NOMAD Science Team

Description of NOMAD Observation Types and HDF5 Datasets

NOT YET COMPLETE

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NOMAD has many possible observation and measurement types

Observation Types
Standard solar occultation (ingress or egress)
Merged solar occultation
Grazing solar occultation
Dayside Nadir
Nightside Nadir
Limb
Calibration

Measurement Types – UVIS
Solar occultation (detector rows binned)
Solar occultation (detector rows unbinned)
Nadir (detector rows binned)
Nadir (detector rows unbinned)
Calibration

Measurement Types – SO/LNO
Standard solar occultation (5 orders + 1 dark per second, change order selection at 50km)
Merged/grazing occultation (5 orders + 1 dark per second, same order selection throughout)
Standard nadir/limb (dark subtracted)
Special occultation (6 orders, dark subtracted onboard)
Special merged/grazing occultation (6 orders, dark subtracted)
Fullscan Slow (diffraction order stepping, dark subtracted onboard)
Fullscan Fast (diffraction order stepping, dark subtracted onboard)
Calibration (many types)

Pipeline

- Each observation/measurement type follows a particular path through the pipeline
  - Contents of each file are calibrated/modified as appropriate

Outline of Pipeline

- Level 0.1A: Conversion to HDF5, dataset ordering and calibration of housekeeping data
- Level 0.1D: Addition of observation type letter
  - SO/LNO only: calculation of diffraction order, splitting of files by diffraction order
- Level 0.1E:
  - SO/LNO occultation only: bad pixel removal, non-linearity correction, flattening of datasets to 2D array
  - LNO nadir: bad pixel removal, vertical binning of detector frame. Straylight detection and removal.
  - LNO limb: bad pixel removal, flattening of datasets to 2D array

Outline of Pipeline

- Level 0.2A: Addition of geometry
  - UVIS/LNO nadir: surface geometry and illumination angles
  - UVIS/SO/LNO occultation/limb: tangent point geometry
- Level 0.3A
  - SO/LNO only: temperature-dependent spectral calibration
- Level 0.3B
  - UVIS nadir only:

Outline of Pipeline

- Level 0.3J
  - SO/LNO occultation only: dark subtraction
- Level 1.0A: Radiometric calibration
  - SO/LNO/UVIS occultation: conversion to transmittance
  - LNO/UVIS nadir/limb: conversion to radiance

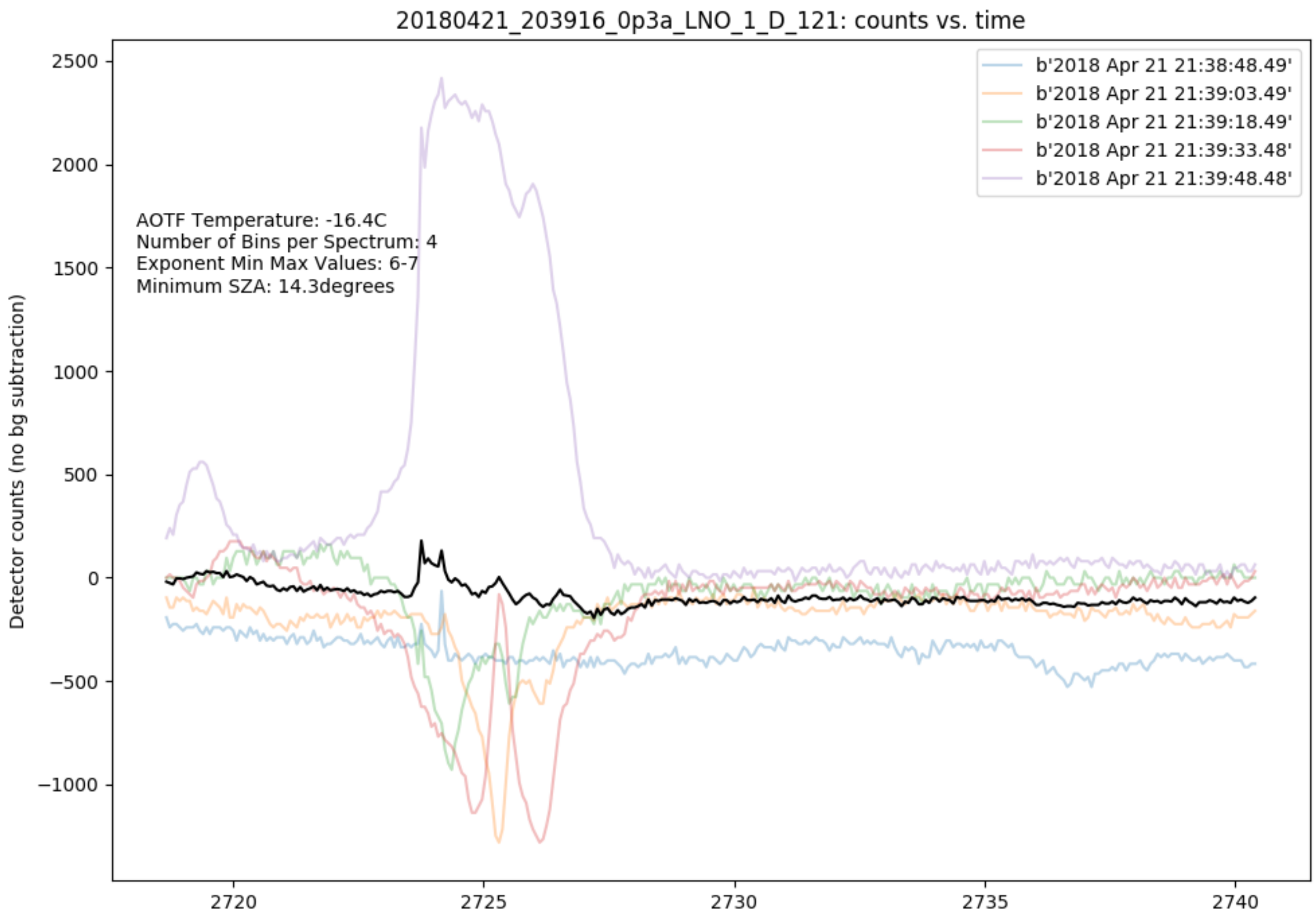
Outline of Pipeline

- Many of these are minor levels, containing incremental data processing steps and therefore are not useful for analysis
  - In time these minor levels will be merged into the major levels
  - Only major levels will be placed on ftp i.e. 0.1A, 0.2A, 0.3A, 1.0A.

- However it is important that all steps that modify the data are described in detail

Pipeline Processes and File Contents

Level 0.1E – LNO Nadir Straylight Removal



Every LNO spectrum is checked.

Only occurs when TGO is in a particular orientation w.r.t the Sun
=> if true, the spectra are removed from the files

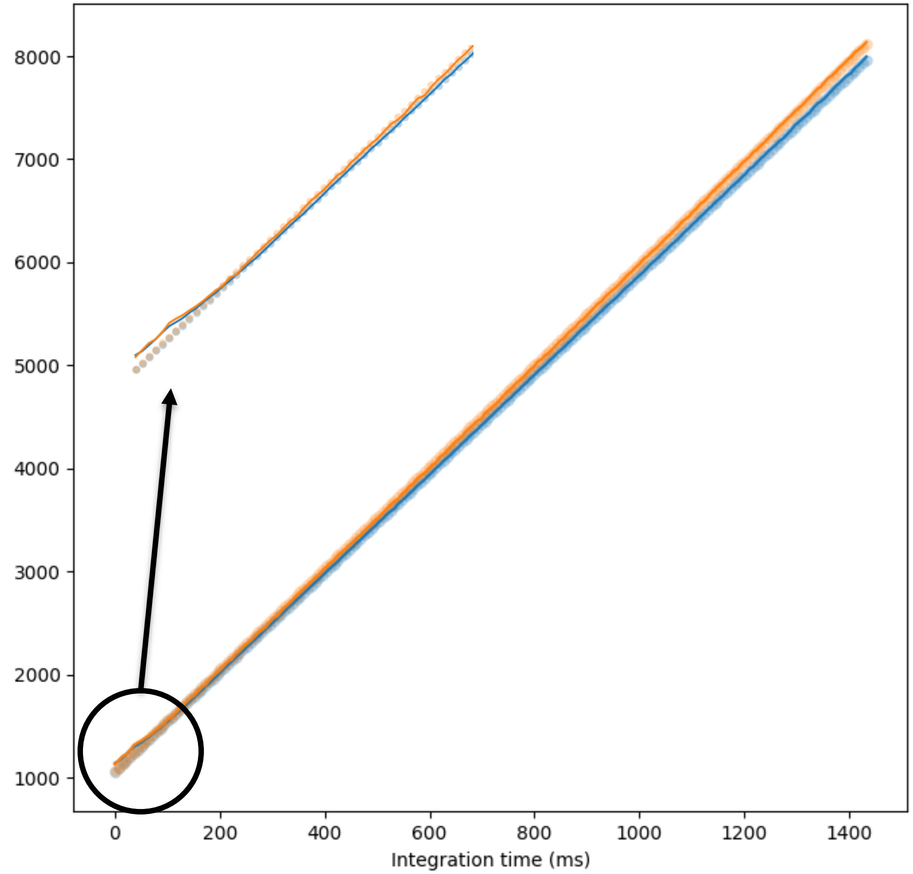
Level 0.1E – LNO Nadir Straylight Removal

- Science/Y spectra set to NaN where straylight is present (data is not recoverable)
- Science/YValidFlag used to indicate which spectra are affected
  - 1D array, one value per spectrum
    - 1 = spectrum is valid
    - 0 = spectrum is invalid

Level 0.1E – Non Linearity Correction

- Only applies to SO data where signal is very low

Any detector counts in non-linear region are modified to match the linear response.



Level 0.1E – Bad Pixel Removal

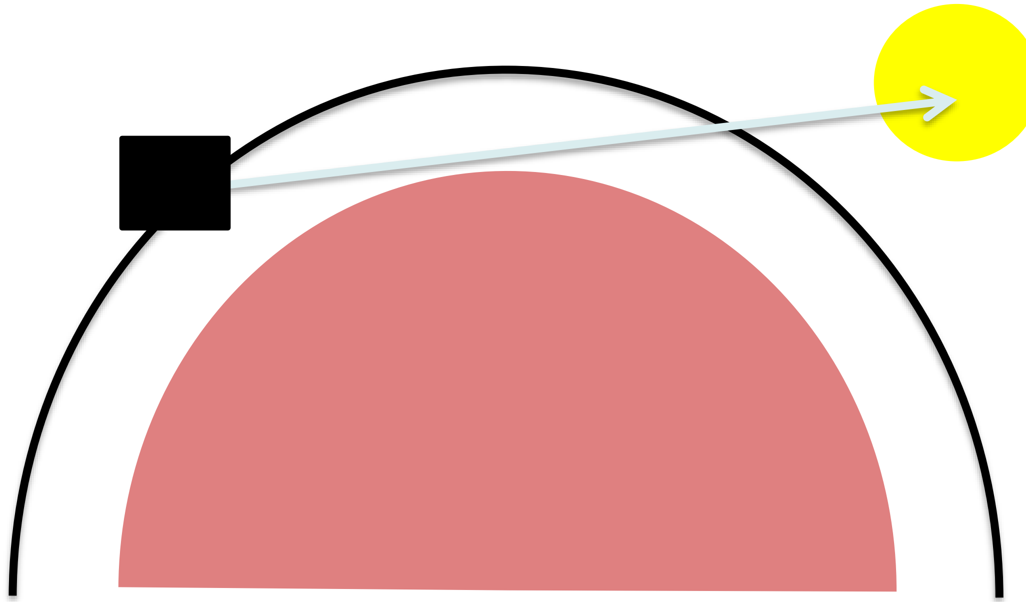
- Some bad pixels occur intermittently
  - Bad pixel removal uses a hybrid approach
    - There is a set table of known bad pixels
    - The values for each pixel during a measurement are checked for

Level 0.2A – LNO/UVIS nadir geometry

- Digital Shape Kernel (DSK) is now used to represent Mars surface
  - Minor differences to latitude / longitude in nadir
  - Incidence/emission/phase angles etc. now reflect real contours of surface to 4 px per degree

Level 0.2A – SO/UVIS occultation geometry

- Occultation Types
  - Ingress (type I)
  - Egress (type E)
  - Merged (type I)
  - Grazing (type I)



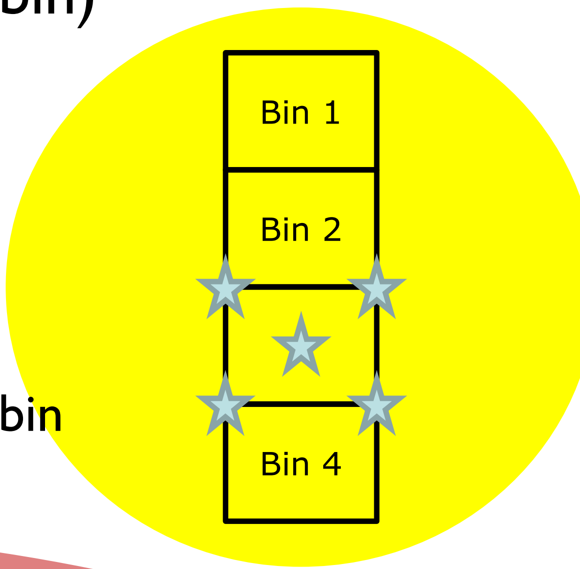
  - A merged occultation contains 2 individual occultations
    - At 0.2A level, merged occultations are not split
  - A grazing occultation contains 1 occultation
    - Starting high in atmosphere, decreasing until a minimum altitude and ending high in atmosphere

Level 0.2A – SO/UVIS

- Several new fields in dataset for calculation types:
  - Surface
  - Areoid
  - Ellipsoid

SO Occultation Geometry

- Nominal occultation science:
  - 4 bins per measurement, each pointing in different directions
    - 4 spectra measured instantaneously at different tangent altitudes
  - 4 pixels per bin (~4x2 arcminute FOV per bin)
  - Each bin has 5 points to define geometry
    - Point0 = centre
    - Points1 to points4 = corners
    - Point0/PointXY defines relative pointing within bin
      - I.e. [0,0]=centre, [±1, ±1] = corners



  - Values set to -999 when FOV of a point drops below Mars surface

SO Occultation Geometry

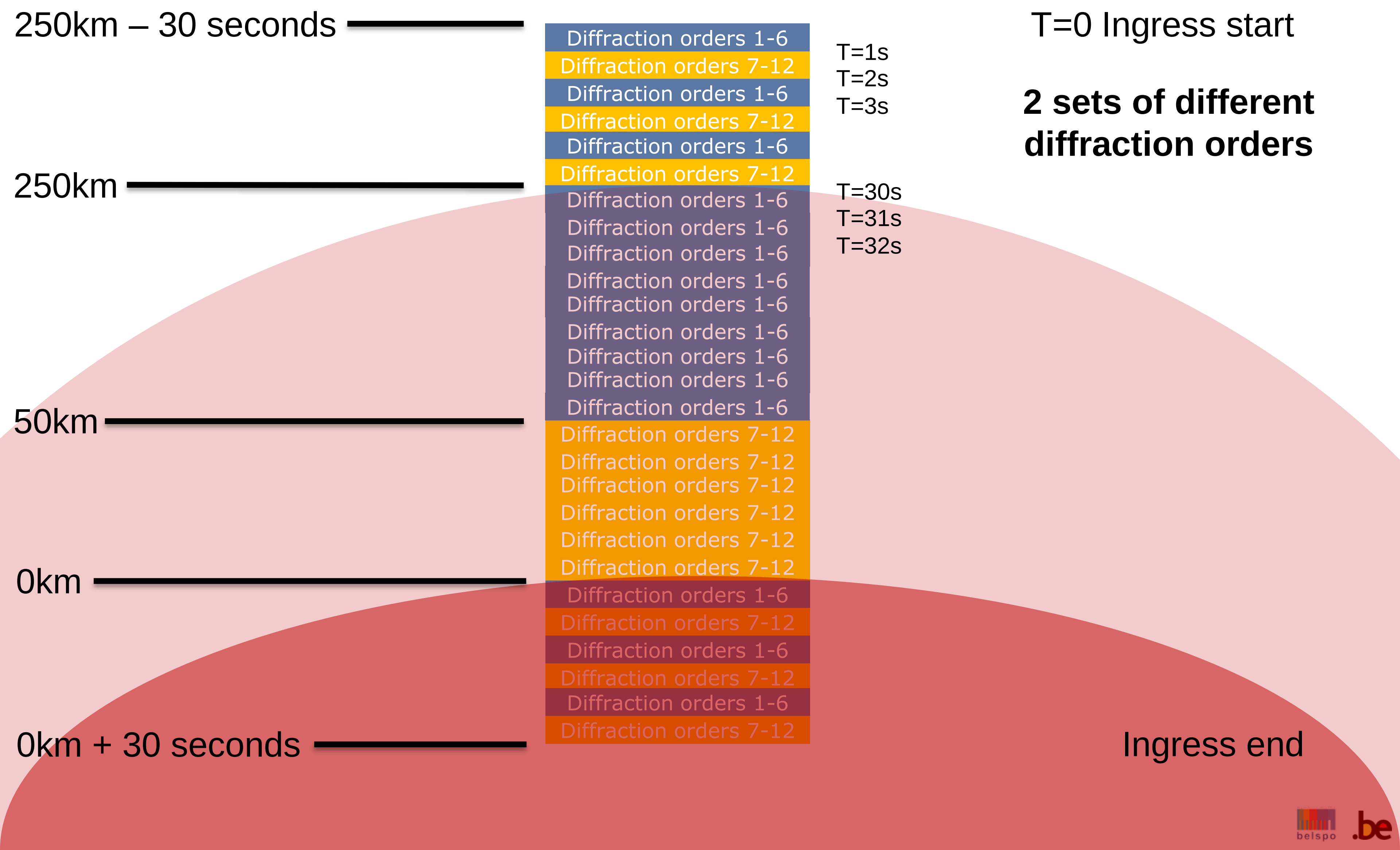
- Binned datasets are flattened to 2D array:
  - Y values (spectra) ordered by bin and measurement
    - Each row contains one spectrum of 320 values
  - Geometry defined by start and end times
    - Each row contains two strings
  - Other fields 1D arrays

Measurement 1 Bin 1
Measurement 1 Bin 2
Measurement 1 Bin 3
Measurement 1 Bin 4
Measurement 2 Bin 1
Measurement 2 Bin 2
Measurement 2 Bin 3
Measurement 2 Bin 4
Measurement 3 Bin 1
…

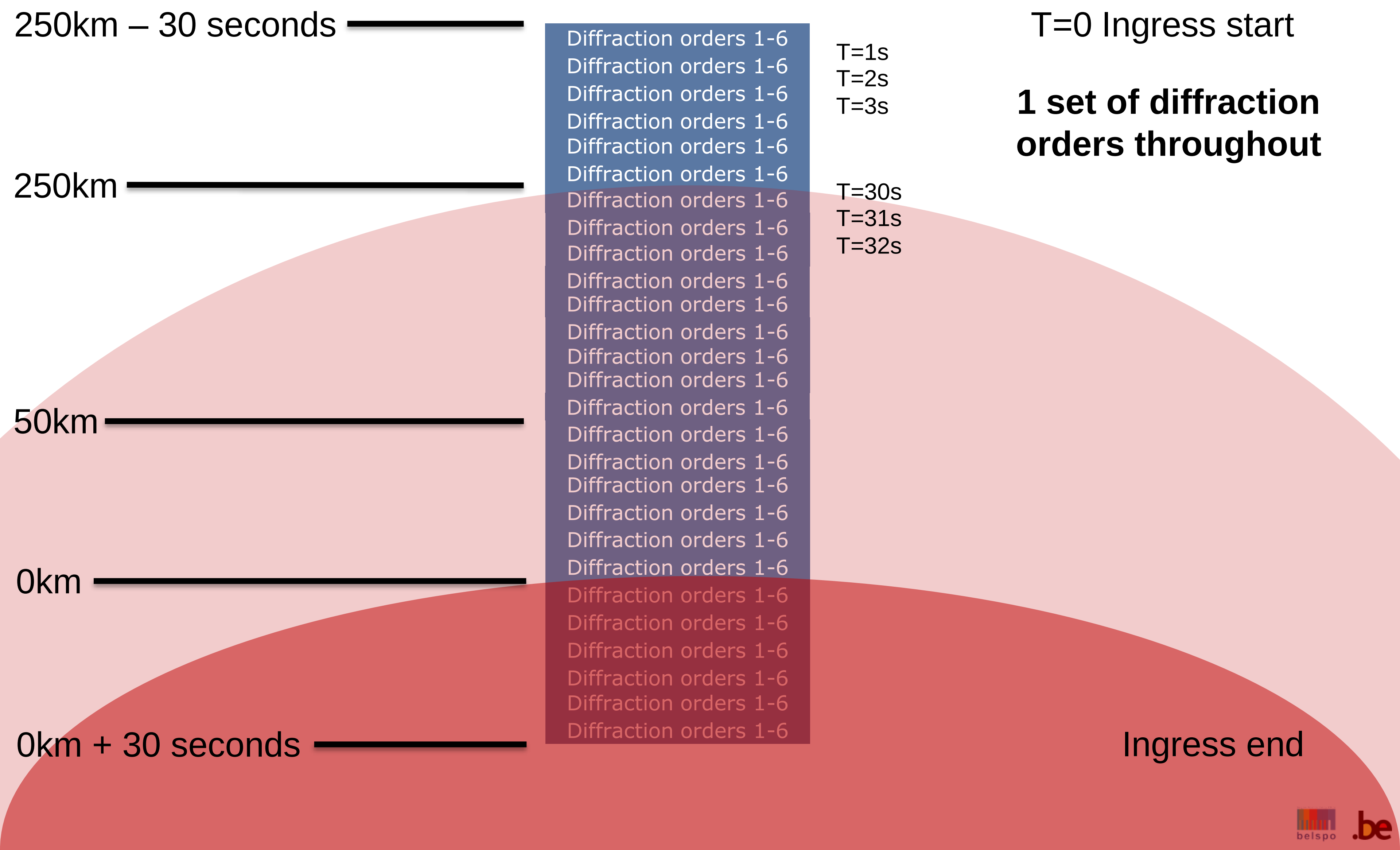
Meas 1 Bin 1 Start	Meas 1 Bin 1 End
Meas 1 Bin 2 Start	Meas 1 Bin 2 End
Meas 1 Bin 3 Start	Meas 1 Bin 3 End
Meas 1 Bin 4 Start	Meas 1 Bin 4 End
Meas 2 Bin 1 Start	Meas 2 Bin 1 End
Meas 2 Bin 2 Start	Meas 2 Bin 2 End
Meas 2 Bin 3 Start	Meas 2 Bin 3 End
Meas 2 Bin 4 Start	Meas 2 Bin 4 End
Meas 3 Bin 1 Start	Meas 3 Bin 1 End
…	…

Meas 1 Bin 1 Value
Meas 1 Bin 2 Value
Meas 1 Bin 3 Value
Meas 1 Bin 4 Value
Meas 2 Bin 1 Value
Meas 2 Bin 2 Value
Meas 2 Bin 3 Value
Meas 2 Bin 4 Value
Meas 3 Bin 1 Value
…

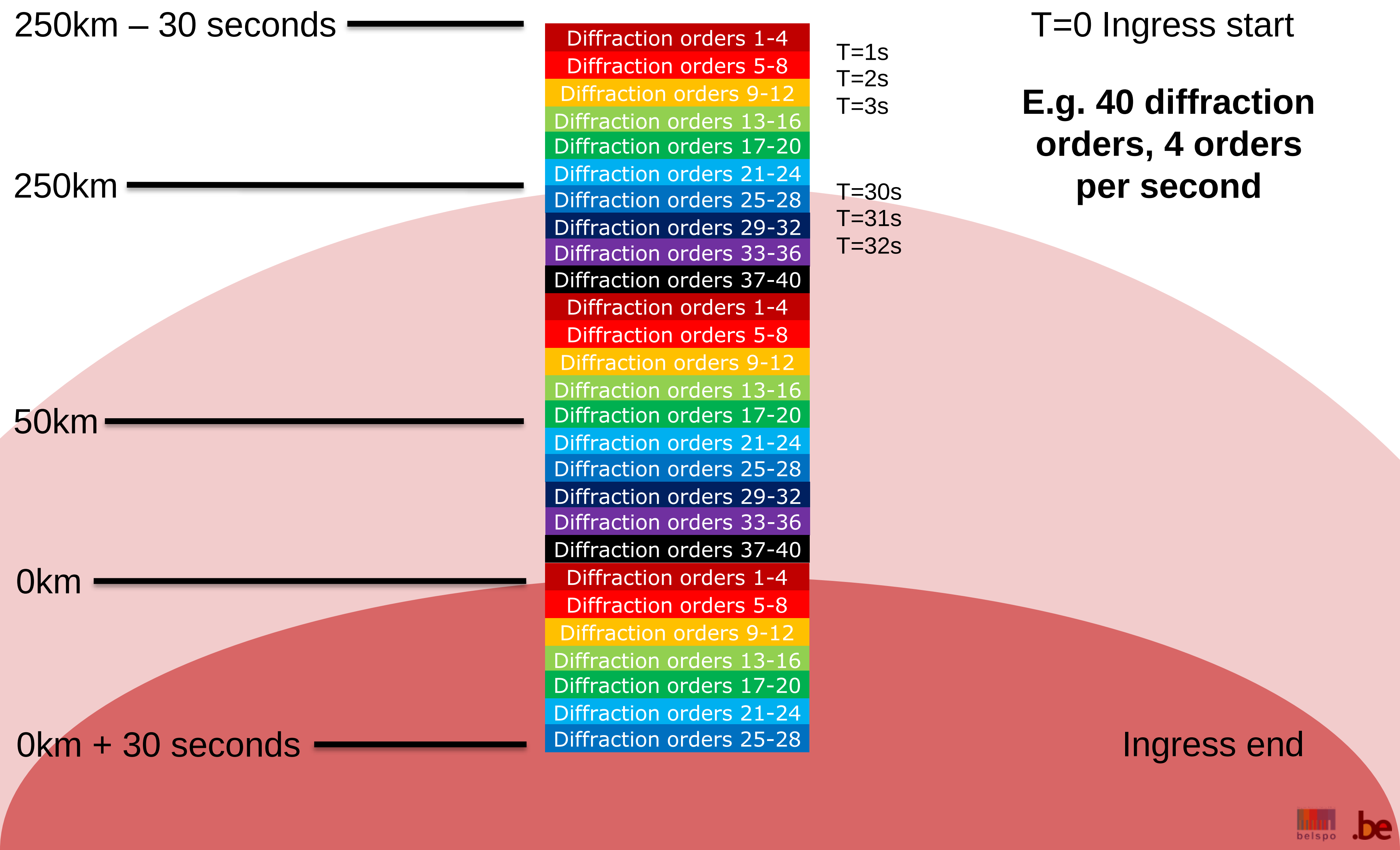
SO Occultation Geometry – Option 1



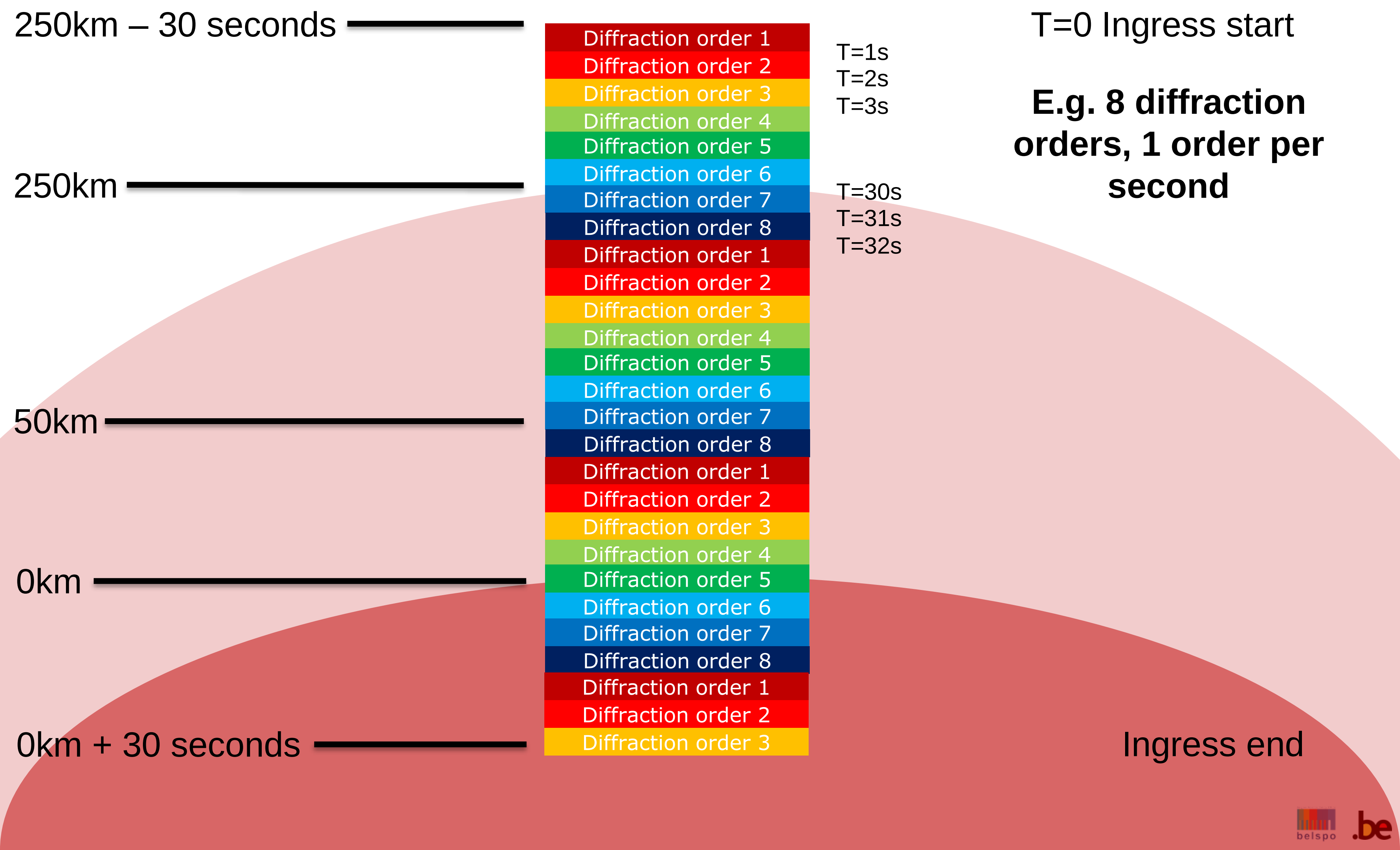
SO Occultation Geometry – Option 2



SO Occultation Geometry – Fast Fullscan

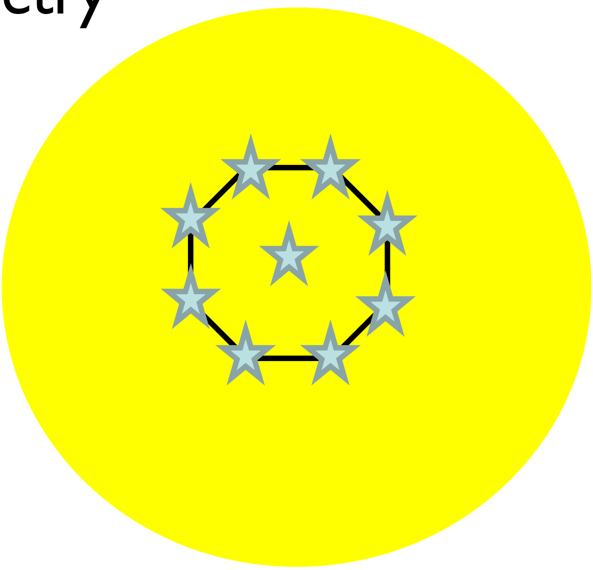


SO Occultation Geometry – Slow Fullscan



UVIS Occultation Geometry

- Nominal occultation science:
  - UVIS has no bins
    - 1 spectrum measured at a time
  - Each spectrum has 9 points to define geometry
    - Point0 = centre
    - Points1 to points8 = octagonal "corners"
      - FOV is spherical



  - Values set to -999 when FOV of a point drops below Mars ellipsoid

UVIS Occultation Geometry

- Y dataset is 3D array:
  - Detector array x time
  - Geometry defined by start and end times
    - Each row contains two strings
  - Other fields are 1D arrays

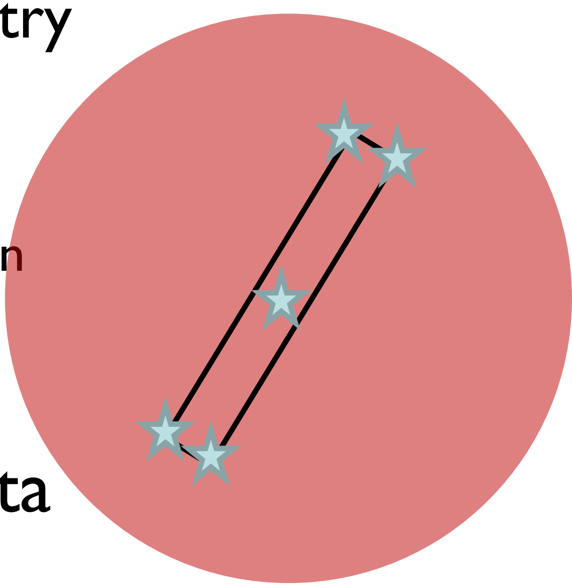
Spectrum 1
Spectrum 2
Spectrum 3
Spectrum 4
Spectrum 5
Spectrum 6
Spectrum 7
Spectrum 8
Spectrum 9
...

Spectrum 1 Start	Spectrum 1 End
Spectrum 2 Start	Spectrum 2 End
Spectrum 3 Start	Spectrum 3 End
Spectrum 4 Start	Spectrum 4 End
Spectrum 5 Start	Spectrum 5 End
Spectrum 6 Start	Spectrum 6 End
Spectrum 7 Start	Spectrum 7 End
Spectrum 8 Start	Spectrum 8 End
Spectrum 9 Start	Spectrum 9 End
...	...

Spectrum 1 Value
Spectrum 2 Value
Spectrum 3 Value
Spectrum 4 Value
Spectrum 5 Value
Spectrum 6 Value
Spectrum 7 Value
Spectrum 8 Value
Spectrum 9 Value
...

LNO Nadir Geometry

- Bins are averaged together to give a single spectrum per measurement
  - Each spectrum has 5 points to define geometry
    - Point0 = centre of FOV
    - Points1 to points4 = corners
    - Point0/PointXY defines relative pointing within bin
      - I.e. [0,0]=centre, [±1, ±1] = corners



- At present, bad pixels remain in nadir data
  - These will be removed in an update soon
  - Work in ongoing to detect other issues e.g. electrical noise

LNO Nadir Geometry

- Values set to -999 if FOV of a point is not pointed to planet
- Need to decide on number of diffraction orders per nadir observation
  - SNR depends on number of orders chosen
    - More orders = better spectral range coverage
    - Fewer orders = better SNR (less averaging required)

LNO Nadir Geometry

- Y dataset is 2D array:
  - Y values spectra x measurement

Spectrum 1
Spectrum 2
Spectrum 3
Spectrum 4
Spectrum 5
Spectrum 6
Spectrum 7
Spectrum 8
Spectrum 9
...

  - Geometry defined by start and end times

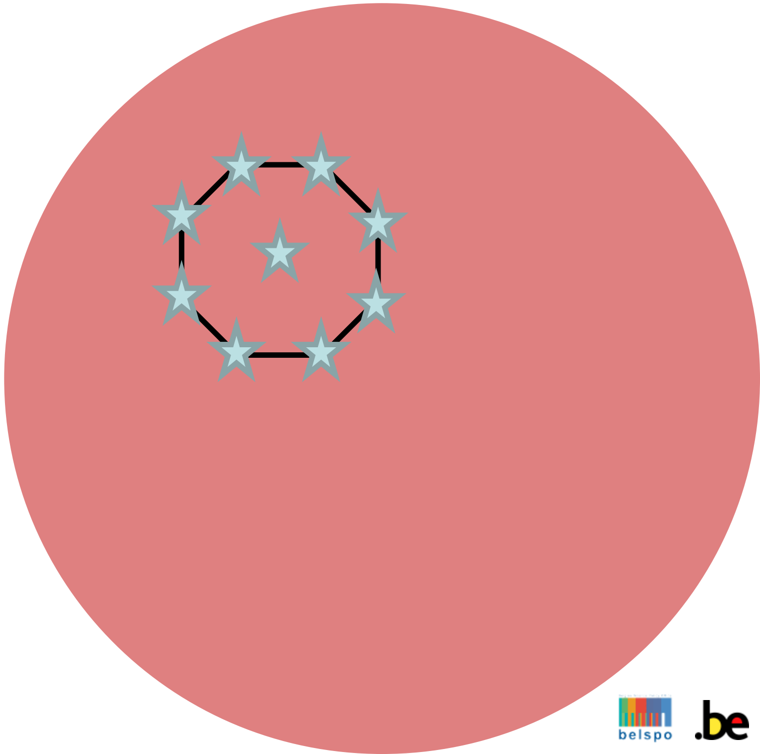
Spectrum 1 Start	Spectrum 1 End
Spectrum 2 Start	Spectrum 2 End
Spectrum 3 Start	Spectrum 3 End
Spectrum 4 Start	Spectrum 4 End
Spectrum 5 Start	Spectrum 5 End
Spectrum 6 Start	Spectrum 6 End
Spectrum 7 Start	Spectrum 7 End
Spectrum 8 Start	Spectrum 8 End
Spectrum 9 Start	Spectrum 9 End
...	...

  - Other fields are 1D arrays

Spectrum 1 Value
Spectrum 2 Value
Spectrum 3 Value
Spectrum 4 Value
Spectrum 5 Value
Spectrum 6 Value
Spectrum 7 Value
Spectrum 8 Value
Spectrum 9 Value
...

UVIS Nadir Geometry

- Nominal nadir science:
  - Single spectrum returned per measurement
  - Each spectrum has 9 points to define geometry
    - Point0 = centre
    - Points1 to points8 = corners
    - Point0/PointXY defines relative pointing within bin
      - I.e. [0,0]=centre, [±1, ±1] = corners of FOV



UVIS Nadir Geometry

- Y dataset is 2D array:
  - Y values spectra x measurement
  - Geometry defined by start and end times
  - Other fields are 1D arrays

Spectrum 1
Spectrum 2
Spectrum 3
Spectrum 4
Spectrum 5
Spectrum 6
Spectrum 7
Spectrum 8
Spectrum 9
...

Spectrum 1 Start	Spectrum 1 End
Spectrum 2 Start	Spectrum 2 End
Spectrum 3 Start	Spectrum 3 End
Spectrum 4 Start	Spectrum 4 End
Spectrum 5 Start	Spectrum 5 End
Spectrum 6 Start	Spectrum 6 End
Spectrum 7 Start	Spectrum 7 End
Spectrum 8 Start	Spectrum 8 End
Spectrum 9 Start	Spectrum 9 End
...	...

Spectrum 1 Value
Spectrum 2 Value
Spectrum 3 Value
Spectrum 4 Value
Spectrum 5 Value
Spectrum 6 Value
Spectrum 7 Value
Spectrum 8 Value
Spectrum 9 Value
...

SO/LNO Spectral Calibration (Level 0.3A)

- Calibration output is controlled by pipeline flags. At present:
  - AOTF_BANDWIDTH_FLAG=0
  - BLAZE_FUNCTION_FLAG=0
- This means that AOTF function and blaze function are calculated and added to file, rather than coefficients
  - Channel/AOTF bandwidth contains
    - [xStart, xEnd, xStep, AOTFvalues]
    - E.g. a wavenumber grid from -100cm^{-1} to +100cm^{-1} in 0.1cm^{-1} steps would be as follows:

-100	100	0.1	x1	x2	x3	x4	x5	...	x2000

    - Where x1 = AOTF function at -100cm^{-1}
    - x2 = AOTF function at -99.9cm^{-1}
    - x2000 = AOTF function at +100cm^{-1} etc.
  - Channel/BlazeFunction contains
    - [xStart, xEnd, xStep, BlazeFunctions]
    - E.g. a pixel grid from pixel 0 to pixel 319 would be as follows:

0	319	1	x1	x2	x3	x4	x5	...	x320

SO/LNO Spectral Calibration (Level 0.3A)

- The flags can be changed to output spectral coefficients instead (of various forms – see slide 20), but we should decide as a team which is preferable
  - Feedback would be very welcome on ease-of-use and calibration accuracy

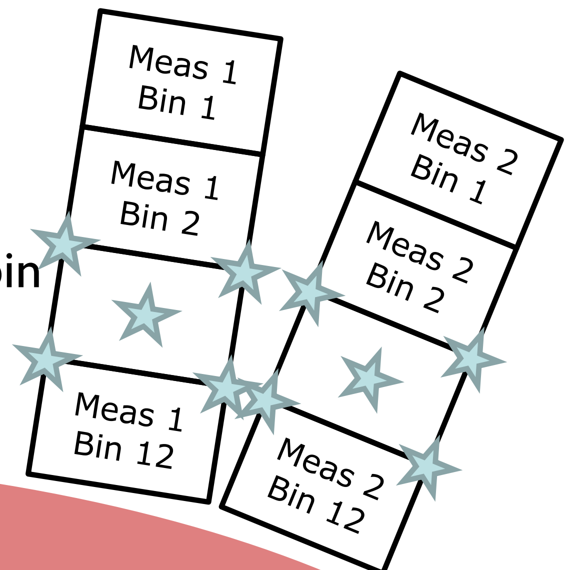
- Raw values probably easier to use at the start
  - Coefficients may be more useful if tweaks are required to specific calibrations

HDF5 File Contents

Special Observations

LNO Limb Geometry

- Limb bins are not averaged together like nadir
  - 12 bins per measurement (at present), each pointing in different directions
  - 12 pixels per bin (~12x4 arcminute FOV per bin)
  - Binned datasets are flattened to 2D arrays (see next slide)
- Each bin has 5 points to define geometry
  - Point0 = centre
  - Points1 to points4 = corners
  - Point0/PointXY defines relative pointing within bin
    - I.e. [0,0]=centre, [±1, ±1] = corners



- Values set to -999 if FOV of a point drops below Mars ellipsoid

LNO Limb Geometry

- Binned datasets are flattened to 2D array:
  - Y values (spectra) ordered by bin and measurement
    - Each row contains one spectrum of 320 values
  - Geometry defined by start and end times
    - Each row contains two strings
  - Other fields 1D arrays
    - One value per row

Measurement 1 Bin 1
Measurement 1 Bin 2
Measurement 1 Bin 3
Measurement 1 Bin 4
Measurement 2 Bin 1
Measurement 2 Bin 2
Measurement 2 Bin 3
Measurement 2 Bin 4
Measurement 3 Bin 1
…

Meas 1 Bin 1 Start	Meas 1 Bin 1 End
Meas 1 Bin 2 Start	Meas 1 Bin 2 End
Meas 1 Bin 3 Start	Meas 1 Bin 3 End
Meas 1 Bin 4 Start	Meas 1 Bin 4 End
Meas 2 Bin 1 Start	Meas 2 Bin 1 End
Meas 2 Bin 2 Start	Meas 2 Bin 2 End
Meas 2 Bin 3 Start	Meas 2 Bin 3 End
Meas 2 Bin 4 Start	Meas 2 Bin 4 End
Meas 3 Bin 1 Start	Meas 3 Bin 1 End
…	…

Meas 1 Bin 1 Value
Meas 1 Bin 2 Value
Meas 1 Bin 3 Value
Meas 1 Bin 4 Value
Meas 2 Bin 1 Value
Meas 2 Bin 2 Value
Meas 2 Bin 3 Value
Meas 2 Bin 4 Value
Meas 3 Bin 1 Value
…

SO/LNO Fullscans

- Normally files are split so one files contains data from one diffraction order only
  - This is not the case for fullscans in nadir or occultation mode, where files can contain 100+ diffraction orders
  - Usual binning rules apply:
    - LNO bins average together
    - SO unbinned but spectra flattened into 2D array
  - Spectral calibration is applied per order
    - Different AOTF and blaze function per spectrum

More information

- Online on FAQ page:
  - http://mars.aeronomie.be/en/exomars/observations/nomad_faqs.html

NOMAD Frequently Asked Questions

Most Important Links

- Observation types
- Data levels
- SO diffraction order to wavenumber conversion table
- LNO diffraction order to wavenumber conversion table
- SO AOTF to diffraction order conversion table (2017 inflight calibration)
- LNO AOTF to diffraction order conversion table (2017 inflight calibration)
- Observation overview database
- NOMAD experiment-to-archive interface document (EAICD)
- List of parameters contained in the HDF5 files
- NOMAD publication list
- More resources can be found on the main page

EAICD contains more information about observation modes, data, etc.

List of parameters in HDF5 files can be found here. Science/Channel/Geometry groups are relevant. Spectral coefficient formats are described on Channel sheet