

# NIFITS 0.4 cheatsheet

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- `nifits` library version 0.0.9

## List of Tables

1	Summary of the <b>NIFITS extensions</b> . . . . .	2
2	<b>NI_MOD</b> : The table of time-dependent collectorwise information. .	2
3	<b>NI_CATM</b> : The complex amplitude transfer matrix. <i>n<sub>apertures</sub></i> is the number of collecting apertures of the array, and <i>n<sub>outputs</sub></i> is the number of outputs of the beam-combiner. . . . .	3
4	<b>NI_KMAT</b> : the post-processing matrix, or kernel matrix (optional). .	3
5	<b>NI_IOUT</b> : the output flux or counts. . . . .	3
6	<b>NI_KIOUT</b> : the post-processed outputs (optional). . . . .	3
7	<b>NI_KCOV</b> : the covariance of post-processed outputs (optional). . .	4
8	<b>NI_FOV</b> : the spatial filtering phasor function. . . . .	5
9	<b>NI_DSAMP</b> : the spectral downsampling matrix (optional). . . . .	6
10	<b>NI_OSWAVELENGTH</b> : the table of oversampled wavelength. . . . .	6
11	<b>NI_IOTAGS</b> : The table of . . . . .	7

## 1 The array information

The OIFITS format provides, in addition to the **OI\_ARRAY** data, the baseline coordinates for each row of the recorded visibility information, which inform the user on the projected array. In NIFITS, this cannot be done by baseline, but the format should still alleviate the burden of computing the effective array layout. The coordinates  $(X, Y)$  of each subaperture of the array, projected into the plane orthogonal to the line of sight, and aligned in rotation to the sky coordinates  $(\alpha, \delta)$  are included in **NI\_MOD** for each frame. They should be given in units of meters (m).

The **OI\_WAVELENGTH** is also kept from the OIFITS standard so as to facilitate insertion into existing databases.

Table 1: Summary of the **NIFITS extensions**

Extension	Required	Content
OI_ARRAY	yes	Interferometer description for compatibility with OIFITS.
OI_WAVELENGTH	yes	Contains the information about wavelength bins.
NI_OSWAVELENGTH	no	Contains the information about oversampled wavelength bins.
NI_DSAMP	no	Contains a matrix allowing a downsampling to the wavelengths of simulation (for NI_OSWAVELENGTH to OI_WAVELENGTH). Identity assumed if absent.
NI_MOD	yes	Contains the time-varying information of the model, in particular the an internal modulation phasor vector, and the projected location of collecting apertures.
NI_CATM	referenced	The complex amplitude transfer matrix containing all static behavior of the system.
NI_KMAT	no	Kernel combination matrix for the linear combination of outputs. Identity is assumed if absent.
NI_IOUT	yes	Contains the collected output flux.
NI_KIOUT	no	Contains post-processed output fluxes.
NI_FOV	referenced	Contains the complex spatial filtering function.
NI_KCOV	no	Contains covariance matrices corresponding to NI_KIOUT.
NI_IOTAGS	no	Contains information on the function of each output and input.

Table 2: NI\_MOD: The table of time-dependent collectorwise information.

Item	format	unit	comment
APP_INDEX	$(n_{in})$ int	NA	Index of sub-aperture (starts at 0)
TARGET_ID	int	d	Index of target in OI_TARGET
TIME	float	s	Time of measurement in seconds relative to the reference given by the DATE-OBS keyword.
MJD	float	day	Modified Julian date
INT_TIME	float	s	Exposure time
MOD_PHAS	$(n_{\lambda u}, n_a)$ complex	NA	Complex phasor of modulation for the collector
APPXY	$(n_{in}, 2)$ float	m	Projected location of sub-apertures in the plane orthogonal to the line of sight and oriented as $(\alpha, \delta)$
ARRCOL	$(n_{in})$ float	m <sup>2</sup>	Collecting area of the sub-aperture
FOV_INDEX	int	NA	If relevant, the entry of the NI_FOV to use for this sub-aperture.

Table 3: **NI\_CATM**: The complex amplitude transfer matrix.  $n_{apertures}$  is the number of collecting apertures of the array, and  $n_{outputs}$  is the number of outputs of the beam-combiner.

Item	format	unit	comment
<b>M</b>	$2 \times n_{\lambda} \times n_{outputs} \times n_{apertures}$ float	NA	The complex amplitude transfer matrix given for all wavelengths. Due to the limitation of the FITS standard, it is stored as real-values with the first dimension containing real and imaginary parts.

Table 4: **NI\_KMAT**: the post-processing matrix, or kernel matrix (optional).

Item	format	unit	comment
<b>u</b>	$n_{outputs} \times n_k$ float	NA	Matrix representing the linear combinations of outputs to extract the relevant observables to be used in the inference.

Table 5: **NI\_IOUT**: the output flux or counts.

Keyword	format	comment
<b>IUNIT</b>	string	The unit $a$ used for output flux. The format must be ingestible by <code>astropy.units.Unit()</code> . e.g. <code>ph / s</code> .

  

Item	format	unit	comment
<b>u</b>	$n_{\lambda} \times n_{outputs}$ float	$a$	The data recorded during the observation either in unit $a$ of photon flux or count flux, or other relevant unit specified in the header.

Table 6: **NI\_KIOUT**: the post-processed outputs (optional).

Keyword	format	comment
<b>IUNIT</b>	string	The unit $a$ used for output flux. The format must be ingestible by <code>astropy.units.Unit()</code> . e.g. <code>ph / s</code> .

  

Item	format	unit	comment
<b>u</b>	$n_{\lambda} \times n_k$ float	$a$	Post-processed outputs recorded during the observation.

Table 7: **NI\_KCOV**: the covariance of post-processed outputs (optional).

Keyword	format	unit	comment
IUNIT	string		The unit used for output flux. The format must be ingestable by <code>astropy.units.Unit()</code> . e.g. ph2 / s2 .
Item	format	unit	comment
u	$n_\lambda \times n_k$ float	$a^2$	An estimate of the covariance matrix reflecting the error on KIOUT data.

## 2 Field of view

Spatial filtering is an important element of the many nulling instruments. This effect is a phasor represented by a complex-valued function of wavelength and at least one spatial dimension projected on sky. The spectral dimension is discretized onto the  $n_\lambda$  spectral channels, but the spatial dimension must allow for a continuous representation. The nature of this function is defined by the keyword **FOV\_MODE** of the **NI\_FOV** extension. This first version of NIFITS implements a single function for the keyword **diameter\_gaussian\_radial** which is a simple wavelength-dependent gaussian fiber mode, including a wavelength-dependent offset. The offset is stored in the **offsets** column of the table for each recorded frame. While straightforward to implement for default values, its offset allows for the inclusion of transverse dispersion effects incurred by ground-based observatories such as the coming Asgard/NOTT and make it a powerful tool.

The injection optics of spatial filters can lead to phase and amplitude effects over the field of view that can bias the measurements ( seen e.g. for GRAVITY). For this reason, the standard should allow the provision for powerful tools to model its effect on the signal.

Future upgrades to this format may include ways to facilitate chromatic shift and rotation of these functions, so as to implement atmospheric dispersion effects without repeating of the **NI\_FOV** matrix.

Table 8: NI\_FOV: the spatial filtering phasor function.

Keyword	format	comment
FOV_MODE	string	Corresponds to a type of function to represent the injection e.g. <code>diameter_gaussian_radial</code> .
FOV_TELDIAM	float	The collecting diameter.
FOV_TELDIAM_UNIT	string	A string giving the unit. Must be readable by <code>astropy.units</code> .

  

Item	format	unit	comment
INDEX	int	NA	The index of the row.
offsets	$(2 \times) n_x$ float	mas	Offset of the center of the mode with respect to the center of the field of view
q	$(2 \times) n_{\lambda} \times n_x$ complex	NA	The phasor values at the sampled points.

### 3 Basic guidelines

The standard is built to have a single interpretation for the user. However, for the creator of the file, some redundancy in the various extensions open choices to the creator in the way their data is stored. It is of the responsibility of the creator to ensure the consistency of the file and avoid duplication of effects. For example, a known optical path residual could be stored in the NI\_MOD array, or factored into the NI\_CATM array. For these cases, the guidelines to observe are :

1. The amplitude effects must be given only once either :
  - Through the modulus of the NI\_MOD array for time-varying effects.
  - Through the moduli of the NI\_CATM array for fixed effects.
  - Through the collecting aperture of the collectors in OLARRAY,
  - Through the field of view function (not recommended).
2. The phase effects should be given only once either :
  - Through the argument of the NI\_MOD array for time varying effects.
  - Through the arguments of the NI\_CATM array for fixed effects.

To put it simply:

- Effects considered static over a number of observations and possibly several nights should be factored into NI\_CATM, so it can be shared by different files. This applies in particular to effects that arise inside the beam-combiner and can be measured with a calibration source.
- Effects that are variable should be factored into NI\_MOD. This includes intentional and unintentional effects e.g.:

Table 9: **NI\_DSAMP**: the spectral downsampling matrix (optional).

Item	format	unit	comment
<b>u</b>	$n_\lambda \times n_{\lambda u}$	float	NA
			The spectral down-sampling matrix.

Table 10: **NI\_OSWAVELENGTH**: the table of oversampled wavelength.

Item	format	unit	comment
<b>EFF_WAVE</b>	$n_\lambda$	float	m
			The central wavelength of each spectral bin.
<b>EFF_BAND</b>	$n_\lambda$	float	m
			The bandwidth of each spectral bin.

- The  $\pi$  phase shift to obtain a null,
- Active modulation of the phase or amplitude,
- Known or expected residual from atmospheric dispersion,
- Measured phase error from metrology,
- Known effects of the local weather conditions and status of the collectors,

## 4 Spectral channel oversampling

For low spectral resolution and broadband instruments it may be important to model the expected behavior of the system at spectral resolution higher than that offered by the instrument itself. NIFITS offers this as optional capability. In this case, the number of spectral channels used throughout the file corresponds to an oversampled number, while the **OI\_WAVELENGTH** definition remains that of the measurement matching the size of the output vector  $\mathbf{g}_o$ , for consistency of metadata referencing, but an additional table **NI\_OSWAVELENGTH** of similar format contains the information of the oversampled bins.

An additional matrix is then provided to inform of the linear combination that constitute the reduction, typically with rows containing series of consecutive ones indicating the values that are coadded, but it may contain more complicated convolution kernels of your spectrograph. This matrix can be stored in **NI\_DSAMP** containing a matrix  $\mathbf{N}$  which multiplies our model operation on the left for each output  $o$ :

$$\mathbf{g}_o = \mathbf{N} \cdot \left[ \mathbf{g}_\lambda \right]. \quad (1)$$

## 5 Input and output function

To facilitate the usage by agnostic user software, it is recommended the users provide indication on the role of the outputs. This is done through the table in the **NI\_IOTAGS** extension. The table has columns representing the main types

Table 11: NI\_IOTAGS: The table of

Column	format	comment
BRIGHT	$n_{out}$ bool	Function applicable to outputs.
DARK	$n_{out}$ bool	Function applicable to outputs.
PHOT	$n_{out}$ bool	Function applicable to outputs.
INPOLA	$n_{in}$ str	Polarization descriptor for each input.
OUTPOLA	$n_{out}$ str	Polarization descriptor for each output.

of outputs which are BRIGHT, DARK and PHOT (i.e. photometric). The cells contain a boolean array aligned with the outputs of combiner matrix, with value true if the descriptor applies to that output. For photometric output, the user will also need to know which input this relates to, but this should be easy to identify looking for the maximum modulus in the CATM matrix cells of the corresponding row.

This table also carries information on the polarization role of the inputs and outputs through the columns INPOLA and OUTPOLA respectively. Here, the information is contained in an array of strings, aligned with the inputs or outputs dimensions. The description of the table is given in Table 11.

In the future, new columns may be added to carry additional information to label or flag the outputs. In most cases, the configuration will remain constant throughout the observations, and this table will therefore have a single row. Otherwise, if this changes from one frame to another, this table will have multiple rows.