# *Addendum*
### Date: 06/03/2017

## Interferometric Data - PIONIER

This section of the SDP standard defines the format for reduced data obtained with PIONIER at the VLTI interferometer. PIONIER is the first interferometric instrument with data to be ingested via the Phase 3 process. The format of the main header of the data files follows the OIFITS2 standard [RD2], but includes additional main header keywords suitable for database queries, while the binary extensions format follows the OIFITS1 standard [RD1]. OIFITS1 is used to exchange visibility data by most interferometers past and present. The format is based on FITS binary extension tables. Version 2.0 of the format was developed by a working group under the auspices of the (former) IAU Commission 54 and includes, while being backwards compatible with OIFITS1, additional support for new data products to be delivered by the VLTI instruments GRAVITY and MATISSE, as well as other interferometric instruments under consideration in the community. In the following, the term OIFITS shall refer to both versions of the standard.

The data format being described in this document applies to PIONIER data. Updates to this document may be required to deal with data from other interferometric instruments at a later stage.

### References

[RD1] Pauls et al. (2005), PASP 117, 1255

[RD2] Duvert et al. (2017), A&A 597, 8

### General requirements

Interferometric (calibrated) data products include (squared) visibility amplitudes and closure phases, together with accompanying information on stations, targets, and wavelengths, that are stored in binary extension tables (in any order), following the main header. The standard applies to single OB, single target and single instrument OIFITS files only.

In order to be compliant with OIFITS, the following extensions OI_ARRAY, OI_TARGET, OI_WAVELENGTH, OI_VIS2, and OI_T3 and their associated mandatory keywords, see Tables 3, 4, 5, 6, 7, 8, must be provided. Neither keywords nor columns appear in a specific sequence in a table extension.

## Data product category and associated ancillary data

The visibility data are the primary products. For each of the main science products, two associated files have to be provided, as described in Table 1 below. Other types of ancillary data may be optionally associated as separate files.

**Table 1: Pre-defined values for the header keywords PRODCATG and ASSOC*i* defining the category of respectively the main science product and the required associated files.**

| Data Type<br>PRODCATG | Description |
|---|---|
| SCIENCE.VISIBILITY | Data derived from complex visibilities including amplitudes and phases and their derivatives such as squared amplitudes and closure phases. Data must be in OIFITS format, and the primary HDU must not contain any data.<br>FITS header keywords according to Table 3-8 must be present. |
| ASSOC*i* | |
| ANCILLARY.PREVIEW | Transfer function (TF), i.e. the squared visibility amplitude measured on calibrators, corrected for their angular diameter. Plots of TF for each spectra in PDF format. Each data set should include both the plot of the OI_VIS2 and OI_T3 quality. |

## FITS Keyword Definitions

**Table 2: Definition and guidelines for the header keywords specific to interferometry**

| Type | Keyword | Description |
|---|---|---|
| (S) | CONTENT | It has to be set to 'OIFITS1'. |
| (S) | INSMODE | Possible values: 'FREE_H', 'GRISM_H', 'FREE_K', 'GRISM_K'. |
| (S) | OBSTECH | It has to be set to 'INTERFEROMETRY'. |
| (F) | BASE_MIN | Minimum projected baseline length [m] in the array of the final pipeline product. If some baselines have been fully rejected (less entries in the final file), they must not be considered to compute the value. |
| (F) | BASE_MAX | Maximum projected baseline length [m] in the array of the final pipeline product. If some baselines have been fully rejected (less entries in the final file), they must not be considered to compute the value. |
| (F) | WAVELMIN | Minimum wavelength [nm]. It corresponds to the minimum of all values in the EFF_WAVE column of the OI_WAVELENGTH table [m] converted into nm. |
| (F) | WAVELMAX | Maximum wavelength [nm]. It corresponds to the maximum of all values in the EFF_WAVE column of the OI_WAVELENGTH table [m] converted into nm. |

| (I) | NUM_CHAN | Total number of spectral channels. The value of TDIM5, TDIM6, TDIM7, TDIM8, TDIM14 must be equal to the number of spectral channels NUM_CHAN. |
|-----|----------|-------------|
| (F) | EXPTIME | Average integration time [s] of a single measurement. The value should be computed as the average of the INT_TIME values in the OI_VIS2 table. |
| (F) | TEXPTIME | Total integration time [s] of all measurements. The value should be set to the maximum of the INT_TIME values in the OI_VIS2 table. |
| (F) | SPEC_RES | The SPEC_RES FITS keyword must represent the spectral resolving power (defined as Lambda / DLambda), and not the spectral resolution. SPEC_RES is therefore a dimensionless (floating point) number. |
| (F) | VIS2ERR | Representative squared visibility error [%]. |
| (F) | T3PHIERR | Representative closure phase error [deg]. |
| (F) | SPEC_ERR | Statistical error in spectral coordinate [nm]. The error is hardcoded to 0.5% of the wavelength as it corresponds to the dispersion of the 6 baselines. |
| (F) | SPEC_SYE | Systematic error in spectral coordinate [nm]. 100 nm for FREE, << 94 nm for GRISM. |

**Table 3: Comprehensive list of primary header keywords for the single object OIFITS interferometric data file.**

```
SIMPLE  =                    T / file does conform to FITS standard
BITPIX  =                   16 / number of bits per data pixel
NAXIS   =                    0 / number of data axes
EXTEND  =                    T / FITS Extension may be present
ORIGIN  = 'ESO     '            / European Southern Observatory
DATE    = '2015-11-27T06:35:39' / file creation date (YYYY-MM-DDThh:mm:ss UT)
DATE-OBS= '2015-11-27T06:35:39.0288' / Observing date
CONTENT = 'OIFITS1 '            / Format of the file
REFERENC= '2011A&A...535A..67L' / Bibliographic reference
TELESCOP= 'ESO-VLTI-A1234'     / ESO telescope (keyword ARRNAME)
INSTRUME= 'PIONIER '            / Instrument name
INSMODE = 'GRISM_H '            / Instrument mode (keyword INSNAME)
SPECSYS = 'TOPOCENT'            / Reference frame for spectral coordinates
OBJECT  = 'l_Car   '            / Original target (TARGET)
RA      =           146.310401 / [deg] target position J2000 (keyword RAEP0)
DEC     =            -62.50787 / [deg] target position J2000 (keyword DECEP0)
EQUINOX =                 2000 / Standard FK5
RADECSYS= 'FK5     '            / Coordinate system
```

```
EXPTIME =      128.000001907349 / [s] Average exposure of a single  measurement
TEXPTIME=      128.000001907349 / [s] Maximum exposure of a single measurement
MJD-OBS =      57353.2730716146 / Start of observations (Modified Julian Date)
MJD-END =      57353.2745530961 / End of observations (Modified Julian Date)
TIMESYS = 'UTC     '            / Time system used
PROG_ID = '096.D-0441(A)'       / ESO programme identification
OBID1   =             200368734 / Observation block ID
PROCSOFT= 'pndrs_v3.52'         / Data reduction software and version
PRODCATG= 'SCIENCE.VISIBILITY' / Data product category
OBSTECH = 'INTERFEROMETRY'      / Observing technique (keyword DPR TECH)
BASE_MIN=      57.9660524541151 / [m] Minimum baseline length
BASE_MAX=      129.309443345079 / [m] Maximum baseline length
WAVELMIN=      1536.03696162463 / [nm] Minimum wavelength
WAVELMAX=       1771.0212887323 / [nm] Maximum wavelength
NUM_CHAN=                     6 / Number of spectral channels
SPEC_ERR=      8.28757350745946 / [nm] Statistical error in spectral coordinate
SPEC_SYE=      16.5751470149189 / [nm] Systematic error in spectral coordinate
SPEC_RES=      34.5315559797759 / Spectral resolving power
VIS2ERR = 0.000404414945611772 / Square Visibility error (median)
T3PHIERR=       1.6275834947949 / [deg] Closure phase error (median)
PROV1   = 'PIONI.2015-11-27T06:32:55.531.fits' / Originating science ARCFILE
PROV2   = 'PIONI.2015-11-27T06:33:36.443.fits' / Originating science ARCFILE
PROV3   = 'PIONI.2015-11-27T06:34:17.484.fits' / Originating science ARCFILE
PROV4   = 'PIONI.2015-11-27T06:34:58.469.fits' / Originating science ARCFILE
PROV5   = 'PIONI.2015-11-27T06:35:39.029.fits' / Originating science ARCFILE
NCOMBINE=                     5 / Number of combined raw science
ASSON1  = '2015-11-26_TF_vis2_setup02_bin03.pdf'
ASSOC1  = 'ANCILLARY.PREVIEW'
ASSOM1  = '166be98ea9403c256948063e120d2b9b' / MD5 checksum
ASSON2  = '2015-11-26_TF_t3phi_setup02_bin03.pdf'
ASSOC2  = 'ANCILLARY.PREVIEW'
ASSOM2  = 'e81f42d709910210ab1b9ad36e5b0723' / MD5 checksum
CHECKSUM= 'LNAaMN4RLN9XLN9X'    / HDU checksum updated 2016-11-17T09:31:54
DATASUM = '           0'        / data unit checksum updated
2015-11-27T06:36:16
END
```

**Table 4: Comprehensive list of extension header keywords of the OI_TARGET table.**

```
XTENSION= 'BINTABLE'            / binary table extension
BITPIX  =                     8 / 8-bit bytes
```

```
NAXIS   =                     2 / 2-dimensional binary table
NAXIS1  =                   106 / width of table in bytes
NAXIS2  =                     1 / number of rows in table
PCOUNT  =                     0 / size of special data area
GCOUNT  =                     1 / one data group
TFIELDS =                    17 / number of fields in each row
TTYPE1  = 'TARGET_ID'           / label for field   1
TFORM1  = '1I      '            / data format of field 1
TTYPE2  = 'TARGET  '            / label for field   2
TFORM2  = '5A      '            / data format of field 2
TTYPE3  = 'RAEP0   '            / label for field   3
TFORM3  = '1D      '            / data format of field 3
TUNIT3  = 'deg     '            / physical unit of field
TTYPE4  = 'DECEP0  '            / label for field   4
TFORM4  = '1D      '            / data format of field 4
TUNIT4  = 'deg     '            / physical unit of field
TTYPE5  = 'EQUINOX '            / label for field   5
TFORM5  = '1E      '            / data format of field 5
TUNIT5  = 'year    '            / physical unit of field
TTYPE6  = 'RA_ERR  '            / label for field   6
TFORM6  = '1D      '            / data format of field 6
TUNIT6  = 'deg     '            / physical unit of field
TTYPE7  = 'DEC_ERR '            / label for field   7
TFORM7  = '1D      '            / data format of field 7
TUNIT7  = 'deg     '            / physical unit of field
TTYPE8  = 'SYSVEL  '            / label for field   8
TFORM8  = '1D      '            / data format of field 8
TUNIT8  = 'm/s     '            / physical unit of field
TTYPE9  = 'VELTYP  '            / label for field   9
TFORM9  = '7A      '            / data format of field 9
TTYPE10 = 'VELDEF  '            / label for field  10
TFORM10 = '7A      '            / data format of field 10
TTYPE11 = 'PMRA    '            / label for field  11
TFORM11 = '1D      '            / data format of field 11
TUNIT11 = 'deg/year'            / physical unit of field
TTYPE12 = 'PMDEC   '            / label for field  12
TFORM12 = '1D      '            / data format of field 12
TUNIT12 = 'deg/year'            / physical unit of field
TTYPE13 = 'PMRA_ERR'            / label for field  13
TFORM13 = '1D      '            / data format of field 13
TUNIT13 = 'deg/year'            / physical unit of field
```

```
TTYPE14 = 'PMDEC_ERR'           / label for field  14
TFORM14 = '1D       '           / data format of field 14
TUNIT14 = 'deg/year'            / physical unit of field
TTYPE15 = 'PARALLAX'            / label for field  15
TFORM15 = '1E       '           / data format of field 15
TUNIT15 = 'deg      '           / physical unit of field
TTYPE16 = 'PARA_ERR'            / label for field  16
TFORM16 = '1E       '           / data format of field 16
TUNIT16 = 'deg      '           / physical unit of field
TTYPE17 = 'SPECTYP '            / label for field  17
TFORM17 = '1A       '           / data format of field 17
EXTNAME = 'OI_TARGET'           / name of this binary table extension
OI_REVN =                     1 / Revision number of the table definition
CHECKSUM= '6clY8ZkY6bkY6ZkY'    / HDU checksum updated 2016-11-17T09:31:54
DATASUM = '2705106827'          / data unit checksum updated
2016-11-17T09:31:54
END
```

**Table 5: Comprehensive list of extension header keywords of the OI_WAVELENGTH table.**

```
XTENSION= 'BINTABLE'            / binary table extension
BITPIX  =                     8 / 8-bit bytes
NAXIS   =                     2 / 2-dimensional binary table
NAXIS1  =                     8 / width of table in bytes
NAXIS2  =                     6 / number of rows in table
PCOUNT  =                     0 / size of special data area
GCOUNT  =                     1 / one data group
TFIELDS =                     2 / number of fields in each row
TTYPE1  = 'EFF_WAVE'            / label for field   1
TFORM1  = '1E       '           / data format of field 1
TUNIT1  = 'm        '           / physical unit of field
TTYPE2  = 'EFF_BAND'            / label for field   2
TFORM2  = '1E       '           / data format of field 2
TUNIT2  = 'm        '           / physical unit of field
EXTNAME = 'OI_WAVELENGTH'       / name of this binary table extension
OI_REVN =                     1 / Revision number of the table definition
INSNAME = 'PIONIER_Pnat(1.5360370/1.7710213)'
CHECKSUM= 'HWNZITKWHTKWHTKW'    / HDU checksum updated 2016-11-17T09:31:54
DATASUM = '1997259261'          / data unit checksum updated
2016-11-17T09:31:54
END
```

**Table 6: Comprehensive list of extension header keywords of the OI_ARRAY table.**

```
XTENSION= 'BINTABLE'           / binary table extension
BITPIX  =                    8 / 8-bit bytes
NAXIS   =                    2 / 2-dimensional binary table
NAXIS1  =                   35 / width of table in bytes
NAXIS2  =                    4 / number of rows in table
PCOUNT  =                    0 / size of special data area
GCOUNT  =                    1 / one data group
TFIELDS =                    5 / number of fields in each row
TTYPE1  = 'TEL_NAME'           / label for field   1
TFORM1  = '3A      '           / data format of field 1
TTYPE2  = 'STA_NAME'           / label for field   2
TFORM2  = '2A      '           / data format of field 2
TTYPE3  = 'STA_INDEX'          / label for field   3
TFORM3  = '1I      '           / data format of field 3
TTYPE4  = 'DIAMETER'           / label for field   4
TFORM4  = '1E      '           / data format of field 4
TUNIT4  = 'm       '           / physical unit of field
TTYPE5  = 'STAXYZ  '           / label for field   5
TFORM5  = '3D      '           / data format of field 5
TUNIT5  = 'm       '           / physical unit of field
EXTNAME = 'OI_ARRAY'           / name of this binary table extension
TDIM5   = '(3)     '           / size of the multidimensional array
OI_REVN =                    1 / Revision number of the table definition
ARRNAME = 'VLTI    '
FRAME   = 'GEOCENTRIC'
ARRAYX  =                   0.
ARRAYY  =                   0.
ARRAYZ  =                   0.
CHECKSUM= '3BG769973AG73797'   / HDU checksum updated 2016-11-17T09:31:54
DATASUM = '1179074880'         / data unit checksum updated
2016-11-17T09:31:54
END
```

**Table 7: Comprehensive list of extension header keywords of the OI_VIS2 table.**

```
XTENSION= 'BINTABLE'           / binary table extension
BITPIX  =                    8 / 8-bit bytes
NAXIS   =                    2 / 2-dimensional binary table
```

```
NAXIS1   =                   148 / width of table in bytes
NAXIS2   =                     6 / number of rows in table
PCOUNT   =                     0 / size of special data area
GCOUNT   =                     1 / one data group
TFIELDS  =                    10 / number of fields in each row
TTYPE1   = 'TARGET_ID'          / label for field   1
TFORM1   = '1I      '           / data format of field 1
TTYPE2   = 'TIME    '           / label for field   2
TFORM2   = '1D      '           / data format of field 2
TUNIT2   = 'sec     '           / physical unit of field
TTYPE3   = 'MJD     '           / label for field   3
TFORM3   = '1D      '           / data format of field 3
TUNIT3   = 'day     '           / physical unit of field
TTYPE4   = 'INT_TIME'           / label for field   4
TFORM4   = '1D      '           / data format of field 4
TUNIT4   = 'sec     '           / physical unit of field
TTYPE5   = 'VIS2DATA'           / label for field   5
TFORM5   = '6D      '           / data format of field 5
TTYPE6   = 'VIS2ERR '           / label for field   6
TFORM6   = '6D      '           / data format of field 6
TTYPE7   = 'UCOORD  '           / label for field   7
TFORM7   = '1D      '           / data format of field 7
TUNIT7   = 'm       '           / physical unit of field
TTYPE8   = 'VCOORD  '           / label for field   8
TFORM8   = '1D      '           / data format of field 8
TUNIT8   = 'm       '           / physical unit of field
TTYPE9   = 'STA_INDEX'          / label for field   9
TFORM9   = '2I      '           / data format of field 9
TTYPE10  = 'FLAG    '           / label for field  10
TFORM10  = '6L      '           / data format of field 10
EXTNAME  = 'OI_VIS2 '           / name of this binary table extension
TDIM5    = '(6)     '           / size of the multidimensional array
TDIM6    = '(6)     '           / size of the multidimensional array
TDIM9    = '(2)     '           / size of the multidimensional array
TDIM10   = '(6)     '           / size of the multidimensional array
OI_REVN  =                     1 / Revision number of the table definition
INSNAME  = 'PIONIER_Pnat(1.5360370/1.7710213)'
ARRNAME  = 'VLTI    '
DATE-OBS = '2015-11-27'
CHECKSUM = 'hFdpiDcohDcohDco'   / HDU checksum updated 2016-11-17T09:31:54
DATASUM  = '2719623913'         / data unit checksum updated
```

```
2016-11-17T09:31:54
END
```

**Table 8: Comprehensive list of extension header keywords of the OI_T3 table.**

```
XTENSION= 'BINTABLE'           / binary table extension
BITPIX  =                    8 / 8-bit bytes
NAXIS   =                    2 / 2-dimensional binary table
NAXIS1  =                  262 / width of table in bytes
NAXIS2  =                    4 / number of rows in table
PCOUNT  =                    0 / size of special data area
GCOUNT  =                    1 / one data group
TFIELDS =                   14 / number of fields in each row
TTYPE1  = 'TARGET_ID'          / label for field   1
TFORM1  = '1I       '          / data format of field 1
TTYPE2  = 'TIME    '           / label for field   2
TFORM2  = '1D       '          / data format of field 2
TUNIT2  = 'sec     '           / physical unit of field
TTYPE3  = 'MJD     '           / label for field   3
TFORM3  = '1D       '          / data format of field 3
TUNIT3  = 'day     '           / physical unit of field
TTYPE4  = 'INT_TIME'           / label for field   4
TFORM4  = '1D       '          / data format of field 4
TUNIT4  = 'sec     '           / physical unit of field
TTYPE5  = 'T3AMP   '           / label for field   5
TFORM5  = '6D       '          / data format of field 5
TTYPE6  = 'T3AMPERR'           / label for field   6
TFORM6  = '6D       '          / data format of field 6
TTYPE7  = 'T3PHI   '           / label for field   7
TFORM7  = '6D       '          / data format of field 7
TUNIT7  = 'deg     '           / physical unit of field
TTYPE8  = 'T3PHIERR'           / label for field   8
TFORM8  = '6D       '          / data format of field 8
TUNIT8  = 'deg     '           / physical unit of field
TTYPE9  = 'U1COORD '           / label for field   9
TFORM9  = '1D       '          / data format of field 9
TUNIT9  = 'm       '           / physical unit of field
TTYPE10 = 'V1COORD '           / label for field  10
TFORM10 = '1D       '          / data format of field 10
TUNIT10 = 'm       '           / physical unit of field
TTYPE11 = 'U2COORD '           / label for field  11
```

9

```
TFORM11 = '1D      '            / data format of field 11
TUNIT11 = 'm       '            / physical unit of field
TTYPE12 = 'V2COORD '            / label for field  12
TFORM12 = '1D      '            / data format of field 12
TUNIT12 = 'm       '            / physical unit of field
TTYPE13 = 'STA_INDEX'           / label for field  13
TFORM13 = '3I      '            / data format of field 13
TTYPE14 = 'FLAG    '            / label for field  14
TFORM14 = '6L      '            / data format of field 14
EXTNAME = 'OI_T3   '            / name of this binary table extension
TDIM5   = '(6)     '            / size of the multidimensional array
TDIM6   = '(6)     '            / size of the multidimensional array
TDIM7   = '(6)     '            / size of the multidimensional array
TDIM8   = '(6)     '            / size of the multidimensional array
TDIM13  = '(3)     '            / size of the multidimensional array
TDIM14  = '(6)     '            / size of the multidimensional array
OI_REVN =                     1 / Revision number of the table definition
INSNAME = 'PIONIER_Pnat(1.5360370/1.7710213)'
ARRNAME = 'VLTI    '
DATE-OBS= '2015-11-27'
CHECKSUM= '21MM30JL20JL20JL'   / HDU checksum updated 2016-11-17T09:31:54
DATASUM = '1007498893'          / data unit checksum updated
2016-11-17T09:31:54
END
```