Euro3D Format Description

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1 Introduction to the Euro3D format

The goal of the Euro3D research training network is to convert integral field spectroscopy from a technique reserved to experts into a powerful common user tool. To achieve this goal, the objectives are twofold. On the one hand, we need to develop common, easy-to-use tools that will allow to exploit the data from 3D instruments. On the other hand, these data need to be used to conduct forefront scientific research, in order to attract the users.
In order to introduce new, young researchers into using this quickly growing, yet relatively new technique, *a common format for the data of all 3D instruments is clearly the most important milestone.*

The Euro3D working group under OPTICON debated about the nature of this format and decided to introduce a format based on 2D images and associated tables. The arguments for this choice are summarized in the minutes of the Euro3D meeting held in Lyon on June 25-26, 2001. Briefly, the choice was made between a pure 3D cube, a 2D image+table and a 2D image+cube. The conditions that no information shall be lost, i.e. no resampling is allowed, excluded the pure 3D cube, given the non-square pixels of several instruments. Between a 2D image+table and 2D image+cube, the 2D image+table was considered the more flexible for irregular patterns, mosaicing etc... especially in view of the much larger IFUs to come.
The Euro3D format is not originally thought as the format used within an instrument, but rather the format in which the data are stored and circulated once the instrumental signature has been removed.

2 Overview of the Euro3D format

The Euro3D format is thus defined as a FITS file including several extensions. The two most important extensions are a 2D image containing 1 (reduced) spectrum per *row*, and a FITS table associating each spectrum of the image with a position on the sky. In addition, extensions on statistics, data quality and science results can be attached.
The proposed format for the FITS file is the following:

Content	Extension
Primary header	[0]
Spectra (Header + 2D float image)	[1]
Statistical error (Header + 2D float image)	[2]
Data Quality (Header + 2D short integer image)	[3]
Position Table	[4]
Science table (1)	[5] Optional
Science table (2)	[6] Optional
...	...

3 The FITS Euro3D file

In the following section, we describe in more detail the Euro3D format.

The Euro3D format shall follow the standard FITS convention.

As such, no subsequent rule defining the Euro3D format shall violate the FITS convention as e.g. described in "A User's Guide for the Flexible Image Transport System (FITS)" version 4.0, April 14, 1997, available at
`http://heasarc.gsfc.nasa.gov/docs/heasarc/fits.html` .

3.1 Primary header

3.1.1 The basic FITS header

The primary header, following the FITS standard *must contain, and in this order* the following keywords:
`SIMPLE`
`BITPIX`
`NAXIS`
`NAXIS`n
...
`END`
The following primary data array will typically be empty.

3.1.2 Announcing the Euro3D extensions

In addition to these keywords, the extensions in the Euro3D format must be 'announced' (following the FITS standard) by adding immediately behind the last NAXISn keyword the keyword:

```
EXTEND = T
```

3.1.3 The Euro3D keyword

In order to identify a Euro3D file, a FITS file written in the Euro3D format should contain (anywhere between EXTEND and END) the following keyword set to logical value True:

```
EURO3D = T
```

3.2 Extensions

Following FITS standard, each extension must include the following keywords (similar to the primary header but replacing SIMPLE by XTENSION):

XTENSION
BITPIX
NAXIS
NAXISn
...
PCOUNT
GCOUNT
...
END

In addition, the following keywords are reserved for extension headers and should be used as described in the sections below:

EXTNAME giving a unique name to the extension
EXTVER = 1 (default), gives the version of the extension
EXTLEVEL = 1 (default), gives the level of the extension

Note that extensions can appear in any order within the FITS file, after the primary header. As such, no order is imposed, we recommend, however, to use the order proposed in Sect. 2, and will discuss the extensions in turn.

3.3 Spectrum extension

This extension is mandatory.

The first extension is a 2-dimensional image and contains the actual physical quantities stored as 1 (one) spectrum per row.
FITS does not allow different starting wavelength and step, thus all spectrum must begin with the same wavelength and have the same sampling. Regions of

no data can be flaged in the data quality extension.
The spectrum extension is identified by `EXTNAME = E3D_SPEC`

```
XTENSION = 'IMAGE'
BITPIX = -32 or -64
NAXIS = 2
NAXIS1 = number of spectra (rows)
NAXIS2 = number of pixels in each spectrum
PCOUNT = 0
GCOUNT = 1
EXTNAME = E3D_SPEC
```

3.4 Statistics extension

This extension is optional.

The statistics extension is a 2-dimensional image, with identical dimensions as the spectrum extension. It stores for each pixel in the spectrum extension its statistical properties, carried over from the reduction process.
The spectrum extension is identified by `EXTNAME = E3D_STAT`.

```
XTENSION = 'IMAGE'
BITPIX = -32 or -64
NAXIS = 2
NAXIS1 = number of spectra (rows)
NAXIS2 = number of pixels in each spectrum
PCOUNT = 0
GCOUNT = 1
EXTNAME = E3D_STAT
```

3.5 Data quality extension

This extension is optional.

The data quality extension is a 2-dimensional image with identical dimensions as the spectrum image. It is used to set a flag for each pixel according to the following convention:

Flag value	Meaning
0	good pixel
1	
2	Calibration file defect
4	
8	
16	
32	Bad pixel
128	Permanent charge trap
256	
512	Unrepaired warm pixel
1024	Repaired warm pixel

The spectrum extension is identified by `EXTNAME = E3D_QUAL`.

```
XTENSION = 'IMAGE'
BITPIX = 16
NAXIS = 2
NAXIS1 = number of spectra (rows)
NAXIS2 = number of pixels in each spectrum
PCOUNT = 0
GCOUNT = 1
EXTNAME = E3D_QUAL
```

3.6 Position table extension

The position table is a binary table which, for each spectrum (i.e. row) in the spectrum extension, contains 3 (and only 3) quantities. Namely:

- the spectrum ID in the form of the corresponding row number in the spectrum extension
- the relative position in ΔX (arcseconds)
- the relative position in ΔY (arcseconds)

```
XTENSION = 'BINTABLE'
BITPIX = 8
NAXIS = 2
NAXIS1 = number of 8 bits bytes in a table row
NAXIS2 = number of rows in the table (equal to the number of rows in the spectrum extension)
TFIELDS = 3?
EXTNAME = E3D_POS
```

`E3D_LENSSHAPE` = number of polygon sides of a spatial resolution element
`E3D_LENSSIZEn`
`E3D_LENSANGn`

The last three parameters describe the shape and size of a spatial resolution element on the sky. `E3D_LENSSHAPE` gives the number of edges of the spatial resolution element (1: circular aperture, 4: rectangular/square aperture, 6: hexagons, etc...), `E3D_LENSSIZEn` (where `n` is equal to the number of sides) defines the size of the resolution elelements in arcseconds on the sky, `E3D_LENSANGn` defines the relative angle between this and the previous side (360/`n` in most cases).

3.7 Science table(s) extension

This extension is optional.

The science table extension is in binary table format and is used to store any scientific quantities derived from each spectrum. For example, these could be for galaxy spectra values such as the line of sight velocity and velocity dispersion, element abundances, etc...

The science table is optional. However, if present, the first 3 entries must be: spectrum number (row number), ΔX, ΔY.

```
XTENSION = 'BINTABLE'
BITPIX = 8
NAXIS = 2
NAXIS1 = number of 8 bits bytes in a table row
NAXIS2 = number of rows in the table (equal to the number of rows in the spectrum extension)
TFIELDS = number of entries (fields) in each row
EXTNAME = E3D_SCI
```

4 FITS keywords

4.1 Standard FITS Keywords

The FITS standard currently defines 53 keywords, listed and explained at
`http://heasarc.gsfc.nasa.gov/docs/fcg/standard_dict.html`

These are:

(blank)	CROTAn	EQUINOX	NAXISn	TBCOLn	TUNITn
AUTHOR	CRPIXn	EXTEND	OBJECT	TDIMn	TZEROn
BITPIX	CRVALn	EXTLEVEL	OBSERVER	TDISPn	XTENSION
BLANK	CTYPEn	EXTNAME	ORIGIN	TELESCOP	
BLOCKED	DATAMAX	EXTVER	PCOUNT	TFIELDS	
BSCALE	DATAMIN	GCOUNT	PSCALn	TFORMn	
BUNIT	DATE	GROUPS	PTYPEn	THEAP	
BZERO	DATE-OBS	HISTORY	PZEROn	TNULLn	
CDELTn	END	INSTRUME	REFERENC	TSCALn	
COMMENT	EPOCH	NAXIS	SIMPLE	TTYPEn	

4.2 Instrument specific FITS Keywords

Instrument specific keywords can be added, following the FITS convention, i.e. they must be ...