.
- **Power Off:** all channels and the SINBAD are in a powered off state. No power is consumed.

In this EAICD, the following nomenclature is used:

- An "observation" is one complete observing run taken by one NOMAD channel e.g. a dayside nadir pass, or a complete solar occultation.
- A "measurement" is a single detector frame/acquisition of Mars as transmitted to Earth.

It should be noted that NOMAD observation sequences are highly programmable and therefore any specific cases described here are subject to change depending on instrument priorities and performance. Figure 9 and Figure 10 show two possible sequences for the infrared channels – the former has on-board background subtraction enabled, and in the latter it is background subtraction is done manually.

Generally, science operations during one orbit around Mars can be split into four distinct observations:

1. On the day side, NOMAD will perform nadir observations with the LNO (in nadir mode) and UVIS (in nadir mode) channels, or limb observations with LNO in occultation mode.
2. At the sunset terminator a solar occultation measurement will be performed with the SO and UVIS (in occultation mode) channels.
3. On the night side, atmospheric emission measurements can be performed, if desired, with LNO and/or UVIS in nadir mode).
4. At the sunrise terminator a solar occultation measurement will be performed with SO and UVIS (in occultation mode).



It is also possible to use LNO instead of SO during solar occultations by moving the flip mirror into the occultation position. Using SO and LNO simultaneously is forbidden due to spacecraft power limitations, including in precooling mode.

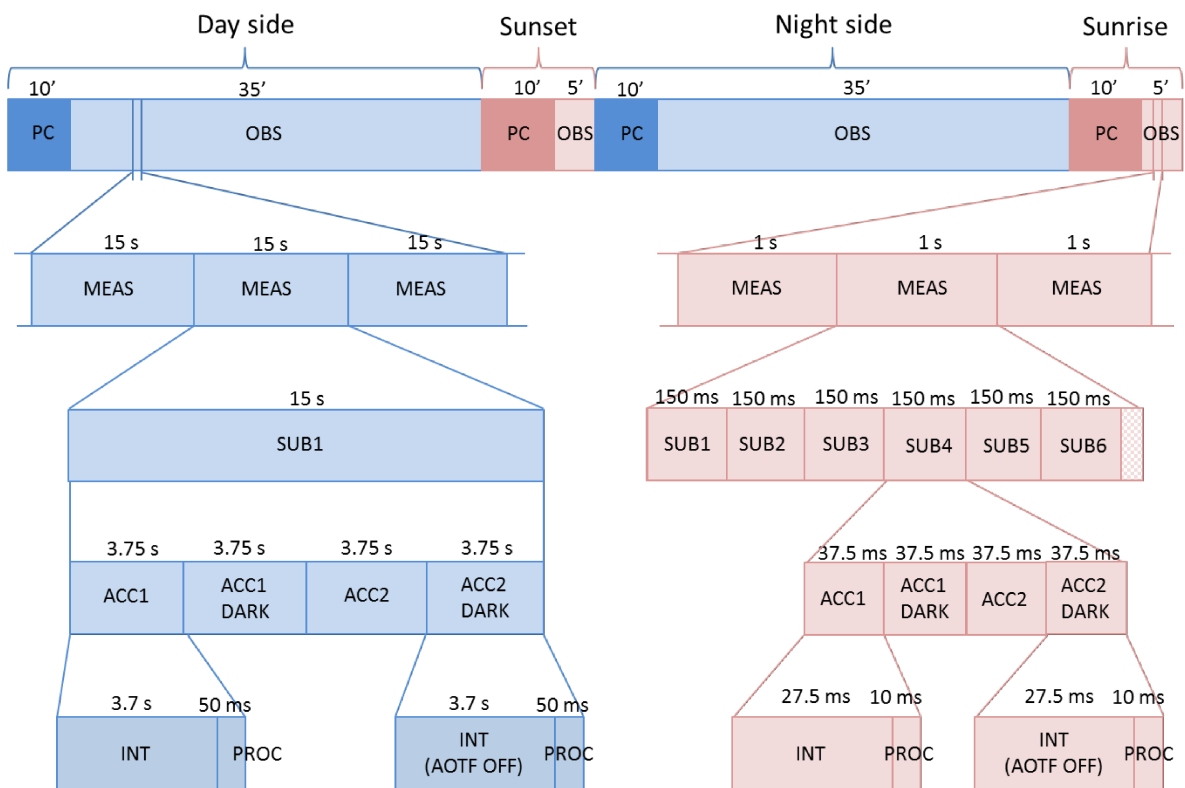


Figure 9: A NOMAD observation sequence with onboard background subtraction. PC = precooling; OBS = observation (nadir or solar occultation); MEAS = measurement; SUB = subdomain; ACC = accumulation; INT = integration time; PROC = process time (including detector read-out, AOTF settling, etc.). Left (blue): nadir observation with 1 subdomain, two accumulations, spectra with 3.7 s integration time. Right (red): solar occultation observation with 6 subdomains, 2 accumulations in subdomain 4, spectra with 27.5 ms integration time. Dark frames are automatically subtracted; the result of which is transmitted back to Earth.

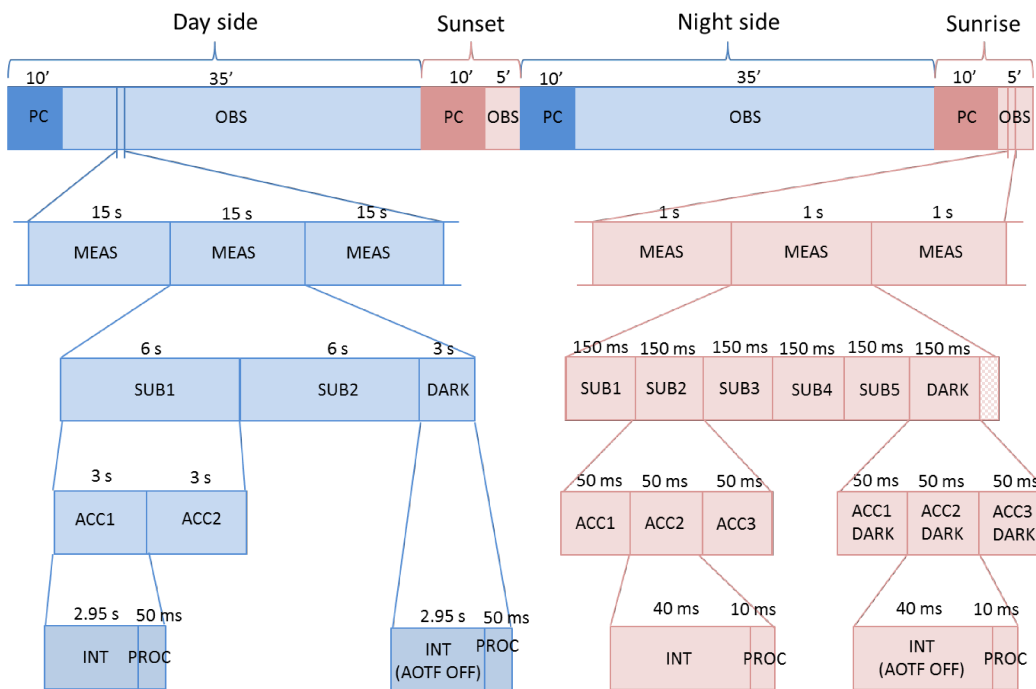


Figure 10: A NOMAD observation sequence with manual background subtraction. PC = precooling; OBS = observation (nadir or solar occultation); MEAS = measurement; SUB = subdomain; ACC = accumulation; INT = integration time; PROC = process time (including detector read-out, AOTF settling, etc.). Left (blue): nadir observation with 2 subdomains, 2 accumulations, spectra with 2.95 s integration time. The dark measurement has only 1 accumulation, so must be multiplied by 2 during processing. Right (red): solar occultation observation with 5 subdomains, 3 accumulations in subdomain 2, spectra with 40 ms integration time. The dark measurement also has 3 accumulations.

2.6.1 Infrared (SO and LNO) Channels

Just before starting a nadir observation or solar occultation measurement with one of the infrared channels it is necessary to cool the detector down to its operating temperature of ~85 K. A command packet is sent from SINBAD to the channel to start this precooling phase. This packet contains parameters such as the cooler temperature set point, an open or closed loop flag and some cooler coefficients allowing smooth regulation. During precooling, which lasts 600 s by default, no spectra are recorded - only housekeeping is sent every second. At the end of the precooling phase, the channel starts a science observation upon reception of a new command packet. This time the command contains parameters that will permit the

channel to do ‘real’ measurements, such as the AOTF frequency and AOTF power set points¹, the detector integration time, window frame dimensions, the binning factor, and more. For nadir, longer integration times are anticipated and therefore the typical sampling rhythm of 15 s has been chosen. During solar occultations integration times will be much shorter and the sampling rhythm is 1 s.

The command parameters needed to program the precooling phase and the science observation phase, are sent from the S/C to NOMAD by means of a TC20 telecommand packet (over the 1553 bus). One such TC20 defines completely one observation sequence (more details see 2.5.3)

The on-board software of the channels offers a wide range of features to tailor the measurements to the scientific needs. During one measurement rhythm, i.e. in the time frame of 1 second (solar occultation) or 15 seconds (nadir) it is possible to perform up to 6 consecutive measurements, each with different parameter settings. In this hopping mode it is possible to measure in 6 different spectral domains (6 AOTF frequency settings corresponding to 6 grating orders). It is possible to switch from a set of 6 initial subdomains (used during the first half of the observation) to a different set of subdomains in the second half of the occultation. This is especially useful during solar occultation, where the science interest in the upper atmosphere can be quite different from that in the lower atmosphere.

Within one subdomain measurement, a series of consecutively recorded spectra can be co-added, increasing the SNR of a single measurement. These added spectra are called accumulations, which are added together in onboard memory and the sum transmitted to Earth. This is particularly useful to avoid detector saturation, either from the instrument thermal background during nadir measurements or from a combination of solar flux and thermal background during occultation measurements. In these situations, an integration time is chosen so that the detector does not saturate, and the number of accumulations is chosen so that each subdomain is filled with integrations. The combination of integration time and number of accumulations must fit within the duration of one subdomain measurement, and all the subdomains must fit within the time frame of one measurement (determined by the channel's rhythm).

Similarly, consecutive rows of pixels can be binned together to further increase the SNR. The data rate is limited to 24 lines per rhythm (1 or 15 seconds for SO or LNO respectively), meaning that it is not possible to record an entire detector frame pixel-by-pixel during a typical measurement. Spectral binning, where adjacent columns are summed, is not performed, hence binning must be done in the spatial direction to produce 24 lines of superpixels. In occultation mode, approximately 18-22 pixels will be illuminated by the Sun, depending on the Sun-Mars distance. A typical frame measured frame is shown in Figure 11.

¹ AOTF power settings were calculated in the laboratory prior to assembly of NOMAD. These will not be updated during the mission.



If 6 subdomains are used, then each subdomain can transmit 4 lines of superpixels only – therefore by binning 5 or 6 rows together, data from all 20 or 24 pixels can be recorded. In nadir mode, 144 pixels will be illuminated, so if 2 subdomains are chosen, a binning factor of 12 will record all illuminated pixels (144 pixels / 12 superpixels per subdomain = 12). The number of illuminated lines in nadir mode will always be >24, therefore vertical binning must always be used to read out all illuminated lines. Typically 144 lines will be illuminated, implying a binning of at least 6. An example of this is given in Table 3.

Rhythm (seconds)	No. of diffraction orders (subdomains)	Observation time per diffraction order (including dark)	No. of lines per rhythm	No. of lines per diffraction order	No. of lines illuminated by Sun/Mars	Pixel binning required
1 (occ.)	5 + 1 dark	1/6 th second	24	4	24	6
1	5+1 dark	1/6 th second	24	4	20	5
1	5+1 dark	1/6 th second	24	4	16	4
1	6 (on board background subtraction)	1/6 th second	24	4	16	4
15 (nadir)	6 (on board background subtraction)	2.5 secs	24	6	144	24
15	4 (back sub.)	3.75 secs	24	6	144	24
15	3 (back sub.)	5 secs	24	8	144	18
15	2 (back sub.)	7.5 secs	24	12	144	12
15	1 (back sub.)	15 secs	24	24	144	6

Table 3: Examples of binning factors required for various observations. Note that the number of lines per rhythm is a data rate limitation imposed by the central processor, and cannot be exceeded. The observation time includes detector readout time, data processing time, and any dark measurements – hence in reality the time spent observing mars can be significantly less than this.

Dark subtraction and the number of diffraction orders are chosen based on a range of factors, as each measurement type has advantages and disadvantages. For SO solar occultations, not subtracting the dark onboard means that the dark frame is transmitted separately. This means that only 5 diffraction orders can be measured, but knowledge of the dark frame means that the transmittance error can be calculated more effectively. Subtracting the dark onboard means that 50% of the available observation time is lost to dark frame measurements, and hence the SNR is reduced, but 6 orders can be measured. For LNO, background subtraction is essential, and the choice of number of diffraction orders is based on the measurement goals for that particular observation. Fewer orders means that more time is spent observing Mars, and hence a higher SNR is achieved, but at the expense of spectral range covered. Typically only 2 or 3 orders should be measured in one observation, if the goal is to measure atmospheric absorption lines. Conversely, measuring 6 diffraction orders gives more spectral coverage, and so can be more useful when absorption lines are not required, for example if the objective is to measure the average reflected radiance in a given

order to measure dust or bulk surface properties. The choice can also depend on the solar zenith angle – a smaller angle means the sun is directly overhead and hence the reflected signal is larger.

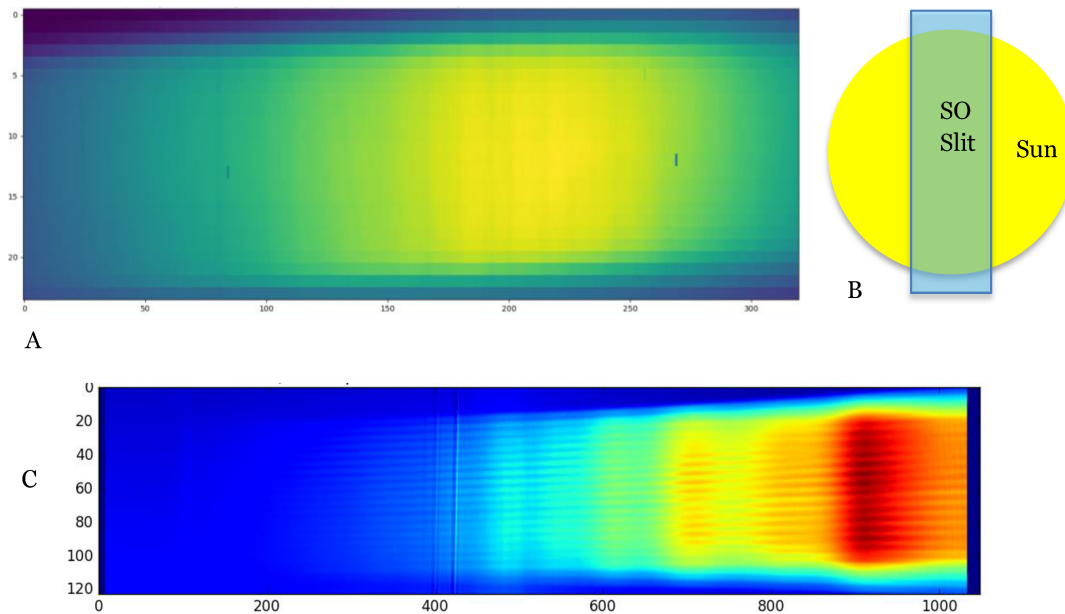


Figure 11: Typical SO occultation (A) and UVIS nadir (C) detector frames. In SO, the horizontal direction is the spectral dimension and the vertical is the spatial dimension corresponding to the long edge of the slit centred on the solar disk (B). In UVIS, the horizontal direction is the spectral dimension, however no spatial information is retained in the vertical dimension – the illumination pattern follows the layout of the optical fibres.

2.6.2 UVIS Channel

The UVIS channel operates without subdomains, and so an entire spectrum can be recorded each time. The pixels illuminated by the Sun or Mars can be binned vertically to produce a frame containing a 1 line x 1024 pixel spectrum, or each pixel value can be transmitted to Earth individually. The number of accumulations, number of lines to bin, spectral region, and integration time can all be programmed like the SO and LNO channels, as can the number of frames generated per second. UVIS is also highly programmable, but typically, one occultation or nadir observation consists of:

1. A reverse-clock measurement to measure the bias readout level, consisting of two lines of spectra.



2. Bias frame(s). This contains a frame of spectra measured with a zero integration time, to determine the voltage offset and electronic noise in the CCD and readout electronics.
3. Science frames, with dark frames every N measurements. Science frames are taken of Mars with the required observation parameters (integration time, binning parameters etc.). Dark frames are taken with the same integration time, binning parameters, but with the selector mechanism in the central position where no light from either solar or nadir fibres can enter the spectrometer. N can be varied from 1 (alternating dark and science frames) to infinity (no dark frames).
4. Final dark and bias frame(s) [optional].

The measurement rate and observation type depends mainly on the available data volume: if large, the value for each detector pixel can be returned individual for processing on ground. When the required data volume is not available, there are 4 possibilities: either the data is vertically-binned, the spectral range is reduced, the measurement rate is reduced (by introducing a delay between acquisitions), or “square superpixels” (i.e. superpixels made of 2x2, 3x3 etc. pixels) can be returned. This applies to both UVIS occultation and nadir; however in occultation mode there are fewer detector rows illuminated and so the vertical range is smaller.

The measurement rate depends on the time taken to acquire the image (integration time), read out the detector, and process/transmit the data. Typically, one vertically binned detector frame (bias, dark or science) is returned every 1/3rd second during occultations or every 5 seconds during nadir observations during a typical science observation. Returning unbinned data requires more time for processing and transmission and hence a lower rate than would be otherwise possible.

2.6.3 Housekeeping and Telemetry

NOMAD is commanded by sending a NOMAD_START_OPERATIONS telecommand [herein referred to as a TC20], which initiates a measurement. Upon reception of the NOMAD_START_OPERATIONS telecommand i.e. a TC20, NOMAD begins an observation. SINBAD will turn on the relevant channels at the correct time. Different types of observations (configurations) can be performed with combinations of the three NOMAD channels: looking at the sun (occultation of the sun by Mars), looking at the limb of Mars, and looking at the surface of Mars beneath TGO (nadir). The TC20 telecommand contains all parameters needed to set up any of these observations.

At all times that NOMAD is switched on, housekeeping (HSK) data is collected by the central processor (SINBAD) and sent to the spacecraft for transmission to Earth. This data contains



instrument-wide voltages and temperature data, plus status and error reports, mainly for engineering purposes and (besides temperature data) are of less importance to this EAICD. One set of HSK data, consisting of three packets, is generated every 30 seconds.

During observations, the channels that are operating generate their own dedicated housekeeping. Science data and supporting data, such as integration time, binning parameters, etc. is also transmitted back to Earth by the channels when they are switched on. The contents of the data returned depends on the channel:

- Each SO/LNO science packet contains a description of the observation parameters provided to the channel by the TC20 telecommand, such as AOTF frequency, number of accumulations, binning type, and whether background subtraction is enabled, etc., to provide context to the science data. Different parameters can be used in different subdomains within one measurement; therefore there is one set of parameters per diffraction order.
- Each UVIS science packet also contains a description of the observation parameters and housekeeping related to each detector frame acquired. In addition to this, UVIS also sends a dedicated packet containing the COP row parameters (TC27) sent to the channel, and an additional housekeeping packet every second whilst operating (TC29). More information can be found in the following section and in the NOMAD User Manual RD09.

2.6.3.1 Packet Type Numbers

Data is uploaded/downloaded from TGO in the form of packets, each type of which has been designated a number. The majority of these are of no interest to PSA users, such as those for patching software or moving the LNO flip mirror, for example. Packet types 122 and 125 are explained in section 0. The TC20 parameters are explained below.

Packet Type Number	Packet Type	Description
TC20	Telecommand	Instruction to start observation
TM22	SO SpaceWire data	Scientific data from SO channel
TM25	LNO SpaceWire data	Scientific data from LNO channel
TM27	UVIS applied parameters	Observation parameters returned from UVIS channel
TM28	UVIS SpaceWire data	Scientific data from UVIS channel
TM29	UVIS SpaceWire housekeeping	Additional housekeeping data from UVIS channel
TM60	SINBAD (NOMAD)	Engineering system logs

	central processor) system logs	from NOMAD central processor (not for PSA users)
TM122	Corrected SO SpaceWire data	Corrected scientific data from SO channel
TM125	Corrected LNO SpaceWire data	Corrected scientific data from LNO channel

Table 4: Packet types and their associated numbers. Packet types 122 and 125 are explained in section 0

2.6.4 NOMAD TC20 Parameters

A TC20 telecommand initiates a science measurement, containing the timing and observational parameters. The latter are shown in bold below:

- SO start time
- SO start time science 1
- SO start time science 2
- SO duration reference 1
- SO duration reference 2
- SO duration time
- **SO COP general (FIXED COP Table)**
- SO COP precooling
- **SO COP science 1 (SUBDOMAIN COP Table)**
- **SO COP science 2 (SUBDOMAIN COP Table)**
- LNO start time
- LNO start time science 1
- LNO start time science 2
- LNO duration reference 1
- LNO duration reference 2
- LNO duration time
- **LNO COP general (FIXED COP Table)**
- LNO COP precooling
- **LNO COP science 1 (SUBDOMAIN COP Table)**
- **LNO COP science 2 (SUBDOMAIN COP Table)**
- UVIS start time
- UVIS duration time
- **UVIS COP row (UVIS COP Table)**

Each of the parameters in bold contains a pointer to a line in the SO FIXED, SO SUBDOMAIN, LNO FIXED, LNO SUBDOMAIN and UVIS COP (Command Operation Parameter) tables, which contain values that specify a particular type of measurement. These COP tables are described in Table 5. A description of the timing parameters is shown in Figure 12.

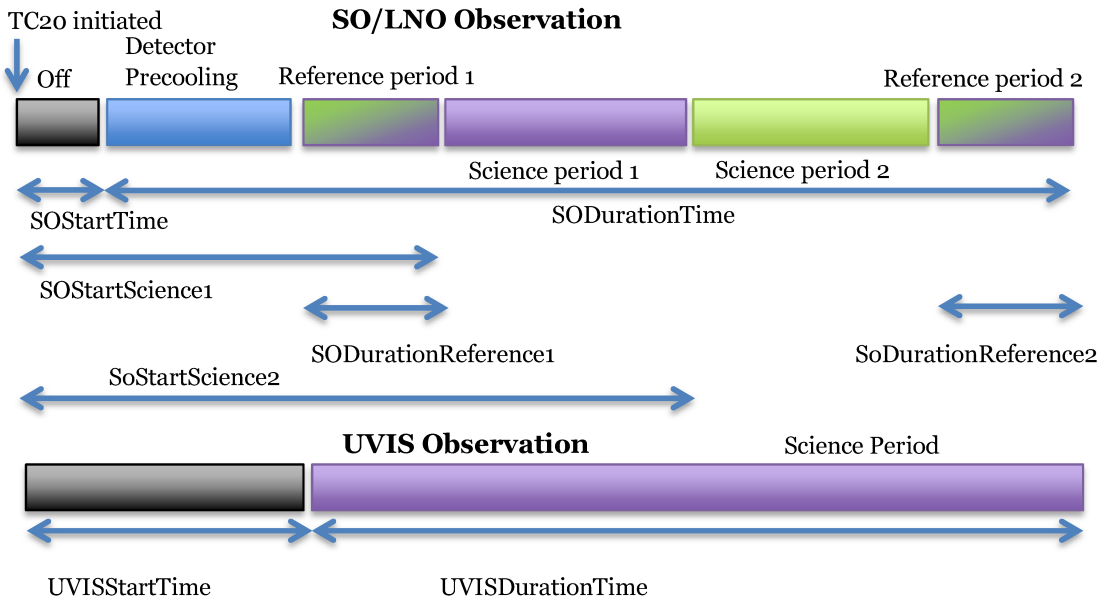


Figure 12: TC20 timing parameters and how they relate to observation start and end times. Note that all references to SO also apply to LNO, however a nadir observation generally uses no reference periods and a single science period only. In these cases, LNOStartTime, the precooling time (10 minutes) and the LNODurationTime parameters are sufficient to calculate the observation timing.



COP Table	Brief description of each line in the table
bira_so_precooling_table.csv	Contains SO detector cooling parameters (not applicable here)
bira_so_fixed_table.csv	Contains SO window size, window position and measurement rhythm parameters
bira_so_sub_domain_table.csv	Contains pointers to lines in the so_science_table. Allows up to 6 different science measurements to be made in one measurement rhythm period. For calibration, only one pointer is typically specified
bira_so_science_table.csv	Contains pointers to the so_stepping and so_aotf tables, plus measurement parameters such as binning, integration time, background subtraction etc.
bira_so_stepping_table.csv	Contains SO stepping parameters typically used for calibration measurements e.g. instructions to step integration time, AOTF frequency, window position, diffraction order etc.
bira_so_aotf_table.csv	Contains SO AOTF RF driver power and frequency parameters for each diffraction order and miniscan.
bira_lno_precooling_table.csv	Contains LNO detector cooling parameters (not applicable here)
bira_lno_fixed_table.csv	Contains LNO window size, window position and measurement rhythm parameters
bira_lno_sub_domain_table.csv	Contains pointers to lines in the lno_science_table. Allows up to 6 different science measurements to be made in one measurement rhythm period. For calibration, only one pointer is typically specified
bira_lno_science_table.csv	Contains pointers to the lno_stepping and lno_aotf tables, plus measurement parameters such as binning, integration time, background subtraction etc.
bira_lno_stepping_table.csv	Contains LNO stepping parameters typically used for calibration measurements e.g. instructions to step integration time, AOTF frequency, window position, diffraction order etc.
bira_lno_aotf_table.csv	Contains LNO AOTF RF driver power and frequency parameters for each diffraction order and miniscan.
bira_uvis_table.csv	Contains the observation parameters for UVIS measurements

Table 5: COP tables in NOMAD

These COP tables are programmed into NOMAD, but can be modified by patching the filesystem. Each line in the tables contain a different selection of values, so by selecting a certain combination of FIXED and SUBDOMAIN lines, many different types of measurements can be made.

2.7 Calibration

2.7.1 Expected Performance

For NOMAD's Critical Design Review, a radiometric model was made to calculate the expected performance of NOMAD's channels in all possible observation modes.

With NOMAD having 5 fields of view (see section 2), pointing in two directions, it was not possible to test them all during ground calibration – and therefore the two nadir channels were given priority (the occultation channels can in theory be calibrated in-flight using the solar reference spectrum taken at the beginning or end of the observation period). Spectral calibration of the occultation channels was performed, but radiometric performance was not tested – and hence, importantly, the theoretical radiometric model is described here. Expected performances will be confirmed during calibration and science phases.

In general, calibration can be split into several individual tests to determine specific instrument characteristics. These are:

- Spectral calibration, including AOTF passband shape and spectral location vs. applied driver frequency and diffraction order limits
- Determination of true SNR (Signal-to-Noise Ratio)
- Mapping of bad detector pixels
- Pixel linearity of response w.r.t. incident radiance
- Detector thermal saturation time/dark current
- Straylight calibration

2.7.1.1 Infrared Channels

Table 6 and Table 7 show the theoretical diffraction order wavelengths for the SO and LNO channels, calculated from the optical parameters of the channels, taken from Neefs et al. (2015). Here:

- λ_c is the central wavelength of that order, which lies on the centre of the detector
- ν_c is the central wavenumber of that order
- $\Delta\lambda_o$ is the range of wavelengths within the free spectral range (FSR) of that diffraction order
- $\Delta\lambda_e$ is the range of wavelengths that are incident on the detector in the given order.

Note that LNO has a smaller total spectral range than SO, therefore has less measurable orders.

Order	λ_c (μm)	ν_c (cm^{-1})	FSR $\Delta\lambda_o$ (μm)	Detector $\Delta\lambda_e$ (μm)
100	4.4302	2257	4.4082 - 4.4524	4.4123 - 4.4477
110	4.0275	2483	4.0093 - 4.0459	4.0112 - 4.0434
120	3.6919	2709	3.6765 - 3.7073	3.6770 - 3.7064
130	3.4079	2934	3.3948 - 3.4210	3.3941 - 3.4213
140	3.1661	3158	3.1532 - 3.1758	3.1517 - 3.1769



150	2.9535	3386	2.9437 - 2.9637	2.9416 - 2.9651
160	2.7689	3612	2.7603 - 2.7776	2.7577 - 2.7798
170	2.6060	3837	2.5984 - 2.6137	2.5955 - 2.6163
180	2.4612	4063	2.4544 - 2.4681	2.4513 - 2.4709
190	2.3317	4289	2.3256 - 2.3379	2.3223 - 2.3409
200	2.2151	4514	2.2096 - 2.2207	2.2062 - 2.2239

Table 6: Theoretical values for λ_c , $\Delta\lambda_o$ and $\Delta\lambda_e$ for SO.

Order	λ_c [μm]	ν_c (cm^{-1})	λ_{o+} [μm]	λ_{e-} [μm]
120	3.6914	2709	3.6761 - 3.7069	3.6765 - 3.7059
130	3.4076	2935	3.3944 - 3.4206	3.3937 - 3.4208
140	3.1641	3160	3.1528 - 3.1754	3.1513 - 3.1765
150	2.9531	3386	2.9433 - 2.9630	2.9412 - 2.9647
160	2.7686	3612	2.7599 - 2.7772	2.7574 - 2.7794
170	2.6057	3838	2.5980 - 2.6134	2.5952 - 2.6159
180	2.4609	4064	2.4541 - 2.4678	2.4510 - 2.4706
190	2.3314	4289	2.3253 - 2.3376	2.3220 - 2.3406
200	2.2148	4515	2.2093 - 2.2204	2.2059 - 2.2235

Table 7: Theoretical values for λ_c , $\Delta\lambda_o$ and $\Delta\lambda_e$ for LNO.

The SNR of a detector pixel in the NOMAD channels is obtained in the radiometric model by taking into account the signal flux and sources of noise incident on that pixel during the given exposure time.

The model showed that in solar occultation mode, the SNR is expected to be around 3000-5000; whilst in nadir, LNO is expected to have an SNR of around 30-100. A wide variation is expected due to variable dust opacities, illumination angles, instrument temperature, etc. These values represent idealized cases, where the integration time is chosen to maximise the signal without saturating the detector and observation conditions are nominal. In nadir mode, where SNRs are lower, a good signal can only be recovered by binning all illuminated pixels in multiple accumulations. Therefore, here all 144 illuminated pixels have been binned, and the number of accumulations has been set to fill a 15s measurement: in reality, each 15 seconds will be split into multiple diffraction orders, plus time will be used for dark measurements and detector readout. For SO and LNO in solar occultation mode, the expected signal is very high and therefore spatial information will be retained.

More information on this can be found in Vandaele, A. C. et al. (2015) "Optical and Radiometric Models of the NOMAD Instrument Part I: The UVIS Channel" and Thomas et al. (2015) "Optical and Radiometric Models of the NOMAD Instrument Part II: The Infrared Channels - SO and LNO (2016)".

2.7.2 On-ground Calibration Measurements

The following tests on the given channels were performed during ground calibration:

- Mapping of bad detector pixels (SO/LNO/UVIS)
- Pixel linearity w.r.t. radiance (SO/LNO/UVIS)
- Detector thermal saturation time/dark current at different temperatures (SO/LNO/UVIS)
- Spectral calibration of channel and/or AOTF at different temperatures (LNO/UVIS nadir)
- Spectral calibration of channel and AOTF (SO)
- Blackbody measurements at various temperatures to correlate observations with SNR model (LNO)
- Straylight calibration (UVIS nadir)

The SO/LNO and UVIS ground calibration papers are currently in preparation. This section will be updated accordingly when complete.

2.7.3 In-flight Calibration Measurements

Three calibrations campaigns were performed prior to the start of the nominal science mission:

- Near-Earth Commissioning (NEC) in April 2016
- Mid-Cruise Checkout (MCC) in June 2016
- Mars Capture Orbit (MCO) in November 2016, after EDM separation and orbit insertion.

In addition to this, if NOMAD has, for any reason, been inactive for a month during the science phase, a calibration campaign will be performed. Otherwise, calibration sessions will be planned within the science phase, as part of normal operations, to assess instrument performance. Some require specific pointing and will be planned with the MOC.

The following operations are planned during Near Earth Checkout:

- Functional check (typical science orbit measurement with pointing)
- Line of sight (LoS) misalignment
- Dark sky (thermal background) calibration
- 'Light sky' calibration
- Spectral calibration
- Straylight calibration
- Earth/Jupiter/Stellar pointing calibration
- UVIS CCD and nadir-to-occultation-mode mechanism calibration

2.7.3.1 LoS Misalignment

The misalignment between the NOMAD solar LoS and the pointing axis of the S/C has to be checked in flight. When a new boresight vector has been calculated, this will be updated in the SPICE kernel for the channel affected. This calibration session will be repeated every 4 to 5 months during the science phase.

2.7.3.2 Dark Sky Calibration

During dark sky calibration sessions, dark current and (thermal) background measurements are performed for different integration times of the detectors. These measurements are used to determine the optimum integration time that does not saturate the detector (nadir), and can also be used to map dead pixels (all channels). For UVIS, a photon transfer curve can be calculated from the data. These differ from the individual dark frames taken during science observations: the latter are simply frames taken with the same integration time as the light frame but with the AOTF off (SO/LNO) or selector mechanism in dark position (UVIS), to allow background subtraction. For dark sky calibrations, the boresights are pointed towards dark space, and many frames are measured consecutively with gradually increasing integration times to produce a curve of signal vs integration time. For LNO nadir measurements, the instrument thermal background dominates the signal from Mars, therefore the saturation integration time can be determined from this curve, in addition to bad pixels (i.e. pixels giving unexpected values) and detector non-linearity (i.e. deviations from a straight line).

2.7.3.3 'Light Sky' Calibration

These are integration time stepping measurements as above, except that the occultation fields of view are pointed towards the sun. These measurements are also used to determine the optimum integration time that does not cause detector saturation for solar occultation measurements, where the sun signal dominates the thermal background.

2.7.3.4 Spectral Calibration

For the SO and LNO channels, a spectral calibration is performed by stepping the AOTF driving frequency through the spectral domain while a source with known emission/absorption lines is being viewed (i.e. the sun). This allows calibration of the AOTF driver and the pixel-wavenumber relation to be derived. UVIS takes a complete spectrum each time, therefore the spectral calibration is derived by comparing the observed solar absorption/emission lines to a reference solar spectrum

2.7.3.5 Straylight Calibration

Straylight calibration sessions serve to check the instrument's immunity to stray light generated inside the instrument by the Sun or solar reflection on the S/C. This involves slewing the spacecraft so that the occultation fields of view (SO/LNO occultation/UVIS occultation) point initially at dark space, then move across the solar disk, and end on dark space again. The amount of solar signal detected when pointing at dark space provides an estimate of the straylight entering the instrument during science measurements. This calibration session has to be done 2 or 3 times during the mission.



2.7.3.6 Earth/Mars/Phobos Pointing Calibration

The boresight of LNO could not be measured on the ground, and therefore this type of measurement is essential to calculate the misalignment between the LNO boresight and the TGO axis + UVIS nadir boresight.

The sun is too bright for calibration of the UVIS nadir channel and TGO is not permitted to point the nadir-facing surface towards the sun – therefore the LoS misalignment calibration of LNO and UVIS nadir requires a fainter source. During Near Earth Commissioning, the Earth was sufficiently close to the spacecraft to be visible by both channels, however the observation was forbidden due to the nadir boresights pointing too close to the Sun.

Other sources, such as Jupiter and stars were attempted during NEC and MCC, but the results were inconclusive, and therefore the misalignment was performed when around Mars by repeatedly scanning the limb of the planet. The nadir boresights were measured successfully during MCO-1 and MCO-2, by scanning the LNO and UVIS nadir fields of view across the limb of Mars to determine the limb crossing time.

2.7.3.7 UVIS CCD and selector mechanism calibration

The UVIS channel records spectra of an illuminated source using either the solar or nadir entrance optics. The selector mechanism, starting from its rest position (dark), travels to the solar occultation hard stop, then to the nadir hard stop, and finally to the solar occultation hard stop again, before returning to the initial rest position. This characterises the fibre-slit alignment, allowing the exact motor position to be determined when the light can pass from the entrance optics into the spectrometer section.

Measurement Type	Channel	Calibration Type	Implementation
Line of sight	All	Boresight misalignment	Boresight vector (implemented in SPICE kernel)
	SO/LNO	Vertical detector calibration	Detector illumination region (implemented in choice of detector region in all observations)
Light sky (sun integration time stepping)	All	Detector linearity, optimum integration time determination	Detector linearity curve (calibration product)
Dark sky (dark space integration time stepping)	All	Detector linearity	Detector linearity curve (calibration product)
	SO/LNO	Bad pixel map	Bad pixel map (calibration product)
	LNO nadir	Optimum nadir integration time determination	Integration time as implemented in all observations by inst. team
Miniscan	SO/LNO	Spectral calibration of AOTF (order and transfer function) and detector (pixel-	AOTF frequency coefficients, AOTF transfer function coefficients, blaze function coefficients



		wavenumber relation), blaze function.	
Fullscan (sun pointing)	SO/LNO occ.	Optimum integration time per diffraction order	Integration time as implemented in all observations by inst. team
	LNO	Solar spectrum per diffraction order for radiance calibration	Solar spectrum per order product (like occultation product without radiometric calibration)
Geometric straylight (solar raster scan)	LNO nadir	Determination of geometric straylight from outside of IFOV	Removal of affected frames
Spectral straylight	UVIS	Determination of spectral straylight from known radiance sources in lab	Straylight correction spectrum

Table 8: Calibration measurement types and how the results are used to calibrate NOMAD.

As described in sections 2.7.2 and 2.7.3, there are a wide range of calibration measurement types, and an equally wide range of calibration parameters derived from these. Table 8 shows how the measurements made relate to the calibration types, and how the calibration is implemented in the pipeline.

The SO/LNO and UVIS in-flight calibration papers are currently in preparation. This section will be updated accordingly when complete.

2.8 Observation Types

All NOMAD observations are defined using one of the observation types listed below. These are split into science observations, where each type is assigned a letter, and calibration observations, which are assigned the letter C:

- I = Ingress (during solar occultation). NOMAD performs an observation during a sunset, where TGO points the boresights to the centre of the Sun. The observation will start some minutes before the line of sight enters the atmosphere (full sun reference spectra) and will continue some minutes after the line of sight has hit the Martian disk (dark spectra). These are standard science measurements where a small selection of diffraction orders are cycled through repeatedly. This is the baseline science observation during an ingress.
- E = Egress (during solar occultation). NOMAD performs an observation during a sunrise, where TGO points the boresights to the centre of the Sun. The observation will start some minutes before the line of sight leaves the Martian disk (dark spectra) and will continue some minutes after the line of sight has left the atmosphere (full sun reference spectra). These are standard science measurements where a small selection



of diffraction orders are cycled through repeatedly. This is the baseline science observation during an egress.

- G = Grazing occultation (during solar occultation). TGO points the boresights to the centre of the Sun, except in this case the line of sight never intersects the planet's surface due to the Sun-Mars-satellite geometry. The observation begins above the atmosphere and ends above the atmosphere. Due to the lack of dark spectra, an error is not calculated and therefore these observations do not pass through the data pipeline. Data will be made available when a calibration routine is ready.
- S = Fullscan (during a solar occultation observation). TGO points the NOMAD boresights to the centre of the Sun during this observation. This has to be done while the FOV passes through the atmosphere, i.e. a normal Ingress or Egress observation has to be sacrificed, or the fullscan has to be combined with the Ingress or Egress observation (only during a long occultation at high beta angle). The SO or LNO channel will perform a sweep over the complete or a subset of the spectral range, one diffraction order at a time. These measurements could be calibrated spectrally and radiometrically, but will not typically pass through the occultation pipeline. If operating simultaneously, UVIS will observe in normal Ingress or Egress mode during this time: a fullscan does not apply to UVIS.
- F = Fullscan (during a nadir observation). TGO will point the NOMAD nadir boresights to nadir during this observation, i.e. a normal dayside or nightside nadir observation has to be sacrificed. The LNO channel will perform a sweep over its complete or a subset of the spectral range, one diffraction order at a time. These measurements can be calibrated spectrally and radiometrically, but will not typically pass through the nadir pipeline (they are typically used for testing purposes). If operating simultaneously, UVIS will observe in normal nadir mode during this time: a fullscan does not apply to UVIS.
- D = Day nadir. TGO will be in its nominal pointing conditions, i.e. the –Y direction is aimed approximately towards the centre of Mars, perpendicular to the surface directly underneath it. The sun is positioned such that the surface is illuminated. In principle NOMAD can measure with LNO and UVIS at any time that the TGO axis is pointing nadir. These are standard science measurements where a small selection of diffraction orders are cycled through repeatedly. This is the baseline science observation during a nadir.
- N = Night nadir. TGO will be in its nominal nadir pointing condition, i.e. –Y direction approximately towards the centre of Mars. The region of the surface in nadir is in darkness. These are standard science measurements where a small selection of diffraction orders are cycled through repeatedly. This is the baseline science observation during a nadir.
- L = Limb observation. One or more NOMAD channel FOVs will be pointed towards the limb of Mars. This can be achieved by rotating the spacecraft, so that the nadir (-Y) face of the spacecraft is pointed to the limb, or for LNO by using the occultation



channel whilst not pointed to the sun. These are standard science measurements where a small selection of diffraction orders are cycled through repeatedly, and measurements will be calibrated using the nadir pipeline.

- C = Calibration. This type encompasses all calibration measurements, including:
 - Pointing calibrations, where TGO performs a line or raster scan around a target (typically the Sun). From these measurements the misalignment can be calculated between the S/C pointing axis and the NOMAD boresights. This misalignment value will be used afterwards to correct the S/C pointing vector.
 - Fullscans, but when the FOV does not pass through the atmosphere. The S/C will point a boresight to the centre of the Sun during this observation, which can be done at any time when the Sun is visible. The NOMAD SO and/or LNO channels will perform a sweep over their complete spectral range. These measurements can be calibrated spectrally but not radiometrically, and hence will not be run through the occultation pipeline.
 - Miniscans, where the NOMAD SO and/or LNO channels will perform a sweep over a fraction of their spectral range whilst pointing towards the sun (but when the FOV does not pass through the atmosphere). These are used for spectral calibration and will never be run through the pipeline – a set of coefficients will be generated and used to calibrate all the other observations.
 - Integration time stepping, where the integration time is gradually increased so that the saturation time can be determined. Channels may be pointed towards any target, e.g. the sun, Mars or dark sky. These are used for detector calibration and will never be run through the occultation or nadir pipelines.

Calibration measurements will not pass through the pipeline and PDS4 products will not be delivered from these observations.

The correct observation type letter will be included in all calibrated PDS4 product filenames that are generated by the PI institute (see section 4.5).

2.8.1 Observation types for raw and partially processed products

Raw and partially processed products are generated by the SOC, and therefore the observation type information is taken from the ESA uplink database. This database contains limited information, and therefore only the I, E, D, N and C letters will be assigned. Others will be assigned as follows:

- "S" type measurements will be assigned the letter I or E depending on whether the observation is an ingress or egress solar occultation.
- "F" or "L" type measurements will be assigned the letter D or N depending on whether the nadir observation is made on the dayside or nightside of the planet.

Any observation in which a NOMAD channel is pointed towards the Sun (where Mars' atmosphere is not in the line of sight) or towards dark space will be given the letter C. This is to be confirmed by the SOC.

2.9 NOMAD Observation Strategy

2.9.1.1 Possible Observation and Measurement Types

As described above, all three channels of NOMAD are very versatile and able to run many different types of measurements and in many different observation modes. For reference, all possible modes and measurement types are given in Table 9 and Table 10.

Observation Types	Description
Ingress solar occultation	Normal solar occultation starting when the line of sight is above the atmosphere and ending when sun is blocked by the surface.
Egress solar occultation	Normal solar occultation starting when the line of sight to the sun is blocked by the surface and ending when it is above the atmosphere.
Merged solar occultation	Double solar occultation, consisting of an ingress, starting above atmosphere, and an egress, ending above atmosphere. These occur when there is insufficient time between the ingress and egress to cool down the infrared detector for the second measurement, and will be split into normal ingress and egress occultations.
Grazing solar occultation	Solar occultation where, due to orbital geometry, the sun is never blocked by the surface. Starting above the atmosphere, the line of sight passes through the atmosphere to a minimum altitude, then increases to end above the atmosphere.
Dayside Nadir	Nadir measurement on the illuminated side of the planet. Observations can be of variable length, beginning and ending near the nightside terminator to cover the whole dayside, or shorter and centred on the subsolar latitude. Can also be split into 3 separate measurements.
Nightside Nadir	Nadir measurement on the nightside of the planet.
Limb	Measurement of the illuminated limb of the planet.
Calibration	Many types e.g. sun pointing, solar line scan, etc.

Table 9: All possible observation types currently envisaged by the NOMAD team

Measurement Types - SO/LNO Channels	Description
Solar occultation (50km switch)	5 diffraction orders + 1 dark per second. When the line of sight reaches 50km, the combination of diffraction orders being measured is changed. No onboard background subtraction.
Solar occultation (0-250km)	5 diffraction orders + 1 dark per second, same order selection throughout. No onboard background subtraction.
Solar occultation (50km switch, dark)	6 diffraction orders per second, diffraction order selection changed at 50km. Dark frames subtracted onboard.



subtraction)	
Solar occultation (0-250km, dark subtraction)	6 diffraction orders per second, same order selection throughout. Dark frames subtracted onboard.
Nadir	Nadir measurement of 2 to 6 diffraction orders per 15 seconds, dark subtracted onboard.
Limb	Limb measurement of 2 diffraction orders per 15 seconds, dark subtracted onboard.
ACS Boresight Limb	Special limb measurement of 2+ diffraction orders, measured during an ACS/MIR or ACS/TIRVIM solar occultation where line of sight is pointed close to the sun but not directly at the solar disk. Onboard dark subtraction.
Fullscan (slow)	Nadir, limb or occultation diffraction order stepping over any range/number of orders, dark subtracted onboard.
Fullscan (fast)	Solar occultation order stepping over any range/number of orders at a high cadence rate, dark subtracted onboard.
Calibration	Many types e.g. line of sight, solar fullscan, solar miniscan, integration time stepping, etc.
Measurement Types - UVIS Channel	Description
Solar occultation (binned)	Detector pixel values are vertically binned onboard. 3 full or partial spectra are recorded per second. No dark subtraction is made onboard.
Solar occultation (unbinned)	Each pixel value is stored individually. Full or partial spectra can be transmitted to Earth at a variety of cadence rates. No dark subtraction is made onboard.
Nadir (binned)	Detector pixel values are vertically binned onboard. Full or partial spectra can be transmitted to Earth at a variety of cadence rates. Occasional dark frames are taken and transmitted to Earth
Nadir (unbinned)	Each pixel value is stored individually. Full or partial spectra can be transmitted to Earth at a variety of cadence rates. Occasional dark frames are taken and transmitted to Earth.
Calibration	Many types e.g. line of sight, integration time tests, etc.

Table 10: All possible measurement types currently envisaged by the NOMAD team.



2.9.1.2 Nominal Observation Modes and Measurement Types

Given the large number, it is not feasible to describe every possible observation mode and measurement type combination, and hence this EAICD will detail only the nominal science modes, as given in Table 11, for which the data will be converted to PDS4 format and delivered to the PSA. This list will increase as more observation types are calibrated.

Channel	Observation Mode	Measurement Type(s)	Description
SO	Ingress	Solar occultation, 0-250km, or 0-50km and 50-250km	5-6 diffraction orders
	Egress	Solar occultation, 0-250km, or 0-50km and 50-250km	5-6 diffraction orders
	Merged	Solar occultation, 250km-0-250km	5-6 diffraction orders. Occultations will be split into Ingress and Egress
LNO	Dayside Nadir	Nadir, observation centred on surface point with lowest solar incidence angle	1-6 diffraction orders
UVIS Occultation	Ingress	Solar occultation, 0-250km	Detector can be vertically/horizontally binned or unbinned
	Egress	Solar occultation, 0-250km	Detector can be vertically/horizontally binned or unbinned
	Merged	Solar occultation, 250km-0-250km	Detector can be vertically/horizontally binned or unbinned. Occultations will be split into Ingress and Egress
UVIS Nadir	Dayside Nadir	Nadir, observation centred on surface point with lowest solar incidence angle	Detector can be vertically/horizontally binned or unbinned

Table 11: Nominal science modes that will be converted to PDS4 format and delivered to the PSA.

3 DATA GENERATION AND ANALYSIS PROCESS

The NOMAD science products are produced by the NOMAD Instrument Team in cooperation with the SGS. The data generation and analysis process is described in this section, and follows the general concept for data generation, validation and archiving described in the Archiving Plan [AD.01].

Science data received by the SGS from the NOMAD team are made available to end users through the ExoMars 2016 archive following the policies described in the Archiving Plan [AD.01].

3.1 Data Flow Overview

Under the full responsibility of the PI institution (IASB-BIRA), the NOMAD team will produce and archive the data of the NOMAD instrument adhering to the recommendations and specifications imposed by ESA/NASA for this mission, with timely delivery of data products in appropriate formats to the ESA PSA.

NOMAD's science and instrument housekeeping data (including copies of all telecommands and relevant S/C housekeeping data), captured via the DSN, collected in the MOC and transferred to the SOC, will be recovered through the ESA DataStore as soon as available during the complete mission duration. The PI institute will archive the science and instrument housekeeping data recovered from the DataStore.

Documentation on the data acquisition, conversion and processing is crucial to the long-term success of the project. Transition from raw to calibrated data will therefore be extensively documented and updated while kept under version control, including software algorithms and code of all stages in the reduction process (recovery, validation, reduction, archiving etc.)

Data products generated by the PI institute will be delivered via the ESA DataStore. All files will be transmitted to/from the DataStore and PI institute using an rsync process.

3.1.1 Data levels

The levels to be delivered to the ESA DataStore are given in Table 12. The ESA SOC delivers raw binary Level 0.0 instrument data via the EDDS. Upon receipt, NOMAD's In-flight Operations Team will immediately perform a consistency check on the data. In case of unexpected behaviour, actions will be undertaken to guarantee the safety of the instrument during further operations.

Raw PDS4 products are generated by the SOC from raw telemetry, and are deposited directly into the PSA archive. Partially processed PDS4 products are also generated by the SOC, and are deposited directly into the PSA archive. In these files, housekeeping data is converted from raw binary to physical units using the following formulae given in the appendix in Table 43, Table 44, Table 45, and Table 46.



The PI data processing pipeline will convert raw data to calibrated (Level 1.0 and above) data on a regular basis, which will be integrated automatically into the NOMAD archive. Calibrated data will be made available in PDS4 format via the PSA. All NOMAD Co-Is will have access to the calibrated data immediately and without restriction. As the conversion from raw to calibrated data is fully automated, a swift delivery of raw, calibrated and ancillary data products to ESA and NASA’s planetary archive systems is achievable once the data processing pipeline is ready and has been reviewed. Production, archiving and delivery of science (Level 2.0, 3.0 and above) data products are under the responsibility of NOMAD’s Science Team jointly steered by PI and Co-PIs.

If errors are detected in an observation that cannot be corrected, the data pipeline will reject the measurement and a corresponding calibrated product will not be produced. This is particular true for solar occultations, where the calibration involves an extrapolation (see section 3.3.20) - a check is performed to ascertain whether the extrapolation is valid or not. If not valid, the data is not processed further.

Primary Data	
Processing Level Description	Processing Level Description
Raw	Raw products from science telemetry packets, in the form of ASCII tables
Partially Processed	HSK corrected data Detector corrections (linearity, dark current, etc) fully reprocessed when in-flight calibration available
Calibrated	Calibrated data + supporting geometry (Level 1.0) Full reprocessed when updated in-flight calibration available SO, LNO and UVIS (solar occultation mode): pixel-wavenumber/wavelength, transmittance LNO, UVIS (nadir mode): pixel-wavenumber/wavelength + radiance
Derived	Retrieved atmospheric profiles/columns with supporting geometry (Level 2.0) Global atmospheric fields from GCM (Level 3.0)



Supplementary Data	
Type	Description
Calibration	Calibration coefficients and lists of files used for calibration purposes
Miscellaneous	Additional data files: Telecommands; data conversion history;

Table 12: ESA PSA data levels for NOMAD as defined in the Science Data Generation, Validation and Archiving Plan.

3.2 Data Processing Pipeline Outline

BIRA-IASB's internal data levels are summarised below, to show which calibration and data conversion steps take place at each level. Those in purple will be generated in PDS4 format and made available on the ESA PSA; the remainder will be generated by the PI team for internal science team use only. A flowchart of this process is shown in Figure 13 **Error! Reference source not found..**

Broadly speaking, observations can be sorted into 3 categories. These are:

- Standard science observations. These are denoted by the observation type letters I, E, N or D. These will pass through the normal data pipeline, meaning that the full data processing treatment will be applied to them, and will be provided to the ESA DataStore by default.
- Special science observations. These are files not denoted by observation type letter C nor those listed above (e.g. S, F or L). Their progression through the pipeline will depend on their type and what calibrations can be done on them. For example:
 - S or F: A solar occultation or nadir fullscan could potentially be spectrally and radiometrically calibrated and with geometry added, however a dedicated pipeline would be required. The standard pipeline splits the files by diffraction order in the early stages, which for a fullscan would result in each measurement being split into a different file, potentially resulting in 100+ files generated per observation. Radiometric calibration of these observations may not be possible, particularly in the case of solar occultation fullscans. Therefore it is not currently envisaged that PDS4 calibrated products will be generated from these observations and delivered to the PSA archive, though this will be reviewed if a calibration routine is developed in future. Raw and partially processed products will still be produced.
 - L: Limb measurements are not in the baseline observation plan, although tests will be made during the mission – which if successful will lead to regular limb measurements, if allowed. These observations can be spectrally and radiometrically using the standard nadir pipeline, however the output



geometry parameters will be different and will therefore need a dedicated section of pipeline to do this.

- When generating nadir PDS4 products, the geometry parameter tangent altitude will be included so that the nadir product definition can be used for both limb and nadir observations. A value of -999 will be used for nadir measurements; likewise surface geometry and illumination parameters (latitude, longitude, solar zenith angle, solar azimuth angle, incidence angle, emission angle, phase angle) will be set to -999 for limb observations. There will also be additional differences between LNO nadir and LNO limb due to the binning of the detector. For these reasons, calibrated limb products will not ordinarily be delivered to the SOC, though this will be reviewed in future.
- Calibration observations. These files are used only to calibrate NOMAD and have no direct scientific value. These files cannot be calibrated and therefore will not be provided to the PSA as PDS4 calibrated products. The SOC will still generate raw and partially-processed products for these observations however. Files containing derived calibration coefficients could be delivered to the ESA DataStore, though the format of such products is not yet defined.

All the steps taken to process the data are detailed below. At BIRA-IASB, the pipeline consists of multiple levels, with each step modifying the files or applying a specific calibration routine. These steps will not be visible to a PSA user, however to explain how the data is calibrated it is essential to detail all the steps taken.

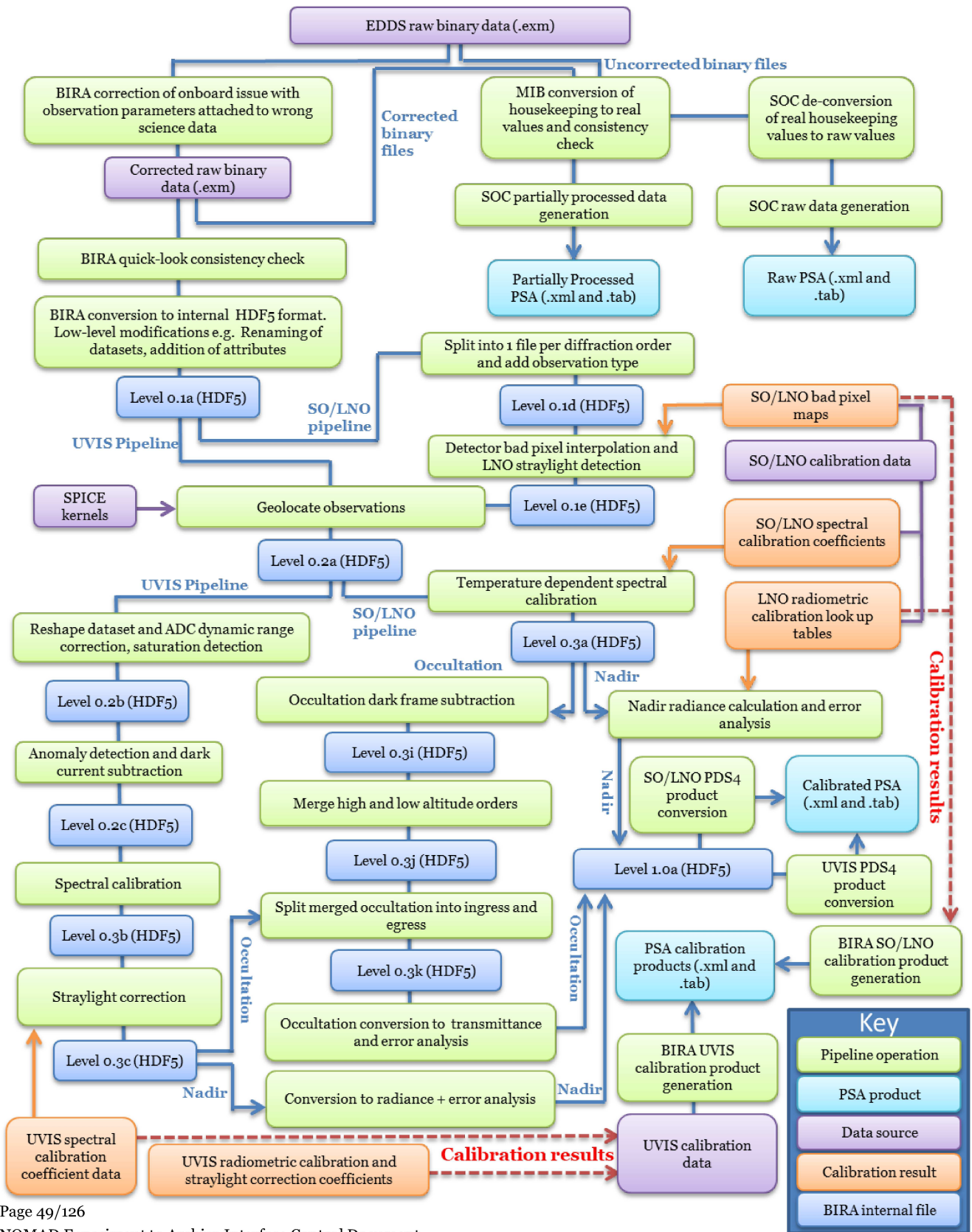




Figure 13: Flowchart outlining the expected data pipeline, including internal data levels and calibration inputs/outputs

3.3 Data Processing Pipeline Conversion Steps

3.3.1 Level 0.ob - SO/LNO Binary Data Correction

During analysis of inflight data, an issue was discovered which can cause errors in the SO and LNO channel binary data files transmitted from the spacecraft. NOMAD is made of a central processor (SINBAD) and three channels (SO, LNO and UVIS). SO and LNO operate very similarly, and so only SO will be discussed here, though LNO is effectively the same. UVIS operates differently and is therefore not affected by this issue.

SINBAD contains several timers, which dictate when actions are performed. It directly controls the SO channel, sending observation parameters (such as AOTF frequency, integration time, binning, etc.) to the channel to initiate measurements. Detector data is then returned from the channel, via a buffer, to SINBAD, which reads this buffer when a specific timer is activated. SINBAD then builds a SpaceWire packet, collating the observation parameters with the data returned from the SO channel and adding a timestamp and housekeeping. This packet is then sent to TGO via SpaceWire as a TM(22) or TM(25) packet. The issue arises occasionally when there is a mismatch between the timer that reads the SO channel buffer and the timer that generates the packet. When the mismatch occurs, the detector data is read from the buffer it is added to the correct packet, but there is then a delay in adding the SINBAD data (observation parameters, timestamp, channel housekeeping) to the same packet. When the delay is sufficiently large, SINBAD has already generated the observation parameters/timestamp/HSK for the next measurement, and so these are erroneously added to the packet. This results in a mismatch between the detector data and the other (observation parameters/timestamp/HSK) data in a SpaceWire packet. No detector data is lost, because the packet is always generated after the data is received by SINBAD, but occasionally the wrong observation parameters/timestamp/HSK data are "glued" onto this packet. The parameters/timestamp/HSK actually come from the next observation, and so it is simple to identify the incorrect packets, as the timestamp has the same value in two consecutive packets – which is never possible as the minimum time between two packets is ~1 second in reality.

3.3.1.1 Creation of TM122 and TM125 packets

To correct this, the EDDS binary files are sent to BIRA and run through a program that checks the measured observation parameters and timestamps against the expected values. When a mismatch is found, it is corrected and a new binary file is generated and sent to the SOC for processing into raw and partially processed PSA data products.

Importantly, to avoid issues with users downloading the wrong files, and to prevent reanalysis of already-corrected files, the corrected binary products are assigned new packet type numbers:

- TM(122) = a corrected TM(22) SO SpaceWire Packet

- TM(125) = a corrected TM(25) LNO SpaceWire Packet

The new files are ingested into the SOC data pipeline as if they were new file types, and the old PDS4 products made from packet types 22 or 25 should not be sent to the PSA archive.

3.3.2 Level 0.1E - LNO straylight

Straylight can be observed in the data when the LNO channel is observing in nadir and the spacecraft is in a particular geometry which only occurs when slewing to an ACS solar occultation. This happens only on the nightside of the planet and so no science is lost. However, a signal is observed in the data, and so the affected frames are removed to avoid misinterpretation of the spectra.

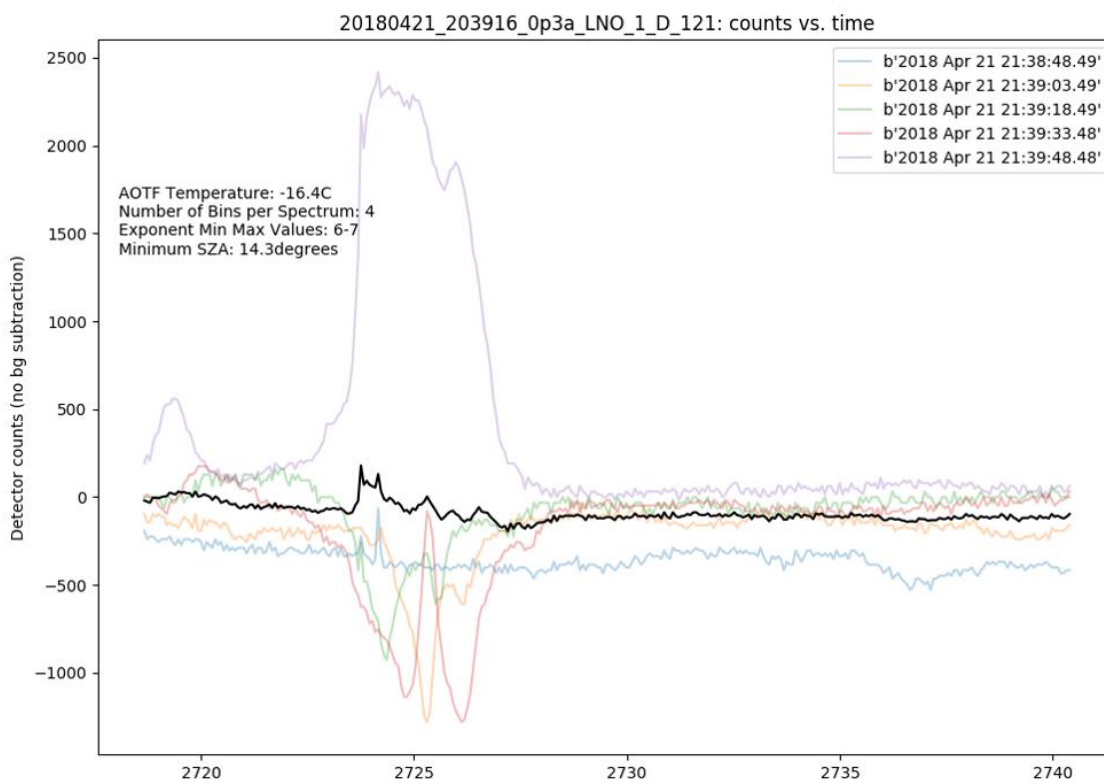


Figure 14: Solar straylight entering LNO has a huge impact on the signal. As LNO is background-subtracted, the straylight manifests itself as positive or negative values depending on whether it hits the detector during the dark or measurement frame.

Frames containing this straylight are removed automatically, based on a set of detection criteria - i.e. spacecraft orientation with respect to the Sun, and anomalous detector values.

The frames directly before and after are also removed, to ensure that all incorrect data is removed. The data is not recoverable when straylight is present, and so all radiance values in the affected frames are set to -999. Assuming straylight has been detected in measurement frame 4, the data would be as shown in Table 13.

LNO Radiance			
Measurement 1, Pixel 1 Value	Pixel 2 Value	...	Pixel 320 Value
Measurement 2, Pixel 1 Value	Pixel 2 Value	...	Pixel 320 Value
NaN	NaN	...	NaN
NaN	NaN	...	NaN
NaN	NaN	...	NaN
Measurement 6, Pixel 1 Value	Pixel 2 Value	...	Pixel 320 Value

Table 13: Radiance values in the tab file, showing how the data is modified if straylight is detected in measurement 4.

3.3.3 Level 0.1E - SO/LNO bad pixel

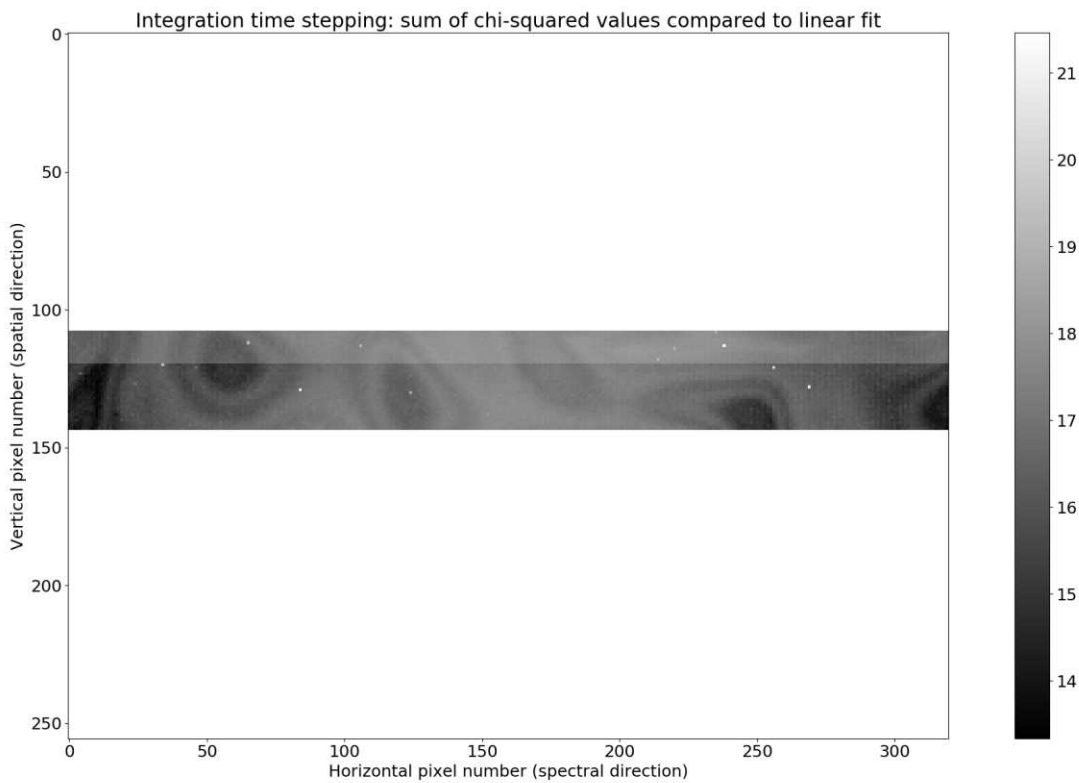


Figure 15: SO bad pixel map. White dots indicate bad pixels. Two observations were required to cover all the pixels required, hence the small difference between the top and bottom rows is likely due to slightly different instrument temperature.

Bad pixels were determined by analysing a subset of spectra and finding the pixels that behave anomalously compared to adjacent pixels throughout a measurement. This method works even for the narrowest absorption lines, as there is always a spectral overlap between consecutive pixels, and so an anomalous value in one pixel only can only be due to the pixel, not the atmosphere or surface of Mars.

If a pixel behaves anomalously the value is corrected by linearly interpolating from adjacent pixels. Pixels at the edge of the detector, where the signal is already very small, are given the same value as the adjacent pixel. It should be noted that some bad pixels only give anomalous readings occasionally, and so some spectra can still contain spikes after transmittance/radiance calibration. These will need to be removed by the PSA user.

3.3.4 Level 0.1E - LNO detector offsets

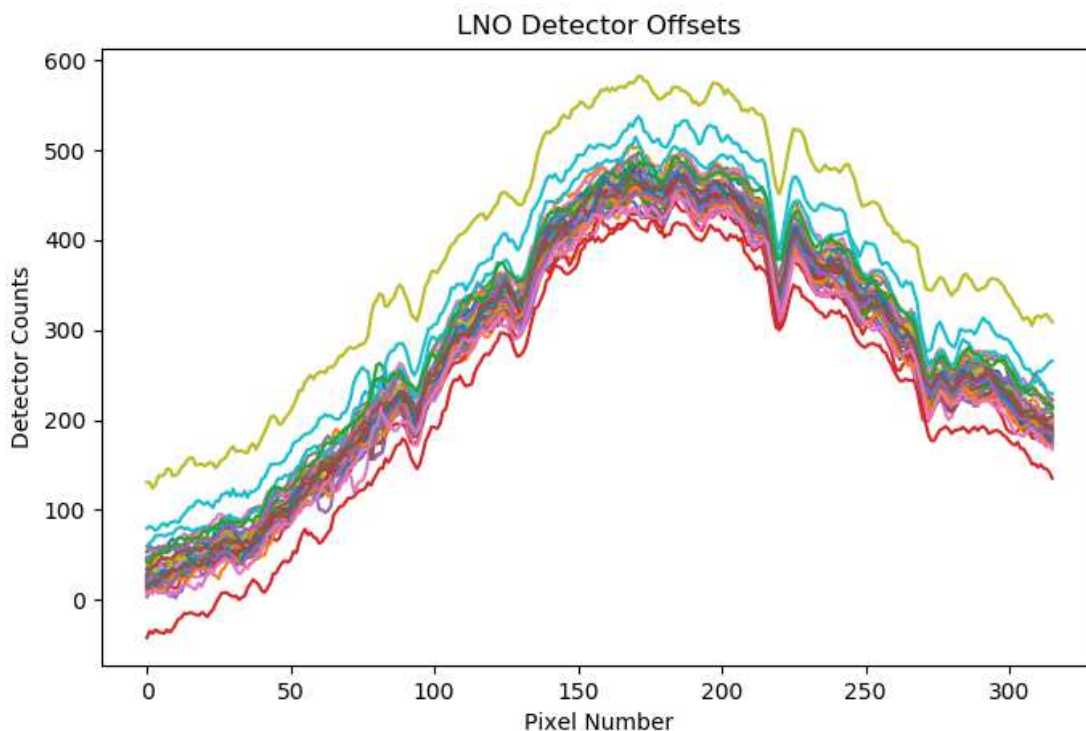


Figure 16: LNO detector spectra before offset correction

The zero offset level can shift up and down due to the detector grounding and the very small values generated by a nadir measurement (Figure 16). To correct this, an offset correction is calculated from the mean of the first 50 pixels. The offsets are subtracted from each spectrum to remove the anomalous offset, as shown in Figure 17.

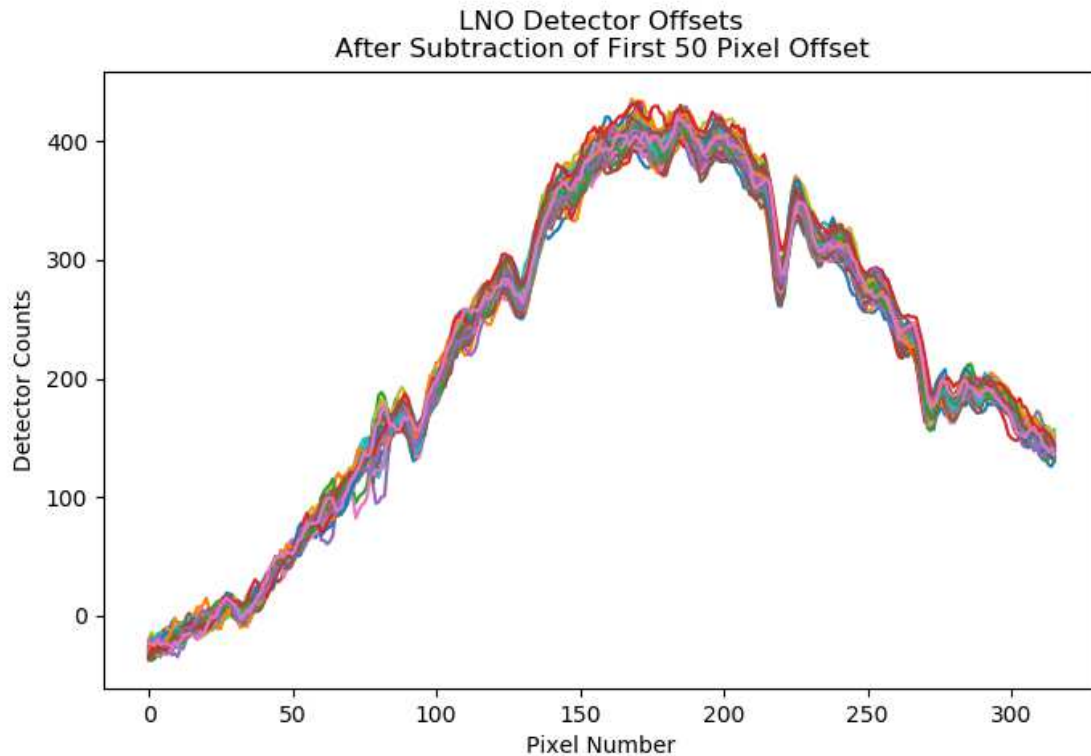


Figure 17: LNO nadir spectra after subtraction of the offset. A second offset is added to shift the curve upwards, removing the negative counts in the first pixels.

Removing the offset means that the first pixels can be less than zero, therefore a second offset is subsequently added to the data. This offset is derived from solar calibration measurements of the same diffraction order, where a ratio is calculated between the mean of the centre pixels [160-240] and the mean of the first 50 pixels when pointing at the sun. An offset is then added to each nadir spectrum so that the same ratio is present in the data.

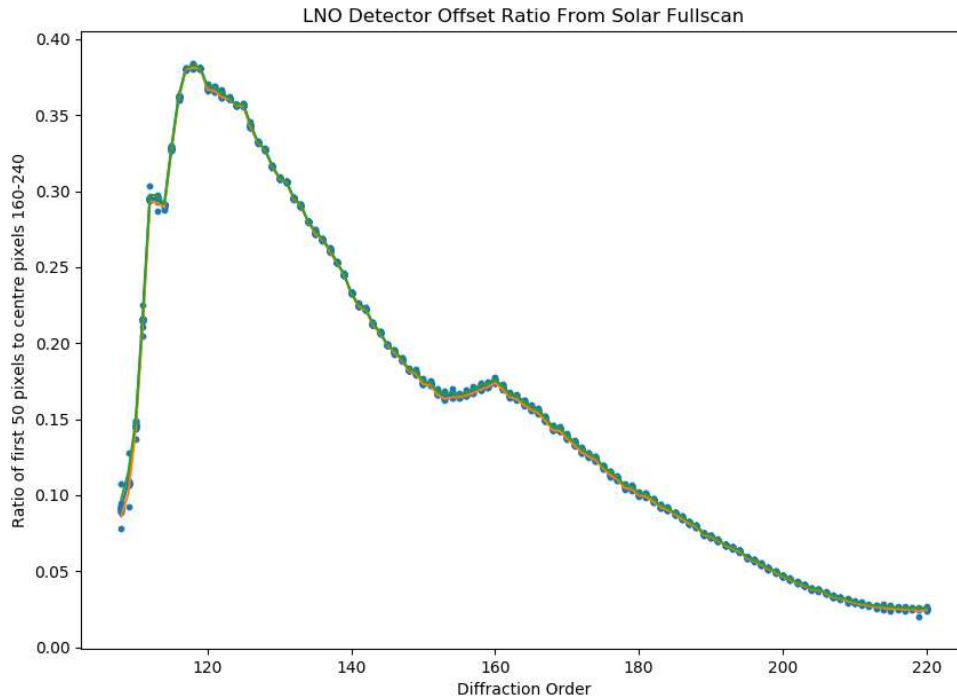


Figure 18: Ratio of mean value of first 50 pixels to mean value of pixels in centre of detector, calculated from viewing the sun for each diffraction order. This ratio is then applied to the data, shifting the nadir curves upwards so that the same ratio is observed in the spectra.

3.3.5 Level 0.1E - LNO nadir data vertically binned

The SNR of the LNO channel is low when observing in nadir, and so the spectra measured for each detector bin (of the same measurement) must be summed together to produce one spectrum.

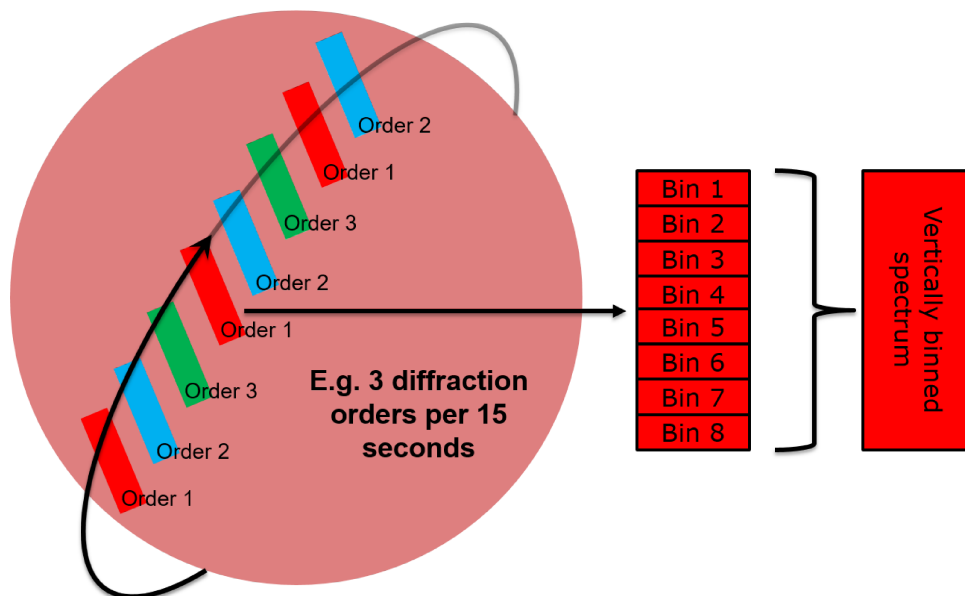


Figure 19: Vertical binning of one LNO nadir detector frame (red). Here 3 diffraction orders are measured, generating 8 individual spectra for a given measurement.

The SO and LNO channel always return 24 lines per measurement period (where the period is 1 second for occultation or 15 seconds for nadir observations). Therefore here, 3 orders are measured per period and so 8 spectra are returned per order. If 4 orders were measured, 6 spectra would be returned; if 2 orders then 12 spectra would be returned, etc. The 6, 8 or 12 LNO nadir spectra are then vertically binned to give a single spectrum per order per measurement period (Figure 19).

The detector bins observe different locations on the planet, but this spatial information is lost when the data is binned - though individual bins do not have sufficient signal to be scientifically useful.

3.3.6 Level 0.1E - SO/LNO detector bins flattened

SO and LNO radiance/transmittance values are converted from a 3D array (size = number of observations x number of bins x 320 pixels) to a 2D array (size = [number of observations x number of bins] x 320 pixels). **BinStart** and **BinEnd** fields contains the start and end detector row for each bin. LNO nadir observations have already been vertically binned into a 2D array, and so the radiance values remain unchanged.

3.3.7 Level 0.2A – Geometry overview

There are three types of shape models used to calculate geometric parameters:

- **Ellipsoid** - this is the most basic shape model, where Mars is modelled as a tri-axial ellipsoid of radii 3396.19km x 3396.19km x 3376.2km
- **Areoid** - this is the equivalent to a "sea level" for Mars, where the gravitational and rotational potential is constant across the entire surface. The zero level is defined by MGS/MOLA using a 4 pixels per degree model
- **Surface** - this is the real surface elevation, calculated from a digital shape kernel (DSK) by MGS/MOLA at a resolution of 4 pixels per degree using the MGM1025 model (Lemoine et al., 2001).

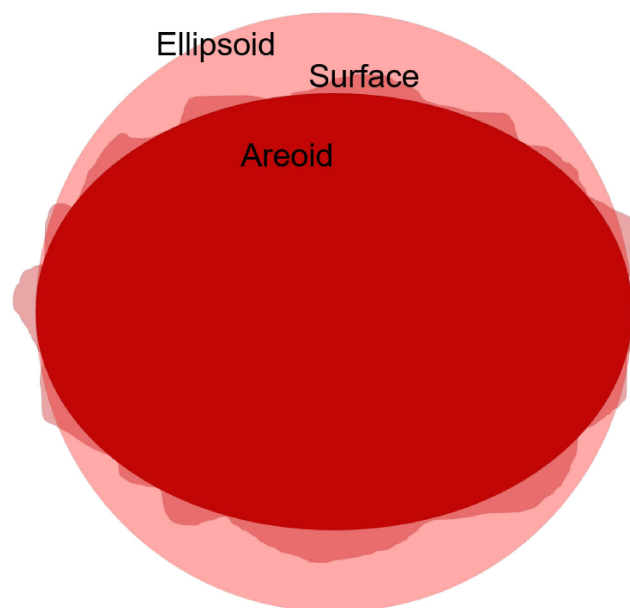


Figure 20: Pictorial representation of the difference between ellipsoid, surface and areoid geometries.

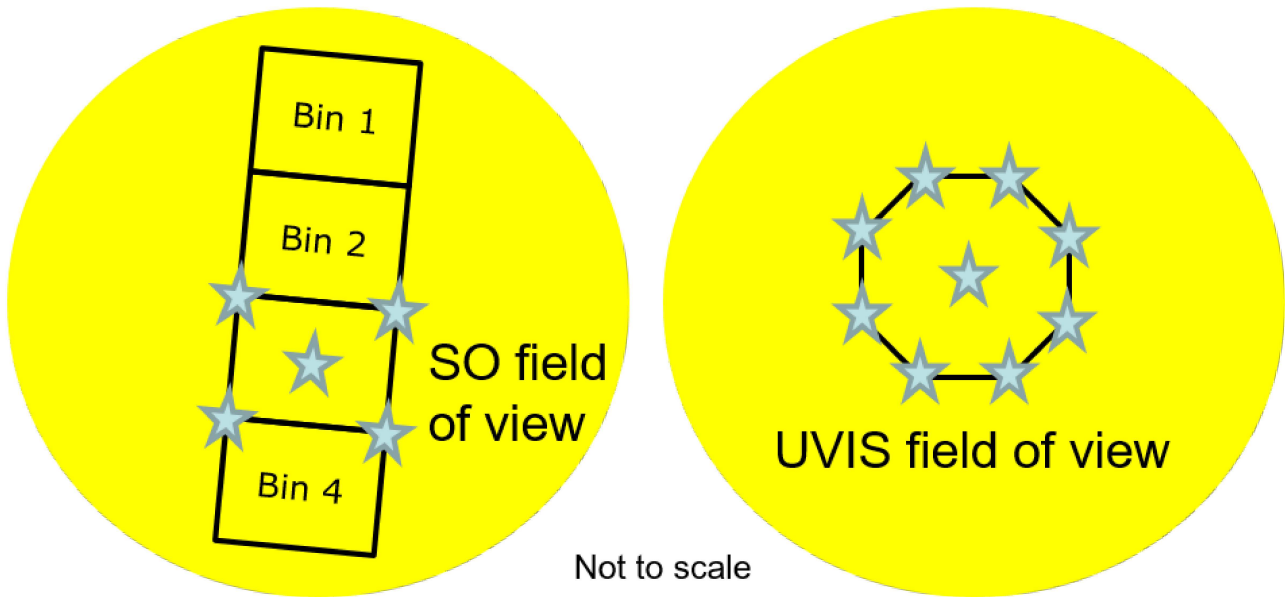


Figure 21: SO and UVIS solar occultation geometry, showing the 5 points per bin for SO and 9 points for UVIS.

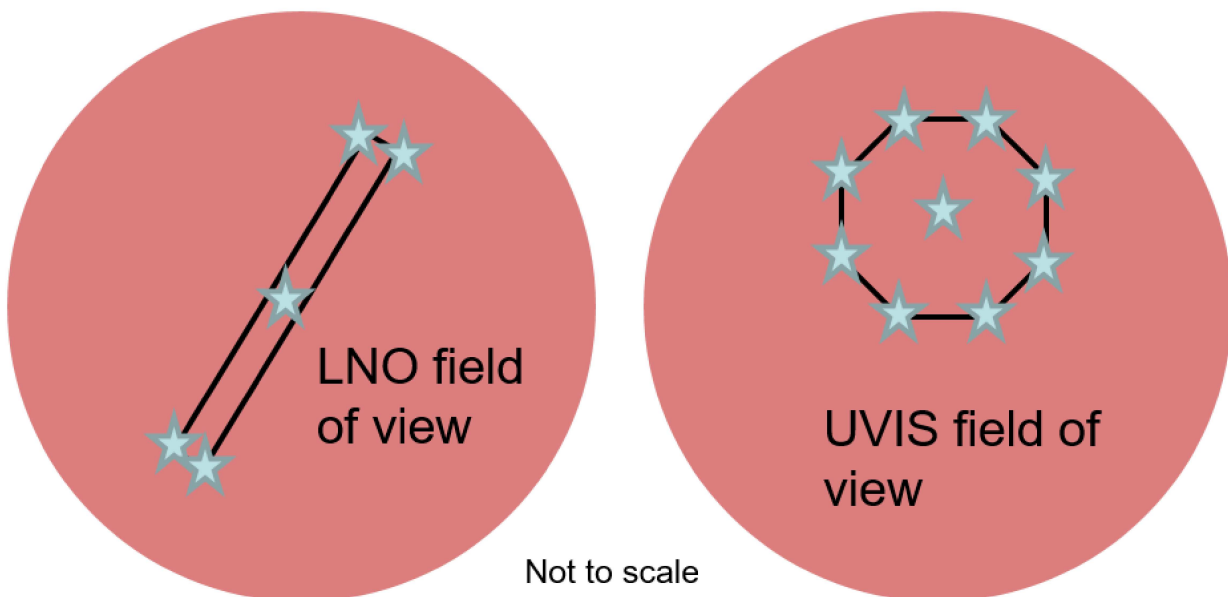


Figure 22: LNO and UVIS nadir geometry, showing the 5 points per bin for SO and 9 points for UVIS

Geometry is stored for each pointing direction (Figure 21 and Figure 22). There are 5 points for SO/LNO solar occultations and nadir observations:

- **Point0** is the centre of the entire field of view of the bin
- **Point1** to **Point4** define the corners of the field of view of the bin

UVIS has a circular aperture, defined by 9 points:

- **Point0** is the centre of the field of view
- **Point1** to **Point8** form an octagon around the field of view edge.

As described above, the LNO nadir frame has been vertically binned, and so there is effectively just one bin per measurement. Therefore points 1-4 define the corners of the entire LNO field of view.

The fields of view of the bins are defined using points as shown in Figure 23. Relevant geometric parameters, such as latitude, longitude and viewing angle information are calculated for each point. The relative x and y positions of each point (the numbers in brackets in Figure 23) are given in the fields PointX0, PointY0, PointX1, PointY1, etc. Their direction is defined by the SPICE instrument kernel reference frame for each channel, where X points along the long edge of the SO/LNO slit and Y the short edge.

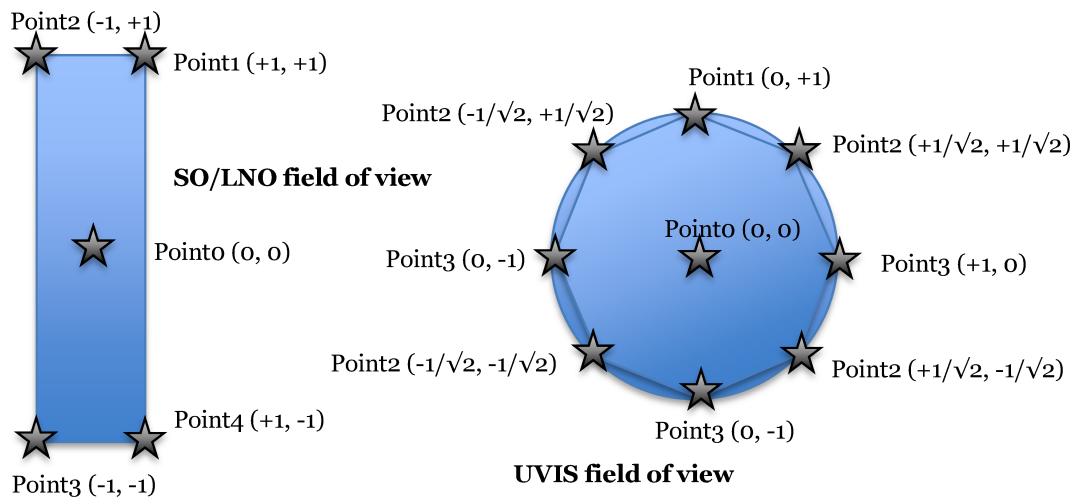


Figure 23: Geometry points as defined in relation to the channels' fields of view.



A complete list of geometric parameters in the metadata and data tables are given in Table 34, Table 35, Table 39 and Table 40. Some geometric parameters do not depend on pointing direction, for example **SubObsLat** and **SubObsLon**. Start and end values are recorded per spectrum acquired, i.e. **SubsObsLatStart** and **SubObsLatEnd**.

Some geometric parameters have different values depending on the point – therefore there are two values (start and end times) per point per spectrum acquired. An integer is appended to the field name to indicate the point number, e.g. **LonStart3** and **LonEnd3** are the start and end longitudes for point 3.

Using the surface shape model means that the geometric surface parameters **EmissionAngle** (angle between surface normal and spacecraft), **PhaseAngle** (angle between sun, surface and spacecraft) and **IncidenceAngle** (angle between Sun and surface normal) are based on the real surface contours rather than a reference ellipsoid. All of the fields above are point-dependent, e.g. **EmissionAngle** is defined as **EmissionAngle0Start**, **EmissionAngle0End**, **EmissionAngle1Start**, etc. for the 0 and 1 correspond to FOV points 0 and 1. Latitude and longitude are effectively independent of shape model and hence are provided for ellipsoid model only.

In solar occultation mode, the geometry is defined at the tangent point, i.e. the point on the Mars ellipsoid closest to the line of sight vector of each point. Each shape model has a different tangent height, but the most important is the height above the areoid, there this is given as **TangentAlt** in the products. Values are given separately for the start and end acquisition time of each spectra and for each field of view point, e.g. **TangentAltoStart**, etc.

LST is the local solar time, in hours, defined using the SPICE kernel definition = $12 + (\text{surface longitude for a point} - \text{solar longitude})/15$

LSubS, the planetocentric solar longitude, commonly referred to as L_s (pronounced "L sub S", or "L-S"), is the position of Mars relative to the Sun measured in degrees from the vernal equinox (start of northern Spring). This number is used as a measure of Martian seasons: Northern Spring/Southern Autumn start at 0° , Northern Summer/Southern Winter start at 90° , Northern Autumn/Southern Spring start at 180° , and Northern Winter/Southern Summer begin at 270° . Values are given separately for the start and end acquisition time of each spectra, e.g. **StartLSubS** and **EndLSubS**, but values do not change with field of view point.

Invalid values are set to -999.0. This could occur, for example, when the solar occultation boresight is pointing towards the surface (therefore tangent altitude is invalid) or if the nadir channel points off-planet during an observation, which can happen if the spacecraft is slewing to/from another measurement.

3.3.7.1 SO/LNO Occultation (50km switch)

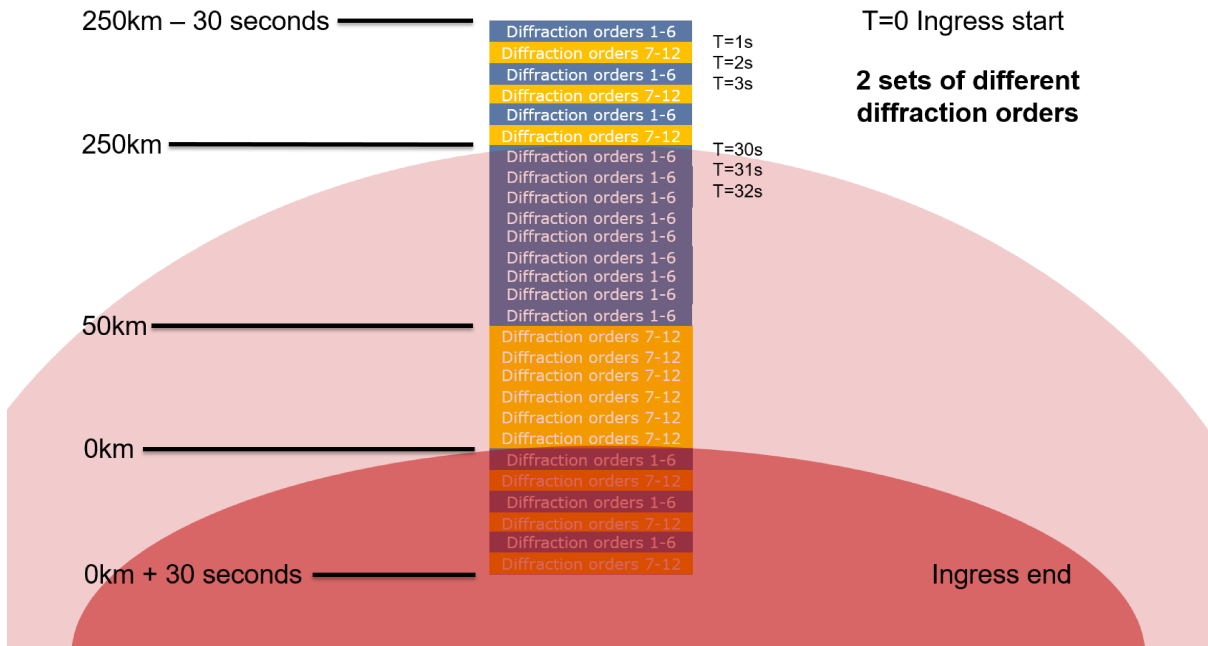


Figure 24: Diagram showing the SO data acquired during a solar occultation where the set of diffraction orders is changed 50km above the surface.

3.3.7.2 SO/LNO Occultation (0-250km)

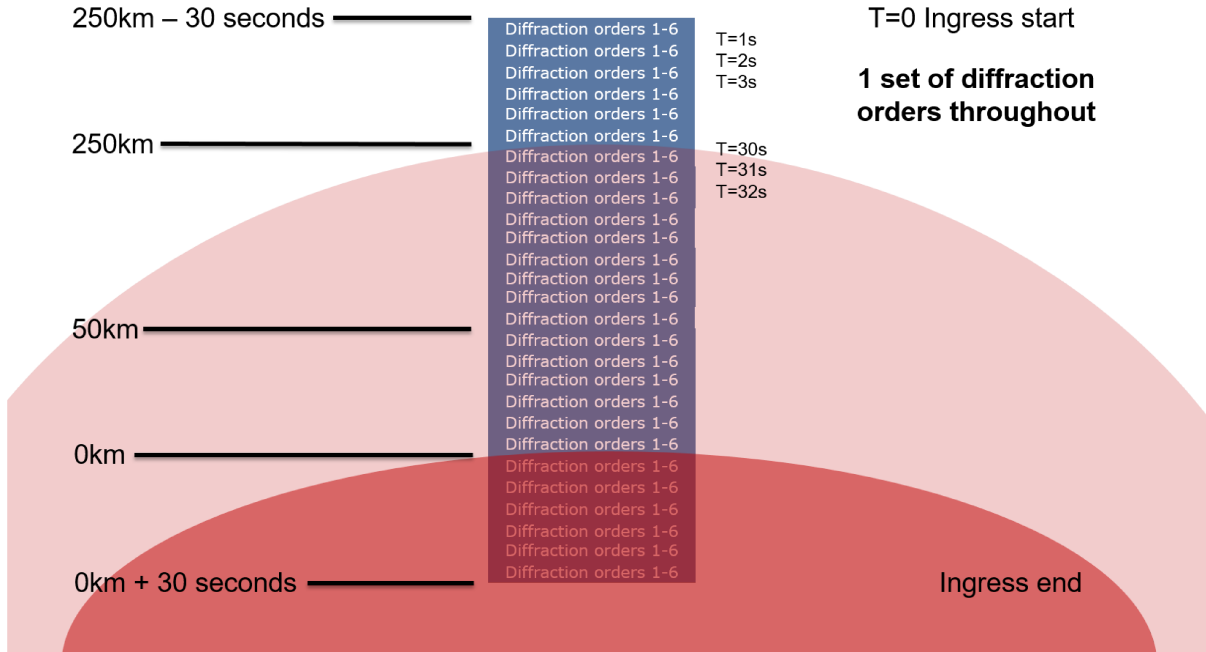


Figure 25: An SO occultation where the same diffraction orders are measured throughout.

Figure 24 and Figure 25 show the principal two types of solar occultations measured by the SO channel. Note that, in cases where onboard dark subtraction is switched off, diffraction orders 6 and 12 are normally dark frames, hence only 5 or 10 diffraction orders are measured.

The SO data has been flattened into a 2D array (section 3.3.6), and so the data is now in the format shown in Table 14, with one spectrum per bin per measurement per row. For each transmittance spectrum there is a **BinStart** and **BinEnd** value to specify the detector rows used to acquire that bin.

SO Transmittance			
Measurement 1, Bin 1, Pixel 1	Pixel 2	...	Pixel 320
Measurement 1, Bin 2, Pixel 1	Pixel 2	...	Pixel 320
Measurement 1, Bin 3, Pixel 1	Pixel 2	...	Pixel 320
Measurement 1, Bin 4, Pixel 1	Pixel 2	...	Pixel 320
Measurement 2, Bin 1, Pixel 1	Pixel 2	...	Pixel 320
Measurement 2, Bin 2, Pixel 1	Pixel 2	...	Pixel 320

BinStart	BinEnd
-----------------	---------------

Bin 1 Detector Row Start	Bin 1 Detector Row End
Bin 2 Detector Row Start	Bin 2 Detector Row End
Bin 3 Detector Row Start	Bin 3 Detector Row End
Bin 4 Detector Row Start	Bin 4 Detector Row End
Bin 1 Detector Row Start	Bin 1 Detector Row End
Bin 2 Detector Row Start	Bin 2 Detector Row End

Table 14: SO transmittance and binning data.

3.3.7.3 LNO nadir

Due to the low SNR in nadir mode, all the LNO bins have been summed into a single spectrum per measurement. Therefore, in the absence of separate bins, the tabulated data contains just one spectrum per measurement. BinStart and BinEnd therefore are the same for all measurements and reflect the start and end row of the detector readout (Table 15).

LNO Radiance			
Measurement 1, Pixel 1	Pixel 2	...	Pixel 320
Measurement 2, Pixel 1	Pixel 2	...	Pixel 320
Measurement 3, Pixel 1	Pixel 2	...	Pixel 320
Measurement 4, Pixel 1	Pixel 2	...	Pixel 320

BinStart	BinEnd
Detector Row Start	Detector Row End
Detector Row Start	Detector Row End
Detector Row Start	Detector Row End
Detector Row Start	Detector Row End

Table 15: LNO radiance and corresponding binning data

3.3.7.4 UVIS Nadir and Occultation

UVIS acquires one spectrum per measurement, with no bins or diffraction orders (Table 16).

UVIS Transmittance/Radiance			
Measurement 1, Pixel 1	Pixel 2	...	Pixel 1048
Measurement 2, Pixel 1	Pixel 2	...	Pixel 1048
Measurement 3, Pixel 1	Pixel 2	...	Pixel 1048
Measurement 4, Pixel 1	Pixel 2	...	Pixel 1048
Measurement 5, Pixel 1	Pixel 2	...	Pixel 1048

Table 16: UVIS transmittance data for a full spectrum (1048 pixels)

3.3.7.5 LNO Limb

At the time of writing, only the LNO channel can observe the limb using its flip mirror while the spacecraft continues in nadir pointing mode. The signal entering the UVIS solar occultation boresight is attenuated, and so the spacecraft must be orientated with the nadir channel pointing towards the limb for both LNO and UVIS to measure it.

LNO observes the limb passively, with no control over pointing, and so the pointing can vary between and within observations. In future it is hoped that the limb can be measured in a controlled way, viewing at a fixed altitude, or with the UVIS nadir boresight.

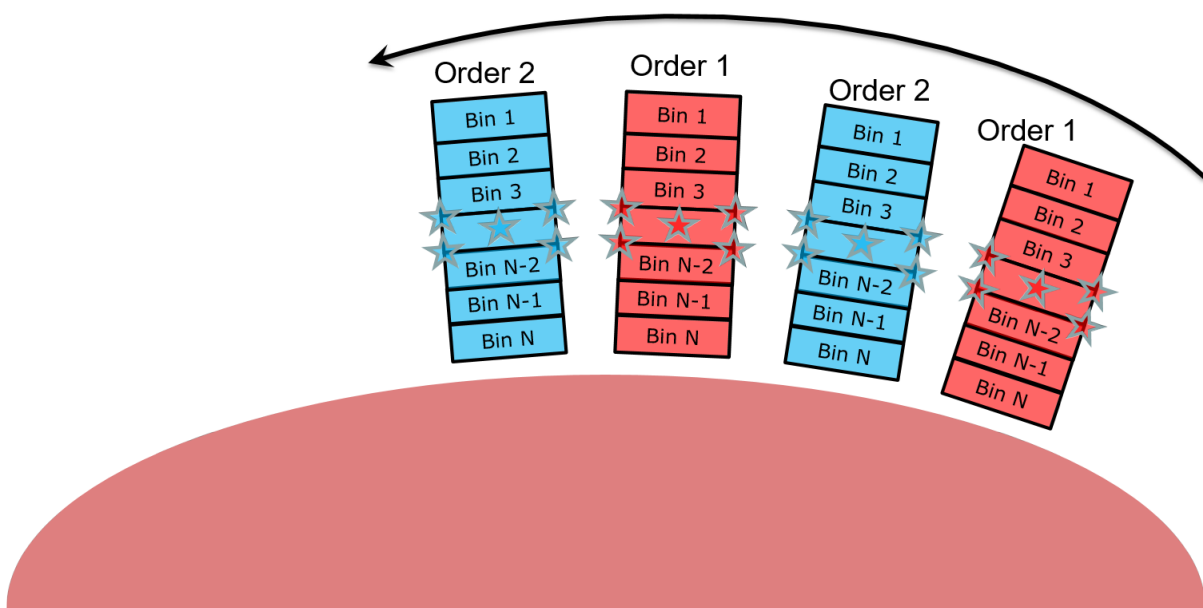


Figure 26: An LNO limb observation using two diffraction orders. The FOV generally sweeps across the limb as the spacecraft moves, in the direction of the short edge of the slit.

The LNO limb data is arranged like SO/LNO solar occultations, split into bins and using the same geometric parameters, even though the SNR is too low per bin to be usable for science. This is because the altitude information is lost if the entire detector is binned, and so the SNR should be increased by summing each bin in time for a given altitude range.

Limb measurements are not yet ready for PDS production, however they will be prepared and made available to the community in future.

3.3.8 Level 0.3A - SO/LNO spectral calibration

Spectral calibration of the SO and LNO channels is complicated by the presence of the AOTF and diffraction grating. Without an AOTF, there would be >100 diffraction orders hitting the detector simultaneously, and so attributing an absorption line to a specific wavelength would be impossible.

The AOTF solves this by permitting only a limited spectral range to pass through it. In an ideal situation, the AOTF transmittance would be a boxcar function, of width exactly equal to the spectral range of the desired diffraction order. However, in reality the AOTF has a more complicated shape, akin to a sinc² function, with sidelobes that allow radiance to pass through it and hit the detector from adjacent diffraction orders. Accurate calibration is essential, so that all features present in a spectrum can be attributed to the principal or adjacent diffraction orders – and the shape of the AOTF function is correct so that the absorption depths of those features can be correctly used to determine the concentration of gas species in the atmosphere of Mars. Similarly, accurate wavenumber calibration of the diffraction grating is required so that the features observed match those in spectroscopic databases. This is further complicated by the effects of instrument temperature – NOMAD is not kept at a fixed temperature, and the metal diffraction grating is mounted to the instrument structure, and therefore can expand and contract as the temperature changes. This results in a temperature-dependent wavelength shift which must be corrected by the spectral calibration calculation. AOTF shape coefficients and spectral resolution vary by diffraction order.

The spectral calibration is, and will be, continually refined during the mission, and so the calibration coefficients and equations are likely to change often. The current published coefficients can be found in Liuzzi et al. 2019 [RD.11], which were derived from solar calibration measurements taken from Mars orbit in 2016. The calibration takes a variety of forms, as detailed below. All coefficients are provided in calibration products in the PSA archive.

3.3.8.1 Grating Calibration

The wavenumber-pixel calibration is:

$$\frac{\nu_p}{m} = F_0 + F_1 p + F_2 p^2$$

Where ν_p is the wavenumber in cm⁻¹ of pixel p in diffraction order m and F_0 , F_1 and F_2 the coefficients of a second order polynomial derived from ground and in-flight spectral calibration campaigns. The wavelength shift due to temperature is accounted for by modifying the values of p used in the equation above. The field **FirstPixel** specifies the first value, and so the values of p are [**FirstPixel**, **FirstPixel** + 1, **FirstPixel** + 2... to **FirstPixel** + 319)

The value of **FirstPixel** is determined from the temperature of NOMAD at the start an observation, and varies linearly with instrument temperature T :

$$\mathbf{FirstPixel} = Q_0 + Q_1 T$$

At present, **FirstPixel** is constant throughout an entire observation, however in future this may be subject to change.

The temperature-dependent calculation of the spectral calibration is hidden from the PSA user, as the wavenumber corresponding to each pixel is given in the PSA products in the fields **Pixel0**, **Pixel1**, ... to **Pixel319**.

The SO and LNO gratings are more efficient in diffraction radiation towards the centre of a diffraction order rather than at the edges, according to the blaze function. This is modelled as a sinc² function:

$$F_{blaze}(p, p_0, w_p) = w_p^2 \frac{\left[\sin \frac{\pi(p - p_0)}{w_p} \right]^2}{\pi^2(p - p_0)^2} \quad (1)$$

where p is the pixel number (from 0 to 319), p_0 is the center of the function in pixel units, and w_p is the width of the blaze function.

The blaze function width is constant in wavenumber across the spectral range, but not in pixels, therefore w_p modelled as a polynomial that varies by order:

$$w_p = H_0 + H_1 m + H_2 m^2$$

Where m is the central diffraction order.

The blaze function centre p_0 varies linearly by diffraction order:

$$p_0(m) = I_0 + I_1 m$$

The spectral resolution of a pixel is largely determined by the slit width. The SO slit is half as wide as the LNO slit, therefore the channel has a higher spectral resolution. The resolution is linear, and at present is assumed to be constant across the detector, and therefore is given as a single value for a given diffraction order:

$$s = R_0 + R_1 m$$

Where s is the spectral resolution in wavenumbers. In future this could be modified so that each pixel had a different resolution. Coefficient values can be taken from Liuzzi et al. 2019.

3.3.8.2 AOTF Calibration

The AOTF function is centred on the desired diffraction order by driving it with a specific radio frequency. This is recorded in the field **AOTFrequency** and varies by diffraction order according to the following equation:

$$m = E_0 + E_1 A + E_2 A^2$$



Note that the diffraction order m is always an integer, and the AOTF frequency is always chosen so that the peak AOTF function matches the centred of a diffraction order.

The relation between the AOTF frequency and the wavenumber is given as:

$$\nu = G_0 + G_1 A + G_2 A^2$$

Where ν the wavenumber in cm^{-1} and A the AOTF frequency in kHz.

AOTF functions for each diffraction order will be provided to the PSA as calibration products.

3.3.9 Level 0.2B - UVIS reshape dataset

If dataset is unbinned, remove unmeasured detector rows from old **Y**, **YMask** and **YError** datasets (size = number of observations x 256 x 1048) to reflect the detector region used (size = number of observations x [**VSTART** - **VEND** + 1] x 1048).

If detector is vertically binned, replace old **Y** (size = number of observations x 256 x 1048), **YMask** and **YError** by a single line per observation (size = number of observations x 1048).

3.3.10 Level 0.2B - UVIS dynamic range correction

When the detector is vertically binned, reconstruct the spectra correcting the jump bug. Due to a communication problem between the on board UVIS electronic and SINBAD, during the binning process, the signal is artificially reset to zero each time it reaches a threshold value of 2^{20} counts ($\sim 10E5$), causing jumps (up or down) in the spectra.

In a spectrum, large signal variations can only be due to an artificial jump or to the steep variations of the solar radiation, but not to the characteristics of the Martian atmosphere/surface that show smooth wavelength dependencies.

The routine perform a first loop by comparing the signal variation between a wavelength pixel and the next one. Two cases: 1) if solar radiation is known to be smooth between these wavelengths, a large signal variation ($7E5$) in the recorded spectrum is due to an artificial jump and is corrected. 2) If solar radiation is known to have a steep variation between these wavelengths, then we expect to have also a similar steep variation in the recorded spectrum. However, a steep increase (/decrease) is likely to produce a jump down (/up) as the chance of reaching the threshold greatly increases. Therefore, a signal decrease (/increase) where the solar radiation is supposed to increase (/decrease) is due to an artificial jump and is corrected.

Practically the first loop starts at the first wavelength pixel (i.e. in the UV around 200 nm where the signal is low and where no jump are supposed to occur), and goes iteratively towards the last wavelength (around 650 nm). The absence of jump in the very first wavelength is yet performed using the same method as the second loop, explained hereafter.

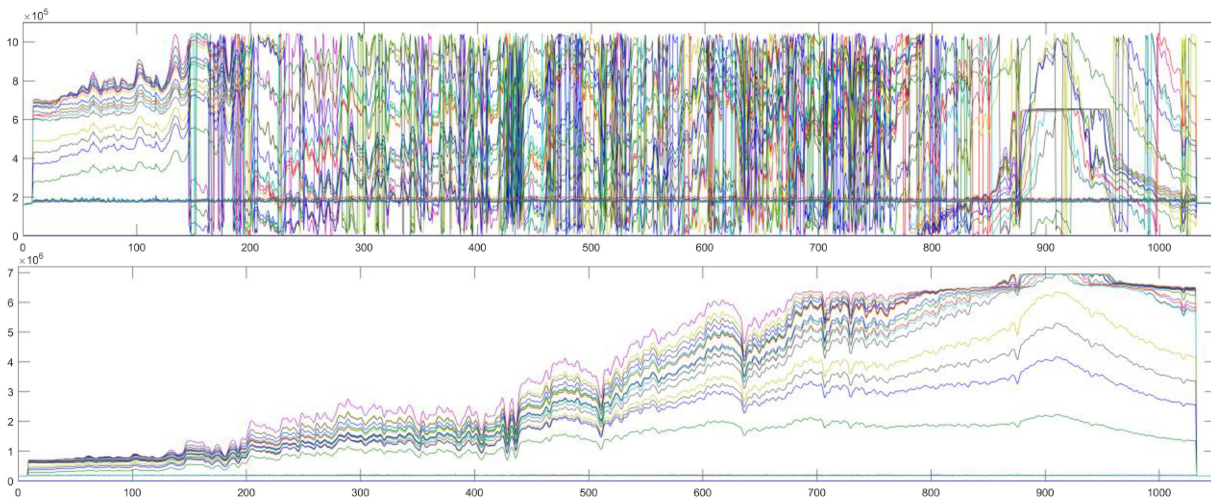


Figure 27: Raw spectra before (top) and after (bottom) dynamic range correction.

After the first loop, almost all jumps have been corrected. However, some particular jumps may subsist: these missed artificial jumps occur when the real variation is relatively large but not large enough so that the artificial jump is not exceeding the detection threshold. A second loop is then performed and uses a comparison between the different spectra: it is performed knowing that the relative variations between two observations are supposed to be similar. Considering again one pair of adjacent wavelengths at a time, an important difference of the relative variation of two consecutive spectra indicate a missing jump.

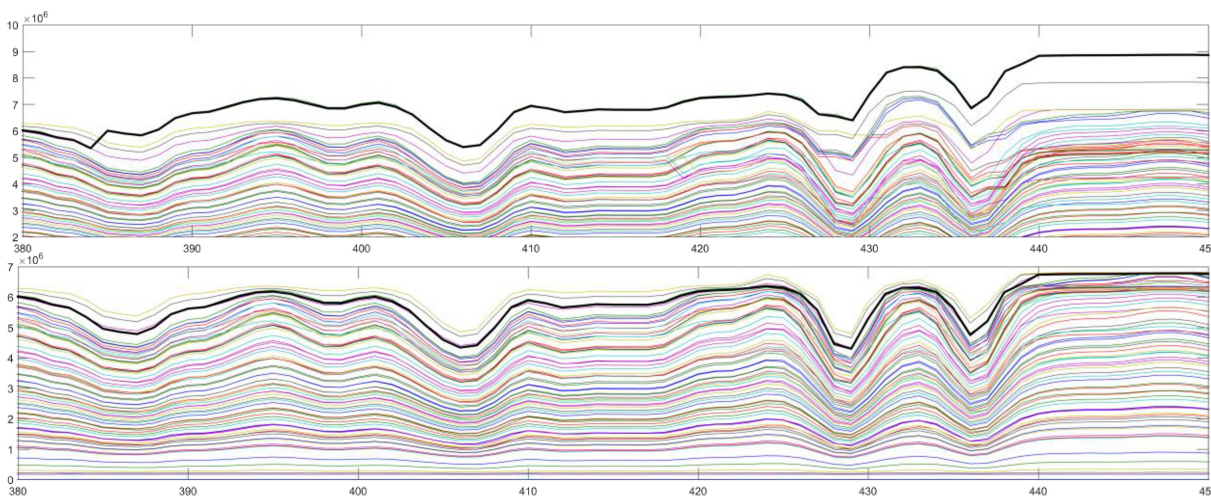


Figure 28: Example of jump corrected after the second loop of the dynamic range correction routine. Top: spectra after first loop. Bottom: spectra corrected after second loop.



3.3.11 Level 0.2B - UVIS detector saturation detection

Check for saturated pixels.

If detected, set relevant pixel in **YMask** to 2.

If detector is vertically binned, pixel saturation is detected only when all measured pixels of a column are saturated.

3.3.12 Level 0.2C - UVIS anomaly detection in dark measurements

Check the presence of anomalies at the pixel level in the dark measurement: detection of cosmic rays and hot pixels; update of the **YMask** (mask set to 3 for cosmic ray); a temporary dark measurement dataset, corrected for cosmic rays, is created and used in the next step of the dark current (DC) removal.

The routine uses comparisons between consecutive dark observations: dark measurements are supposed to be relatively constant over all pixels of a full CCD frame. Exceptions occur: 1) with “hot pixels” which behave differently than other pixels and 2) with cosmic ray hits on the CCD. The routine identifies these perturbed pixels and assigns them: as “hot pixels” when the pixel appear perturbed in several dark measurements and as “cosmic ray” when the pixel is perturbed in only one dark measurement.

The temporary dark measurement dataset created to be used in DC removal is obtained by replacing the values of all cosmic ray pixels by the mean on all non-perturbed pixels from the CCD frame of the dark measurement considered.

3.3.13 Level 0.2C - UVIS dark current removal

Removal of the dark current using the dark measurements (corrected for cosmic rays, cf. previous step) taken before and after a set of science frames. Knowing the temperature at which each science frame has been recorded, one linearly extrapolates a dark frame corresponding to this temperature between the two measured dark frames and subtracted it from the science frame.

Dark frame is set to zero in the **Y** dataset, bias and reverse clock are preserved.

3.3.14 Level 0.2C - UVIS anomaly detection

Check the presence of anomalies at the pixel level in the science measurements: detection of cosmic rays, dummy pixels and update of the **YMask** (mask set to 3 for cosmic ray). The routine uses comparisons between consecutive observations: it takes the ratio at all wavelengths between consecutive spectra. This ratio must remain smooth all along the wavelengths, due to the smooth wavelength dependencies of the Martian atmosphere/surface properties. Therefore when an abrupt change is detected at one (or some consecutive) wavelength(s), it means that a cosmic ray has hit the detector at these wavelengths which are then flagged.

3.3.15 Level 0.3B - UVIS spectral calibration

Convert the pixel number into real wavelength (nm) updating **X** and **XUnitFlag**.

The wavelength-pixel calibration is derived from ground and in-flight spectral calibration measurements of known spectral radiance sources. The conversion formula takes the form:

$$\lambda = a p^4 + b p^3 + c p^2 + d p + e$$

Where λ is the wavelength in nm of pixel p (where the first pixel in the prescan region is set to 1 up to 1048 in the overscan region) and a, b, c, d, e are the coefficients of a fifth order polynomial derived from ground and in-flight spectral calibration campaigns.

The pixels 1 to 8 and 1033 to 1048 are set to -999 as they are virtual pixels corresponding respectively to the prescan and overscan region.

3.3.16 Level 0.3C - UVIS straylight removal

If the dataset is unbinned, vertically bins the data on the ROI selected [lines 130 to 210] taking into account the **YMask** and divides it by the number of line used. A **YMaskROI** dataset is created corresponding to the **YMask** on the ROI while the **YMask** is binned (size = number of observations x 1048) and set to 1 when there are more than 15% of the lines that are saturated on this pixel. If an observation contains a **YMask** with a 1, the Straylight will not be removed and the flag **YValidFlag** is to 0.

If the dataset is binned, **Y** is divided by the number of line.

Remove the infrared straylight based on an estimation of the quantity of IR entering inside UVIS telescope (between 650 and 1100nm). This estimation rely on a typical IR spectra of Mars given by M. Wolff simulation and rescale to fit the real measurement at 650nm of UVIS. This IR quantity is then converted into Straylight by extrapolating the behaviour of the Spare model corresponding to the injection of IR radiation.

Once the IR straylight is removed, remove the UV-Visible Straylight (based on Yuquin NIST method) by multiplying **Y** by a correction matrices [1048x1048] determined on Spare model of UVIS.

Those methods to remove the Straylight will evolve in the future. The IR spectra should be simulate taking into account the geometry of the observation and an a priori knowledge of the concentrations in the atmosphere.

Update the **Y**, **YMask** and in the case of an initial unbinned dataset update **YMaskROI** and **YValidFlag**.

3.3.17 Level 0.3I – SO/LNO occultation dark frame subtraction

In nominal occultation science observations, where 5 diffraction orders and one dark frame are measured per second, the dark frames are added to the science files and the darks are discarded. In some measurements, the dark frame is subtracted onboard automatically, in which case the SO file passes this step unmodified.

3.3.18 Level 0.3J – SO/LNO occultation merge high and low altitude orders

In nominal occultations science observations, two different combinations of diffraction orders can be measured during one solar occultation – one set for high altitudes and one set for low altitudes. To prepare for the transmittance conversion, any orders which are measured in both sets are merged together to form a single observation, and the bins within the merged file are sorted by altitude, from low to high.

3.3.19 Level 0.3K – SO/LNO/UVIS split merged occultations into ingress and egress

The SO and LNO detectors require 10 minutes of precooling time to cool down the detector to cryogenic temperatures. If the time between ingress and egress occultations is too small, and there is insufficient time to cool the detector for the egress, the two occultations are merged together and the detector remains on throughout. Such merged occultations are split into separate ingress and egress files.

3.3.20 Level 1.0A – SO/LNO/UVIS occultation transmittance calibration

The transmittance calculation follows the method of Trompet et al. 2016 and is summarised in Figure 29 and below:

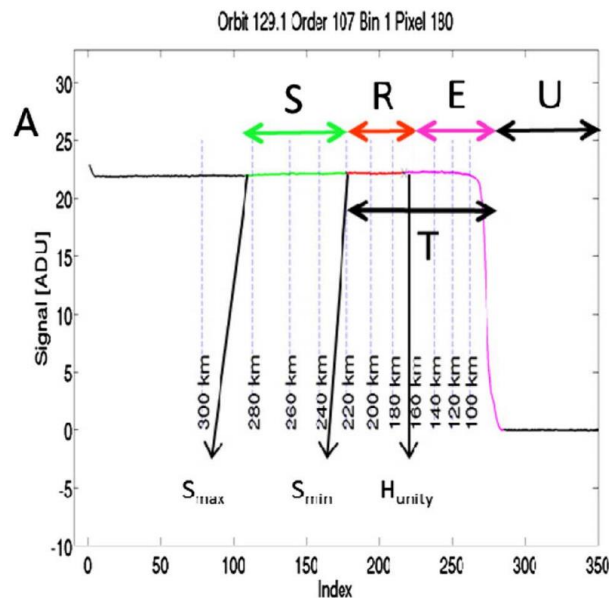


Figure 29: Each solar occultation spectrum is split into 5 regions, S, R, E, U and T, corresponding to a given tangent altitude range.

Above the top of the atmosphere, defined by H_{unity} , the solar reference region, S, is used to calculate a linear regression. The linear regression is extrapolated into the region E, where atmospheric absorptions are present. Transmittances are calculated by dividing the spectra measured in the T region by the extrapolated line, with several checks performed to ensure that the linear regression is correct. The transmittance noise, stored in the field **YError**, is calculated for all pixel of all spectra in the T region, using the standard deviation of the signal in the U and S regions.

Spectra from a given bin are rejected if certain criteria are not met: if the transmittance in the R region is too low with respect the **YError** or standard deviation, or if the **SNR** is too low overall. In this case, the transmittance is calculated but the bin is considered rejected and the corresponding **YValidFlag** values are set to 0.

In extreme cases, where the signal is too low to perform the extrapolation, or if there are insufficient points in a region to perform the calculation, the spectra in that bin are completely removed from the file. This only occurs if either there is a problem with the measurement parameters or spacecraft, or for particular types of observations e.g. grazing occultations where the tangent altitude never reaches the low atmosphere.

An **SNR** field is populated for all spectra and all pixels by dividing **Y** by **YError**. At the time of writing, H_{unity} is set to 180km for all orders. This will be refined when the data has been analysed more thoroughly.

3.3.21 Level 1.0A - LNO nadir/limb radiance calibration

LNO radiometric calibration is performed using a look-up table derived from laboratory measurements made during the ground calibration campaign, potentially combined with in-flight solar measurements in future. The look-up table contains radiance-to-counts conversion values for all pixels in all diffraction orders (Figure 30).

The sensitivity of the instrument varies by diffraction order – higher orders (165 – 190) have a higher sensitivity, whereas around order 150 it has a minimum sensitivity as shown in Figure 31. This affects the choice of diffraction orders used in flight, particularly for LNO where the signal is low. Radiances for every pixel are provided in the fields **Pixel0 radiance**, **Pixel1 radiance**, ... **Pixel319 radiance**, all with units of $W/cm^2/sr/cm^{-1}$.

At present the error is calibrated directly from the data, using the first 50 pixels of the first uncalibrated spectrum (in counts) of the observation. A polynomial is plotted through the selected data, and this is subtracted from the data to remove the continuum shape. A standard deviation is then calculated as a single value (in counts) for the whole observation, and converted to radiance for every pixel using the look-up table. Values are stored in the

fields **Pixel0 radiance error**, **Pixel1 radiance error**, ... **Pixel319 radiance error**, all with units of $W/cm^{-2}/sr/cm^{-1}$. AN SNR can be calculated by dividing each radiance by its associated error value.

LNO radiometric calibration is currently ongoing and will be the subject of an upcoming paper (in preparation). The description will be modified when LNO radiometric calibration is improved.

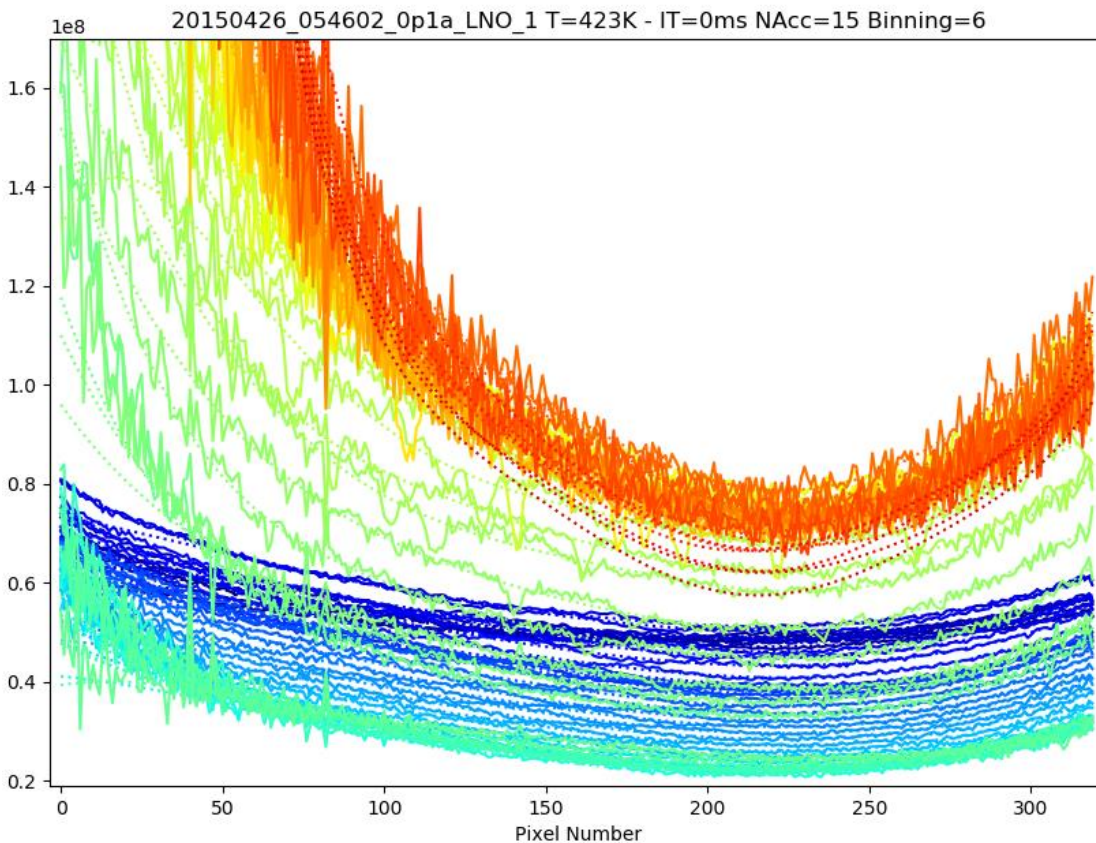


Figure 30: Draft LNO radiance to pixel counts for different diffraction orders, as calculated during ground calibration. For low orders (blue), the blackbody signal is relatively strong and therefore the noise is low. For higher orders (yellow and red), the signal is low and therefore noise is present. A sixth order polynomial is plotted through the data to extract the shape of the curve from the noise. The first 50 pixels are not included in the fit as these are very noisy due to the low signal at the edge of the detector.

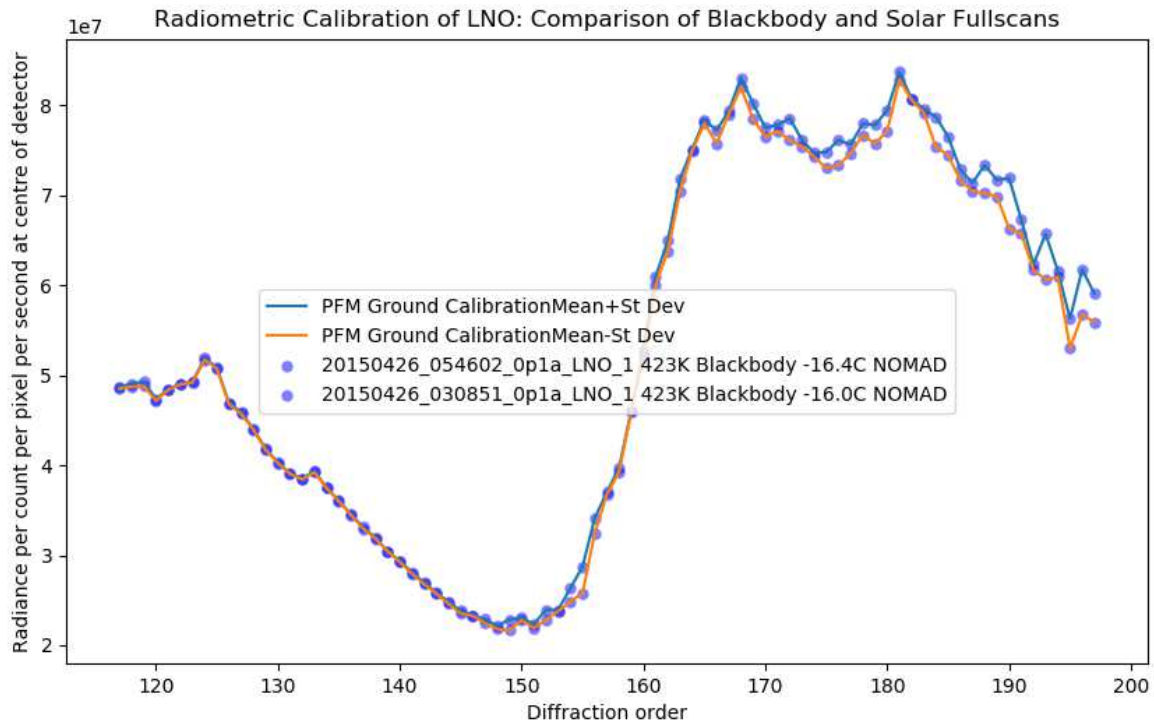


Figure 31: Radiance to counts conversion for different diffraction orders, measured at the centre of the detector. This corresponds to the sensitivity curve of the LNO channel. The lines correspond to the minimum and maximum values measured during multiple blackbody measurements.

3.3.22 Level 1.0A - UVIS nadir radiance calibration

Convert detector pixel counts into radiance (W/m²/nm/sr) by multiplying **Y** by the instrumental function (determined during the ground calibration campaign) contained in a look-up table and save to **Y** dataset. Set **YUnitFlag** and **YTypeFlag**.

YError.



3.4 Validation

The following sections describe the process by which the data products are validated.

3.4.1 Instrument Team Validation

Various consistency checks will be performed on the data, as described below.

3.4.1.1 Consistency Check 1

The engineering team at BIRA-IASB and the OU will check the incoming housekeeping data to ensure that the values received are within acceptable limits. Large anomalies will be dealt with through ESA, while small instrument issues will be flagged in the pipeline through the use of quality flags.

3.4.1.2 Consistency Check 2

A consistency check will be performed on the calibrated PDS4 products prior to delivery to the SOC. The check will ensure that the pipeline has been correctly implemented and that the science results are accurate and sensible.

3.4.2 Peer Review

The SGS will conduct a full peer review of all of the data types that the NOMAD team intends to archive. The review data will consist of fully formed bundles populated with candidate final versions of the data and other products and the associated metadata.



3.5 Data Delivery Schedule

Deliverables	Schedule
Corrected TM122 and TM125 binary raw data in .EXM format	Immediately* delivered to the ESA DataStore.
Raw data in PDS4 format	Immediately converted by SOC to PDS4 format
Partially processed data in PDS4 format	Immediately converted by SOC to PDS4 format
Calibrated PDS4 data with supporting geometry (Level 1.0)	Immediately* delivered to the ESA DataStore. Data will be made available via the PSA once the initial embargo is lifted.
Retrieved atmospheric profiles in PDS4 format (Level 2.0)	When data is ready and validated, up to a maximum of 12 months after generation of Level 1.0 data
Gridded maps and correlations in PDS4 format (Level 3.0)	When data is ready and validated, up to a maximum of 12 months after generation of Level 2.0 data

Table 17: List of deliverables with corresponding delivery schedule (to the ESA DataStore).

** When fully operational, the interface between NOMAD and SOC will operate in near real time. Once all the required data for a given observation has arrived from the ESA DataStore, a product is made by NOMAD rapidly (<24 hours) and will be immediately transferred to the ESA DataStore where it is then prepared for delivery to the PSA. Delays will be incurred only if suspect or corrupted data is discovered.*

4 DATA ORGANISATION AND CONTENTS

This section describes the basic organization of a NOMAD bundle, and the naming conventions used for the products, collections and bundle, collection, and basic product filenames.

4.1 Format and Conventions

4.2 Bundle Content and Structure

The bundle structure is defined by the SOC, and is shown in Figure 32.

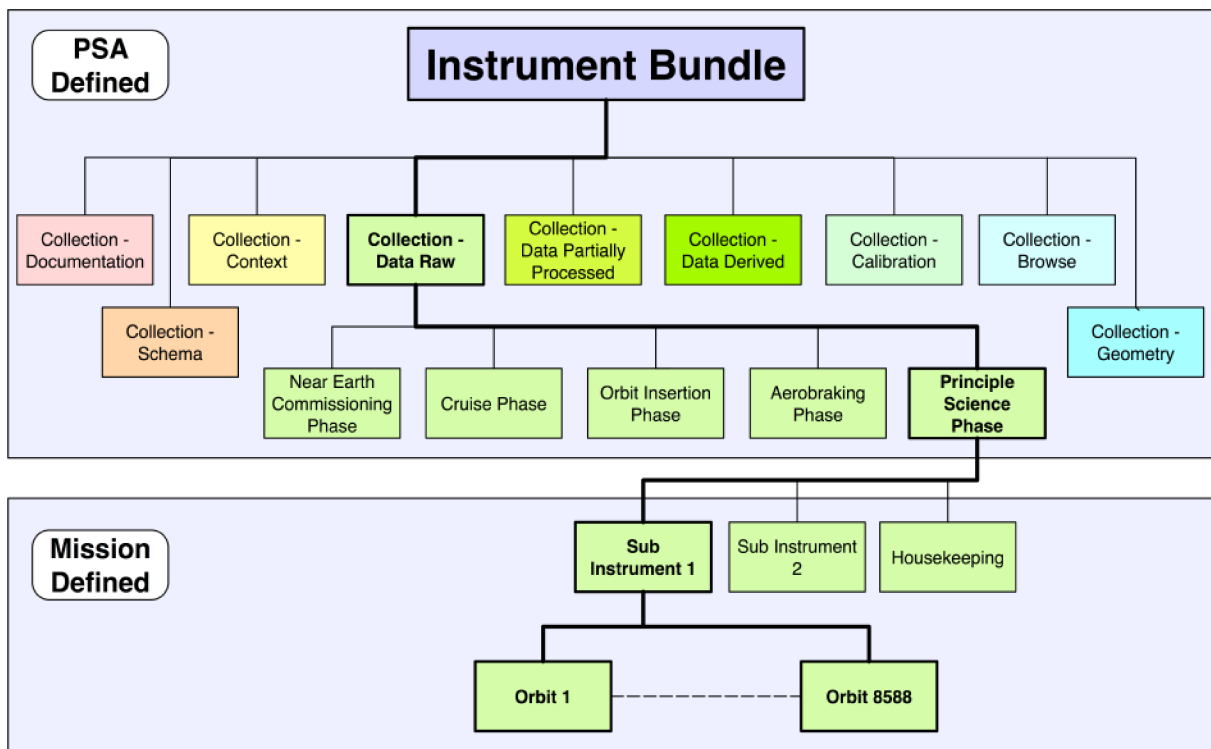


Figure 32: Instrument bundle structure in the PSA. Note that lowest level is subject to further subdivisions not shown here.

4.3 Logical Identifier Formation

The logical identifier for NOMAD is: urn:esa:psa:em16_tgo_nom

4.4 Data Directory Naming Convention

The subdivisions of the data_raw, data_par and data_cal directories is shown in Figure 33, and depends on the mission phase. The data is divided by sub instrument between mission phase and the time/orbit subdivisions shown here, as follows:

- Data (data_raw, data_partial, data_calibrated, etc.)
 - Mission phase (Near_Earth_Commissioning, Cruise, etc.)
 - Orbit range (in groups of 100 orbits, if applicable for the phase)
 - Orbit number (if applicable for the phase)

The sub level(s) vary depending on the mission phase:

- Near Earth Commissioning and Mid-Cruise Checkout: split by xxx
- Cruise phase: split by week
- Mars Capture Orbit: split by orbit
- Aerobraking: split by 100 orbits
- Science phase: split by 100 orbits, then split by orbit within that.

Where an observation spans multiple orbits, the time that the TC20 was executed in UTC is used to decide which directory the whole observation is placed in.

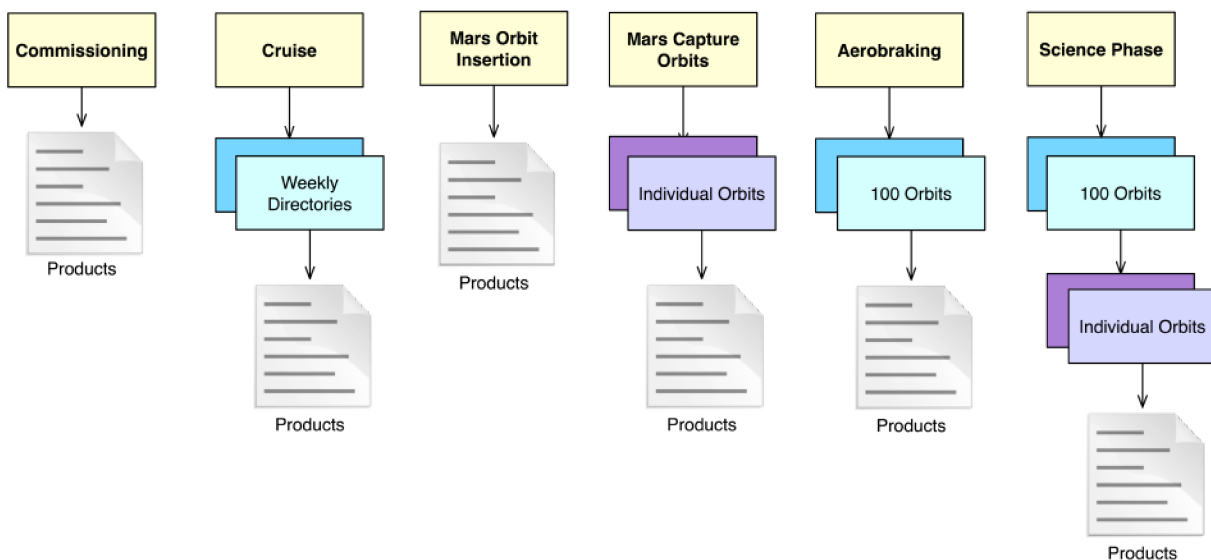


Figure 33: Separation of the data directories into further subdivisions. The number and type of separation depends on the mission phase.

The number and type of products contained within each orbit will depend on the mission phase and observations made within that orbit. One observation, as defined as one TC20 telecommand, will be split as shown in Figure 34. Products vary by channel and observation type, therefore multiple branches are required. SO/LNO products are further split into one product per diffraction order.

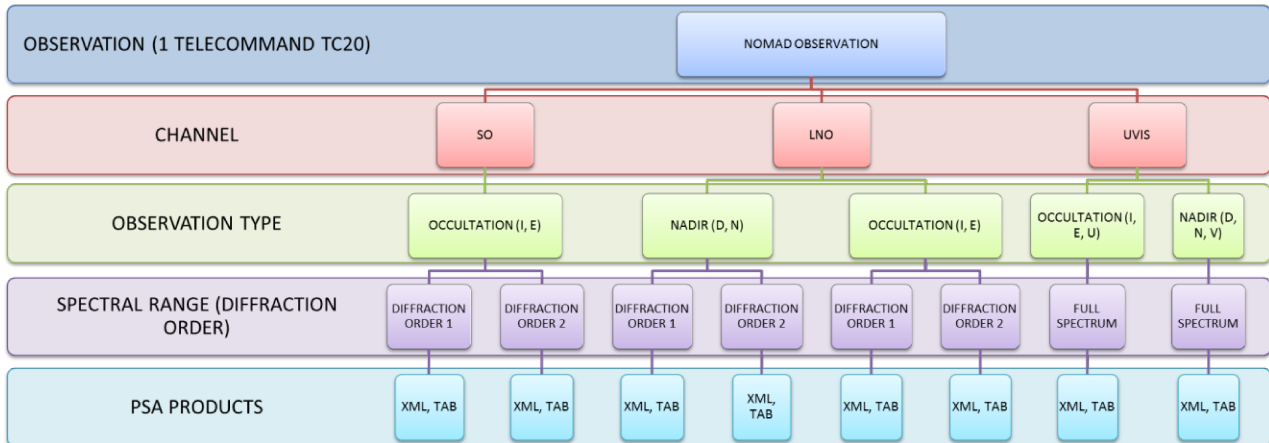


Figure 34: PSA product tree, showing how one nominal science observation is split by channel, observation type and diffraction order (if applicable) into multiple PDS4 products. SO and LNO can measure up to 6 diffraction orders, plus the 6 orders can be changed during a single observation – hence there could be 12 XML and TAB products generated from a single SO/LNO observation.

4.5 File Naming Convention

4.5.1 Raw and Partially Processed Products

Raw and partially processed products, as stored on the ESA DataStore and PI institute filesystems, are named as follows:

```
nmd_<level>_<comm_type>_<pkt_type>_<YYYYMMDD1>T<hhmmss1>-
<YYYYMMDD2>T<hhmmss2>-<pkt_type_no>-<obs_type>-<orbit_no>-<obs_number>-
<version>
```

where:

- *<level>* is the PSA data level, e.g. raw, par (for partially processed).
- *<comm_type>* is the communication type used by NOMAD. "hk" designates packets sent via the 1553 connection, and "sc" for packets sent via SpaceWire.
- *<pkt_type>* is the packet type sent by NOMAD. This is "so" for the SO channel science data, "lno" for LNO data, "uvis" for UVIS data, "hk1" and "hk2" for housekeeping packets and "Sinbad" for data from SINBAD.



- `<YYYYMMDD1>T<hhmmss1>` is the observation start time in years, months, days, hours, minutes and seconds respectively.
- `<YYYYMMDD2>T<hhmmss2>` is the observation end time in years, months, days, hours, minutes and seconds respectively.
- `<pkt_type_no>` is the NOMAD packet type number as described in section 2.6.3.1 and RD10. For example, SO science data is sent in packets of type 22 or 122, LNO are types 25 or 125, etc. This has been implemented for UVIS in particular, which has three packet types (27, 28 and 29) all sent via Spacewire.
- `<obs_type>` is the observation type, e.g. I=occultation ingress, E=occultation egress, etc. These are defined in section 2.8.
- `<orbit_no>` is the TGO orbit number. 0 = cruise phase
- `<obs_no>` is the observation number within the given orbit.
- `<version>` is the pipeline version number.

Therefore a typical PDS4 would be named as follows:

```
nmd_par_sc_lno_20161120T235932-20161121T004931-25-C-9-3_2.0.xml
nmd_par_sc_lno_20161120T235932-20161121T004931-25-C-9-3_2.0.tab
```

The version number is removed when delivered to the PSA archive, therefore archived products would be renamed to:

```
nmd_par_sc_lno_20161120T235932-20161121T004931-25-C-9-3.xml
nmd_par_sc_lno_20161120T235932-20161121T004931-25-C-9-3.tab
```

4.5.2 Calibrated Products

PDS4 calibrated products have a different naming convention, with more detail concerning the observation type and spectral range where appropriate:

```
nmd_cal_sc_<channel>_<YYYYMMDD1>T<hhmmss1>-<YYYYMMDD2>T<hhmmss2>-
<altitude_type>-<obs_type>-<diffraction_order>
```

where:

- `<channel>` is “so” for the SO channel science data, “lno” for LNO data, or “uvis” for UVIS data.
- `<YYYYMMDD1>T<hhmmss1>` is the observation start time in years, months, days, hours, minutes and seconds respectively.
- `<YYYYMMDD2>T<hhmmss2>` is the observation end time in years, months, days, hours, minutes and seconds respectively.
- `<altitude_type>` is for SO/LNO solar occultations only. See section 3.3.19.
- `<obs_type>` is the observation type, e.g. I=occultation ingress, E=occultation egress, etc. These are defined in section 2.8.
- `<diffraction_order>` is the observed SO/LNO diffraction order, in the range 90-225, if appropriate.

4.6 Data volume estimation

Data volume estimates for NOMAD, running in E-IRD compliant mode, are given in Table 18.

When the data rate is high, UVIS will operate regularly in full frame mode, therefore these values will increase significantly for nadir observations to fill the volume allocated to NOMAD by the SOC.

Data Level	Channel	Total data volume
EDDS Data Volume	All	18.7 Mb per orbit
		0.22 Gb per day
		6.73 Gb per MTP
PSA Raw Data Volume	All	40 Mb per orbit
		0.48 Gb per day
		14.4 Gb per MTP
PSA Partially Processed Data Volume	All	40 mb per orbit
		0.48 Gb per day
		14.4 Gb per MTP
PSA Calibrated Data Volume	SO Occ	65.0 mb per orbit
	LNO Nadir	8.7 mb per orbit
	UVIS Occ	31.9 mb per orbit
	UVIS Nadir	7.1 mb per orbit
	All	112.7 mb per orbit
		1.4 Gb per day
	40.6 Gb per MTP	

Table 18: Data volume estimates for NOMAD

The ESA DataStore volume is dynamically allocated at ESAC and can be adjusted to the needs of each mission as the mission progresses. The extent to which this allocation is used is routinely monitored and a request for additional space can be actioned within hours.



4.7 NOMAD Science Data Organisation

The NOMAD science data is organised into 1 instrument bundle listed in Table 19. The following sections describe the contents of each of these bundles in more detail.

Bundle Title	Bundle Logical Identifier	Description
NOMAD Instrument Bundle	em16_tgo_nom	Master Bundle for NOMAD Instrument data

Table 19: NOMAD data bundle

4.7.1 NOMAD Bundle 1

High-level description of the bundle and bundle content, including responsibility for the generation of specific products.

Collection Logical ID	Description
context	Mission and Observation Aims
<u>xml_schema</u>	PDS format conventions
document	Ancillary documents describing NOMAD
calibration	Files containing calibration coefficients
data_raw	Raw data (generated by SOC)
data_par	Partially processed data (generated by SOC)
data_cal	Calibrated data (delivered by NOMAD team)
data_der	Derived data (delivered by NOMAD team; TBD)

Table 20: NOMAD Bundle 1 Content

5 DATA PRODUCT FORMATS

NOMAD data products are formatted in accordance with the PDS4 specifications (see [AD.03], [AD.04] and [AD.05]) following the rules in the ExoMars 2016 Archiving Guide [AD.02]. This section provides details on the formats used for each of the products included in the NOMAD science data.

5.1 Primary Products Formats

This section describes the format and record structure of each of the data file types. The generated files are separated into the following collections:

- Documentation
 - Information to understand and use the data products, e.g.
 - Interface control document for NOMAD archive (this document)
 - Descriptions of calibration pipelines
 - Published technical papers describing the instrument, functions, studies and science objectives, subject to publishers' rules.
- Schema
 - Documents describing file structure and PDS4/PSA conventions
- Context
 - Documents containing PDS4 registration data e.g. mission and instrument information
- Data_raw
 - Raw data, as returned from the spacecraft
- Data_par
 - Partially processed data, with housekeeping converted to physical units
- Data_cal
 - Calibrated data, with housekeeping and science data converted to physical units with geometry and other parameters added.
- Data_der
 - TBD: Derived data e.g. gridded maps and other higher-level products
- Calibration:
 - Calibration files, containing AOTF functions, bad pixel maps, etc. derived from ground and inflight calibration campaigns



5.2 Raw Data Products

Conversion from EDDS to PDS4 raw data products is performed by the SOC. Detailed descriptions of each parameter are given below, separated by product type.

5.2.1 NOMAD Housekeeping 1 Product

Product Field Name	Description	Data Type	Data Units
PACKET TYPE 23	0 = no packet data, 23 = data in packet	Integer	None
PACKET SIZE 23	size of packet	Integer	Bytes
COARSE TIME STAMP 23	packet timestamp coarse	Integer	None
FINE TIME STAMP 23	packet timestamp fine	Integer	None
TM COUNT 23	packet number (of this type)	Integer	None
+12V_SO_CCC (raw/pp)	+12 V measured on CCC board of SO	Integer (raw)/ float (pp)	None (raw)/ volts (pp)
-12V_SO_CCC (raw/pp)	-12 V measured on CCC board of SO	Integer (raw)/ float (pp)	None (raw)/ volts (pp)
+8.5V_SO_HSK (raw/pp)	+8.5 V measured on HSK board of SO	Integer (raw)/ float (pp)	None (raw)/ volts (pp)
-8.5V_SO_HSK (raw/pp)	-8.5 V measured on HSK board of SO	Integer (raw)/ float (pp)	None (raw)/ volts (pp)
+3.3V_SO_CCC (raw/pp)	+3.3 V measured on CCC board of SO	Integer (raw)/ float (pp)	None (raw)/ volts (pp)
+2.5V_SO_CCC (raw/pp)	+2.5 V measured on CCC board of SO	Integer (raw)/ float (pp)	None (raw)/ volts (pp)
+5V_SO_HSK (raw/pp)	+5 V measured on HSK board of SO	Integer (raw)/ float (pp)	None (raw)/ volts (pp)
-5V_SO_HSK (raw/pp)	-5 V measured on HSK board of SO	Integer (raw)/ float (pp)	None (raw)/ volts (pp)
FPA1_FULL_SCALE_TEMP_SO (raw/pp)	SO focal plane array full scale temperature	Integer (raw)/ float (pp)	None (raw)/ kelvin (pp)
FPA2_ZOOMED_TEMP_SO (raw/pp)	SO focal plane array zoomed temperature	Integer (raw)/ float (pp)	None (raw)/ kelvin (pp)
SENSOR_1_TEMP_SO (raw/pp)	temperature sensor 1 near SO AOTF housing	Integer (raw)/ float (pp)	None (raw)/ Celsius (pp)
SENSOR_2_TEMP_SO (raw/pp)	temperature sensor 2 near SO grating structure	Integer (raw)/ float (pp)	None (raw)/ Celsius (pp)
SENSOR_3_TEMP_SO (raw/pp)	temperature sensor 3 near SO detector structure	Integer (raw)/ float (pp)	None (raw)/ Celsius (pp)
AOTF_TEMP_SO (raw/pp)	temperature inside SO AOTF box	Integer (raw)/ float (pp)	None (raw)/ Celsius (pp)
RF_AMPLITUDE_SO (raw/pp)	RF amplitude of SO AOTF driver	Integer (raw)/ float (pp)	None (raw)/ volts (pp)
GROUND_POTENTIAL	ground potential measured on SO	Integer (raw)/ float	None (raw)/ volts (pp)



SO_HSK (raw/pp)	HSK board	(pp)	
MOTOR_POWER_DAC_CODE_SO (raw/pp)	SO cooler motor power DAC control	Integer	None (raw)/ ADU (pp)
CHECKSUM 23	packet checksum	Hexadecimal	None
PACKET TYPE 26	0 = no packet data, 26 = data in packet	Integer	None
PACKET SIZE 26	size of packet	Integer	Bytes
COARSE TIME STAMP 26	packet timestamp coarse	Integer	None
FINE TIME STAMP 26	packet timestamp fine	Integer	None
TM COUNT 26	packet number (of this type)	Integer	None
+12V_LNO_CCC (raw/pp)	+12 V measured on CCC board of LNO	Integer (raw)/ float (pp)	None (raw)/ volts (pp)
-12V_LNO_CCC (raw/pp)	-12 V measured on CCC board of LNO	Integer (raw)/ float (pp)	None (raw)/ volts (pp)
+8.5V_LNO_HSK (raw/pp)	+8.5 V measured on HSK board of LNO	Integer (raw)/ float (pp)	None (raw)/ volts (pp)
-8.5V_LNO_HSK (raw/pp)	-8.5 V measured on HSK board of LNO	Integer (raw)/ float (pp)	None (raw)/ volts (pp)
+3.3V_LNO_CCC (raw/pp)	+3.3 V measured on CCC board of LNO	Integer (raw)/ float (pp)	None (raw)/ volts (pp)
+2.5V_LNO_CCC (raw/pp)	+2.5 V measured on CCC board of LNO	Integer (raw)/ float (pp)	None (raw)/ volts (pp)
+5V_LNO_HSK (raw/pp)	+5 V measured on HSK board of LNO	Integer (raw)/ float (pp)	None (raw)/ volts (pp)
-5V_LNO_HSK (raw/pp)	-5 V measured on HSK board of LNO	Integer (raw)/ float (pp)	None (raw)/ volts (pp)
FPA1_FULL_SCALE_TEMP_LNO (raw/pp)	LNO focal plane array full scale temperature	Integer (raw)/ float (pp)	None (raw)/ kelvin (pp)
FPA2_ZOOMED_TEMP_LNO (raw/pp)	LNO focal plane array zoomed temperature	Integer (raw)/ float (pp)	None (raw)/ kelvin (pp)
SENSOR_1_TEMP_LNO (raw/pp)	temperature sensor 1 near LNO AOTF housing	Integer (raw)/ float (pp)	None (raw)/ Celsius (pp)
SENSOR_2_TEMP_LNO (raw/pp)	temperature sensor 2 near LNO grating structure	Integer (raw)/ float (pp)	None (raw)/ Celsius (pp)
SENSOR_3_TEMP_LNO (raw/pp)	temperature sensor 3 near LNO detector structure	Integer (raw)/ float (pp)	None (raw)/ Celsius (pp)
AOTF_TEMP_LNO (raw/pp)	temperature inside LNO AOTF box	Integer (raw)/ float (pp)	None (raw)/ Celsius (pp)
RF_AMPLITUDE_LNO (raw/pp)	RF amplitude of LNO AOTF driver	Integer (raw)/ float (pp)	None (raw)/ volts (pp)
GROUND_POTENTIAL_LNO_HSK (raw/pp)	ground potential measured on LNO HSK board	Integer (raw)/ float (pp)	None (raw)/ volts (pp)
MOTOR_POWER_DAC_CODE_LNO (raw/pp)	LNO cooler motor power DAC control	Integer	None (raw)/ ADU (pp)
CHECKSUM 26	packet checksum	Hexadecimal	None
PACKET TYPE 29	0 = no packet data, 29 = data in	Integer	None



	packet		
PACKET SIZE 29	size of packet	Integer	Bytes
COARSE TIME STAMP 29	packet timestamp coarse	Integer	None
FINE TIME STAMP 29	packet timestamp fine	Integer	None
TM COUNT 29	packet number (of this type)	Integer	None
+10V_RAIL_VOLTAGE (raw/pp)	+10 V measured on UVIS board	Integer (raw)/ float (pp)	None (raw)/ volts (pp)
-10V_RAIL_VOLTAGE (raw/pp)	-10 V measured on UVIS board	Integer (raw)/ float (pp)	None (raw)/ volts (pp)
+5V_RAIL_VOLTAGE (raw/pp)	+5 V measured on UVIS board	Integer (raw)/ float (pp)	None (raw)/ volts (pp)
-5V_RAIL_VOLTAGE (raw/pp)	-5 V measured on UVIS board	Integer (raw)/ float (pp)	None (raw)/ volts (pp)
+12V_RAIL_CURRENT (raw/pp)	+12V rail current	Integer (raw)/ float (pp)	None (raw)/ milliamps (pp)
-12V_RAIL_CURRENT (raw/pp)	-12V rail current	Integer (raw)/ float (pp)	None (raw)/ milliamps (pp)
+5V_RAIL_CURRENT (raw/pp)	+5V rail current	Integer (raw)/ float (pp)	None (raw)/ milliamps (pp)
-5V_RAIL_CURRENT (raw/pp)	-5V rail current	Integer (raw)/ float (pp)	None (raw)/ milliamps (pp)
CCD_IMAGE_CLOCK_HIGH (raw/pp)	CCD image clock HI	Integer (raw)/ float (pp)	None (raw)/ volts (pp)
CCD_IMAGE_CLOCK_LOW (raw/pp)	CCD image clock LO	Integer (raw)/ float (pp)	None (raw)/ volts (pp)
CCD_READOUT_REGISTER_HIGH (raw/pp)	CCD readout register HI	Integer (raw)/ float (pp)	None (raw)/ volts (pp)
CCD_READOUT_REGISTER_LOW (raw/pp)	CCD readout register LO	Integer (raw)/ float (pp)	None (raw)/ volts (pp)
SUBSTRATE_VOLTAGE_VSS (raw/pp)	Substrate Voltage (VSS)	Integer (raw)/ float (pp)	None (raw)/ volts (pp)
OUTPUT_GATE_VOLTAGE_VOG (raw/pp)	Output gate voltage (VOG)	Integer (raw)/ float (pp)	None (raw)/ volts (pp)
OUTPUT_DRAIN_VOLTAGE_VOD (raw/pp)	Output drain voltage (VOD)	Integer (raw)/ float (pp)	None (raw)/ volts (pp)
RESET_DRAIN_VOLTAGE_VRD (raw/pp)	Reset transistor drain voltage (VRD)	Integer (raw)/ float (pp)	None (raw)/ volts (pp)
DIODE_DRAIN_VOLTAGE_VDD (raw/pp)	Diode drain voltage (VDD)	Integer (raw)/ float (pp)	None (raw)/ volts (pp)
TEMP_1_PROXIMITY_BOARD (raw/pp)	Temp 1 (Proximity Board)	Integer (raw)/ float (pp)	None (raw)/ Celsius (pp)
TEMP_2_CCD (raw/pp)	Temp 2 (CCD)	Integer (raw)/ float (pp)	None (raw)/ Celsius (pp)



TEMP_3_DETECTOR_BOARD (raw/pp)	Temp 3 (Detector Board)	Integer (raw)/ float (pp)	None (raw)/ celsius (pp)
MOTOR_CURRENT_A (raw/pp)	Motor current	Integer (raw)/ float (pp)	None (raw)/ milliamps (pp)
CHECKSUM 29	packet checksum	Hexadecimal	None

Table 21: NOMAD HSK 1 raw and partially processed (pp) PDS4 product fields

5.2.2 NOMAD Housekeeping 2 Product

The housekeeping 2 product is purely for engineering purposes and contains no useful information for PSA users.

5.2.3 NOMAD SO 22 and 122 Science Product

Product Field Name	Description	Data Type	Data Units
PACKET_SIZE	size of packet	Integer	Bytes
TIMESTAMP COARSE	packet timestamp coarse	Integer	None
TIMESTAMP FINE	packet timestamp fine	Integer	None
TM COUNT	packet number (of this type)	Integer	None
TC_EXECUTION_TIMESTAMP COARSE	packet timestamp coarse	Integer	None
TC_EXECUTION_TIMESTAMP FINE	packet timestamp fine	Integer	None
CHANNEL_ID	1= SO, 2= LNO	Integer	None
FLIP_MIRROR_INFO	0= contingency position (solar), 1= default position (nadir), 255= unknown position	Integer	None
HSK_TIMESTAMP COARSE	housekeeping packet timestamp coarse	Integer	None
HSK_TIMESTAMP FINE	housekeeping packet timestamp fine	Integer	None
HSK_TM_COUNT	packet number (of this type)	Integer	None
+12V_SO_CCC (raw/pp)	+12 V measured on CCC board of SO	Integer (raw)/ float (pp)	None (raw)/ volts (pp)
-12V_SO_CCC (raw/pp)	-12 V measured on CCC board of SO	Integer (raw)/ float (pp)	None (raw)/ volts (pp)
+8.5V_SO_HSK (raw/pp)	+8.5 V measured on HSK board of SO	Integer (raw)/ float (pp)	None (raw)/ volts (pp)
-8.5V_SO_HSK (raw/pp)	-8.5 V measured on HSK board of SO	Integer (raw)/ float (pp)	None (raw)/ volts (pp)



+3.3V_SO_CCC (raw/pp)	+3.3 V measured on CCC board of SO	Integer (raw)/ float (pp)	None (raw)/ volts (pp)
+2.5V_SO_CCC (raw/pp)	+2.5 V measured on CCC board of SO	Integer (raw)/ float (pp)	None (raw)/ volts (pp)
+5V_SO_HSK (raw/pp)	+5 V measured on HSK board of SO	Integer (raw)/ float (pp)	None (raw)/ volts (pp)
-5V_SO_HSK (raw/pp)	-5 V measured on HSK board of SO	Integer (raw)/ float (pp)	None (raw)/ volts (pp)
FPA1_FULL_SCALE_TEMP_SO (raw/pp)	SO focal plane array full scale temperature	Integer (raw)/ float (pp)	None (raw)/ kelvin (pp)
FPA2_ZOOMED_TEMP_SO (raw/pp)	SO focal plane array zoomed temperature	Integer (raw)/ float (pp)	None (raw)/ kelvin (pp)
SENSOR_1_TEMP_SO (raw/pp)	temperature sensor 1 near SO AOTF housing	Integer (raw)/ float (pp)	None (raw)/ Celsius (pp)
SENSOR_2_TEMP_SO (raw/pp)	temperature sensor 2 near SO grating structure	Integer (raw)/ float (pp)	None (raw)/ Celsius (pp)
SENSOR_3_TEMP_SO (raw/pp)	temperature sensor 3 near SO detector structure	Integer (raw)/ float (pp)	None (raw)/ Celsius (pp)
AOTF_TEMP_SO (raw/pp)	temperature inside SO AOTF box	Integer (raw)/ float (pp)	None (raw)/ Celsius (pp)
RF_AMPLITUDE_SO (raw/pp)	RF amplitude of SO AOTF driver	Integer (raw)/ float (pp)	None (raw)/ volts (pp)
GROUND_POTENTIAL_SO_HSK (raw/pp)	ground potential measured on SO HSK board	Integer (raw)/ float (pp)	None (raw)/ volts (pp)
MOTOR_POWER_DAC_CODE_SO (raw/pp)	SO cooler motor power DAC control	Integer	None (raw)/ ADU (pp)
SIZE_OF_TC_COPY	Size of "LAST_TELECOMMAND" parameter. Equal to (number of subdomains measured)*25	Integer	Bytes
SIZE_OF_SCIENCE_DATA	Size of "SO_SCIENCE_DATA" parameter. Equal to 16+480* (number of spectra returned)	Integer	Bytes
LAST_TELECOMMAND	See section 5.2.7.1	Hexadecimal	None
SO_SCIENCE_DATA	See section 5.2.7.2	Hexadecimal	None

Table 22: NOMAD SO raw and partially processed (pp) PDS4 product fields

5.2.4 NOMAD LNO 25 and 125 Science Product

Product Field Name	Description	Data Type	Data Units
PACKET_SIZE	size of packet	Integer	Bytes



TIMESTAMP COARSE	packet timestamp coarse	Integer	None
TIMESTAMP FINE	packet timestamp fine	Integer	None
TM COUNT	packet number (of this type)	Integer	None
TC_EXECUTION_TIMES TAMP COARSE	packet timestamp coarse	Integer	None
TC_EXECUTION_TIMES TAMP FINE	packet timestamp fine	Integer	None
CHANNEL_ID	1= SO, 2= LNO	Integer	None
FLIP_MIRROR_INFO	0= contingency position (solar), 1= default position (nadir), 255= unknown position	Integer	None
HSK_TIMESTAMP COARSE	housekeeping packet timestamp coarse	Integer	None
HSK_TIMESTAMP FINE	housekeeping packet timestamp fine	Integer	None
HSK_TM_COUNT	packet number (of this type)	Integer	None
+12V_LNO_CCC (raw/pp)	+12 V measured on CCC board of LNO	Integer (raw)/ float (pp)	None (raw)/ volts (pp)
-12V_LNO_CCC (raw/pp)	-12 V measured on CCC board of LNO	Integer (raw)/ float (pp)	None (raw)/ volts (pp)
+8.5V_LNO_HSK (raw/p p)	+8.5 V measured on HSK board of LNO	Integer (raw)/ float (pp)	None (raw)/ volts (pp)
- 8.5V_LNO_HSK (raw/pp)	-8.5 V measured on HSK board of LNO	Integer (raw)/ float (pp)	None (raw)/ volts (pp)
+3.3V_LNO_CCC (raw/pp)	+3.3 V measured on CCC board of LNO	Integer (raw)/ float (pp)	None (raw)/ volts (pp)
+2.5V_LNO_CCC (raw/pp)	+2.5 V measured on CCC board of LNO	Integer (raw)/ float (pp)	None (raw)/ volts (pp)
+5V_LNO_HSK (raw/pp)	+5 V measured on HSK board of LNO	Integer (raw)/ float (pp)	None (raw)/ volts (pp)
-5V_LNO_HSK (raw/pp)	-5 V measured on HSK board of LNO	Integer (raw)/ float (pp)	None (raw)/ volts (pp)
FPA1_FULL_SCALE_TEM P_LNO (raw/pp)	LNO focal plane array full scale temperature	Integer (raw)/ float (pp)	None (raw)/ kelvin (pp)
FPA2_ZOOMED_TEMP_ LNO (raw/pp)	LNO focal plane array zoomed temperature	Integer (raw)/ float (pp)	None (raw)/ kelvin (pp)
SENSOR_1_TEMP_LNO (raw/pp)	temperature sensor 1 near LNO AOTF housing	Integer (raw)/ float (pp)	None (raw)/ Celsius (pp)
SENSOR_2_TEMP_LNO (raw/pp)	temperature sensor 2 near LNO grating structure	Integer (raw)/ float (pp)	None (raw)/ Celsius (pp)
SENSOR_3_TEMP_LNO (raw/pp)	temperature sensor 3 near LNO detector structure	Integer (raw)/ float (pp)	None (raw)/ Celsius (pp)
AOTF_TEMP_LNO (raw/ pp)	temperature inside LNO AOTF box	Integer (raw)/ float (pp)	None (raw)/ Celsius (pp)
RF_AMPLITUDE_LNO (r	RF amplitude of LNO AOTF	Integer (raw)/ float	None (raw)/ volts (pp)



aw/pp)	driver	(pp)	
GROUND_POTENTIAL_LNO_HSK (raw/pp)	ground potential measured on LNO HSK board	Integer (raw)/ float (pp)	None (raw)/ volts (pp)
MOTOR_POWER_DAC_CODE_LNO (raw/pp)	LNO cooler motor power DAC control	Integer	None (raw)/ ADU (pp)
SIZE_OF_TC_COPY	Size of "LAST_TELECOMMAND" parameter. Equal to (number of subdomains measured)*25	Integer	Bytes
SIZE_OF_SCIENCE_DATA	Size of "LNO_SCIENCE_DATA" parameter. Equal to 16+480* (number of spectra returned)	Integer	Bytes
LAST_TELECOMMAND	See section 5.2.7.1	Hexadecimal	None
LNO_SCIENCE_DATA	See section 5.2.7.2	Hexadecimal	None

Table 23: NOMAD LNO raw and partially processed (pp) PDS4 product fields

5.2.5 NOMAD UVIS 27 Science Product

Product Field Name	Description	Data Type	Data Units
PACKET_SIZE	size of packet	Integer	Bytes
TIMESTAMP_SECONDS	packet timestamp coarse	Integer	None
TIMESTAMP_MICROSECONDS	packet timestamp fine	Integer	None
TM_COUNT	packet number (of this type)	Integer	None
UVIS_RESET_SELECTOR	selector mechanism reset flag	Integer	None
MODE	Functional mode for this set of scans (1 = SO, 2 = Nadir, 3=Calibration Selector, 5 = Cruise Checkout Test Card)	Integer	None
ACQUISITION_MODE	CCD readout mode (0 = Full CCD, 1 = Vertical Binning)	Integer	None
BIAS_AVERAGE	Number of 'Bias' scans to average.	Integer	None
DARK_AVERAGE	Number of 'Dark' scans to average.	Integer	None
SCIENCE_AVERAGE	Number of 'Science' scans to average.	Integer	None
V_START	Top Right Corner, Y - Coordinate	Integer	None
V_END	Bottom Left Corner, Y - Coordinate	Integer	None
H_START	Top Right Corner, X - Coordinate	Integer	None



H_END	Bottom Left Corner, X - Coordinate	Integer	None
VOD_VALUE	Value to apply to VOD DAC	Integer	ADU
VRD_VALUE	Value to apply to VRD DAC	Integer	ADU
START_DELAY	Delay from start command (Number of 5 millisecond increments to pause between receipt of start command and actual acquisition.)	Integer	None
ACQUISITION_DELAY	Delay between two successive acquisitions (Number of 5 millisecond increments to pause between receipt of start command and actual acquisition.)	Integer	None
INTEGRATION_TIME	Exposure delay before the CCD readout starts. (Time to accumulate image prior to readout). 0 < value < 20000: 0 to 20000 ms in 1 ms increments; 20000 < value < 21600: 20 to 180 s in 0.1 s increments	Integer	None
NUMBER_OF_ACQUISITIONS	Number of acquisitions to return in current sweep	Integer	None
NUMBER_OF_FLUSHES	Number of flush operations to carry out	Integer	None
DARK_TO_OBSERVATION_STEPS	Steps to drive motor from dark to observation mode	Integer	None
OBSERVATION_TO_DARK_STEPS	Steps to drive motor from observation mode to dark	Integer	None
MOTOR_DELAY	Sets stepper motor drive frequency	Integer	None
MOTOR_START_POSITION	Sets the starting pole position for the SO and NADIR motor sequences	Integer	None
B7_SET_ON_OFF_CHIP_BINNING	0 = Binning is performed in the FPGA, 1 = Binning is performed on chip	Integer	None
B6_MOTOR_HOLD	0 = No motor hold, 1 = default = active motor hold to accurately keep the fixed measurement position.	Integer	None
B5_LED	0 = default = LED Off (always off for inflight), 1 = LED On for ground testing.	Integer	None
B4_LOCATE_DARK	0 = default = don't sweep the motor from Dark->SO->Dark->ND. 1 = do a full sweep to reset motor position.	Integer	None
B3_SCI_HK	0 = default = not to include the full HK in sci packets (but include the three Temperatures); 1 = full HK in sci pkts	Integer	None
B2_INTEGRATION_TIME_INCREMENT	Integration time increment, 0 = no increments, 1 = causes the sequencer to increase the integration time after each pair of acquisitions in a way that is useful for photon transfer curve measurement, resulting in times that increase by a factor of 1,1, 2,2, 3,3, 4,4, 5,5 etc	Integer	None
B1_LOOP_DARK	Loop Dark is for alternating between Dark & Science measurements. 0 = no loop (but still do the first and last dark scans), 1 = loop Dark--> Obs	Integer	None
B0_LED_CONTROL	bit 0 (Lsb) = LED permanently ON (for cal);	Integer	None
HORIZONTAL_AND_COMBINED	Number of columns for Horizontal binning, or size of side for square "super pixels" for Combined binning.	Integer	None



BINNING_SIZE			
CONTROL_BITS	Bit 0: 1 to inhibit Noise measurement. Bit 1: 0 for Reverse clocking in Noise measurement, 1 for Forward clocking. Bit 2: 0 for two rows of Noise measurement, 1 for one row. Bit 3: 1 to inhibit Leading Bias. Bit 4: 1 to inhibit Leading Dark. Bit 5: 1 to inhibit Science. Bit 6: 1 to inhibit Trailing Bias. Bit 7: 1 to inhibit Trailing Dark. Bit 8: 1 to inhibit Sweep While Flush (R-clocks dis/en-abled with 3us period). Bit 9: 1 for Synthetic Data Bit 11: 1 = HK inhibited (TM29 HK o/p suppressed, used during full frames / SINBAD comms tests) , 0=HK TM29 output at defined rates (1 per sec in SO and 1 per 15 seconds in ND) Bits 15..12 I-clock timing adjustment	Integer	None

Table 24: NOMAD UVIS TM(27) raw and partially processed (pp) PDS4 product fields

5.2.6 NOMAD UVIS 28 Science Product

Product Field Name	Description	Data Type	Data Units
PACKET_SIZE	size of packet	Integer	Bytes
TIMESTAMP COARSE	packet timestamp coarse	Integer	None
TIMESTAMP FINE	packet timestamp fine	Integer	None
TM_COUNT	packet number (of this type)	Integer	None
MODE	Functional mode for this set of scans (1 = SO, 2 = Nadir, 3=Calibration Selector, 5 = Cruise Checkout Test Card)	Integer	None
ACQUISITION_MODE	CCD readout mode (0 = Full CCD, 1 = Vertical Binning)	Integer	None
BIAS_AVERAGE	Number of 'Bias' scans to average.	Integer	None
DARK_AVERAGE	Number of 'Dark' scans to average.	Integer	None
SCIENCE_AVERAGE	Number of 'Science' scans to average.	Integer	None
V_START	Top Right Corner, Y - Coordinate	Integer	None
V_END	Bottom Left Corner, Y - Coordinate	Integer	None
H_START	Top Right Corner, X - Coordinate	Integer	None
H_END	Bottom Left Corner, X - Coordinate	Integer	None
VOD_VALUE	Value to apply to VOD DAC	Integer	ADU
VRD_VALUE	Value to apply to VRD DAC	Integer	ADU
START_DELAY	Delay from start command (Number of 5 millisecond increments to pause between receipt of start command and actual	Integer	None



	acquisition.)		
ACQUISITION_DELAY	Delay between two successive acquisitions (Number of 5 millisecond increments to pause between receipt of start command and actual acquisition.)	Integer	None
INTEGRATION_TIME	Exposure delay before the CCD readout starts. (Time to accumulate image prior to readout). 0<value<20000: 0 to 20000 ms in 1 ms increments; 20000<value<21600: 20 to 180 s in 0.1 s increments	Integer	None
NUMBER_OF_ACQUISITIONS	Number of acquisitions to return in current sweep	Integer	None
NUMBER_OF_FLUSHES	Number of flush operations to carry out	Integer	None
DARK_TO_OBSERVATION_STEPS	Steps to drive motor from dark to observation mode	Integer	None
OBSERVATION_TO_DARK_STEPS	Steps to drive motor from observation mode to dark	Integer	None
MOTOR_DELAY	Sets stepper motor drive frequency	Integer	None
MOTOR_START_POSITION	Sets the starting pole position for the SO and NADIR motor sequences	Integer	None
B7_SET_ON_OFF_CHIP_BINNING	0 = Binning is performed in the FPGA, 1 = Binning is perform on chip	Integer	None
B6_MOTOR_HOLD	0 = No motor hold, 1 = default = active motor hold to accurately keep the fixed measurement position.	Integer	None
B5_LED	0 = default = LED Off (always off for inflight), 1 = LED On for ground testing.	Integer	None
B4_LOCATE_DARK	0 = default = don't sweep the motor from Dark->SO->Dark->ND. 1 = do a full sweep to reset motor position.	Integer	None
B3_SCI_HK	0 = default = not to include the full HK in sci packets (but include the three Temperatures); 1= full HK in sci pkcts	Integer	None
B2_INTEGRATION_TIME_INCREMENT	Integration time increment, 0 = no increments, 1 = causes the sequencer to increase the integration time after each pair of acquisitions in a way that is useful for photon transfer curve measurement, resulting in times that increase by a factor of 1,1, 2,2, 3,3, 4,4, 5,5 etc	Integer	None
B1_LOOP_DARK	Loop Dark is for alternating between Dark & Science measurements. 0 = no loop (but still do the first and last dark scans), 1 = loop Dark--> Obs	Integer	None
Bo_LED_CONTROL	bit 0 (Lsb) = LED permanently ON (for cal);	Integer	None



HORIZONTAL_AND_COMBINED_BINNING_SIZE	Number of columns for Horizontal binning, or size of side for square "super pixels" for Combined binning.	Integer	None
CONTROL_BITS	<p>Bit 0: 1 to inhibit Noise measurement.</p> <p>Bit 1: 0 for Reverse clocking in Noise measurement, 1 for Forward clocking.</p> <p>Bit 2: 0 for two rows of Noise measurement, 1 for one row.</p> <p>Bit 3: 1 to inhibit Leading Bias.</p> <p>Bit 4: 1 to inhibit Leading Dark.</p> <p>Bit 5: 1 to inhibit Science.</p> <p>Bit 6: 1 to inhibit Trailing Bias.</p> <p>Bit 7: 1 to inhibit Trailing Dark.</p> <p>Bit 8: 1 to inhibit Sweep While Flush (R-clocks dis/en-abled with 3us period).</p> <p>Bit 9: 1 for Synthetic Data</p> <p>Bit 11: 1 = HK inhibited (TM29 HK o/p suppressed, used during full frames / SINBAD comms tests) , 0=HK TM29 output at defined rates (1 per sec in SO and 1 per 15 seconds in ND) Bits 15..12 I-clock timing adjustment</p>	Integer	None
REVERSE_FLAG_AND_DATA_TYPE_FLAG_REGISTER	Transmit the Reverse flag to show which data packet contains reverse clocked data: b(o) - 0 = normal data, 1 = reverse clocked data. Next two bits define data type: 00 = Dark Scan, 01 = Bias Scan, 10 = Science Data	Integer	None
POSITIVE_10_V_RAIL_VOLTAGE (raw/pp)	+10 V measured on UVIS board	Integer (raw)/float (pp)	None (raw)/volts (pp)
NEGATIVE_10_V_RAIL_VOLTAGE (raw/pp)	-10 V measured on UVIS board	Integer (raw)/float (pp)	None (raw)/volts (pp)
POSITIVE_5_V_RAIL_VOLTAGE (raw/pp)	+5 V measured on UVIS board	Integer (raw)/float (pp)	None (raw)/volts (pp)
NEGATIVE_5_V_RAIL_VOLTAGE (raw/pp)	-5 V measured on UVIS board	Integer (raw)/float (pp)	None (raw)/volts (pp)
POSITIVE_12_V_RAIL_CURRENT (raw/pp)	+12V rail current	Integer (raw)/float (pp)	None (raw)/milliamps (pp)
NEGATIVE_12_V_RAIL_CURRENT (raw/pp)	-12V rail current	Integer (raw)/float (pp)	None (raw)/milliamps (pp)
POSITIVE_5_V_RAIL_CURRENT (raw/pp)	+5V rail current	Integer (raw)/float (pp)	None (raw)/milliamps (pp)
NEGATIVE_5_V_RAIL_CURRENT (raw/pp)	-5V rail current	Integer (raw)/float (pp)	None (raw)/milliamps



			(pp)
CCD_IMAGE_CLOCK_HI H (raw/pp)	CCD image clock HI	Integer (raw)/ float (pp)	None (raw)/ volts (pp)
CCD_IMAGE_CLOCK_LO (raw/pp)	CCD image clock LO	Integer (raw)/ float (pp)	None (raw)/ volts (pp)
CCD_READOUT_REGISTE R_HIGH (raw/pp)	CCD readout register HI	Integer (raw)/ float (pp)	None (raw)/ volts (pp)
CCD_READOUT_REGISTE R_LOW (raw/pp)	CCD readout register LO	Integer (raw)/ float (pp)	None (raw)/ volts (pp)
SUBSTRATE_VOLTAGE_VS S (raw/pp)	Substrate Voltage (VSS)	Integer (raw)/ float (pp)	None (raw)/ volts (pp)
OUTPUT_GATE_VOLTAGE _VOG (raw/pp)	Output gate voltage (VOG)	Integer (raw)/ float (pp)	None (raw)/ volts (pp)
OUTPUT_DRAIN_VOLTAG E_VOD (raw/pp)	Output drain voltage (VOD)	Integer (raw)/ float (pp)	None (raw)/ volts (pp)
RESET_TRANSISTOR_DRA IN_VOLTAGE_VRD (raw/pp)	Reset transistor drain voltage (VRD)	Integer (raw)/ float (pp)	None (raw)/ volts (pp)
DIODE_DRAIN_VOLTAGE_ VDD (raw/pp)	Diode drain voltage (VDD)	Integer (raw)/ float (pp)	None (raw)/ volts (pp)
TEMPERATURE_1 (raw/pp)	Temp 1 (Proximity Board)	Integer (raw)/ float (pp)	None (raw)/ Celsius (pp)
TEMPERATURE_2 (raw/pp)	Temp 2 (CCD)	Integer (raw)/ float (pp)	None (raw)/ Celsius (pp)
TEMPERATURE_3 (raw/pp)	Temp 3 (Detector Board)	Integer (raw)/ float (pp)	None (raw)/ celsius (pp)
MOTOR_CURRENT_A (raw /pp)	Motor current	Integer (raw)/ float (pp)	None (raw)/ milliamps (pp)
UVIS_SCIENCE_DATA	See section 5.2.7.3	Hexadecimal	ADU

Table 25: NOMAD UVIS TM(28) raw and partially processed (pp) PDS4 product fields

5.2.7 NOMAD UVIS 29 Science Product

Product Field Name	Description	Data Type	Data Units
PACKET_SIZE	size of packet	Integer	Bytes
TIMESTAMP_SECONDS	packet timestamp coarse	Integer	None
TIMESTAMP_MICROSECONDS	packet timestamp fine	Integer	None
TM_COUNT	packet number (of this type)	Integer	None
+10V_RAIL_VOLTAGE (raw/pp)	+10 V measured on UVIS board	Integer (raw)/ float (pp)	None (raw)/ volts (pp)
-10V_RAIL_VOLTAGE (raw/pp)	-10 V measured on UVIS board	Integer (raw)/ float (pp)	None (raw)/ volts (pp)

+5V_RAIL_VOLTAGE (raw/pp)	+5 V measured on UVIS board	Integer (raw)/float (pp)	None (raw)/ volts (pp)
-5V_RAIL_VOLTAGE (raw/pp)	-5 V measured on UVIS board	Integer (raw)/float (pp)	None (raw)/ volts (pp)
+12V_RAIL_CURRENT (raw/pp)	+12V rail current	Integer (raw)/float (pp)	None (raw)/ milliamps (pp)
-12V_RAIL_CURRENT (raw/pp)	-12V rail current	Integer (raw)/float (pp)	None (raw)/ milliamps (pp)
+5V_RAIL_CURRENT (raw/pp)	+5V rail current	Integer (raw)/float (pp)	None (raw)/ milliamps (pp)
-5V_RAIL_CURRENT (raw/pp)	-5V rail current	Integer (raw)/float (pp)	None (raw)/ milliamps (pp)
CCD_IMAGE_CLOCK_HIGH (raw/pp)	CCD image clock HI	Integer (raw)/float (pp)	None (raw)/ volts (pp)
CCD_IMAGE_CLOCK_LOW (raw/pp)	CCD image clock LO	Integer (raw)/float (pp)	None (raw)/ volts (pp)
CCD_READOUT_REG_HIGH (raw/pp)	CCD readout register HI	Integer (raw)/float (pp)	None (raw)/ volts (pp)
CCD_READOUT_REG_LOW (raw/pp)	CCD readout register LO	Integer (raw)/float (pp)	None (raw)/ volts (pp)
SUBSTRATE_VOLTAGE_VSS (raw/pp)	Substrate Voltage (VSS)	Integer (raw)/float (pp)	None (raw)/ volts (pp)
OUTPUT_GATE_VOLTAGE_VOG (raw/pp)	Output gate voltage (VOG)	Integer (raw)/float (pp)	None (raw)/ volts (pp)
OUTPUT_DRAIN_VOLTAGE_VOD (raw/pp)	Output drain voltage (VOD)	Integer (raw)/float (pp)	None (raw)/ volts (pp)
RESET_DRAIN_VOLTAGE_VRD (raw/pp)	Reset transistor drain voltage (VRD)	Integer (raw)/float (pp)	None (raw)/ volts (pp)
DIODE_DRAIN_VOLTAGE_VDD (raw/pp)	Diode drain voltage (VDD)	Integer (raw)/float (pp)	None (raw)/ volts (pp)
TEMP_1_PROXIMITY_BOARD (raw/pp)	Temp 1 (Proximity Board)	Integer (raw)/float (pp)	None (raw)/ Celsius (pp)
TEMP_2_CCD (raw/pp)	Temp 2 (CCD)	Integer (raw)/float (pp)	None (raw)/ Celsius (pp)
TEMP_3_DETECTOR_BOARD (raw/pp)	Temp 3 (Detector Board)	Integer (raw)/float (pp)	None (raw)/ Celsius (pp)
MOTOR_CURRENT_A (raw/pp)	Motor current	Integer (raw)/float (pp)	None (raw)/ milliamps (pp)

Table 26: NOMAD UVIS TM(29) raw and partially processed (pp) PDS4 product fields

5.2.7.1 SO/LNO Last Telecommand Parameters

The SO or LNO channels' telecommand parameters are recorded for each subdomain measured during an observation, consisting of 25 bytes per subdomain.



Parameter name	Byte number	Size (bits)	Description	
spare	0	5	spare	
AOTF power cmd		1	AOTF power command flag	
write cooler parameters		1	write coolers parameter flag	
start accumulation		1	start accumulations flag	
force AOTF enable	1	1	force AOTF enable flag	
hsk enable		1	housekeeping enable flag	
DEGF		1	detector gain flag	
DVAF		1	detector video amplifier flag	
force size AB		1	force size A/B flag	
prog enable		1	programming enable flag	
SBSF		1	spectral background subtraction flag	
detector enable		1	detector enable flag	
NRACC		2	8	number of accumulations
DWNL		3	8	height of detector window (i.e. number of lines in detector window)
DWYA		4	8	number of first line in detector window
BF	5	8	binning factor	
DEIT	6	24	detector integration time	
	7			
	8			
spare	9	5	spare	
DS		1	detector supply flag	
DDS		1	data source flag	
DVS		1	data valid source flag	
spare	10	8	spare	
spare	11	1	spare	
TGA		7	AOTF delay	
AOPS	12	8	AOTF power setting	
AOFS	13	32	AOTF frequency setting	
	14			
	15			
	16			



spare	17	8	spare
spare	18	4	spare
PFCM		1	closed loop flag
CED1		1	cooler enable flag 1
CED2		1	cooler enable flag 2
CED3		1	cooler enable flag 3
spare	19+20	3	spare
PCP		13	cooler set point (target temperature)
spare	21	8	spare
C1	22	4	cooler closed loop coefficient 1
spare		4	spare
spare	23	2	spare
C2		4	cooler closed loop coefficient 2
spare		2	spare
spare	24	4	spare
C3		4	cooler closed loop coefficient 3

Table 27: SO or LNO last telecommand parameters in the raw and partial processed PDS4 products

5.2.7.2 SO/LNO Science Data

SO and LNO science data is transmitted as lines of spectra, with one measurement typically consisting of 24 lines by 320 pixels each. The data is stored as 14-bit numbers, consisting of a 2 bit exponent (one value per line of spectra) and 12 bits of data per individual pixel. For each subdomain, a timetag is also stored, to indicate the relative timing of the subdomain measurement w.r.t. the execution time recorded in the packet. As shown in Figure 10, subdomains are measured consecutively, not simultaneously, and so the timetag for the 6th subdomain (if present) will be greater than the timetag for the 1st subdomain. The exponent and timetag data is contained within 16 bytes which are always present irrespective of number of subdomains. This is followed by the 320 x 12bit (1.5 byte) detector pixel readouts x number of lines of spectra recorded (up to a maximum of $16+320*1.5*24 = 11536$ bytes).

Byte	Bit	Field	Comments
0	7	0	
	6	0	
	5	Exponent 6	equals 1111 if no subdomain 6 is present



	4					
	3					
	2					
	1					
	0					
1	7	Exponent 5	equals 11111 if no subdomain 5 is present			
	6					
	5					
	4					
	3					
	2					
	1					
	0					
2	7	Exponent 4	equals 11111 if no subdomain 4 is present			
	6					
	5					
	4					
	3					
	2					
	1					
	0					
3	7	Exponent 3	equals 11111 if no subdomain 3 is present			
	6					
	5					
	4					
	3					
	2					
	1					
	0					
4	7	Exponent 2	equals 11111 if no subdomain 2 is present			
	6					
	5					
	4					
	3					
	2					
	1					
	0					
5	7	Exponent 1	equals 11111 if no subdomain 1 is present			
	6					
	5					
	4					
	3					
	2					
	1					
	0					
6	15	Time Tag 6	Time Tag for subdomain 6 Equals FFFF when no subdomain 6 is present			
	14					
	13					
	12					
	11					
	10					
	9					
	8					
	7			7		
				6		
5						
3						



	2		
	1		
	0		
6-7	15	Time Tag 5	Time Tag for subdomain 5 Equals FFFF when no subdomain 5 is present
	...		
	0		
8-9	15	Time Tag 4	Time Tag for subdomain 4 Equals FFFF when no subdomain 4 is present
	...		
	0		
10-11	15	Time Tag 3	Time Tag for subdomain 3 Equals FFFF when no subdomain 3 is present
Etc.			
16	7	Pixel 0 value	Detector data
	6		
	5		
	4		
	3		
	2		
	1		
	0		
17	7	Pixel 0 value	Detector data
	6		
	5		
	4		
	3	Pixel 1 value	Detector data
	2		
	1		
	0		
18	7		
	6		
	5		
	4		
	3		
	2		
	1		
	0		
Etc.			

Table 28: SO or LNO detector data in the raw and partial processed PDS4 products



5.2.7.3 UVIS Science Data

UVIS can perform in 16-bit or 20-bit mode, depending on the settings used. Typically, if the detector data is vertically binned then each spectral point is recorded as 20bits (however 16bit is possible); if running in unbinned mode then only 16bits can be recorded per pixel.

The packet data size depends on the number of lines of spectra (N) and the number of pixels per line, up to a maximum of 90 bytes + 15 lines * 1048 pixels * 2 bytes in unbinned mode where N=15. In 20bit mode, the maximum size per packet is 90 bytes + 3 lines * 1048 * 2.5 bytes (where N=3 here). N=1,2,3 for normal science; N>3 is used only for downloading full frames. The first UVIS science packet of each observation has a size of 4282 bytes where N=2 i.e. 90 + 2 lines * 1048 pixels * 2 bytes.

5.3 Partially Processed Data Products

Conversion to partially processed data products is performed by the SOC. As can be seen in the above tables, the partially processed data files contain the same fields as the raw data, except that housekeeping temperatures and voltages have been converted into physical units e.g. Celsius, Volts, Amps, etc.

Science data, including attributes LAST_TELECOMMAND_SUBDOMAIN_1 to 6 have been left unchanged. Detailed descriptions of each parameter are given above and conversion formulae can be found in the appendix; further details are included in the NOMAD Data Operations Handbook [RD10].

5.4 Calibrated Data Products

As shown in , the pipeline is split between channel (SO/LNO and UVIS) and observation type (nadir and solar occultation). There are also calibration observations that do not pass through either pipeline, and are instead used only to derive the calibrated products.

5.4.1 Data Collections

The outputs of both are quite different, as the former will produce calibrated atmospheric transmittances (with values ranging from 0 to 1); while the latter will produce spectra with units of radiance factor i.e. a ratio between the signal reflected from Mars and the signal coming directly from the Sun. Both pipelines will also provide a spectral calibration axis, in nanometres for UVIS and wavenumbers for SO/LNO. In addition to this, calibrated data products will contain geolocation data, as derived from the SPICE kernels; however the types of location data will differ for occultation and nadir. Some auxiliary housekeeping products, such as temperatures and voltages, are not included, while some observation parameters are expanded and included as separate fields in the PDS4 products. A particular example of this is the LAST_TELECOMMAND_SUBDOMAIN attribute: in the raw and partially processed collections, this data is encoded in a hexadecimal format; whereas here it will be expanded to



provide human-readable values of interest to scientists. Also, a best estimate of the measurement error is added as an attribute, and the quality flags are included in the metadata. Some parameters will be promoted to metadata to allow PSA users to search for specific datasets based on supplied keywords.

Details of the contents of the PDS4 TAB and XML products are grouped into the following general groups:

- Telecommand information
- Instrument details
- Quality flags
- Measurement parameters
- Geometry parameters
- Science data
- Additional information

These are described in the following sections below, starting with the XML metadata fields

5.4.1.1 XML telecommand information

Product Field Name	Data Type	Data Units
so_start_time	Integer	Seconds
so_start_science1	Integer	Seconds
so_start_science2	Integer	Seconds
so_duration_reference1	Integer	Seconds
so_duration_reference2	Integer	Seconds
so_duration_time	Integer	Seconds
so_cop_general	Integer	No Units
so_cop_precooling	Integer	No Units
so_cop_science1	Integer	No Units
so_cop_science2	Integer	No Units
lno_start_time	Integer	Seconds
lno_start_science1	Integer	Seconds
lno_start_science2	Integer	Seconds
lno_duration_reference1	Integer	Seconds
lno_duration_reference2	Integer	Seconds
lno_duration_time	Integer	Seconds
lno_cop_general	Integer	No Units
lno_cop_precooling	Integer	No Units
lno_cop_science1	Integer	No Units
lno_cop_science2	Integer	No Units



uvis_start_time	Integer	Seconds
uvis_duration_time	Integer	Seconds
uvis_cop_row	Integer	No Units

Table 29: TC20 telecommand parameters

5.4.1.2 XML instrument details

Product Field Name	Description	Data Type	Data Units
cop_table_version	Version of the COP table in instrument	String	No Units
xcalib_ref	Reference to the calibration procedure used to calibrate the X axis	String	No Units
ycalib_ref	Reference to the calibration procedure used to calibrate the Y axis	String	No Units
yerror_ref	Reference to the procedure used to calculate the error on the Y axis	String	No Units
observation_mode	Description of observation mode, e.g. fullscan, calibration, nominal science, etc.	String	No Units
geometry	Geometry description	String	No Units
desc	Measurement description based on COP row executed	String	No Units
channel_name	Name of the channel and telescope used, and number of sciences (if applicable)	String	No Units
nspec	Number of spectra in the file. 1 subdomain = 1 spectrum	Integer	No Units
nsubdomain	Number of subdomains (SO/LNO only)	String	No Units
datecreated	Date the file was made	String	No Units
observation_type	Letter taken from ITL file descriptor e.g. C = calibration, I = ingress occultation, E = egress, N = nadir, etc.	String	No Units

Table 30: Instrument description metadata

5.4.1.3 XML quality flags

Product Field Name	Description	Data Type	Data Units
hsk_disturbed	Housekeeping values are disturbed (e.g. by electrical interference). Not yet implemented	Integer	No Units
hsk_out_of_bounds	Housekeeping values are out of	Integer	No Units

	bounds		
discarded_packets	Packet(s) were discarded during this observation	Integer	No Units
bad_pixels_hinterpolated	Bad pixels have been removed by horizontal interpolation	Integer	No Units
bad_pixels_vinterpolated	Bad pixels have been removed by vertical interpolation	Integer	No Units
bad_pixels_masked	Bad pixels have been removed by masking	Integer	No Units
detector_saturated	Detector saturated during measurement (N/A for calibrations)	Integer	No Units
lno_straylight	LNO geometric straylight detected in 1 or more frames	Integer	No Units
high_instrument_temperature	Channel temperature exceeds normal operating temperature (LNO: 10C on baseplate)	Integer	No Units
pointing_error	Pointing is not correct or perturbation detected. Not yet implemented	Integer	No Units
uvis_occ_boresight	UVIS solar occultation boresight was used instead of default SO	Integer	No Units
lno_occ_boresight	LNO solar occultation boresight was used instead of default SO	Integer	No Units
mir_occ_boresight	ACS MIR solar occultation boresight was used instead of default SO	Integer	No Units
tirvim_occ_boresight	ACS TIRVIM solar occultation boresight was used instead of default SO	Integer	No Units

Table 31: List of quality flags present in the metadata.

5.4.1.4 XML SO/LNO measurement parameters

Measurement parameters vary by channel, hence there are two tables: one for SO/LNO and one for UVIS

Product Field Name	Description	Data Type	Data Units
aotf_frequency	AOTF frequency used for this spectrum	Float	Kilohertz
diffraction_order	Measured diffraction order	Integer	No Units
number_of_accumulations	Number of detector accumulations in measurement	Integer	No Units



spectral_resolution	Spectral resolution of each pixel in wavenumbers	Float	Wavenumbers
integration_time	Detector integration time	Float	Milliseconds

Table 32: Infrared metadata measurement parameters

5.4.1.5 XML UVIS measurement parameters

Product Field Name	Description	Data Type	Data Units
Mode	1 = SO; 2 = Nadir; 3=Calibration Selector; 5 = Cruise Checkout Test Card	Integer	No Units
AcquisitionMode	0 = Full CCD, 1 = Vertical Binning, 3 Stepper calibration, 5 - test card	Integer	No Units
BiasAverage	0=1 frame per acquisition; 1=2 frames per acquisition, etc.	Integer	No Units
DarkAverage	0=1 frame per acquisition; 1=2 frames per acquisition, etc.	Integer	No Units
ScienceAverage	0=1 frame per acquisition; 1=2 frames per acquisition, etc.	Integer	No Units
VStart	Detector starting row number	Integer	No Units
VEnd	Detector ending row number	Integer	No Units
HStart	Detector ending column number	Integer	No Units
HEnd	Detector starting column number	Integer	No Units
StartDelay	Number of 5 millisecond increments to pause between receipt of start command and actual acquisition.	Integer	No Units
AcquisitionDelay	Number of 5 millisecond increments to pause between receipt of start command and actual acquisition.	Integer	No Units
IntegrationTime	Detector integration time	Integer	Milliseconds
NumberOfAcquisitions	If B1LoopDark=0, then this parameter is the number of acquisitions to perform before doing a dark measurement	Integer	No Units
NumberOfFlushes	Bits 0 to 3: number of flushes to perform to remove charge accumulated on detector Bits 4 to 7: number of purges to perform to remove charge accumulated on detector	Integer	No Units
DarkToObservationSteps	Number of steps to drive motor from dark to observation position	Integer	No Units
ObservationToDarkSteps	Number of steps to drive motor from observaton to dark position	Integer	No Units
MotorDelay	Motor delay resolution: If Bit 7=0: Bits 0 to 6 give motor delay of 1 to 127ms in steps	Integer	No Units



	of 1ms; if Bit 7=1: Bits 0 to 6 give motor delay of 8 to 1016ms in steps of 8ms		
MotorStartPosition	Define starting pole position for driving the motor to occultation and nadir positions	Integer	No Units
BoLEDControl	LED permanently ON (for cal)	Integer	No Units
B1LoopDark	Alternate between dark and science measurements. 0 = no loop (but still do the first and last dark scans), 1 = run dark frames	Integer	No Units
B2IntegrationTimeIncrement	Integration time increment: 0 = no increments, 1 = causes the sequencer to increase integration time after each pair of acquisitions (increasing by a factor of 1,1, 2,2, 3,3, 4,4, 5,5 etc.)	Integer	No Units
B3SciHSK	0 = default = not to include the full HSK in science packets (but include the 3 temperatures); 1= full HSK in science packets	Integer	No Units
B4LocateDark	0 = default = don't sweep the motor from dark-occultation-dark-nadir. 1 = do a full sweep to reset motor position	Integer	No Units
B5LED	0 = default = LED Off (always off for inflight); 1 = LED On for ground testing	Integer	No Units
B6MotorHold	0 = No motor hold; 1 = default = active motor hold to accurately keep the fixed measurement position	Integer	No Units
B7SetOnOffChipBinning	0 = Binning is performed in the FPGA, 1 = Binning is perform on chip	Integer	No Units
HorizontalAnd CombinedBinningSize	Bits 0 to 3: values 0 to 15 indicate a horizontal binning factor of 1 to 16; Bit 7: 1 to enable combined binning (with square super-pixels)	Integer	No Units
ControlBits	Bit 0: 1=inhibit noise frame; Bit 1: 0=reverse clock noise measurement, 1=forward clock; Bit 2: 0=2 rows of noise frames, 1=1 row; Bit 3: 1=inhibit leading bias; Bit 4: 1=inhibit leading dark; Bit 5: 1=inhibit science; Bit 6: 1=inhibit trailing bias; Bit 7: 1=inhibit trailing dark; Bit 8: 1=inhibit sweep while flush; Bit 9: 1=synthetic data; Bit 11: 1=suppress TM29 packets, 0=output TM29 packets at 1 per sec in occultation and 1 per 15 seconds in nadir; Bits 12 to 15: I-clock timing adjustment	Integer	No Units

Table 33: UVIS metadata measurement parameters.

5.4.1.6 XML nadir geometry parameters

Metadata geometry parameters are provided to ease the user in finding relevant observation data. A single observation can cover a large swath of the surface, and so parameters can vary greatly between the start, centre and end, particularly for those observations that pass near the poles. Therefore minimum/maximum/first/last values are provided where appropriate. In the case of latitude and longitude, mean values are also included as these provide a practical way to determine the approximate location of each observation.

Product Field Name	Description	Data Type	Data Units
first_lon	First surface longitude of the observation	Float	Degrees
last_lon	Last surface longitude of the observation	Float	Degrees
min_lon	Minimum surface longitude of the observation	Float	Degrees
max_lon	Maximum surface longitude of the observation	Float	Degrees
first_lat	First surface latitude of the observation	Float	Degrees
last_lat	Last surface latitude of the observation	Float	Degrees
min_lat	Minimum surface latitude of the observation	Float	Degrees
max_lat	Maximum surface latitude of the observation	Float	Degrees
first_lst	First local solar time of surface point of the observation	Float	Hours
last_lst	Last local solar time of surface point of the observation	Float	Hours
first_alt	First tangent point altitude of the observation (limb observation only; -999 for nadir)	Float	Kilometres
last_alt	Last tangent point altitude of the observation (limb observation only; -999 for nadir)	Float	Kilometres
first_incidence_angle	First solar incidence angle of the observation	Float	Degrees
last_incidence_angle	Last solar incidence angle of the observation	Float	Degrees
min_incidence_angle	Minimum solar incidence angle of the observation	Float	Degrees
max_incidence_angle	Maximum solar incidence angle of the observation	Float	Degrees
first_emission_angle	First emission angle of the observation	Float	Degrees
last_emission_angle	Last emission angle of the observation	Float	Degrees
min_emission_angle	Minimum emission angle of the observation	Float	Degrees
max_emission_angle	Maximum emission angle of the observation	Float	Degrees
first_phase_angle	First phase angle of the observation	Float	Degrees
last_phase_angle	Last phase angle of the observation	Float	Degrees
min_phase_angle	Minimum phase angle of the observation	Float	Degrees



max_phase_angle	Maximum phase angle of the observation	Float	Degrees
first_sub_obs_lon	First sub-satellite longitude of the observation	Float	Degrees
last_sub_obs_lon	Last sub-satellite longitude of the observation	Float	Degrees
min_sub_obs_lon	Minimum sub-satellite longitude of the observation	Float	Degrees
max_sub_obs_lon	Maximum sub-satellite longitude of the observation	Float	Degrees
first_sub_obs_lat	First sub-satellite latitude of the observation	Float	Degrees
last_sub_obs_lat	Last sub-satellite latitude of the observation	Float	Degrees
min_sub_obs_lat	Minimum sub-satellite latitude of the observation	Float	Degrees
max_sub_obs_lat	Maximum sub-satellite latitude of the observation	Float	Degrees
first_lsubs	First planetocentric longitude of the observation	Float	Degrees
last_lsubs	Last planetocentric longitude of the observation	Float	Degrees
first_sub_sol_lon	First sub-solar longitude of the observation	Float	Degrees
last_sub_sol_lon	Last sub-solar longitude of the observation	Float	Degrees
first_sub_sol_lat	First sub-solar latitude of the observation	Float	Degrees
last_sub_sol_lat	Last sub-solar latitude of the observation	Float	Degrees

Table 34: Nadir geometry metadata

5.4.1.7 XML solar occultation geometry parameters

Product Field Name	Description	Data Type	Data Units
first_lon	First tangent point longitude of the observation	Float	Degrees
last_lon	Last tangent point longitude of the observation	Float	Degrees
min_lon	Minimum tangent point longitude of the observation	Float	Degrees
max_lon	Maximum tangent point longitude of the observation	Float	Degrees
first_lat	First tangent point latitude of the observation	Float	Degrees
last_lat	Last tangent point latitude of the observation	Float	Degrees
min_lat	Minimum tangent point latitude of the observation	Float	Degrees
max_lat	Maximum tangent point latitude of the observation	Float	Degrees
first_lst	First local solar time of tangent point of the observation	Float	Hours
last_lst	Last local solar time of tangent point of the observation	Float	Hours
first_alt	First tangent point altitude above the Mars areoid of the observation	Float	Kilometres
last_alt	Last tangent point altitude above the Mars areoid of the observation	Float	Kilometres
first_sub_obs_lon	First sub-satellite longitude of the observation	Float	Degrees
last_sub_obs_lon	Last sub-satellite longitude of the observation	Float	Degrees
min_sub_obs_lon	Minimum sub-satellite longitude of the observation	Float	Degrees



max_sub_obs_lon	Maximum sub-satellite longitude of the observation	Float	Degrees
first_sub_obs_lat	First sub-satellite latitude of the observation	Float	Degrees
last_sub_obs_lat	Last sub-satellite latitude of the observation	Float	Degrees
min_sub_obs_lat	Minimum sub-satellite latitude of the observation	Float	Degrees
max_sub_obs_lat	Maximum sub-satellite latitude of the observation	Float	Degrees
first_lsubs	First planetocentric longitude of the observation	Float	Degrees
last_lsubs	Last planetocentric longitude of the observation	Float	Degrees
first_sub_sol_lon	First sub-solar longitude of the observation	Float	Degrees
last_sub_sol_lon	Last sub-solar longitude of the observation	Float	Degrees
first_sub_sol_lat	First sub-solar latitude of the observation	Float	Degrees
last_sub_sol_lat	Last sub-solar latitude of the observation	Float	Degrees

Table 35: Occultation geometry metadata



5.4.1.8 XML Additional Information

Some calibrated data fields are populated using data taken from the raw and partially processed products generated by the SOC. Hence these parameters are defined by ESA rather than the NOMAD team.

Product Field Name	Description	Data Type	Data Units
target/name	Name of target (Mars or Sun)	String	No units
target/type	Type of target (planet or sun)	String	No units
mission_phase_name	Phase of mission	String	No units
mission_phase_identifier	Phase of mission (short form)	String	No units
start_orbit_number	Orbit in which observation starts	Integer	No units

Table 36: Addition metadata in the XML products

The TAB files contain the full dataset, with each row of the table corresponding to a single spectrum. When operating in normal science mode, UVIS nadir/occultation (observation modes D, N, U, V) and LNO nadir (D, N) output one spectrum per measurement. SO/LNO in occultation mode (I, E) have several detector bins, and can return multiple spectra per measurement (each with a different FOV).

5.4.1.9 TAB SO/LNO nadir measurement parameters

Product Field Name	Description	Data Type	Data Units
ObservationDatetimeStart	UTC start datetime of spectrum acquisition	String	No Units
ObservationDatetimeEnd	UTC end datetime of spectrum acquisition	String	No Units
AOTFFrequency	AOTF frequency used for this spectrum (can vary for fullscan measurements)	Float	Kilohertz
BinTop	Detector starting row number (all bins)	Integer	No Units
BinHeight	Detector row height (all bins)	Integer	No Units
BinStart	Starting row of given detector bin	Integer	No Units
BinEnd	End row of given detector bin	Integer	No Units
DiffractionOrder	Measured diffraction order (can vary for fullscan measurements)	Integer	No Units
Exponent	Exponent value for each spectrum. See 5.2.7.2.	Integer	No Units
InstrumentTemperature	Temperature of instrument	Float	Celsius
DetectorTemperature	Temperature of detector	Float	Kelvin

Table 37: Infrared calibrated nadir science parameters.

5.4.1.10 TAB UVIS nadir measurement parameters

Product Field Name	Description	Data Type	Data Units
ObservationDatetimeStart	UTC start datetime of spectrum acquisition	String	No Units
ObservationDatetimeEnd	UTC end datetime of spectrum acquisition	String	No Units
ReverseFlagAndData TypeFlagRegister	Bit 0: 0=normal data, 1=reverse clocked data; Bits 1 to 2: data type flag, where 0=dark frame, 1=noise, 2=bias frame, 4=science frame	Integer	No Units
InstrumentTemperature	Temperature of instrument	Float	Celsius
DetectorTemperature	Temperature of detector during observation	Float	Celsius

Table 38: UVIS calibrated nadir science parameters

5.4.1.11 TAB nadir geometry parameters

Product Field Name	Description	Data Type	Data Units
StartSubObsLon	Starting sub-satellite longitude	Float	Degrees
EndSubObsLon	Ending sub-satellite longitude	Float	Degrees
StartSubObsLat	Starting sub-satellite latitude	Float	Degrees
EndSubObsLat	Ending sub-satellite latitude	Float	Degrees
StartLSubS	Starting planetocentric longitude Ls	Float	Degrees
EndLSubS	Ending planetocentric longitude Ls	Float	Degrees
StartSubSolLon	Starting sub-solar longitude	Float	Degrees
EndSubSolLon	Ending sub-solar longitude	Float	Degrees
StartSubSolLat	Starting sub-solar latitude	Float	Degrees
EndSubSolLat	Ending sub-solar latitude	Float	Degrees
PointXN (where N=geometry point number)	Relative X position of point w.r.t. bin or slit, where -1 to 1 define edges	Float	No Units
PointYN (where N=geometry point number)	Relative Y position of point w.r.t. bin or slit, where -1 to 1 define edges	Float	No Units
LonStartN (where N=geometry point number)	Starting surface latitude for this point	Float	Degrees
LonEndN (where N=geometry point number)	Ending surface latitude for this point	Float	Degrees
LatStartN (where N=geometry point number)	Starting surface latitude for this point	Float	Degrees
LatEndN (where N=geometry point number)	Ending surface latitude for this point	Float	Degrees
LSTStartN (where N=geometry point number)	Starting local solar time of surface point	Float	Hours
LSTEndN (where N=geometry point number)	Ending local solar time of surface point	Float	Hours



N=geometry point number)			
TangentAltStartN (where N=geometry point number)	Starting tangent point altitude for this point (limb only) or -999 for nadir	Float	Degrees
TangentAltEndN (where N=geometry point number)	Ending tangent point altitude for this point (limb only) or -999 for nadir	Float	Degrees
IncidenceAngleStartN (where N=geometry point number)	Starting incidence angle for this point	Float	Degrees
IncidenceAngleEndN (where N=geometry point number)	Ending incidence angle for this point	Float	Degrees
EmissionAngleStartN (where N=geometry point number)	Starting emission angle for this point	Float	Degrees
EmissionAngleEndN (where N=geometry point number)	Ending emission angle for this point	Float	Degrees
PhaseAngleStartN (where N=geometry point number)	Starting phase angle for this point	Float	Degrees
PhaseAngleEndN (where N=geometry point number)	Ending phase angle for this point	Float	Degrees

Table 39: Calibrated nadir geometry parameters

5.4.1.12 TAB solar occultation geometry parameters

Product Field Name	Description	Data Type	Data Units
StartSubObsLon	Starting sub-satellite longitude	Float	Degrees
EndSubObsLon	Ending sub-satellite longitude	Float	Degrees
StartSubObsLat	Starting sub-satellite latitude	Float	Degrees
EndSubObsLat	Ending sub-satellite latitude	Float	Degrees
StartLSubS	Starting planetocentric longitude Ls	Float	Degrees
EndLSubS	Ending planetocentric longitude Ls	Float	Degrees
StartSubSolLon	Starting sub-solar longitude	Float	Degrees
EndSubSolLon	Ending sub-solar longitude	Float	Degrees
StartSubSolLat	Starting sub-solar latitude	Float	Degrees
EndSubSolLat	Ending sub-solar latitude	Float	Degrees
PointXN	Relative X position of point w.r.t. bin or slit, where -1 to 1 define edges	Float	No Units
PointYN	Relative Y position of point w.r.t. bin or slit, where -1 to 1 define edges	Float	No Units
LonStartN	Starting tangent point longitude for this point	Float	Degrees
LonEndN	Ending tangent point longitude for this point	Float	Degrees
LatStartN	Starting tangent point latitude for this point	Float	Degrees



LatEndN	Ending tangent point latitude for this point	Float	Degrees
LSTStartN	Starting local solar time of tangent	Float	Hours
LSTEndN	Ending local solar time of tangent	Float	Hours
AltStartN	Starting tangent point altitude for this point	Float	Degrees
AltEndN	Ending tangent point altitude for this point	Float	Degrees

Table 40: Calibrated solar occultation geometry parameters

5.4.1.13 TAB Science Data

There is one wavelength/wavenumber (X), radiance/transmittance (Y) and radiance/transmittance error (YError) value for every pixel.

Product Field Name	Description	Data Type	Data Units
XN (where N=pixel number)	X (spectral) values	Float	cm ⁻¹ (SO/LNO) nm (UVIS)
YN (where N=pixel number)	Calibrated transmittances (occultation) or radiances nadir. Values are set to nan if error.	Float	No units (occultation) W/cm ² /sr/cm ⁻¹ (nadir)
YErrorN (where N=pixel number)	Error on transmittances (occ) or radiances (nadir). Values are set to nan if error.	Float	No units (occultation) W/cm ² /sr/cm ⁻¹ (nadir)
YValidFlag	Flag to specify if spectrum is good (=1) or bad (=0).	Integer	No units

Table 41: Calibrated science data.

Some of the parameters above are described in more detail below, including the point geometry and how it relates to the fields of view of the channels.

5.4.2 Calibration Collection

5.4.2.1 SO and LNO

The Calibration Collection contains coefficients and lists the files that were used to generate these coefficients. The many types of calibrations are presented in section 2.7, all of which are available in Liuzzi et al. 2019 [RD11] and are therefore already in the public domain. These are:

- 3 coefficients for the wavenumber-pixel calibration (F_0 , F_1 , F_2)
- 3 coefficients for the temperature dependency of the wavenumber-pixel calibration (Q_0 , Q_1 , Q_2)



- 3 coefficients for the blaze function width (H_0, H_1, H_2)
- 3 coefficients for the blaze function centre (I_0, I_1, I_2)
- 3 coefficients for the spectral resolution per pixel (R_0, R_1, R_2)
- 3 coefficients for order-AOTF frequency calibration (E_0, E_1, E_2)
- 3 coefficients for wavenumber-AOTF frequency calibration (G_0, G_1, G_2)

To aid PSA users, we have provided AOTF functions as ancillary products. There is one product for each diffraction order, containing wavenumbers and normalised AOTF function. When ready, we will provide a bad pixel map for SO and LNO in the appropriate binned format (corresponding to the detector rows binned during a science observation).

The optimum calibration coefficients will change over time, therefore new coefficients will be issued as the mission progresses either via reference to published works or through the creation of new PDS4 calibration products.

If the new parameter reflects an improvement over a previous calibration, the PDS products will be regenerated and redelivered to the PSA. If the new parameter reflects a change in instrument behaviour, the change will be applied only to new products from that date forward.

5.4.2.2 UVIS

For UVIS there are:

- 5 coefficients for pixel-wavelength calibration
- a matrices of [1048x1048] coefficients for visible straylight calibration
- 8 straylight spectra, 8 transmission filters spectra and the radiometric calibration of the lamp used for IR straylight calibration
- an instrumental function of 1048 point for the radiance conversion
- UVIS_SolarLargeVariationsRef.mat: a reference spectrum recorded by UVIS in the Martian conditions used by the “Create_UVIS_SolarLargeVariationsRef.m” function to identify the wavelengths with large solar variations to be then used in the dynamic range correction routine.

The optimum calibration coefficients will change over time, therefore new coefficients will be issued as the mission progresses. If the new parameter reflects an improvement over a previous calibration, the PDS products will be regenerated and redelivered to the PSA. If the new parameter reflects a change in instrument behaviour, the change will be applied only to new products from that date forward.

5.4.3 Browse Collection

5.4.3.1 SO Nominal Science Occultation

The Browse Collection contains thumbnail images showing how the signal level on a pixel is extrapolated to perform the calibration and how the signal varies as the field of view passes through the atmosphere. Features in the atmosphere that reduce the signal are visible in the images.

A browse product is created for the bins of every diffraction order where the calibration has not been rejected (see 3.3.20). An example is given in Figure 35.

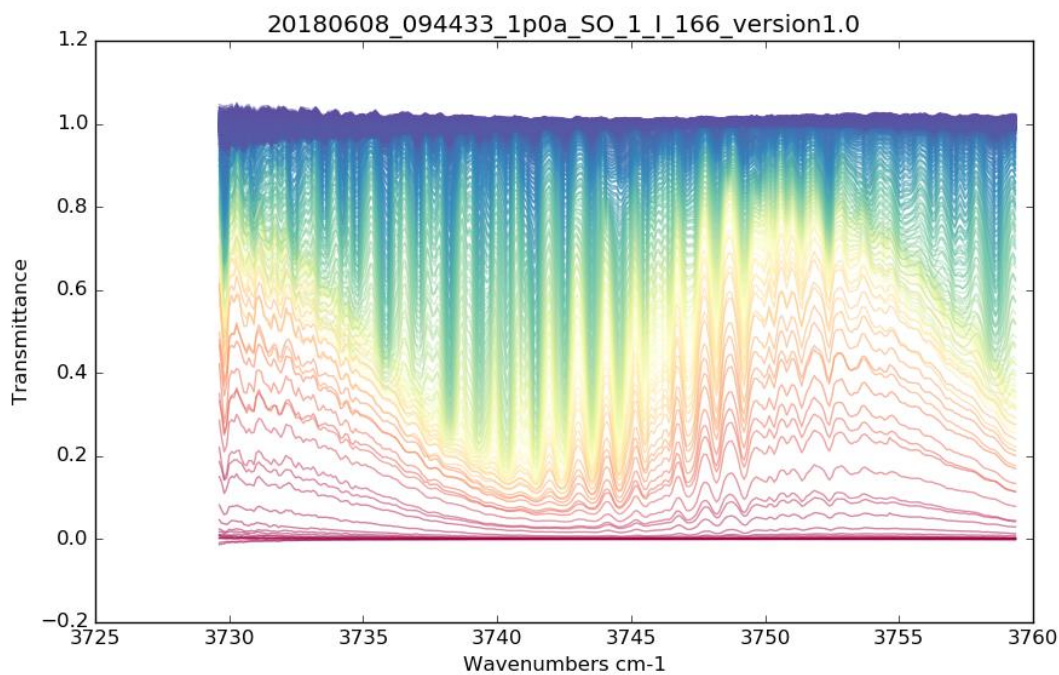


Figure 35: An example of an SO browse product, showing the signal versus altitude for the accepted bins of one diffraction order. The colour denotes the transmittance.

5.4.3.2 LNO Nominal Science Nadir Observation

A 2D image of wavenumber vs time, where the radiance is denoted by the colour of each pixel, is generated for each diffraction order of a nadir observation. An example is given in Figure 36.

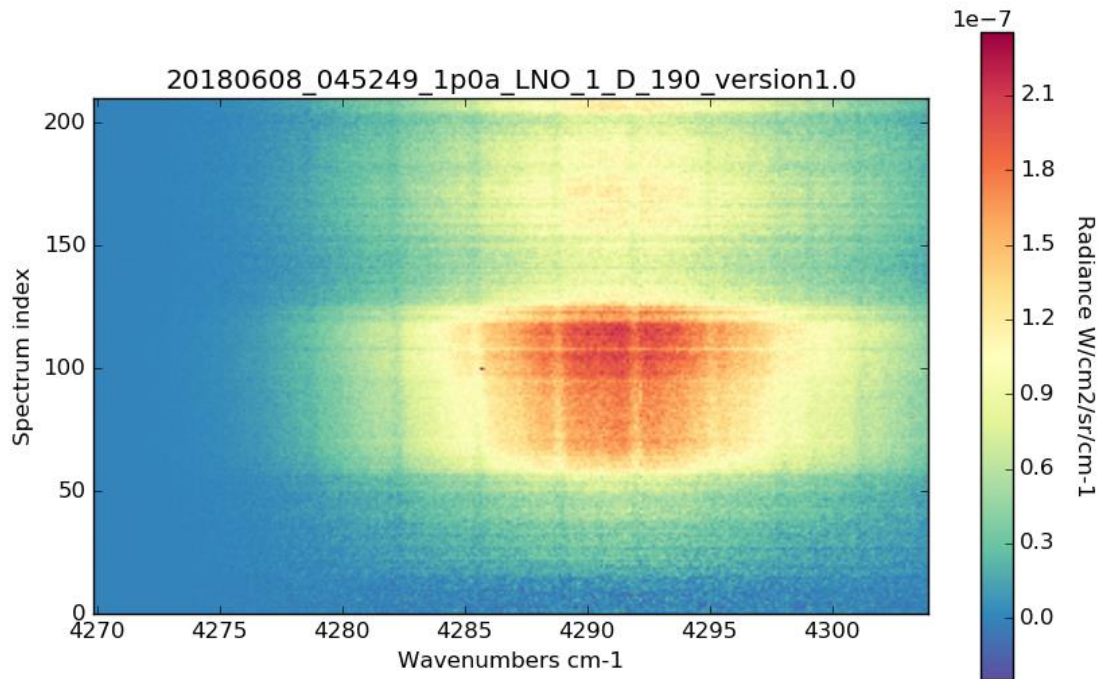


Figure 36: An example of an LNO browse product, showing how the signal varies throughout the given observation for every pixel. The faint vertical bands are atmospheric absorption lines present in the data.

5.4.3.3 UVIS Nadir Observation

The Browse Collection contains thumbnail images (one per orbit) showing the evolution of the radiance for every wavelength throughout the orbit.

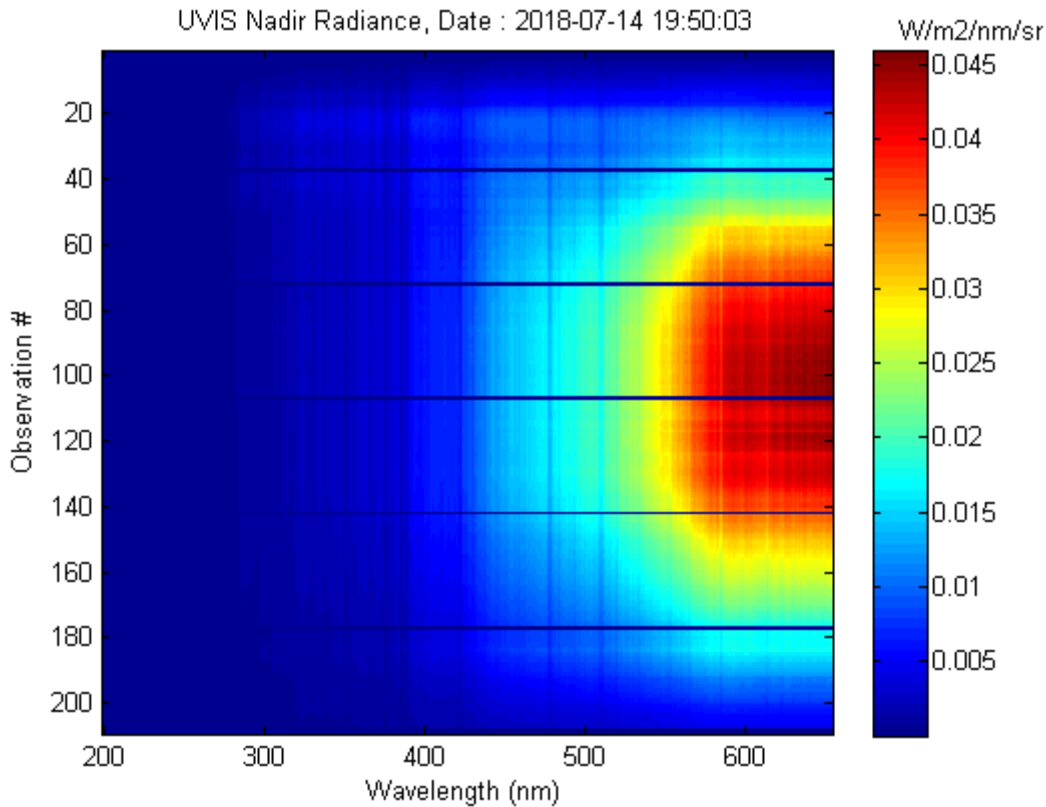


Figure 37 : Example of an UVIS Nadir browse product, showing the radiance evolution during one observation

5.4.3.4 UVIS Occultation Observation

To be completed when the UVIS occultation calibration is ready. It is envisaged that the UVIS occultation browse products will be very similar to those of SO.

5.5 Derived Data Products

Derived data will contain gas species abundances, initially in the form of a vertical profile (for solar occultations) or as a nadir swath (for nadir). Later derived products will be in the form of gridded datasets, as a function of latitude, longitude and altitude above the Martian surface. These datasets will be provided in PDS4 format at regular intervals once the higher level analysis pipeline is complete and has been verified.



The exact structure of the products is to be determined still, however we expect that it will be similar to the calibrated data products.

5.6 Supplementary Products Formats

Auxilliary spacecraft data e.g. housekeeping, operational heater currents, etc., TGO SPICE kernels, and uploaded telecommand data will be required by NOMAD. These will be archived by the SOC independently of the NOMAD team.

6 APPENDIX

6.1 Temperature Sensors on NOMAD

A list of available temperature sensors in NOMAD is given in Table 42. Those named ANC_* are monitored by the TGO spacecraft, and hence are read out continuously, even when NOMAD is switched off.

TGO data is archived separately to NOMAD products. More details to be provided by the SOC.

Instrument Part/Channel	Name	Description
NOMAD	ANC 1 NOMINAL	SO channel temperature, as monitored by the TGO spacecraft
NOMAD	ANC 1 REDUNDANT	SO channel temperature, as monitored by the TGO spacecraft
NOMAD	ANC 2 NOMINAL	LNO channel temperature, as monitored by the TGO spacecraft
NOMAD	ANC 2 REDUNDANT	LNO channel temperature, as monitored by the TGO spacecraft
NOMAD	ANC 3 NOMINAL	UVIS Channel (Spacecraft monitoring) . Due to a wiring issue on the spacecraft, this monitoring sensor is not available in flight.
NOMAD	ANC 3 REDUNDANT	UVIS channel temperature, as monitored by the TGO spacecraft
SINBAD	DC_DC_MODULE_TEMPERATURE	Temperature of DC/DC module
SINBAD	POWER_BOARD_TEMPERATURE	Temperature of POW board
SINBAD	LNO_DETECTOR_TEMPERATURE	Temperature of LNO cold section
SINBAD	LNO_TEMPERATURE	Temperature of LNO
SINBAD	UVIS_TEMPERATURE	Temperature of UVIS
SINBAD	SO_TEMPERATURE	Temperature of SO
SO	FPA_1_FULL_SCALE_TEMPERATURE_SO	SO focal plane array full scale temperature
SO	FPA_2_ZOOMED_TEMPERATURE_SO	SO focal plane array zoomed temperature
SO	SENSOR_1_TEMPERATURE_SO	Temperature sensor 1 near SO AOTF housing
SO	SENSOR_2_TEMPERATURE_SO	Temperature sensor 2 near SO grating structure
SO	SENSOR_3_TEMPERATURE_SO	Temperature sensor 3 near SO detector structure
SO	AOTF_TEMPERATURE_SO	Temperature inside SO AOTF box
LNO	FPA_1_FULL_SCALE_TEMPERATURE_LNO	LNO focal plane array full scale temperature
LNO	FPA_2_ZOOMED_TEMPERATURE_LNO	LNO focal plane array zoomed temperature
LNO	SENSOR_1_TEMPERATURE_LNO	Temperature sensor 1 near LNO AOTF housing



LNO	SENSOR_2_TEMPERATURE_LNO	Temperature sensor 2 near LNO grating structure
LNO	SENSOR_3_TEMPERATURE_LNO	Temperature sensor 3 near LNO detector structure
LNO	AOTF_TEMPERATURE_LNO	Temperature inside LNO AOTF box
UVIS	TEMPERATURE_1	Temp 1 (Proximity Board)
UVIS	TEMPERATURE_2	Temp 2 (CCD)
UVIS	TEMPERATURE_3	Temp 3 (Detector Board)

Table 42: A list of temperature sensors embedded in NOMAD. NOMAD ANC temperature sensors will be monitored and read out continuously by spacecraft. SINBAD temperatures are recorded by the central processor when switched on. SO/LNO/UVIS temperatures are read out only while that channel is operating.

6.2 Conversion of Housekeeping Raw Data to Physical Units

The following tables contain calibration coefficients for conversion of raw housekeeping values to physical units.

code	parameter name	transfer function	size (bits)	description	Raw Value Range	Calculated Value Range	Calculated Units
NMHK1103	DC_DC_MODULE_TEMPERATURE	$\text{real_val } (^{\circ}\text{C}) = 0.1362 * \text{code} - 273.2$	16	temperature of DC/DC module	1638 to 2739	-50.10 to 99.85	deg C
NMHK1104	POWER_BOARD_TEMPERATURE	$\text{real_val } (^{\circ}\text{C}) = 0.1362 * \text{code} - 273.2$	16	temperature of POW board	1638 to 2739	-50.10 to 99.85	deg C
NMHK1105	LNO_DETECTOR_TEMPERATURE	$\text{real_val } (^{\circ}\text{C}) = -0.0721 * \text{code} + 99.702$	16	temperature of LNO cold section	0 to 3747	99.70 to -170.46	deg C
NMHK1106	LNO_TEMPERATURE	$\text{real_val } (^{\circ}\text{C}) = -4.7346538\text{E-}09 * \text{code} * \text{code} * \text{code} + 3.1940866\text{E-}05 * \text{code} * \text{code} - 0.093183624 * \text{code} + 121.48852$	16	temperature of LNO	362 to 4095	91.72 to -49.61	deg C
NMHK1107	UVIS_TEMPERATURE	$\text{real_val } (^{\circ}\text{C}) = -4.7346538\text{E-}09 * \text{code} * \text{code} * \text{code} + 3.1940866\text{E-}05 * \text{code} * \text{code} - 0.093183624 * \text{code} + 121.48852$	16	temperature of UVIS	362 to 4095	91.72 to -49.61	deg C
NMHK1108	SO_TEMPERATURE	$\text{real_val } (^{\circ}\text{C}) = -4.7346538\text{E-}09 * \text{code} * \text{code} * \text{code} + 3.1940866\text{E-}05 * \text{code} * \text{code} - 0.093183624 * \text{code} + 121.48852$	16	temperature of SO	362 to 4095	91.72 to -49.61	deg C
NMHK1109	ADC_1_REFERENCE_VOLTAGE_0_V	$\text{real_val } (\text{V}) = \text{code} * (5/4095)$	16	reference voltage 0 V for ADC1	0 to 10	0 to 0.013 V	V
NMHK1110	ADC_1_REFERENCE_VOLTAGE_3_3_V	$\text{real_val } (\text{V}) = \text{code} * (5/4095)$	16	reference voltage 3.38 V for ADC1	2702 to 2826	3.3 to 3.45 V	V



NMHK1111	SO_VOLTAGE	$real_val(V) = 0.0105 * code - 0.116$	16	voltage for SO	11 to 3059	0 to 32	V
NMHK1112	LNO_VOLTAGE	$real_val(V) = 0.0107 * code - 0.1282$	16	voltage for LNO	12 to 3003	0 to 32	V
NMHK1113	UVIS_VOLTAGE	$real_val(V) = 0.0106 * code - 0.117$	16	voltage for UVIS	11 to 3030	0 to 32	V
NMHK1114	SO_CURRENT	$real_val(A) = 0.0003 * code - 0.0413$	16	current of SO	139 to 3000	0 to 0.859	A
NMHK1115	LNO_CURRENT	$real_val(A) = 0.0003 * code - 0.0511$	16	current of LNO	173 to 3013	0 to 0.85	A
NMHK1116	UVIS_CURRENT	$real_val(A) = 4E-05 * code - 0.0111$	16	current of UVIS	310 to 4095	0 to 0.153	A
NMHK1117	HEATER_CURRENT	$real_val(A) = 0.0001 * code - 0.0147$	16	current of operational heaters	106 to 4095	0 to 0.4	A
NMHK1118	ADC_2_REFERENCE_VOLTAGE_3_3_V	$real_val(V) = code * (5/4095)$	16	reference voltage	2702 to 2826	3.3 to 3.45	V

Table 43: SINBAD housekeeping conversion formulae

code	parameter name	transfer function (a)	size (bits)	description	Raw Value Range	Calculated Value Range	Calculated Units
NMHK2310	POSITIVE_12_V_MEASURED_ON_SO_CCC	$real_val(V) = code * (3/8192) * (47+12)/12$	16	+12 V measured on CCC board of SO	-8192 to 8191	-14.75 to 14.75	V
NMHK2311	NEGATIVE_12_V_MEASURED_ON_SO_CCC	$real_val(V) = code * (3/8192) * (47+12)/12$	16	-12 V measured on CCC board of SO	-8192 to 8191	-14.75 to 14.75	V
NMHK2312	POSITIVE_8_5_V_MEASURED_ON_SO_HSK	$real_val(V) = code * (3/8192) * (33.2+10)/10$	16	+8.5 V measured on HSK board of SO	-8192 to 8191	-12.96 to 12.96	V
NMHK2313	NEGATIVE_8_5_V_MEASURED_ON_SO_HSK	$real_val(V) = code * (3/8192) * (33.2+10)/10$	16	-8.5 V measured on HSK board of SO	-8192 to 8191	-12.96 to 12.96	V
NMHK2314	POSITIVE_3_3_V_MEASURED_ON_SO_CCC	$real_val(V) = code * (3/8192) * (2.5+10)/10$	16	+3.3 V measured on CCC board of SO	-8192 to 8191	-3.75 to 3.75	V
NMHK2315	POSITIVE_2_5_V_MEASURED_ON_SO_CCC	$real_val(V) = code * (3/8192)$	16	+2.5 V measured on CCC board of SO	-8192 to 8191	-3 to 3	V
NMHK2316	POSITIVE_5_V_MEASURED_ON_SO_HSK	$real_val(V) = code * (3/8192) * (10+10)/10$	16	+5 V measured on HSK board of SO	-8192 to 8191	-6 to 6	V
NMHK2317	NEGATIVE_5_V_MEASURED_ON_SO_HSK	$real_val(V) = code * (3/8192) * (10+10)/10$	16	-5 V measured on HSK board of SO	-8192 to 8191	-6 to 6	V
NMHK2318	FPA_1_FULL_SCALE_TEMPERATURE_SO	$x = code * (3/8192) * (10/29.1)$ $real_val(°K) = -460.66 * x * x * x +$	16	SO focal plane array full scale temperature	0 to 8191	74.46 to 539.7	deg K



		$1053,2 * x * x * x - 813,45 * x * x - 227,36 * x + 539,7$					
NMHK2319	FPA_2_ZOOMED_TEMPERATURE_SO	$real_val (V) = code * (3 / 8192)$	16	SO focal plane array zoomed temperature	-8192 to 8191	-3 to 3	V
NMHK2320	SENSOR_1_TEMPERATURE_SO	$real_val (°C) = (code * (3 * 1000 / 8192) + 3 / 11) / 51$	16	temperature sensor 1 near SO AOTF housing	-8192 to 8191	-58.83 to 58.82	deg C
NMHK2321	SENSOR_2_TEMPERATURE_SO	$real_val (°C) = (code * (3 * 1000 / 8192) + 3 / 11) / 51$	16	temperature sensor 2 near SO grating structure	-8192 to 8191	-58.83 to 58.82	deg C
NMHK2322	SENSOR_3_TEMPERATURE_SO	$real_val (°C) = (code * (3 * 1000 / 8192) + 3 / 11) / 51$	16	temperature sensor 3 near SO detector structure	-8192 to 8191	-58.83 to 58.82	deg C
NMHK2323	AOTF_TEMPERATURE_SO	$real_val (°C) = (code * (3 * 1000 / 8192) + 3 / 11) / 51$	16	temperature inside SO AOTF box	-8192 to 8191	-58.83 to 58.82	deg C
NMHK2324	RF_AMPLITUDE_SO	$real_val (V) = code * (3 / 8192)$	16	RF amplitude of SO AOTF driver	-8192 to 8191	-3 to 3	V
NMHK2325	GROUND_MEASURED_ON_SO_HSK	$real_val (V) = code * (3 / 8192)$	16	ground potential measured on SO HSK board	-8192 to 8191	-3 to 3	V
NMHK2326	MOTOR_POWER_DAC_CODE_SO	$real_val = code$	16	SO cooler motor power DAC control	-8192 to 8191	0 to 8191	ADU

Table 44: SO housekeeping conversion formulae

code	parameter name	transfer function (a)	size (bits)	description	Raw Value Range	Calculated Value Range	Calculated Units
NMHK2610	POSITIVE_12_V_MEASURED_ON_LNO_CCC	$real_val (V) = code * (3 / 8192) * (47 + 12) / 12$	16	+12 V measured on CCC board of LNO	-8192 to 8191	-14.75 to 14.75	V
NMHK2611	NEGATIVE_12_V_MEASURED_ON_LNO_CCC	$real_val (V) = code * (3 / 8192) * (47 + 12) / 12$	16	-12 V measured on CCC board of LNO	-8192 to 8191	-14.75 to 14.75	V
NMHK2612	POSITIVE_8_5_V_MEASURED_ON_LNO_HSK	$real_val (V) = code * (3 / 8192) * (33.2 + 10) / 10$	16	+8.5 V measured on HSK board of LNO	-8192 to 8191	-12.96 to 12.96	V
NMHK2613	NEGATIVE_8_5_V_MEASURED_ON_LNO_HSK	$real_val (V) = code * (3 / 8192) * (33.2 + 10) / 10$	16	-8.5 V measured on HSK board of LNO	-8192 to 8191	-12.96 to 12.96	V
NMHK2614	POSITIVE_3_3_V_MEASURED_ON_LNO_CCC	$real_val (V) = code * (3 / 8192) * (2.5 + 10) / 10$	16	+3.3 V measured on CCC board of LNO	-8192 to 8191	-3.75 to 3.75	V
NMHK2615	POSITIVE_2_5_V_MEASURED_ON_LNO_CCC	$real_val (V) = code * (3 / 8192)$	16	+2.5 V measured on CCC board of LNO	-8192 to 8191	-3 to 3	V



NMHK2616	POSITIVE_5_V_MEASURED_ON_LNO_HSK	real_val (V) = code*(3/8192)*(10+10)/10	16	+5 V measured on HSK board of LNO	-8192 to 8191	-6 to 6	V
NMHK2617	NEGATIVE_5_V_MEASURED_ON_LNO_HSK	real_val (V) = code*(3/8192)*(10+10)/10	16	-5 V measured on HSK board of LNO	-8192 to 8191	-6 to 6	V
NMHK2618	FPA_1_FULL_SCALE_TEMPERATURE_LNO	$x = \text{code} * (3/8192) * (10/29.1)$ real_val (°K) = $-460,66 * x * x * x + 1053,2 * x * x - 813,45 * x + 539,7$	16	LNO focal plane array full scale temperature	0 to 8191	74.46 to 539.7	deg K
NMHK2619	FPA_2_ZOOMED_TEMPERATURE_LNO	real_val (V) = code*(3/8192)	16	LNO focal plane array zoomed temperature	-8192 to 8191	-3 to 3	V
NMHK2620	SENSOR_1_TEMPERATURE_LNO	real_val (°C) = (code*(3*1000/8192)+3/11)/51	16	temperature sensor 1 near LNO AOTF housing	-8192 to 8191	-58.83 to 58.82	deg C
NMHK2621	SENSOR_2_TEMPERATURE_LNO	real_val (°C) = (code*(3*1000/8192)+3/11)/51	16	temperature sensor 2 near LNO grating structure	-8192 to 8191	-58.83 to 58.82	deg C
NMHK2622	SENSOR_3_TEMPERATURE_LNO	real_val (°C) = (code*(3*1000/8192)+3/11)/51	16	temperature sensor 3 near LNO detector structure	-8192 to 8191	-58.83 to 58.82	deg C
NMHK2623	AOTF_TEMPERATURE_LNO	real_val (°C) = (code*(3*1000/8192)+3/11)/51	16	temperature inside LNO AOTF box	-8192 to 8191	-58.83 to 58.82	deg C
NMHK2624	RF_AMPLITUDE_LNO	real_val (V) = code*(3/8192)	16	RF amplitude of LNO AOTF driver	-8192 to 8191	-3 to 3	V
NMHK2625	GROUND_MEASURED_ON_LNO_HSK	real_val (V) = code*(3/8192)	16	ground potential measured on LNO HSK board	-8192 to 8191	-3 to 3	V
NMHK2626	MOTOR_POWER_DAC_CODE_LNO	real_val = code	16	LNO cooler motor power DAC control	0 to 8191	0 to 8191	ADU

Table 45: LNO housekeeping conversion formulae

code TM(29)	code TM(28)	parameter name	transfer function	size (bits)	description	Raw Value Range	Calculated Value Range	Calculated Units
NMHK2910	NMTM2810	POSITIVE_10_V_RAIL_VOLTAGE	real_val (V) = code * (3980/4096) / 20000 * (100+20)	16	+10V rail voltage	1500 to 1833	9 to 11	V
NMHK2911	NMTM2811	NEGATIVE_10_V_RAIL_VOLTAGE	real_val (V) = -code * (3980/4096) / 20000 * 100	16	-10V rail voltage	1800 to 2200	minus 9 to minus 11	V
NMHK2912	NMTM2812	POSITIVE_5_V_RAIL_VOLTAGE	real_val (V) = code * (3980/4096) / 20000 * (20+30.1)	16	+5V rail voltage	1600 to 2400	4 to 6	V
NMHK2913	NMTM2813	NEGATIVE_5_V_RAIL_VOLTAGE	real_val (V) = -code * (3980/4096) / 20000 * 100	16	-5V rail voltage	1600 to 2400	minus 4 to 6	V

		_VOLTAGE	$(3980/4096) / 20000 * 50$			2400	minus 6	
NMHK2914	NMTM2814	POSITIVE_12_V_RAIL_CURRENT	$real_val (mA) = code * (3980/4096) * 0.2$	16	+12V rail current	0 to 500	0 to 100	mA
NMHK2915	NMTM2815	NEGATIVE_12_V_RAIL_CURRENT	$real_val (mA) = code * (3980/4096) * 0.2$	16	-12V rail current	0 to 500	0 to 100	mA
NMHK2916	NMTM2816	POSITIVE_5_V_RAIL_CURRENT	$real_val (mA) = code * (3980/4096) * 0.2$	16	+5V rail current	0 to 250	0 to 50	mA
NMHK2917	NMTM2817	NEGATIVE_5_V_RAIL_CURRENT	$real_val (mA) = code * (3980/4096) * 0.002$	16	-5V rail current	0 to 5000	0 to 10	mA
NMHK2918	NMTM2818	CCD_IMAGE_CLOCK_HIGH	$real_val (V) = code * (3980/4096) / 20000 * (20 + 80)$	16	CCD image clock HI	1600 to 3000	8 to 15	V
NMHK2919	NMTM2819	CCD_IMAGE_CLOCK_LOW	$real_val (V) = code * (3980/4096) / 1000$	16	CCD image clock LO	0 to 3000	0 to 3	V
NMHK2920	NMTM2820	CCD_READOUT_REGISTER_HIGH	$real_val (V) = code * (3980/4096) / 20000 * (20 + 80)$	16	CCD readout register HI	1600 to 3000	8 to 15	V
NMHK2921	NMTM2821	CCD_READOUT_REGISTER_LOW	$real_val (V) = code * (3980/4096) / 1000$	16	CCD readout register LO	0 to 3000	0 to 3	V
NMHK2922	NMTM2822	SUBSTRATE_VOLTAGE_VSS	$real_val (V) = code * (3980/4096) / 2490 * (6.8 + 2.49)$	16	Substrate Voltage (VSS)	2087 to 2870	8 to 11	V
NMHK2923	NMTM2823	OUTPUT_GATE_VOLTAGE_VOG	$real_val (V) = code * (3980/4096) / 1000$	16	Output gate voltage (VOG)	1000 to 5000	1 to 5	V
NMHK2924	NMTM2824	OUTPUT_DRAIN_VOLTAGE_VOD	$real_val (V) = code * (3980/4096) / 20000 * (249 + 20)$	16	Output drain voltage (VOD)	2007 to 2379	27 to 32	V
NMHK2925	NMTM2825	RESET_TRANSISTOR_DRAIN_VOLTAGE_VRD	$real_val (V) = code * (3980/4096) / 20000 * (20 + 150)$	16	Reset transistor drain voltage (VRD)	1764 to 2236	15 to 19	V
NMHK2926	NMTM2826	DIODE_DRAIN_VOLTAGE_VDD	$real_val (V) = code * (3980/4096) / 20000 * (20 + 226)$	16	Diode drain voltage (VDD)	1788 to 2033	22 to 25	V
NMHK2927	NMTM2827	TEMPERATURE_1	$real_val (°C) = code * (3980/4096) / 2.49 - 273.27$	16	Temp 1 (Proximity Board)	530 to 930	minus 60 to + 100	deg C
NMHK2928	NMTM2828	TEMPERATURE_2	$real_val (°C) = code * (3980/4096) / 2.49 - 273.27$	16	Temp 2 (CCD)	530 to 930	minus 60 to + 100	deg C
NMHK2929	NMTM2829	TEMPERATURE_3	$real_val (°C) = code * (3980/4096) / 2.49 - 273.27$	16	Temp 3 (Detector Board)	530 to 930	minus 60 to + 100	deg C
NMHK2930	NMTM2830	MOTOR_CURRENT_A	$real_val (mA) = code * (3980/4096) * 0.2$	16	Motor current	0 to 600	0 to 120	mA

Table 46: UVIS housekeeping conversion formulae



6.2.1 TC20 Parameters

The timestamped TC20 sent to NOMAD will be stored in a PDS4 compatible product by the SOC and archived in the PSA. Discussion is ongoing with the SOC on how this data should be stored.