



# NIRSpec Technical Note

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## The correction of path losses for uniform and point sources

### Abstract:

This technical note contains a description of the path loss correction for uniform and point sources present in the baseline NIRSpec data processing for its slit, integral-field and multi-object spectroscopy modes. After presenting briefly the effect to be corrected, we describe the format of the associated reference files and give an overview of the various ways of generating these references files that we foresee for different stages of the mission (on-ground [this version] and in orbit [future versions]). We conclude by describing the associated correction method.

Change log		
Version	Date	Description
1	31 March 2016	Creation. This version of the technical note had an incorrect reference (duplication with another technical note), 004 instead of 017. This is corrected in version 2.
2	01 August 2016	Corrected reference number.
3	23 October 2016	Update after the review by STScI

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## 1 INTRODUCTION AND SCOPE OF THE NOTE

This technical note contains a description of the path loss correction for uniform and point sources present in the baseline NIRSpec data processing for its slit, integral-field and multi-object spectroscopy modes. After presenting briefly the effect to be corrected, we describe the format of the associated reference files, and give an overview of the various ways of generating revisions of these references files foreseen for different stages of the mission (on-ground [this version] and in orbit [future versions]). We conclude by describing the associated correction method.

## 2 APPLICABLE AND REFERENCE DOCUMENTS

### 2.1 Applicable documents

Table 2-1: List of applicable documents.

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### 2.2 Reference documents

Table 2-2: List of reference documents.

RD01	Format and Delivery Procedures for JWST ETC Reference Files. K. Gilbert et al.	JWST-STScI-00XXXX, SM-12
RD02	On the prediction error variance of three common spatial interpolation schemes. P. C. Kyriakidis and M. F. Goodchild.	2006; International Journal of Geographical Information Science, vol. 20, 8, p823-855

### 3 THE PATH-LOSS CORRECTION

#### 3.1 What are we correcting for?

The radiometric calibration of the NIRSpec instrument is based on a fairly standard combination of flat-fielding and spectrophotometric correction steps. The last step will be based on observations of spectrophotometric standard stars for each mode of observation. The initial calibration applied to the data will be valid of a point source centred in an aperture (micro-shutter mini-slit, slice, slit...). As a consequence a correction needs to be introduced to account for sources that are not point like and for non-centred point sources.

**Complex sources** - In the “vanilla” pipeline concept, the correction for complex sources that can neither be considered as point-like or uniform (i.e. spatially uniform over the size of the aperture) is not included. The computation of such a correction will be complex and will require modelling of the spatial distribution of light in the object as a function of wavelength. It is beyond the scope of this technical note to tackle this problem and we will only cover the non-centred point source and uniform source cases.

**Geometrical and diffraction losses** – The path loss correction will include two different light loss sources linked to the use of apertures: a so-called “geometrical-loss” component, which corresponds to light from the source that does not make it through the aperture (applicable only to point sources; not applicable to the IFU); a so-called “diffraction-loss” component attributed to losses in the pupil plane of the instrument following the aperture where part of the light diffracted by the aperture will not make it through the pupil and will be lost (mainly relevant for point source, see discussion for uniform sources in section 5.1). The path-loss correction will include the combination of both components, which quite often are very difficult to disentangle.

**Path-loss versus aperture correction** – Given that this correction is due to the use of an aperture (micro-shutter mini-slit, slice, slit...), we tend to use the name aperture-loss correction as another name for the path-loss correction. This can cause some confusion as traditionally, for imaging instruments the aperture correction refers to the correction for light lost when performing a summation at pixel-level on the detectors (summation box). We emphasize that the summation-box loss correction is not part of the path-loss / aperture-loss correction for NIRSpec.

#### 3.2 What does the correction depend on?

The path-loss correction will depend on the following parameters:

- The type of object (point-source or uniform).
- For a point source, the position of the source within the aperture.

- The aperture used for the observation (micro-shutter mini-slits; slit; integral field).
  - In the case of the MOS mode, it will also depend on the type of micro-shutter mini-slit that is used (in particular the geometrical-loss component). We will differentiate between the following cases: MOS<sub>1x1</sub> (individual shutter); MOS<sub>1x2</sub> (mini-slit made of two shutters); and MOS<sub>1x3</sub> (mini-slit made of 1x3 shutters). Cases involving different mini-slit patterns can usually be approximated by one of these 3 basic cases.
  - In the case of the SLIT mode, each slit will have to have its own reference files.
  - In the case of the IFU mode, we will not distinguish between individual slices so there will be single reference for the IFU mode.
- The wavelength.

## 4 REFERENCE FILES

### 4.1 Format

A reference file will be generated for each type of aperture (see section 3.1) and each reference file will cover both the point source and uniform source cases (different FITS file extensions). It is important to note that the reference file will contain the correction factor related to the path losses but not the actual losses (it is more comparable to an “efficiency” value).

Point sources - As the correction depends on wavelength and the position of the point source within the aperture, the associated extension will therefore contain a 3D data cube.  
Uniform sources – For uniform sources, the correction depends only on wavelength so the associated extension will only contain a 1D spectrum.

The format of the reference file is described in. It includes an extension for the data and one for the associated variance.

As no explicit instructions were provided for the pipeline reference files, the choice of keywords for the primary header reflects the instructions that were provided for the exposure time calculator reference files at the end of 2015 (RD01).

**Table 4-1: Format of the reference file.**

<b>.plrff</b>	<b>Path-loss reference file</b>
<b>FITS extension</b>	<b>Description</b>
0 [PRIMARY]	<p>Primary header with an empty primary data array. This header will contain, as a minimum, the following keywords:</p> <pre> SIMPLE =                                T / file conforms to FITS standards BITPIX =                                8 / number of bits per pixel NAXIS  =                                0 / number of axes (empty data array) EXTEND =                                T / file has extension(s) TELESCOP= 'JWST' / telescope INSTRUME= 'NIRSPEC' / applicable instrument SYSTEM  = 'REFERENCE FILE' / purpose of the file (example) REFTYPE = 'PIPELINE' / reference file type FILETYPE= 'PLRF' / file type PEDIGREE= 'GROUND' / file category (example) COMPNAME= 'MOS1x3' / applicable component (example) AUTHOR  = 'ESA' / author (example) DESCRIP = 'path loss reference file for MOS' / short description (example) LITREF  = 'NTN-2016-004' / literature reference for the data (example) DATE    = '2006-05-23T20:20:00' / UTC-GMT creation time END </pre>
1 [PS]	<p>3D image FITS extension containing the path-loss correction values for point sources. Its header will contain, as a minimum the following keywords:</p> <pre> XTENSION= 'IMAGE' / extension type EXTNAME  = 'PS' / extension name BITPIX   = -32 / number of bits per pixel (float) NAXIS    = 3 / number of axes (3D data cube) NAXIS1   = 11 / x-axis length(dispersion direction) - example NAXIS2   = 33 / y-axis length(spatial direction) - example </pre>

	<pre> NAXIS3 = 11 / z-axis length (wavelength) - example PCOUNT = 0 / number of parameters per group GCOUNT = 1 / number of groups BSCALE = 1. / data scaling factor BZERO = 0. / data zero point BUNIT = / data unit CTYPE1 = 'UNITLESS' / x-axis unit (fraction of aperture or pitch) CTYPE2 = 'UNITLESS' / y-axis unit (fraction of aperture or pitch) CTYPE3 = 'METER' / z-axis unit (wavelength) CDELT1 = 0.1 / step size along the x-axis - example CDELT2 = 0.1 / step size along the y-axis - example CDELT3 = 0.47E-6 / step size along the z-axis CRPIX1 = 1 / ref. pixel along the x-axis CRPIX2 = 1 / ref. pixel along the y-axis CRPIX3 = 1 / ref. pixel along the z-axis CRVAL1 = -0.5 / ref. pixel coordinate (x-axis) CRVAL2 = -1.5 / ref. pixel coordinate (y-axis) CRVAL3 = 0.6E-6 / ref. pixel coordinate (z-axis) AWIDTH = 104.42E-6 / aperture or pitch width in meter ALENGTH = 201.61E-6 / aperture or pitch length in meter END </pre> <p>Note the choice of BSCALE = 1.0 and BZERO = 0.0, which corresponds to the case where no scaling is applied to the data values.</p>
2 [PSVAR]	<p>3D image FITS extension containing the variance associated to the path-loss correction values for point sources. Its header will contain, as a minimum the following keywords:</p> <pre> XTENSION= 'IMAGE' / extension type EXTNAME = 'PSVAR' / extension name BITPIX = -32 / number of bits per pixel (float) NAXIS = 3 / number of axes (3D data cube) NAXIS1 = 11 / x-axis length (dispersion direction) - example NAXIS2 = 33 / y-axis length (spatial direction) - example NAXIS3 = 11 / z-axis length (wavelength) - example PCOUNT = 0 / number of parameters per group GCOUNT = 1 / number of groups BSCALE = 1. / data scaling factor BZERO = 0. / data zero point BUNIT = 'UNITLESS' / data unit CTYPE1 = 'UNITLESS' / x-axis unit (fraction of aperture or pitch) CTYPE2 = 'UNITLESS' / y-axis unit (fraction of aperture or pitch) CTYPE3 = 'METER' / z-axis unit (wavelength) CDELT1 = 0.1 / step size along the x-axis - example CDELT2 = 0.1 / step size along the y-axis - example CDELT3 = 0.47E-6 / step size along the z-axis CRPIX1 = 1 / ref. pixel along the x-axis CRPIX2 = 1 / ref. pixel along the y-axis CRPIX3 = 1 / ref. pixel along the z-axis CRVAL1 = -0.5 / ref. pixel coordinate (x-axis) CRVAL2 = -1.5 / ref. pixel coordinate (y-axis) CRVAL3 = 0.6E-6 / ref. pixel coordinate (z-axis) AWIDTH = 104.42E-6 / aperture or pitch width in meter ALENGTH = 201.61E-6 / aperture or pitch length in meter END </pre> <p>Note the choice of BSCALE = 1.0 and BZERO = 0.0, which corresponds to the case where no scaling is applied to the data values.</p>
3 [UNI]	<p>1D image FITS extension containing the path-loss correction values for uniform sources. Its header will contain, as a minimum the following keywords:</p> <pre> XTENSION= 'IMAGE' / extension type EXTNAME = 'UNI' / extension name BITPIX = -32 / number of bits per pixel (float) NAXIS = 1 / number of axes (1D spectrum) NAXIS1 = 11 / x-axis length (wavelength) - example </pre>

	<pre> PCOUNT = 0 / number of parameters per group GCOUNT = 1 / number of groups BSCALE = 1. / data scaling factor BZERO = 0. / data zero point BUNIT = 'UNITLESS' / data unit CTYPE1 = 'METER' / x-axis unit (wavelength) CDELT1 = 0.47E-6 / step size along the x-axis CRPIX1 = 1 / ref. pixel along the x-axis CRVAL1 = 0.6E-6 / ref. pixel coordinate (x-axis) AWIDTH = 104.42E-6 / aperture or pitch width in meter ALENGTH = 201.61E-6 / aperture or pitch length in meter END </pre> <p>Note the choice of BSCALE = 1.0 and BZERO = 0.0, which corresponds to the case where no scaling is applied to the data values.</p>
4 [UNIVAR]	<p>1D image FITS extension containing variance associated to the path-loss correction values for uniform sources. Its header will contain, as a minimum the following keywords:</p> <pre> XTENSION= 'IMAGE' / extension type EXTNAME = 'UNIVAR' / extension name BITPIX = -32 / number of bits per pixel (float) NAXIS = 1 / number of axes (1D spectrum) NAXIS1 = 11 / x-axis length (wavelength) - example PCOUNT = 0 / number of parameters per group GCOUNT = 1 / number of groups BSCALE = 1. / data scaling factor BZERO = 0. / data zero point BUNIT = 'UNITLESS' / data unit CTYPE1 = 'METER' / x-axis unit (wavelength) CDELT1 = 0.47E-6 / step size along the x-axis CRPIX1 = 1 / ref. pixel along the x-axis CRVAL1 = 0.6E-6 / ref. pixel coordinate (x-axis) AWIDTH = 104.42E-6 / aperture or pitch width in meter ALENGTH = 201.61E-6 / aperture or pitch length in meter END </pre> <p>Note the choice of BSCALE = 1.0 and BZERO = 0.0, which corresponds to the case where no scaling is applied to the data values.</p>

## 4.2 List of reference files

There will be one reference file per type of aperture, except for the IFU where this correction is not implemented in this delivery. The reference files are listed in Table 4-2.

**Table 4-2: List of reference files.**

File	Aperture	Pedigree	Comments
jwst-nirspec-mos1x1.plrf.fits	MOS1x1	DUMMY	For mini-slit patterns different from 1x1, 1x2 or 1x3, the closest approximation should be used.
jwst-nirspec-mos1x2.plrf.fits	MOS1x2	DUMMY	
jwst-nirspec-mos1x3.plrf.fits	MOS1x3	DUMMY	
jwst-nirspec-slit-a200-1.plrf.fits	A200_1	DUMMY	
jwst-nirspec-slit-a200-2.plrf.fits	A200_2	DUMMY	
jwst-nirspec-slit-b200.plrf.fits	B200	DUMMY	
jwst-nirspec-slit-a400.plrf.fits	A400	DUMMY	
jwst-nirspec-slit-a1600.plrf.fits	A1600	DUMMY	
jwst-nirspec-ifu.plrf.fits	IFU	DUMMY	We do not differentiate between individual slices. Real DUMMY file (filled with values of unity).



## 5 GENERATING THE REFERENCE FILES

### 5.1 On-ground

For this delivery (March 2016), the reference files have been generated using the model of the instrument developed by the instrument team, which include a lot of information based on the as-built characteristics of NIRSpec and a as-designed model of the telescope with a single and fairly old realisation of the telescope wave front error map (strong limitation for the geometrical-loss component of the correction).

Observations of point sources with different positions within the apertures have been acquired at several times during NIRSpec ground testing. Most of the time, the sampling of the apertures by these observations was limited but they will nevertheless provide very good anchor point for the models. It was not possible to perform this analysis in time for this delivery so the results from the model have not yet been compared to the measurements.

**[MOS and SLIT modes] Computation for point sources** – The computation of the path losses for a point source have been computed using a Python script able to perform coherent Fourier propagation of a planar input wave front (i.e. a point source) through the telescope and the instrument down to the detector plane and for a grid of wavelengths and source positions within an aperture. The output of this computation consists of 2 cubes (source position along the 2 axes + wavelength) containing the absolute geometrical and diffraction losses, respectively (when using a model they can be disentangled).

In order to generate the reference files two additional steps were necessary:

- The geometrical and diffraction losses were transformed into efficiencies and combined, yielding an absolute path-loss correction cube.
- As the reference for NIRSpec radiometric calibration corresponds to a centred point source, the path-loss correction must be relative to a perfectly centred object. As a consequence, at each wavelength the path-loss cube was normalised to its value for a centred source.

**[IFU mode] Computation for point sources** – In the case of the IFU, the situation is more complex because neighbouring slices will capture the flux of the source falling out of a given slice and the path loss correction does not include any geometrical loss component. At the same time, as the intensity of the point source will be recovered by summing over multiple slices (some of them with a very off-centred source), the effective diffraction losses correspond to the diffraction losses of each slice used in the summation weighted by the intensity of the source falling on this slice. The computation is therefore less straightforward than for the MOS and SLIT modes and will include the following steps:

- Compute the geometrical and diffraction losses for a single slice (we do not differentiate between slices so this computation will be valid for every slice) for a grid of positions and wavelengths. Contrary to what is done for the MOS and SLIT

modes, the grid of positions perpendicular to the dispersion direction extend well beyond the limits of the slice in order to be able to cover the case of the neighbouring slices.

- Prepare the absolute path-loss cube by computing an intensity-weighted sum of the diffraction losses for a grid of source positions (this time restricted to the limits of a single slice) and wavelengths.
- Convert the absolute loss values into efficiency values (1.0 minus losses) and normalise the cube to the case of a centred point source.

For this delivery (March 2016), the IFU file is a dummy one filled with unity values.

**[All modes] Computation for uniform sources** – The path-loss correction for uniform sources needs to contain the correction required to go from a centred point source (reference for the radiometric calibration) to a uniform source. As for this delivery we are using a model-only approach, we had to make an assumption concerning the absolute path-loss component associated to a uniform source and we assumed it was zero (fully non-coherent illumination, no diffraction effect). As a consequence, the correction for uniform source corresponds to the inverse of the path losses correction for a centred source (i.e.  $1.0 / \text{path loss correction}$ ); in most cases this will yield values larger than 1.0).

**Error propagation** - It is difficult to estimate the errors associated to this computation and for this first delivery we have used an arbitrary constant value of 5 % (no justification).

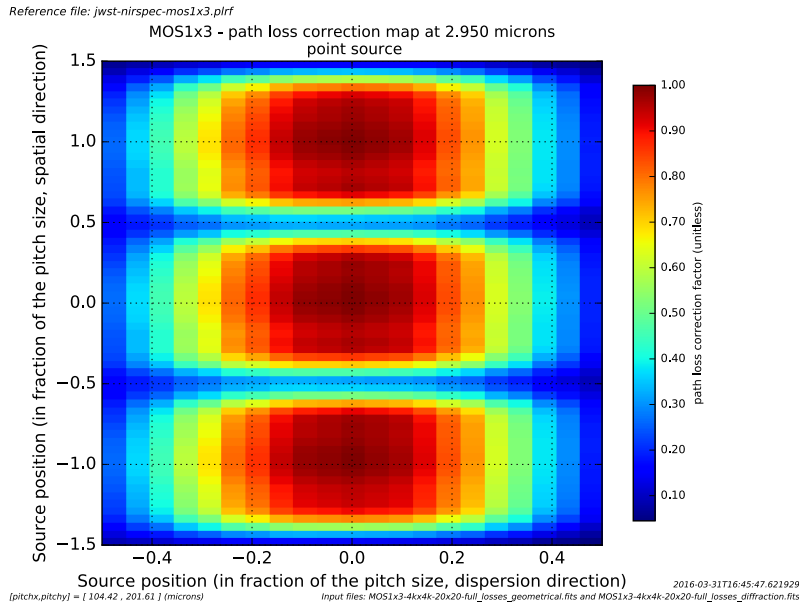
***Caveat / Limitation / Things to be improved [this delivery]:***

- The computation should be repeated for several possible realisations of the OTE wave front error maps. This should be used to estimate some of the error components attached to the computation.
- The computation should be repeated for grids of samplings and sizes for the Fourier transform matrices to estimate the errors associated to the computation scheme itself.
- The validity of the assumption that the path-loss component for uniform sources is zero should be discussed (how does it fit within the non-coherent Fourier propagation scheme). Note that this discussion is only relevant for the model-only approach as when real measurements will be used, the relative path-loss component for uniform sources will be embedded in the flat-field correction (which is based on uniform illumination exposures).
- Improve the estimation of the associated errors.

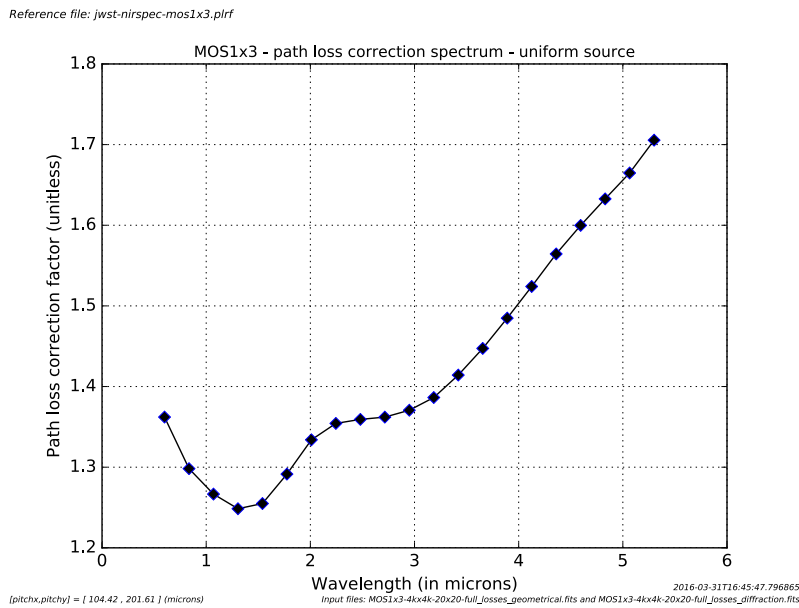
***What can be trusted?***

- The “conceptual data format” of these reference files (3D cubes + 1D spectra, type of units, type of correction).
- The order of magnitude of the corrections.

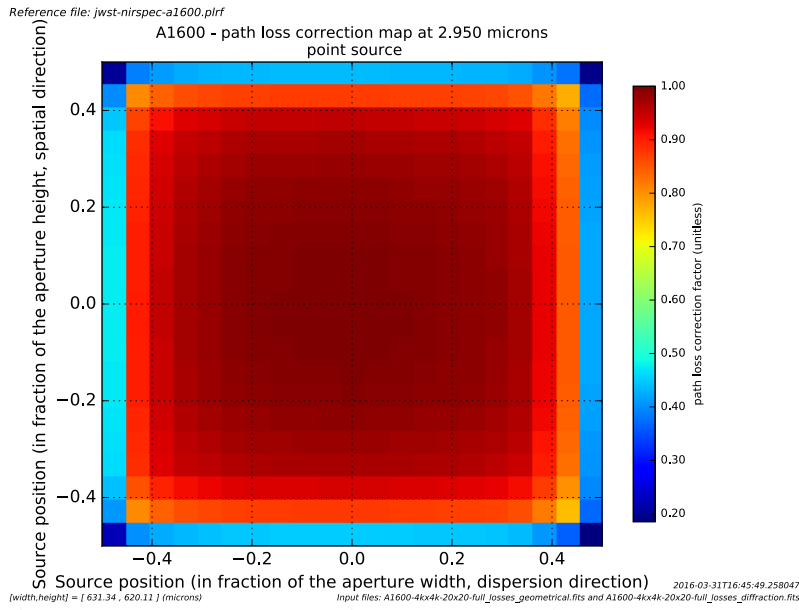
A few examples of the path loss correction data are shown in the figures and plots below.



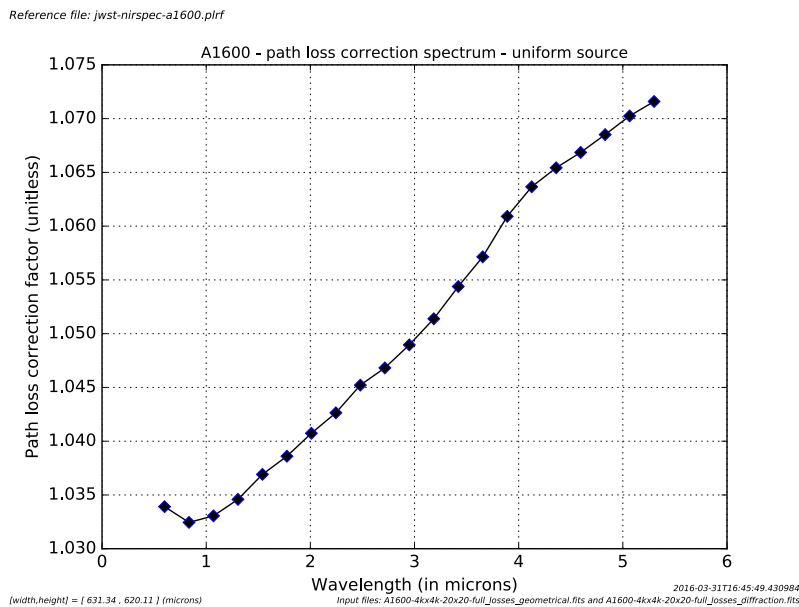
**Figure 5-1: Path loss correction map for a point source at 2.95 microns for the MOS1x3 mini-slit case.**



**Figure 5-2: Path loss correction spectrum for a uniform source and the MOS1x3 mini-slit.**



**Figure 5-3: Path loss correction map for a point source at 2.95 microns for the A1600 aperture case.**



**Figure 5-4: Path loss correction spectrum for a uniform source and the A1600 aperture.**

## 5.2 In-orbit

Section not available for this delivery [need to point toward specific commissioning / calibration activities].

## 6 CORRECTION METHOD

### 6.1 Computing the correction

**Point source** - The correction will be computed when preparing the 2D irregular data product. This data product will contain the wavelength  $\lambda_{pixel}$  (assumed to be in meter) for each of its pixel. On input, we also need the position of the point source within the aperture ( $\delta x_{source}, \delta y_{source}$ ) along the spatial and spectral direction (expressed in fraction of the aperture size [for slits and slices] or pitch [for micro-shutters]; zero corresponding to a centred source).

For each pixel the path loss correction will be computed as:

$$\delta \varepsilon_{pixel} [\text{unitless}] = \Delta_{interpolated}(\lambda_{pixel}, \delta x_{source}, \delta y_{source})$$

In this equation,  $\Delta_{interpolated}$  is the linear interpolation of the point-source reference file data at  $(\lambda_{pixel}, \delta x_{source}, \delta y_{source})$ . We recommend to interpolate first spatially and then in wavelength. No extrapolation should be performed (correction value set to zero and a quality flag tracking the absence of correction should be set).

The results can be stored as a new extension in the 2D irregular data product.

**Uniform source** - The correction will be computed when preparing the 2D irregular data product. This data product will contain the wavelength  $\lambda_{pixel}$  (assumed to be in meter) for each of its pixel.

For each pixel the path loss correction will be computed as:

$$\delta \varepsilon_{pixel} [\text{unitless}] = \Delta_{interpolated}(\lambda_{pixel})$$

In this equation,  $\Delta_{interpolated}$  is the linear interpolation of the uniform-source reference file data at  $\lambda_{pixel}$ . No extrapolation should be performed (correction value set to zero and a quality flag tracking the absence of correction should be set).

The results can be stored as a new extension in the 2D irregular data product.

**Error propagation (variance only):** as a starting point, a linear interpolation of the variance image can be used. A more accurate version for the especially for the point-source case would be the one described in equation 16 of Kyriakidis & Goodchild (RDo2).

### 6.2 Applying the correction

The correction computed following the guideline described in the previous section is to divide the pixel value by the path loss correction value derived from the reference file.