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Change record from previous version 7.0

Affected Section(s)	Changes / Reason / Remarks
All	Email address usd-help@eso.org removed. Use instead the online form https://support.eso.org/ to request help from ESO operations support staff.
Keyword dictionary	Section 5.1: OBJECT: for moving objects, added that a well-established name for the source (e.g. ALPHA CEN B) may also be used. Section 5.1: FLUXCAL= UNCALIBRATED not allowed for science imaging data. Section 5.1: TIMESYS: added that UTC and TAI are the only supported values. Section 5.10: no self reference when using the complementary keywords. Section 5.10: modified example value for HDUVERS keyword. Section 5.16: M_EPOCH: added that it applies to multi-epoch data formatted according to section 12.5.1 only.
Matrix Table 8	M_EPOCH: added that it applies to multi-epoch data formatted according to section 12.5.1 only.
Interface changes	---- ancillary products ---- Section 4.3.5: The white light image inherits the HDUCLASS scheme of the science data cube in case of multiple HDUs. ---- catalogues ---- Section 12.2.8: added section about propagation of keyword values from science files to a catalogue.
New data format	Section 12.5 about multi-epoch catalogues: an additional data format based on multiple element arrays has been introduced.
Section 12.2.4	Added that the end of a data array should be padded with *NaN* in case it has less data points than the repeat count given in TFORM.
Section 12.3	Rewrote text of the data link section to make it clearer.
Section 12.4	Modified structuring of the main section and subsections.
Section 12.5.1	Added "with the exact same (string or numeric) value".
Section 14	ANCILLARY.IMAGE: extended definition
Typos	Section 12.5: TOFRM*i* →TFORM*i* Section 5.18: keyword dictionary, TUCD*i* keyword: [RD1] → [RD2]

Contents

1. Introduction

1.1 Scope

Phase 3 denotes the process of preparation, validation and ingestion of science data products (SDPs) for storage in the ESO science archive facility, and subsequent data publication to the scientific community. SDPs are data products with instrument and atmospheric signatures removed, calibrated in physical units, with noise properties (like limiting magnitude or signal-to-noise ratio) quantified and documented. SDPs are produced by:

1. principal investigators (PIs) of ESO observing programmes primarily from ESO public surveys, and large programmes,
2. ESO scientists using the ESO pipelines as part of the quality control (QC) process or from specific, dedicated, re-processing projects for homogenous raw data sets,
3. users of non-ESO telescopes such as GTC, NGTS, etc
4. PIs of ESO normal programmes on voluntary basis,
5. members of the community interested in publishing data from archival research.

Phase 3 ensures the successful integration of SDPs into the archive, which in turns allows archive users access to well traceable and characterised science data products, easily discoverable, from a homogeneous and consistent archive.

ESO supports the users in carrying out the Phase 3 process by defining ESO/SDP data standards, by devising procedures and providing the infrastructure for the delivery of SDPs, and by supplying tools for the data preparation.

The procedures and tools that support the data provider in validating the compliancy of data products with the SDP standards are available online on the Phase 3 web[1].

1.2 Purpose

This document specifies the data standard that SDPs must comply with for successful completion of Phase 3. This document is intended to provide information for the users who are to prepare their data for the submission through Phase 3. It also provides the reference which specifies the science data standards for instrument scientists and pipeline developers for either new or existing ESO instruments. When implementing the standard, software engineers are strongly advised to work in close collaboration with experts familiar with the astronomical concepts involved in the definition of the various keywords.

This document defines the structure and data format of reduced data products starting from high-level requirements down to the detailed definitions of FITS keywords per type of data product. The target audience consists of 1) principal investigators and their collaborators who return reduced data products resulting from ESO/non-ESO observations for public release to the astronomical community through the ESO archive, 2) ESO scientists involved in the QC process or in specific re-processing projects, 3) instruments scientists and pipeline developers for the new and existing ESO instruments, 4) archive users who need to understand the structure and format of the SDPs they intend to use for their own science.

1.3 How to read this document

This document starts by defining the general data format requirements (section 3) for Science Data Products to be submitted through Phase 3, and the different product categories supported (section 4). Section 5 contains the definitions of all keywords applicable in the context of SDPs. The details may be skipped on a first reading and the Phase 3 user may directly jump on the section of interest to understand the data format structure, specific calibration and characterisation requirements

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[1] https://www.eso.org/sci/observing/phase3.html

depending on the category of data to be submitted: images (section 6), flux maps (section 7), spectra (section 8), source lists (section 9), IFS cubes (section 10), interferometric products (section 11), or science catalogues (section 12). In order to identify the list of required, recommended and optional FITS keywords for the characterisation of Phase 3 science data products according to the data product category, the user will focus on section 13.

Please use the online form https://support.eso.org/ in case you need any Phase 3 support.

1.4 Abbreviations and acronyms

This document employs several abbreviations and acronyms to refer concisely to an item, after it has been introduced. The following list is aimed to help the reader in recalling the extended meaning of each short expression:

APEX	Atacama Pathfinder EXperiment
ARTEMIS	Architectures de bolomètres pour des Télescopes à grand champ de vue dans le domaine sub-Millimétrique au Sol
ASG	Archive Science Group
DICD	Data Interface Control Document
DOI	Digital Object Identifier
ERIS	Enhanced Resolution Imager and Spectrograph
ESO	European Southern Observatory
FEROS	Fiber-fed Extended Range Optical Spectrograph
FITS	Flexible Image Transport System
Gaia-ESO/GES	A spectroscopic public survey
GTC	Gran Telescopio Canarias - GRANTECAN
HARPS	High Accuracy Radial velocity Planet Searcher
HDU	Header Data Unit
IFS	Integral Field Spectroscopy
IVOA	International Virtual Observatory Alliance
KMOS	K-band Multi Object Spectrograph
LABOCA	Large APEX BOlometer CAmera
MEF	Multi Extension FITS file
MUSE	Multi Unit Spectroscopic Explorer
NGTS	Next Generation Transit Survey
OB	Observation Block
OmegaCAM	Wide-field imager for the Cassegrain focus of the VST on Paranal
PESSTO	Public ESO Spectroscopic Survey of Transient Objects
P3	Phase 3
PI	Principal Investigator
SDP	Science Data Product
SINFONI	Spectrograph for INtegral Field Observations in the Near Infrared
SPHERE	Spectro-Polarimetric High-contrast Exoplanet REsearch
UCD	Unified Content Descriptor
UType	A label for a concept defined within a data model
VIRCAM	VISTA InfraRed CAMera
VISTA	Visible and Infrared Survey Telescope for Astronomy
VO	Virtual Observatory
VLT	Very Large Telescope
VLTI	Very Large Telescope Interferometer
VST	VLT Survey Telescope
XSHOOTER	Multi wavelength medium resolution spectrograph
zCOSMOS	A large redshift survey undertaken in the COSMOS field

2. Related Documents

2.1 Applicable Documents

The following documents, of the exact version shown, form part of this document to the extent specified herein. In the event of conflict between the documents referenced herein and the content of this document, the content of this document shall be considered as superseding.

AD1 Definition of the Flexible Image Transport System (FITS), The FITS Standard, Version 4.0, 2018 August 13, FITS Working Group Commission 5: Documentation and Astronomical Data International Astronomical Union, http://fits.gsfc.nasa.gov/iaufwg/

AD2 ESO Data Interface Control Document (DICD), ESO-044156, Issue: 6, Date: 21 June 2016 https://archive.eso.org/cms/tools-documentation/eso-data-interface-control.html

AD3 OIFITS1 - Pauls et al. (2005), PASP 117, 1255

AD4 OIFITS2 – Duvert et al. (2017), A&A 597, 8

2.2 Reference Documents

The following documents, of the exact version shown herein, are listed as background references only. They are not to be construed as a binding complement to the present document.

RD1 Representations of celestial coordinates in FITS (Paper II), Calabretta, M. R., and Greisen, E. W., Astronomy & Astrophysics, 395, 1077-1122, 2002.

RD2 The UCD1+ controlled vocabulary, version 1.3, IVOA Recommendation 27 May 2018, http://www.ivoa.net/documents/UCD1+/20180527/index.html

RD3 IVOA Spectral data model, version 1.1, IVOA Recommendation 20 November 2011, http://www.ivoa.net/documents/SpectrumDM/20111120/index.html

RD4 An IVOA Standard for Unified Content Descriptors, version 1.10, IVOA Recommendation 19 August 2005 http://www.ivoa.net/documents/cover/UCD-20050812.html

RD5 Representations of spectral coordinates in FITS (Paper III), Greisen, E. W., Calabretta, M. R., Valdes, F. G., and Allen, S. L., Astronomy & Astrophysics, 446, 747-771, 2006.

RD6 FITS format description for pipeline products with data, error and data quality information, Kuemmel, Ballester & Kuntschner, VLT-SPE-ESO-19500-5667, Issue 1.0, 11 July 2012. ftp://ftp.eso.org/pub/dfs/pipelines/doc/VLT-SPE-ESO-19500-5667_DataFormat.pdf

RD7 Oke, J. B., & Gunn, J. E. 1983, ApJ, 266, 713

RD8 IAU Trans. Int. Astron. Union, Proc. of the 15th General Assembly Sydney 1973 and Extraordinary General Assembly Poland 1973, G. Contopoulos and A. Jappel, Eds., vol. 15 B, Reidel Dordrecht, the Netherlands (1974), p. 166

RD9 Note on the description of polarization data, version 1.0, IVOA Note February 3, 2010 http://www.ivoa.net/documents/Notes/Polarization/

3. General Requirements

3.1 FITS data format

All types of *scientific* data products must generally conform to the Definition of the Flexible Image Transport System (FITS), FITS Standard Version 3.0 [AD1].

Furthermore, the data format must comply with the specifications published in the ESO Data Interface Control Document [AD2], if applicable in the context of SDPs.

For *ancillary files*, which are associated to science products without being directly searchable, any file format including the FITS format is accepted.

3.2 Unsupported formats

The tiled-table convention[2] for compressing FITS binary tables is not supported by the Phase 3 infrastructure.

3.3 Compression

Integer imaging data may be submitted in tile-compressed FITS format as implemented in the *fpack* utility[3], which provides lossless data compression.

In contrast, the compression of floating point imaging data using *fpack* is inherently lossy and its benefit must be balanced carefully against potential data degradation. The Phase 3 data provider is responsible for flagging compressed data in the accompanying Phase 3 data release description, data format section. The usage of a lossy compression scheme should be indicated explicitly together with an assessment of the resulting effect on data quality.

3.4 Filenames

3.4.1 Maximum filename size

For any file the total length of its name, including the suffix, is limited to a maximum of 68 characters (FITS limitation).

3.4.2 Uniqueness of filenames

Filenames must be unique within a given Phase 3 batch[4] as the user-defined directory structure on the Phase 3 FTP area cannot be preserved during the archive process. In practical terms it means if multiple subdirectories are used on the Phase 3 FTP server to organise the data of a batch, the data provider needs to make sure that there are no files having the same file name (in different directories of course).

3.4.3 Filename suffixes

The filenames of science data products and associated ('ancillary') FITS files are subject to the permitted set of filename suffixes:

`.fits`	FITS, uncompressed
`.fits.fz`	FITS imaging, compressed (using *fpack*)

3.5 CONTINUE FITS convention

The CONTINUE FITS convention for values exceeding 68 characters is not supported by ESO [AD2]. This implies a total length of the keyword value of max 68 characters.

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[2] https://fits.gsfc.nasa.gov/registry/tiletablecompression.html

[3] http://heasarc.gsfc.nasa.gov/fitsio/fpack/

[4] See the Phase 3 overview and help on the web at:
https://www.eso.org/sci/observing/phase3/overview.html

4. Categories of science products and associated ancillary files

The keyword PRODCATG defines the data product category of science files in terms of one of the predefined values listed in Table 1.

The keyword PRODCATG is also used to define the category of associated ancillary data in the FITS file format. The category of associated ancillary data that are not in the FITS file format is defined in the FITS header of the corresponding science data product via the ASSOC*i* keyword (see section 4.2 below).

4.1 Science products

Science Data Products are data products with instrument and atmospheric signature removed, calibrated in physical units, with noise properties quantified and documented and with error propagation in each processing step to obtain a final error estimate for the science data.

PRODCATG	Data format	Section
SCIENCE.IMAGE	Single image stored in the primary HDU ("associated file format") or in an extension ("MEF format")	Section 6.2.1
SCIENCE.MEFIMAGE	Multiple images stored in multi-extension FITS format (MEF)	Section 6.2.2
SCIENCE.IMAGE.FLUXMAP	Flux map, single image stored in the primary HDU	Section 7
SCIENCE.SPECTRUM	Single target one-dimensional spectrum in binary table format (single row array).	Section 8
SCIENCE.SRCTBL	Source list stored as FITS binary table resulting from the detection of sources on an image (both single image or MEF image). Merged multi-band source lists do not qualify as source lists but should be submitted as catalogue data instead.	Section 9
SCIENCE.CUBE.IFS	3D cube for IFS with two spatial axes and one spectral axis.	Section 10
SCIENCE.VISIBILITY	Visibility and closure phase for optical interferometry	Section 11
SCIENCE.CATALOG	Scientific catalogue in single FITS binary table	Section 12.2.1
SCIENCE.MCATALOG	Metadata definition file of a catalogue submitted in a tile-by-tile fashion, i.e. partitioned in multiple FITS binary tables	Section 12.2.2.1
SCIENCE.CATALOGTILE	Data file for a catalogue submitted in a tile-by-tile fashion, i.e. partitioned in multiple FITS binary tables	Section 12.2.2.2

Table 1: List of science data product categories

4.2 Associated ancillary products

The ESO Archive is directly searchable for science data products using the respective archive services available on the ESO Archive web pages. Ancillary data products are associated to scientific data products to support their exploitation without being directly searchable through the ESO Archive interfaces.

An ancillary data product provided together with a data release should contain additional data that is not included in the science data product itself. The ancillary file should not replicate information present elsewhere. In particular keep in mind that Phase 3 generally mandates that the data documentation is to be provided in the release description PDF file. Referential information and other metadata must be defined in the header of the science file in terms of FITS keywords. ESO/ASG has the overall responsibility to assess whether the provided ancillary data files qualify for ingestion into the ESO science archive facility as independent science data products instead.

Certain science data products require the submission of specific ancillary products as given in the data format definitions, for instance mosaicked images, like the VISTA tile image, require a weight map image to be associated.

Moreover, depending on the kind of scientific data, the data provider can deliver additional ancillary products. Typical examples are preview images, graphics or reports generated in the course of the data reduction process. The file type of ancillary products may be, for instance, JPEG or PNG image, PS or PDF graphics, ASCII text, or in FITS file format.

The category of ancillary data products that are in the FITS file format is defined within their FITS header with the keyword PRODCATG.

Type[5]	Keyword	Description
(S)	PRODCATG	Data product category

The category of ancillary data products that are not in the FITS file format is defined in the FITS header of the corresponding science data product in terms of the following indexed keywords:

Type	Keyword	Description
(S)	ASSOCi	Specifies the product category of the associated non-FITS file given by ASSONi.

The names of the associated ancillary products are recorded in the FITS header of the corresponding science data product in terms of the following indexed keywords:

Type	Keyword	Description
(S)	ASSONi	The list of files (FITS / non-FITS) associated to this data product. i is a sequential number starting from 1. If n files are associated to the product, the indexed keywords ASSONi and ASSOCi should appear n times (i=1,...,n).
(S)	ASSOMi	Specifies the md5sum of the associated non-FITS file given by ASSONi. Applies to non-FITS files only.

Requirements:
Req-1. Each ancillary file must be associated to at least one science file and can be associated to more than one science file.
Req-2. An associated FITS file cannot contain other associations in turn, i.e. nested associations are not supported.

The delivery of any ancillary file is subject to i) the scientific use and ii) the agreement between ESO and the data submitter that these data will be stored and published through the archive services.

4.3 Required and recommended ancillary products

This section describes ancillary products that are either required or recommended, in order to support scientific exploitation of the science data or to support archive services.

4.3.1 Exposure map

In the context of co-adding multiple exposures, the exposure map records the variation of the accumulated exposure time (in seconds) of 2D image mosaic and 3D IFU data cubes per pixel and

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[5] The capital letters I, L, R, and S indicate the keyword's data type integer number, boolean, floating point number, and string type, respectively.

per spaxel, respectively. It encodes the pattern of multiple offset exposures being combined into the final product while taking any possible masking of bad or invalid pixels into account.

The exposure map is a 2D FITS image associated to the main science data as an ancillary file. It shares the dimensions (AXIS1, AXIS2), WCS definitions and number of image extensions (if any) with the 2D image mosaics, or, in case of 3D IFU data cubes, the exposure map inherits the dimensions and WCS definition of the first two axis of the data cube (AXIS1, AXIS2, etc).

The exposure map encodes the total exposure time per pixel/spaxel in units of seconds (BUNIT = 's' / exposure time in seconds) using floating point decimals (BITPIX = -32) or 16 bit scaled decimals (BITPIX = 16, see FITS standard).

The total exposure time per pixel is the sum of the exposure times of the exposures contributing to the given pixel/spaxel possibly including fractional contributions depending on the interpolation scheme.

The exposure map is constraint to values >0 for data pixels/spaxels representing a valid signal, or value=0 for void pixels/spaxels. Note: It is recommended to set the values of void pixel/spaxel in the science data to *NaN*.

BLANK, *NaN* or any other special value are not allowed in the exposure map.

EXPTIME, to be recorded in the header of the main science file, is defined to be the median of the pixels values of the exposure map excluding any value=0 pixel.

Note: the exposure map does not serve as substitute for the WEIGHTMAP.

If the effective exposure time varies within the data cube the pixel count map may be optionally (see Appendix section 14) provided along with the main science file in addition to the exposure map.

PRODCATG	ANCILLARY.EXPMAP
Usually applied to:	SCIENCE.IMAGE, SCIENCE.MEFIMAGE, SCIENCE.CUBE.IFS
Applicability and Recommendation	If the effective exposure time varies within the science image or data cube, it is strongly recommended to provide the exposure map along with the main science file.

4.3.2 Gain map

The gain map (e-/ADU) specifies for each pixel the number of electrons that contributed to one ADU in that pixel of an image. The number of electrons n*e* contributing to a pixel of an image product i(x,y) is therefore defined as:

n*e* (x,y) = gainmap(x,y) * i(x,y)

and the Poisson noise *sp* in that image is:

sp = sqrt(gainmap(x,y) * i(x,y)) in electrons, and
sp = sqrt(i(x,y) / gainmap(x,y)) in data units.

Note that for background subtracted images, *sp* represents only the Poisson noise of sources in the image.

To compute the gain map, factors such as the detector gain G, the exposure time t*exp* for each pixel, and any multiplicative factors used to scale the image (e.g. flat-fielding) have to be taken into account. For example, an image that is scaled in ADU/s and has been divided by a flat field F(x,y), the gain map is:

gainmap(x.y) = G * texp * F(x,y)

The gain map of a co-added image ic(x,y) is the sum of the gain maps of the individual images i$_i$(x,y), i.e.

gainmap$_c$(x,y) = Σ_i gainmap$_i$(x,y))

For mosaics created from partial overlapping images, different numbers of images and therefore gain maps might contribute to any individual pixel, and only the contributing images are included in this sum.

The gain map has the same dimensions as the image array.

PRODCATG	ANCILLARY.GAINMAP
Usually applied to:	SCIENCE.IMAGE, SCIENCE.MEFIMAGE
Applicability and Recommendation	Due to the mosaic nature of some products, computing an average gain value captured in a single GAIN keyword would not reflect the reality thus it is recommended to compute a gain map instead.

4.3.3 Mask image

The mask image describes the data quality of an image array by flagging bad pixels using integer numbers >0. For example: bright stars (=1), readout spikes (=2) etc. Mask value =0 indicates 'good' data. Binary masks defined as powers of 2 are allowed. The detailed definition of mask values >1 shall be documented in the Phase 3 release description.

The mask image is a FITS file with the same dimension and number of extensions (if any) as the FITS file that contains the image data. The mask has integer data type, e.g. BITPIX = 8 or 16.

PRODCATG	ANCILLARY.MASK
Usually applied to:	SCIENCE.IMAGE, SCIENCE.MEFIMAGE, SCIENCE.IMAGE.FLUXMAP
Applicability and Recommendation	Recommended

4.3.4 Weight map

The weight map or confidence map describes the pixel-to-pixel variation of the statistical significance of the image array in terms of a number that is proportional to the inverse variance of the background, i.e. not including the Poisson noise of sources. Ideally, the background noise (in counts/sec) includes the readout noise, the Poisson noise of the sky and other background, and any other contribution to the noise other than from astronomical objects.

If the weight map is provided in the "associated file format" (see sections 6.2.1.1 and 6.2.2), it should be a FITS file with PRODCATG set to 'ANCILLARY.WEIGHTMAP'. Otherwise, if the weight map is provided within the same FITS file as the image data array (see section 6.2.1.2), the weight map should be identified by setting the HDUCLAS2 header keyword to 'CONF' in the corresponding HDU of the SCIENCE.IMAGE file. The weight map should have the same structure, i.e. number of FITS extensions, if any, and dimensions as the science image data array.

PRODCATG	ANCILLARY.WEIGHTMAP
HDUCLAS2	CONF
Usually applied to:	SCIENCE.IMAGE, SCIENCE.MEFIMAGE
Applicability and Recommendation	Mandatory for many observational techniques, for instance the common *jitter* or *dither* techniques, imply that several exposures, with mutual offsets, are co-added to form the final product and the statistical significance of the pixel data may significantly vary across the image array.

4.3.5 White-light image

A white-light image, also known as a broad-band image, is a 2D image obtained by averaging a data cube along the wavelength axis between WAVELMIN and WAVELMAX. Pixels having data quality issues should be excluded from the average.
The white-light FITS image has the same dimension and WCS as the science data cube's spatial axes (NAXIS1 and NAXIS2).
The white-light image inherits the HDUCLASS scheme of the science data cube in case of multiple HDUs.

Each data cube **must** be associated with one unique white light image with PRODCATG set to 'ANCILLARY.IMAGE.WHITELIGHT'. Further images, like line images, *may* be associated in addition (unless otherwise specified, those other images need to be labelled by the default PRODCATG=ANCILLARY.IMAGE).

PRODCATG	ANCILLARY.IMAGE.WHITELIGHT
Usually applied to:	SCIENCE.CUBE.IFS
Applicability and Recommendation	Mandatory to support archive query services.

4.4 Optional ancillary products

A comprehensive list of the optional ancillary files published so far for the SDPs available from the archive science interface is available in the Appendix (see section 14). Please contact us if, as a data provider, you would like to submit ancillary files that are not covered by the table.

5. Keyword dictionary for science data products

This section gives a list of keywords and their definitions, grouped into different subsections. Please refer to the Table 8 in Section 13 for the applicability of these keywords depending on the category (PRODCATG) of data product.

5.1 General keywords

Type[6]	Keyword	Description
(S)	ORIGIN	Observatory or facility where the data were originally obtained (not where data processing was done). Can be adopted from the original data. Normally, set to 'ESO' or 'ESO-PARANAL'.
(S)	TELESCOP TELESCi (i = 1,2,…)	ESO telescope designation. To be adopted from the original data[7]. When combining data having different TELESCOP designations, then the keyword shall be set to TELESCOP = 'MULTI', and the list of different telescope designations shall be stored in keywords TELESCi, where i is a sequential number between 1 and 99, without leading zeros. TELESCi - Distinct list of telescope designations using TELESCOP designations of the original data.

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[6] The capital letters I, L, R, and S indicate the keyword's data type as either integer number, boolean, floating point number, and string type, respectively.
[7] OmegaCAM represents an exception in which TELESCOP cannot be propagated directly because the raw data contains inconsistent values for the TELESCOP keyword.

Type[6]	Keyword	Description
(S)	INSTRUME INSTRi (i = 1,2,…)	Instrument name. To be usually adopted from the original data. It shall not contain information unrelated to the instrument name, e.g. 'EFOSC/3.2' should be 'EFOSC' instead. If any SDP originates from more than one instrument, the value shall be INSTRUME = 'MULTI', and the individual instrument names shall be stored in keywords INSTRi, where i is a sequential number between 1 and 999, without leading zeros. INSTRi - Distinct list of instrument names using INSTRUME names of the original data.
(S)	FILTER FILTERi (i = 1,2,…)	Filter name. To be adopted from the appropriate keyword of the raw data, e.g. HIERARCH ESO INS FILT1 NAME. If this is not the case, please use the online form https://support.eso.org/ to request Phase 3 support. To identify a band-merged data product, i.e. a data product that results from the combination of data acquired in multiple spectral bands, the value of the filter keyword shall be set to FILTER = 'MULTI', and the individual filter names shall be stored in keywords FILTERi where i is a sequential number between 1 and 99, without leading zeros. The sequence of filter names should be ordered according to increasing wavelength, that is, the central wavelength of FILTERi should be less or equal than the central wavelength of FILTER(i+1). FILTERi - Distinct list of spectral bands using FILTER names of the original imaging products.
(S)	OBJECT[8]	Should be set to the target designation as given by the Principal Investigator, for instance OBJECT = 'NGC3603'. If the OBJECT keyword does exist in the extensions of data of type SCIENCE.CUBE.IFS, and space permits, it is recommended to adopt the OBJECT keyword value from the primary header and to append an indicative suffix for the type of extension, e.g. (STAT) or (DATA).
(R)	RA DEC	Equatorial coordinates in decimal degrees (J2000). Image/tile centre[9], barycentre of image arrays in MEF format; spectroscopic target position[10]; centre of the survey field in case of catalogues.
(R) %.0f	EQUINOX	Standard FK5 (years). EQUINOX is mandatory and has to be set to 2000 if the reference frame is FK5. EQUINOX = 2000.0 is tolerated for the ICRS coordinate reference frame.
(S)	RADESYS	Coordinate reference frame. ICRS or FK5.

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[8] For spectroscopic public surveys and large programmes, the value of the OBJECT keyword shall be set to the survey source identifier, which shall be unique within the survey/programme. In case of a moving object (e.g. high proper motion), the aim is to have an OBJECT keyword value that remains the same across different epochs. To achieve this, we recommend setting the name of the object either using a well-established name of the source (e.g. ALPHA CEN B) or using the coordinates that correspond to the epoch of the first data product of that object submitted in the corresponding Phase 3 collection. That single name is then propagated to any subsequent data products for that object delivered to the ESO Archive via Phase 3.

[9] Assuming image pixel coordinates starting from (1,1), then the centre of a simple (i.e. single) image of dimension NAXIS1*NAXIS2 is located at (0.5*NAXIS1+0.5, 0.5*NAXIS2+0.5).
[10] Estimates like the center of the slit or the telescope pointing positions shall not be used.

Type[6]	Keyword	Description
(S)	TIMESYS	Keyword used to indicate the time system, either TAI or UTC. If this keyword is absent, 'UTC' *must* be assumed. If you intend to use values other than 'UTC' and 'TAI', please use the online form https://support.eso.org/ to request Phase 3 support.
(R)	DIT	Detector integration time[11], if uniform for all exposures included in this product.

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[11] To be obtained from the keyword HIERARCH ESO DET DIT of the original data for VISTA and from the keyword HIERARCH ESO DET WIN1 DIT1 for OmegaCAM.

Type[6]	Keyword	Description
(R)	EXPTIME[12]	Total integration time per data element (pixel, spectral bin, spaxel) Unit: time second (s); Range: >0. EXPTIME indicates the potential sensitivity of the data relative to observations using the same instrument and mode under similar observing conditions (but possibly different observing strategies). EXPTIME is independent of the chosen data unit, i.e. invariant against rescaling the data (see also the definition of PHOTZP in case of imaging). EXPTIME shall be defined based on the exposure time of the original raw science data considering, where applicable, detector sub-integrations, stacking of multiple exposures and mosaicking. For non-infrared instruments, the total integration time per exposure is available in the EXPTIME keyword of the raw data. In case of instruments using detector sub-integrations, the total integration time per exposure is the sum of all individual sub-integrations. For instance, for near-infrared instruments, the total integration time per exposure is given by the product of detector integration time and number of sub-integrations, DIT*NDIT. **Stacking of exposures:** For data products (images, 1D spectra, IFU data cubes) resulting from the (aligned) co-addition of N (>1) exposures with the same pointing and spectral range, EXPTIME shall be set to the sum $EXPTIME = \sum_{i=1}^{N} EXPTIME(i)$. In case of image stacking, pointing offsets between individual exposures are supposed to be small. Examples: *jitter* and *dither* technique. In case of chopping, nodding, and offset sky, EXPTIME should only account for science data exposures on-target but not for off-target exposures. **Mosaic mode:** If the data product has been constructed from multiple exposures whose positions are offset from each other to sample a region of the sky that is significantly larger than the instrumental FoV, then the total integration time usually varies considerably across the sampled region and an exposure map is required (ANCILLARY.EXPMAP, see section 4.3.1). In this case the EXPTIME keyword shall be set to the median exposure excluding any value=0 pixels (i.e. pixels without data shall be ignored). If a standard offset pattern with constant integration time per exposure is used for mosaicking, then the exposure map is dispensable and EXPTIME can be set to the nominal total integration time obtained in at least 50% of the combined data (ignoring pixels without data). For instance: the pattern of 6*N_jitter offset VIRCAM exposures filling the standard 1° x 1.5° survey tile, where most pixels result from the combination of two*N_jitter exposures, implies EXPTIME(mosaic) = 2*N_jitter*EXPTIME(exposure) with N_jitter denoting the number of exposures per offset at positions each shifted by a small telescope movement (<30 arcsec). Stacking and mosaicking may be used in combination. When collating spectra from a multi-arm spectrograph, e.g. X-SHOOTER, EXPTIME shall be set to the median exposure time of the individual arms. Note: EXPTIME<0 in the raw data need to be curated before propagating them to the resulting data products.

Type[6]	Keyword	Description
(R)	TEXPTIME	Arithmetic sum of the integration time of all exposures included in this product (in seconds). Note that in the case where there is stacking and no mosaic mode, the value of TEXPTIME is equal to EXPTIME defined above. Note that an exposure's integration time is DIT*NDIT if sub-integrations are involved. TEXPTIME shall be less than or equal to (MJD-END – MJD-OBS).
(R) %.8f	MJD-OBS	Specifies the start of the observation in terms of the modified Julian date; the start of the earliest exposure if the data product results from the combination of multiple exposures. To be adopted from the original data. The computation of the MJD-OBS value shall include on-target exposures only. For catalogues, MJD-OBS should be set to the minimum MJD-OBS of the original raw data products that led to the generation of the catalogue records.
(R) %.8f	MJD-END	Specifies the end of the observation; the end of the latest exposure if the data product results from the combination of multiple exposures. MJD-END is at least equal to (MJD-OBS + EXPTIME/86400) of the latest exposure, where 86400 scales back from seconds to days. In case significant overheads are involved, those shall be added. For examples, please consult the Phase 3 page of Frequently Asked Questions[13]. The computation of the MJD-END value shall include on-target exposures only. For catalogues, MJD-END should be set to the maximum MJD-END of the original raw data products that led to the generation of the catalogue records.

---

[12] For ESO La Silla-Paranal raw data, the definition of the EXPTIME keyword depends on instrument. For infrared instruments, except VIRCAM, EXPTIME corresponds to the DIT keyword. Otherwise, for VIRCAM and non-infrared instruments, EXPTIME corresponds to the total integration time per exposure.

[13] https://www.eso.org/sci/observing/phase3/faq.html

Type[6]	Keyword	Description
(S)	PROG_ID PROGID*i*	The identification code assigned to each observing run by the Observing Programme Committee (OPC) in the format TP.C-NNNN(R) where: • T is the leading character indicating the programme type • P is the period number • C is the programme scientific category • NNNN is a running number • R is the observing run identifier Normally, PROG_ID should be copied from the keyword HIERARCH ESO OBS PROG ID of the original data. Starting period P105, the run identification code will have the following structure: PPP.AAAA.nnn where • PPP is the ESO period during which the cycle of the proposal starts. • AAAA is a string of 4 characters, numeric and uppercase alphabetic • nnn is a 0-padded 3 digit integer identifying the run. More detailed information about the identification code and its evolution with time is available from the archive web page[14]. If any SDP originates from more than one observing run or observing programme, the value shall be PROG_ID = 'MULTI', and the individual programme IDs shall be stored in keywords PROGID*i*, where *i* is a sequential number between 1 and 99, without leading zeros. PROGID*i* - Distinct list of identification codes using PROG_ID codes of the original products.
(I)	OBID*i*	Set of Observation Block (OB) IDs to identify the original observations this product results from. The Observation block IDs is a unique numeric ID that was assigned to the observation block by the Observation Handling Subsystem. Normally, OBID*i* should be copied from the keyword HIERARCH ESO OBS ID of the original data. Data may have been combined from one or from multiple observations. In case a product is based on a single observation, it has to be identified by the keyword OBID1. If the original data, which has been combined to form the final product, was obtained in more than one observation block, the complete set of original observations should be listed using the indexed keyword OBID*i*, where *i* is an integer index between 1 and 9999, with no leading zeros. The presence of the keyword OBID2 indicates the multi-OB charactert. OBID*i* should appear as many times as needed to identify the full set of observations of which data have been included to generate this product. If the product includes data from *n* observations, OBID*i* with index *i* running from 1 to *n* should be provided. Conversely a given Observation Block ID must be listed in all the products that are based on this observation. OBID*i* - Distinct list of OB IDs of the original products.

Type[6]	Keyword	Description
(I)	NCOMBINE	Number of raw science data files that were combined to generate this data product. Calibration and acquisition data files do not contribute to this count. For example, for a product resulting from the co-addition of N observations with NEXP exposures per observation, the number of raw science data files should be equal to N*NEXP. If individual exposures were rejected before combination into the product, NCOMBINE should be adjusted accordingly. The computation of the NCOMBINE value shall include on-target exposures only.
(S)	OBSTECH	Technique used during the observation. Normally, OBSTECH should be adopted from the keyword HIERARCH ESO DPR TECH of the original data. If this is not the case, please use the online form https://support.eso.org/ to request Phase 3 support. For GTC data, use the value from the OBSMODE keyword.
(S)	FLUXCAL	FLUXCAL characterises the quality of the flux calibration in terms of two possible values: 'ABSOLUTE' or 'UNCALIBRATED'. For science imaging data, it certifies the validity of PHOTZP and has to be set to 'ABSOLUTE'. For spectroscopic data, it represents the type of flux calibration, whether 'ABSOLUTE' or 'UNCALIBRATED' e.g. when normalised to the continuum.
(S)	PROCSOFT	Indicates the reduction software system including its version number used to produce this data product.

(S)	REFERENC	Should point to the primary scientific publication associated to this data product describing content, coverage, process of creation and scientific quality. According to the FITS Standard, it is recommended that either the 19-digit bibliographic identifier used in the Astrophysics Data System bibliographic databases (http://adswww.harvard.edu/) or the Digital Object Identifier (DOI, http://doi.org) be included in the value string when available.
		
		If you provide the DOI, the link should be given as in the following example:
		`REFERENC= 'doi:10.1051/0004-6361/201730605'`
		while in the case you provide the BibCode, the link should be given as follows:
		`REFERENC= '1924MNRAS..84..308E'`

5.2 Processing provenance

5.2.1 Provenance keywords

Type	Keyword	Description
(S)	PROV*i*	Processing provenance in terms of the list of science files originating this data product. The list of files must not contain duplicates. Files used for calibration purposes (e.g. sky frames) shall not be included in the list. The PROVi keywords refer to the precursor products and not to the raw data, unless the raw data are the immediate precursors. *i* is a sequential number starting from 1 with no leading zeros. PROV*i* should appear as many times as needed to identify the complete set of science data files this product has been generated from.

		PROV*i* are pointers to files in the ESO Archive, which can be either original raw data or science data products depending on the level of reduction. Raw files are specified in terms of their ARCFILE name, e.g. 'VCAM.2010-03-27T08:58:58.083' (no .fits suffix). Data products may be referenced by their ARCFILE name, or, alternatively, supposed that they belong to the same Phase 3 collection as the referencing product file, by their ORIGFILE name (with suffix). ARCFILE and ORIGFILE references can be mixed within the same file.

Requirements

Req-1. PROV*i* keywords must reside in the primary HDU of the FITS file;

Req-2. PROV*i* records represent pointers to files rather than pointers to FITS extensions, i.e. there is no trailing extension number in square brackets;

Req-3. The requirement that PROV must refer to files in the ESO archive has the consequence that intermediate products to be referenced must be submitted to ESO not later than the products resulting thereof. It means for example that one cannot submit extracted source lists in a given data release and then the originating images in a subsequent release.

5.2.2 Provenance extension

If the processing provenance exceeds 9999 records, it is required to record the complete list of files in one dedicated FITS binary table (BINTABLE) extension instead of using header keywords (section 5.2.1). For instance, this scheme is used in the case of very deep observations in which several thousand raw files are co-added ('stacked') to obtain the final result. The header must not contain any PROV*i* keyword in this case to avoid ambiguity.

Each science data product, for which processing provenance is recorded using the dedicated FITS extension (and not in terms of PROV*i* keywords), must include the following flag in the primary FITS header:

Type	Keyword	Description
(L)	PROVXTN	TRUE if processing provenance recorded in FITS extension.

The originating science files are recorded in the table column labelled 'PROV'. The table has as many records as needed to identify the complete set of science data files that generated the data product. The requirements for the definition of the provenance records listed in the previous section (section 5.2.1) apply here as well.

FITS header definition for the Phase 3 provenance extension:

```
XTENSION= 'BINTABLE'           / FITS Extension first keyword
BITPIX  =                    8 / Number of bits per data pixel
NAXIS   =                    2 / Number of data axes
NAXIS1  =                   %d / Length of data axis 1
NAXIS2  =                   %d / Length of data axis 2
PCOUNT  =                    0 / Parameter count
GCOUNT  =                    1 / Group count
TFIELDS =                   %d / Number of fields in each row
TTYPE1  = 'PROV'                / Label for field 1
TFORM1  = '68A'                 / Data format of field 1
CHECKSUM=                   %s / HDU checksum
DATASUM =                   %s / Data unit checksum
EXTNAME = 'PHASE3PROVENANCE'   / Defines Phase 3 processing provenance
END
```

5.2.3 Provenance per catalogue record (spectroscopic programs)

Spectroscopic programmes like Gaia-ESO, PESSTO or zCOSMOS produce high-level results in the form of catalogues where each record contains the results of the analysis of one or more reduced spectra (which are Phase 3 products themselves).

5.2.3.1 One catalogue record – one spectrum

To encode the link between catalogue record and original spectrum, the catalogue must contain a column with a ORIGFILE or ARCFILE reference that identifies for each row the 1D spectrum from which the catalogued parameters are measured.

ORIGFILE refers to the filenames of the 1D spectra within the current collection. ARCFILE refers to the ESO archive identifier of the form ADP.<timestamp>. The referenced ORIGFILE may be part of a previously submitted Phase 3 batch within the same collection. The latest version of the ORIGFILE at the time of closing the catalogue batch is adopted.

The special keyword TXLNKi must be defined in the catalogue file.

Type	Keyword	Description
(S)	TXLNKi	Type of data link to the original spectrum: ORIGFILE or ARCFILE.

If the processing provenance has been defined in this way, i.e. per catalogue record, then the PROVi keywords are not applicable and must **not** be included in the HDU.

Example:

Header listing for HDU #1:

```
PRODCATG='SCIENCE.CATALOG'
(...)
```

Header listing for HDU #2:

```
XTENSION= 'BINTABLE'
EXTNAME = 'PHASE3CATALOG'
(..)
TTYPE8 = 'FILENAME'
TFORM8 = '68A '
TCOMM8 = 'FITS file name of the original spectrum'
TUCD8  = 'meta.ref'
TXLNK8 = 'ORIGFILE' / Data link to the original spectrum
(..)
```

5.2.3.2 One catalogue record - many spectra

To encode the link between catalogue record and original spectra, the provenance extension mechanism should be used with the following extended schema for which an example is given below:

```
EXTNAME = 'PHASE3PROVENANCE'
TTYPE1  = 'PROV' (in terms of ARCFILE or ORIGFILE, or both)
TTYPE2  = 'CNAME'
```

The TTYPE2 of the PHASE3PROVENANCE extension must contain the value of the TTYPEi which is flagged as primary identifier in the PHASE3CATALOG extension. In the example above, that value is 'CNAME'. In other words, the column CNAME (defined by TTYPE2) of the PHASE3PROVENANCE extension contains the primary identifiers of the main catalogue, i.e. the values from the column having TUCD='meta.id;meta.main'.

The column PROV (TTYPE1) contains the complete set of references to the files the particular CNAME record originates from, hence, there will be N records all bearing the same CNAME value, if N is the number of files the measurements of this catalogue record originate from.
Valid PROV references are both the ARCFILE (identifier without FITS extension) and the ORIGFILE (with FITS extension).

5.3 Data specific keywords

Type	Keyword	Description
(S)	BUNIT	Describes the physical unit of the array value. The value of this keyword should conform to the recommendations outlined in the ESO DICD [AD2], Chapter 8. For imaging data 'adu' (Analog-to-Digital converter Unit), or 'adu/s' for exposure time-normalised data are widely used, and the actual physical scale is given in terms of the photometric zeropoint (PHOTZP). For data that is calibrated to absolute flux BUNIT may be, for instance, 'W.m**(-2)' or 'Jy'. That keyword does not apply to 1D spectroscopic data as described in section 8 and for which units of the data arrays are specified via the TUNITi keywords instead.
(R)	GAIN	Specifies the detector sensitivity in number of electrons per data unit (averaging across all exposures making up this data product). Thus, if the data was normalised by exposure time, the 'effective gain' is the detector gain scaled by the total exposure time.
(R)	DETRON	Specifies the detector readout noise in electrons. It is what an individual detector delivers and can be taken from the header of the raw data. In the case of multiple detectors like OmegaCAM the DETRON value is the average of the values for the different detectors.
(R)	EFFRON	Specifies the median over all pixels of the effective readout noise. The effective readout noise is the noise contribution of the detector readout to the background noise, in electrons. It is computed taking into account how many images contribute to each pixel (i.e. the square root of the number of exposures times the readout noise per exposure) and any scaling of the image such as flat fielding.
(R)	WEIGHT	This is the median over all pixels of the weight map. The median should exclude zero pixels from the computation. Zero pixels are pixels that did not receive any exposure or that are flagged as bad.

5.4 WCS keywords

The following guidelines apply to 2D images, flux maps, and to the two celestial dimensions 3D data cubes.

If data processing includes image resampling, or, in case of data cubes, resampling in the celestial dimensions, then the following guidelines should be taken into account when defining the mapping between resampled image coordinates and celestial ('world') coordinates.

1) The *pixel scale* should be compatible with the spatial resolution of the finally processed imaging data. Rough guide: 2 pixels/FWHM. Possible undersampling of the original data may be compensated by using appropriate observational techniques, like dithering, in combination with image reconstruction techniques, like Drizzle. It implies to adopt a suitable pixel scale for the final image which is smaller than the instrumental pixel scale. Bad seeing data does not have to be resampled.

2) The *orientation* of the final image or data cube should be chosen to ensure that the image footprint defined by the WCS represents the actual sky coverage of the data as accurate as possible. The size of void regions containing pixels without exposure should be minimised at the same time, i.e., efficient use of the footprint should be made.

Whenever possible the intrinsic orientation of the observational data, e.g. given by the instrument position angle on the sky, should be maintained (see Figure 1). Otherwise, in case of more complex shapes of the illuminated area due to co-addition of multiple exposures, possibly with variable instrument orientation, the WCS rotation should be chosen so that the total area of void regions is being minimised.
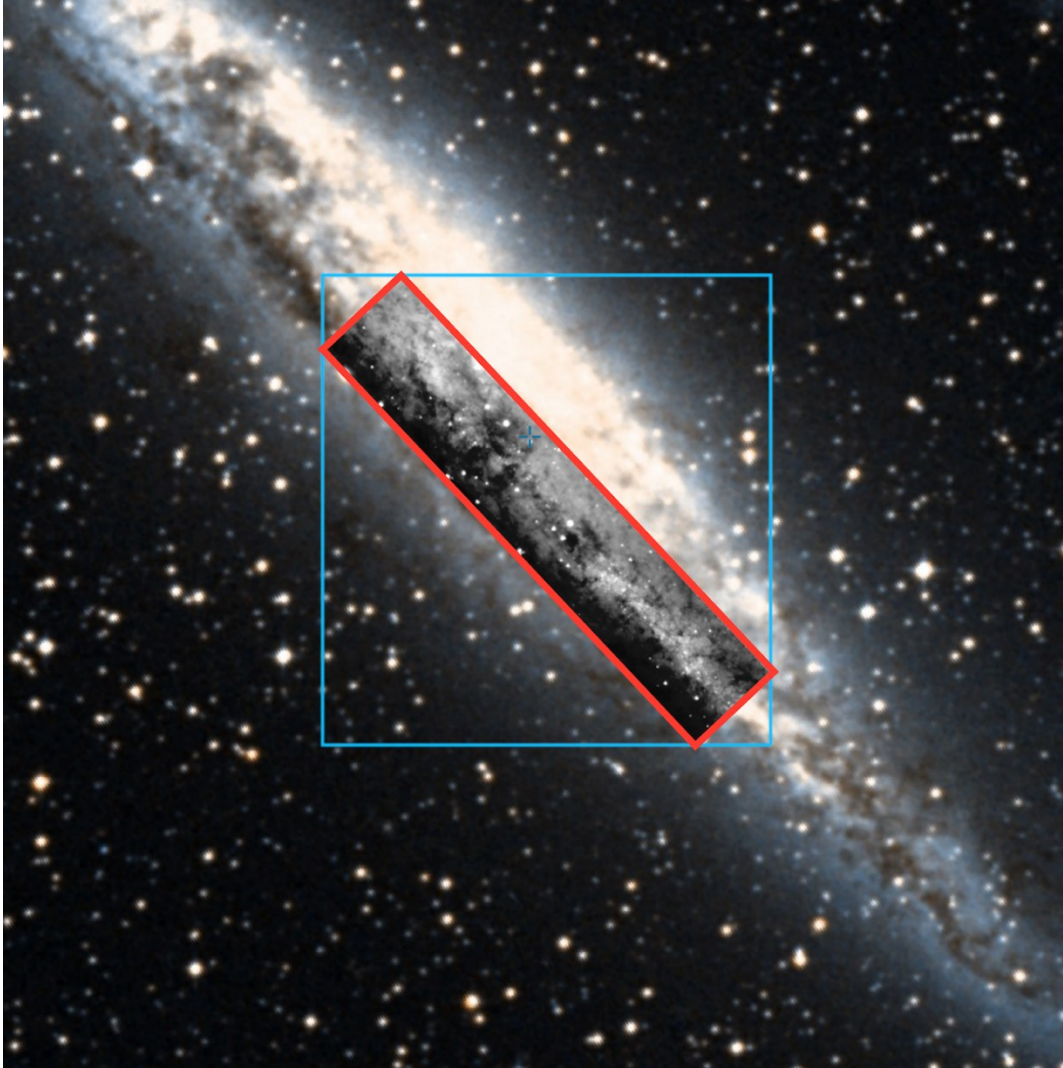
Figure 1: Mosaic of MUSE six pointings sampling a contiguous rectangular region of ca. 5.3' x 1.0' aligned along the orientation of the main axis of NGC4945. Red: Suitably oriented WCS, accurately representing the sky coverage. Blue: inefficient footprint using default orientation (North up) with significant void regions and excessive data volume.

- The SDP standard does not allow the usage of CDELTn+CROTAn, PCi_j or PCij conventions. Please use the CDi_j matrix instead.
- Only one set of WCS keywords per header is supported.

Type	Keyword	Description
(R)	CRVALi	Coordinate value at reference pixel of axis i.
(R)	CRPIXi	Reference pixel in axis i.
(S)	CTYPEi	Pixel coordinate system of axis i.
(S)	CUNITi	Specifies the unit of the coordinate transformation. Units for celestial coordinate systems must be degrees.
(R)	CDi_j	Transformation matrix element.
(R)	CSYERi	Systematic error in axis i (unit given by CUNITi, usually degree).
(R)	CRDERi	Random error in axis i (unit given by CUNITi, usually degree). CRDER1 and CRDER2 may be set both to $1/\sqrt{2}$ times the RMS accuracy of the astrometric registration if errors are isotropic (and similarly for CSYERi).

Example of WCS keywords for an image:

```
CRVAL1  =               53.11604 / 03:32:27.8, RA at ref pixel
CRVAL2  =                -27.791 / -27:47:27.6, DEC at ref pixel
CRPIX1  =                433.780 / Ref pixel in X
CRPIX2  =                410.550 / Ref pixel in Y
CTYPE1  = 'RA---TAN'             / pixel coordinate system
CTYPE2  = 'DEC--TAN'             / pixel coordinate system
CUNIT1  = 'deg'                  / unit of coordinate
CUNIT2  = 'deg'                  / unit of coordinate
CD1_1   =     4.12200000000E-05 / Transformation matrix element
CD1_2   =                    0. / Transformation matrix element
CD2_1   =                    0. / Transformation matrix element
CD2_2   =    -4.12200000000E-05 / Transformation matrix element
RADESYS= 'ICRS    '             / Coordinate reference frame
```

5.5 Image photometric zeropoint

Type	Keyword	Description
(R)	PHOTZP	Photometric zeropoint that relates the pixel data to magnitudes (MAG) according to the equation $$MAG=-2.5*log(data)+PHOTZP+APCOR,$$ i.e. (atmospheric) extinction correction and any applicable scaling with exposure time should be absorbed into PHOTZP. PHOTZP should also incorporate the correction for atmospheric extinction, but <u>not</u> the aperture correction APCOR term (if any). Normally, PHOTZP does not incorporate corrections for galactic extinction/reddening, or otherwise it should be explicitly expressed in the data release description. The PHOTZP/PHOTZPER/PHOTSYS keywords must encode the photometric scale according to the most relevant calibration.
(R)	PHOTZPER	Recommended keyword to indicate the (1 sigma) uncertainty of the photometric zeropoint PHOTZP.
(S)	PHOTSYS	Specifies the photometric system for the magnitudes reported in the binary table (source list, catalogue). May take either the value 'VEGA' or 'AB' to indicate whether the photometric zero point is expressed in Johnson magnitudes or in Oke's AB photometric system, respectively. In case of tabular data PHOTSYS applies to the photometric parameters at large (like source flux, magnitude, color) unless the photometric system is otherwise specified, e.g. per parameter. If multiple bands are provided in different photometric systems, this information can be recorded in the respective TTYPE, e.g. by appending the suffix '_VEGA' and '_AB', respectively. PHOTSYS does *not* apply to the MAGLIMi keywords, whose values have to be given in the AB photometric system invariably.

5.6 Spectroscopic keywords

Type	Keyword	Description
(S)	SPECSYS	Frame of reference for spectral coordinates. The list of recognised values are taken from [AD1] and are reproduced in Table 2 for convenience.
(L)	EXT_OBJ	The value of this keyword shall be set to TRUE if the spectrum refers to an extended object. To FALSE if it is pointlike.
(L)	CONTNORM	TRUE if the spectrum is normalised to the continuum.
(L)	TOT_FLUX	The TOT_FLUX keyword shall be set to T (true) to indicate that the flux data represent the total source flux. This is the case if, for instance, observations were obtained under photometric conditions and measures were taken to capture the total source flux e.g. by choosing a slit sufficiently wide with respect to the seeing or when correction for slit loss was applied to the measurements. If TOT_FLUX is true, FLUXCAL must be set to 'ABSOLUTE'.
(R)	FLUXERR	FLUXERR provides the fractional uncertainty on the flux scale expressed as a percentage in the range between 0 and 100. FLUXERR is an estimate that includes all contributing effects, in case of flux maps in particular: the instrumental calibration, atmospheric conditions in terms of PWV and stability, and the calibration source. Example: FLUXERR = 15. indicates an overall uncertainty of the flux calibration of 15%.

(R)	WAVELMIN WAVELMAX	For 1D extracted spectra (SCIENCE.SPECTRUM), WAVELMIN / WAVELMAX should describe the minimum and maximum wavelengths in nanometers outside of which the described spectrum does not carry any valuable scientific information.
		For example, if a spectrum is zero-padded on the lower wavelengths, then the WAVELMIN should not be lower than the wavelength associated to the first bin where the spectrum has a flux > 0. Similarly, if a spectrum is zero-padded at the higher wavelengths, then the WAVELMAX should not be higher than the wavelength associated to the last bin where the spectrum has a flux > 0.
		It must be true that: SPECTRUM.WAVE[1] <= WAVELMIN < WAVELMAX <= SPECTRUM.WAVE[NELEM]
		where NELEM is the pixel length of the wavelength array.
		For 3D data cubes (SCIENCE.CUBE.IFS), WAVELMIN / WAVELMAX correspond to the physical wavelength (nm) of the first / last plane of the science data cube carrying scientifically useful information.
		For data cubes with partial spatial coverage at the end of the wavelength range (e.g. KMOS): WAVELMIN/MAX should refer to the first/last WL plane having a fill factor of at least 50%.
		WAVELMIN / WAVELMAX need to be specified in either air or vacuum wavelength consistent with the definition of the spectral axis.
		For PIONIER interferometric data, in case of less than 5 channels (including the special case of one single channel) the finite width of each channel must be taken into account. WAVELMIN/MAX are defined at the full width of half maximum (FWHM). In case of more than 5 channels it is possible to operate with the following approximation: WAVELMIN := min(EFF_WAVE), i.e. it corresponds to the minimum of all values in the EFF_WAVE column of the OI_WAVELENGTH table [m] converted into nm. WAVELMAX := max(EFF_WAVE), i.e. to the maximum of all values in the EFF_WAVE column of the OI_WAVELENGTH table [m] converted into nm.
		For catalogue data: WAVELMIN/MAX refer to the transmission curves of the images from which the catalogue was extracted.

(R)	LAMRMS	The root-mean-square (RMS) of the residuals of the wavelength solution along the wavelength axis [nm]. The keyword LAMRMS refer to a well defined measurement on the calibration data (whereas the keyword SPEC_ERR refer to an estimate of the error in the science data that might come from LAMRMS or other information). More precisely, LAMRMS is the root-mean-square of the residuals, defined as: LAMRMS = sqrt(sum_i(R_i2)/N) where R_i= residual of wavelength solution for i-th arc line, N = numbers of arc lines = LAMNLIN. It is an estimator for the uncertainty in each residual under the assumption that all uncertainties are equal and that the model that was subtracted is the correct/appropriate model for the data (so that the errors are random and not systematic).
(R)	LAMNLIN	The number of arc lines used in the fit of the wavelength solution.
(R)	SPEC_BIN	The average spectral coordinate bin size in [nm]. It characterises the spectral sampling in the case of the spectrum binary table format for 1D spectra.
(R)	SPEC_ERR	Statistical error in spectral coordinate [nm], applicable to the case when the WCS is not used. The keyword SPEC_ERR refer to an estimate of the error in the science data that might come from LAMRMS or other information. Identifying a best estimate for SPEC_ERR requires the PI's judgement. In most cases, including UVES and XSHOOTER, the formula SPEC_ERR = LAMRMS / sqrt(LAMNLIN) is a good approximation if the scatter is mainly due to random measurements errors and those errors are similar for all lines. Note that the value of LAMRMS / sqrt(LAMNLIN) is a lower limit to SPEC_ERR.
(R)	SPEC_SYE	The keyword SPEC_SYE aims at capturing the systematic error in spectral coordinate and is expressed in nanometers [nm]. Possible sources of systematic error include any residual offset of the wavelength calibration and any error related to broadening of the lines due to the observation setup and the observation conditions. If systematic uncertainties are known to represent an insignificant contribution to the overall error budget on the wavelength axis, or all the systematic errors have been accounted for in the submitted data product spectrum, then SPEC_SYE can be set to zero.
(R)	RA_ERR DEC_ERR	Error on spectroscopic target position [deg]. In case of a long-slit or MXU observation, the value of those keywords could be set to half the width of the slit.
(I)	NELEM	It represents the pixel length of the data arrays.

SPECSYS values	Definition
TOPOCENT	Topocentric
GEOCENTR	Geocentric
BARYCENT	Solar system barycentric

HELIOCEN	Heliocentric
LSRK	Local standard of rest (kinematic)
LSRD	Local standard of rest (dynamic)
GALACTOC	Galactocentric
LOCALGRP	Local Group barycentric
CMBDIPOL	Cosmic microwave background dipole
SOURCE	Source rest frame

Table 2: For convenience, we quote here the list of SPECSYS values taken from [AD1].

5.6.1 VO interoperability keywords

Type	Keyword	Description
(S)	VOCLASS	The data model name and version, e.g. 'SPECTRUM V1.0'.
(S)	VOPUB	The name of the publisher, namely 'ESO/SAF'.
(S)	TITLE	The title of the dataset is a short, human-readable description of a dataset, and should be less than one line of text. The value of the OBJECT keyword should be contained in the TITLE value. Within a collection, all TITLE keyword values shall be unique.
(R)	APERTURE	Aperture angular size, in degrees [deg]. It shall be set to the width of the slit or the diameter of the fiber.
(R)	TELAPSE	Total elapsed time in seconds [s], defined as MJD-END - MJD-OBS.
(R)	TMID	Exposure midpoint (MJD). It shall be set to (MJD-OBS + MJD-END)/2.0.
(R)	SPEC_VAL	Characteristic spectral coordinate value in nanometers [nm]. It is set to (WAVELMAX+WAVELMIN)/2.0.
(R)	SPEC_BW	Width of the spectrum in nanometers [nm]. It is set to WAVELMAX-WAVELMIN.

5.7 APEX specific keywords

Type	Keyword	Description
(S)	MAPMODE	APEX map modes being used. Format: comma-separated list of the following keywords: OTF — on-the-fly mapping SPIRALRAS — raster of spirals SPIRAL — single spiral; normally only used for pointings, not for deep maps *Example:* `MAPMODE = 'SPIRALRAS,OTF'`

(S)	FEBE*i*	APEX frontend/backend combination propagated from the original raw FITS file.
		
		Examples:
		`FEBEi = 'LABOCA-ABBA'`
		`FEBEi = 'SABOCA-ABBA'`
		`FEBEi = 'ARTEMIS200-BEAR2'`
		`FEBEi = 'ARTEMIS350-BEAR1'`
		`FEBEi = 'ARTEMIS450-ARTBE'`
		`FEBEi = 'ARTEMIS450-BEAR1'`

5.8 Interferometry keywords

Type	Keyword	Description
(S)	CONTENT	It has to be set to 'OIFITS1' for PIONIER.
(S)	INSMODE	Possible values for PIONIER: 'FREE_H', 'GRISM_H', 'FREE_K', 'GRISM_K'.
(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.
(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)	VIS2ERR	Representative squared visibility error [%].
(F)	T3PHIERR	Representative closure phase error [deg].

5.9 Polarimetric information

Type	Keyword	Description
(S)	STOKES	List of Stokes parameters, using symbols from the set {I Q U V RR LL RL LR XX YY XY YX POLI POLA}, separated by '/' with additional '/' at beginning and end. Example: '/I/Q/U/V/' NULL values are allowed if no polarization applies (defaults to 'I'). The symbols should be specified in the order as expressed in the above list. The frame of reference for the Stokes parameters shall follow the convention described in the IAU resolution by Commissions 25 and 40 at the IAU XVth General Assembly in Sydney in 1973 [RD8]. For a definition of POLI/POLA, please refer to the published IVOA Note [RD9].

5.10 HDUCLASn and complementary keywords

The keywords required for the encoding of error and data quality information in the context of the HDUCLASn keyword recommendation [RD6] are listed below.

Type	Keyword	Description
(S)	HDUCLASS	A character string giving a general identifier of the data format used, here: = 'ESO' that is the ESO format.
(S)	HDUCLAS1	A character string specifying the general data classification = 'IMAGE' in case PRODCATG='SCIENCE.IMAGE' or PRODCATG = 'SCIENCE.CUBE.IFS'
(S)	HDUCLAS2	A character string specifying what the extension contains, to be chosen from the following list: 'DATA', 'ERROR', 'QUALITY', 'CONF' or 'BKG_DATA', 'BKG_ERROR', 'BKG_CONF'.
(S)	HDUCLAS3	A character string specifying the type of error or data quality. There are four different error types supported: 'MSE' (mean squared), 'RMSE' (root mean square), 'INVMSE' (inverse mean squared), 'INVRMSE' (inverse root mean square). There are 4 different data quality types supported: 'MASKZERO', 'MASKONE', 'FLAG32BIT' (Euro3D-like), 'FLAG16BIT' (see section 5 of [RD6]).
(S)	HDUDOC	A character string giving the document (preferably published) that describes the format/classification used, here: = 'SDP' / Document with class description
(S)	HDUVERS	A character string giving the specific version of the document specified by HDUDOC, e.g. = 'SDP version 8' for SDP version number 8

In addition, each HDU has to possess sufficient information to group itself with other HDUs in the global context with the help of the following complementary keywords:

Type	Keyword	Description
(S)	SCIDATA	Identifies the extension name (EXTNAME value) of the corresponding science data HDU.
(S)	ERRDATA	Identifies the extension name (EXTNAME value) of the corresponding error HDU if it exists.
(S)	QUALDATA	Identifies the extension name (EXTNAME value) of the corresponding data quality HDU if it exists.
(S)	CONFDATA	Identifies the extension name (EXTNAME value) of the corresponding confidence HDU if it exists.
(S)	BKGDATA	Identifies the extension name (EXTNAME value) of the corresponding background data HDU if it exists.
(S)	BKGERR	Identifies the extension name (EXTNAME value) of the corresponding background error HDU if it exists.
(S)	BKGCONF	Identifies the extension name (EXTNAME value) of the corresponding background confidence HDU if it exists.

More details can be found in [RD6]. The complementary keywords should not be used to declare self-references. For instance, the header of a science HDU should not list the SCIDATA keyword. Below is an example of usage of the above keywords for a file with three extensions, one with science data, one with error and one with data quality.
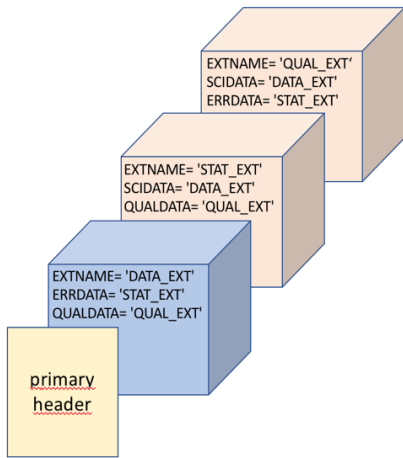
```
XTENSION= 'IMAGE'          / IMAGE extension
EXTNAME = 'DATA EXT'       / This extension contains science values
HDUCLASS= 'ESO'            / class name (ESO format)
HDUDOC  = 'SDP'            / ESO Science Data Products standard
HDUVERS = 'SDP version 8'  / version number
HDUCLAS1= 'IMAGE'          / data classification
HDUCLAS2= 'DATA'           / this extension contains the science data
ERRDATA = 'STAT_EXT'       / pointer to the error extension
QUALDATA= 'QUAL_EXT'       / pointer to the quality extension
END

XTENSION= 'IMAGE'          / IMAGE extension
EXTNAME = 'STAT_EXT'       / This extension contains error values
HDUCLASS= 'ESO'            / class name (ESO format)
HDUDOC  = 'SDP'            / document with class description
HDUVERS = 'SDP version 8'  / version number
HDUCLAS1= 'IMAGE'          / data classification
HDUCLAS2= 'ERROR'          / this extension contains the error data
HDUCLAS3= 'MSE'            / error type
SCIDATA = 'DATA_EXT'       / pointer to the science extension
QUALDATA= 'QUAL_EXT'       / pointer to the quality extension

XTENSION= 'IMAGE'          / IMAGE extension
EXTNAME = 'QUAL_EXT'       / This extension contains quality values
HDUCLASS= 'ESO'            / class name (ESO format)
HDUDOC  = 'SDP'            / document with class description
HDUVERS = 'SDP version 8'  / version number
HDUCLAS1= 'IMAGE'          / data classification
HDUCLAS2= 'QUALITY'        / this extension contains the quality data
HDUCLAS3= 'MASKZERO'       / quality type
SCIDATA = 'DATA_EXT'       / pointer to the data extension
ERRDATA = 'STAT_EXT'       / pointer to the error extension
END
```

5.11 Data quality parameters

Type	Keyword	Description
(R)	ABMAGLIM	5-sigma limiting AB magnitude [RD7] in terms of the flux of an unresolved source (i.e. point source) assuming, whenever possible, optimal signal extraction. ABMAGLIM quantifies the noise level of the image outside of astronomical sources i.e. due to the combined effect of instrumental, atmospheric and diffuse sky background emission. In the case of SCIENCE.IMAGE, the limiting AB magnitude refers to the passband defined by FILTER. In the case of SCIENCE.CUBE.IFS the limiting AB magnitude refers to the associated whitelight broad-band image with wavelength interval between WAVELMIN and WAVELMAX[15]. Note: In case of non-uniform magnitude limit across the field of view, e.g. due to the combination of several offset exposures, ABMAGLIM refers to the median, i.e. the level reached in at least 50% of the mapped area. ABMAGLIM and BNOISE differ in terms of unit (AB mag vs. Jansky) and adopted significance level (5 sigma vs. 1 sigma). The two numbers are related by: ABMAGLIM ~ -2.5 $\log_{10}$ BNOISE + 7.1526. *In practice:* one can capture the 5-sigma limiting AB magnitude in carrying out either the aperture photometry or the optimal

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[15] The 5σ noise shall be estimated within an image area that corresponds to the broad-band PSF. Then, the measured noise is converted to AB magnitudes assuming a flat spectrum ($f_{\mathbf{v}}$=const.)

extraction. In the latter case, if the PSF is gaussian with a full-width half maximum PSF_FWHM, then the optimal extracted magnitude relates to the noise in a PSF smoothed image $\sigma_{smoothed}$ as:

$$ABMAGLIM = -2.5 \log_{10} (5 * \sigma_{smoothed} * PSF\_FWHM^2 * \pi / (2 \ln 2)) + PHOTZP$$

The noise $\sigma_{smoothed}$ can be measured in the smoothed image. For an image with uncorrelated noise σ, it can be computed as:

$$\sigma_{smoothed} = (\sigma / PSF\_FWHM) * (2 \ln 2 / \pi)^{0.5}$$

In case of aperture-based photometry, the optimal aperture size according to the actual image quality should be adopted (i.e. circular aperture diameter D_{opt}= 1.35*PSF_FWHM, <u>for a Gaussian PSF</u>), the corresponding aperture correction should be applied, and a correction with respect to optimal extraction (Δ_{mag} = 0.11 mag, <u>for a Gaussian PSF</u>) should be applied also. Magnitude limits, which were obtained with aperture sizes different from the optimal size should be corrected according to the table below.

D_{Ap}/D_{opt}	Mag
0.467	0.361
0.513	0.287
0.564	0.219
0.621	0.158
0.683	0.105
0.751	0.061
0.826	0.028
0.909	0.007
1.000	0.000
1.100	0.008
1.210	0.031
1.331	0.071
1.464	0.126
1.611	0.196
1.772	0.278
1.949	0.370

The table gives the dependency of limiting magnitude on aperture diameters D_{Ap} with respect to the optimal diameter D_{opt}= 1.35*PSF_FWHM .
It is computed on the assumption of uncorrelated noise and Gaussian PSF.

(R)	BNOISE	Point source sensitivity limit due to background noise (1σ level) in units of Jansky (Jy). In case of variations across the image, BNOISE refers to the median, i.e. the level reached in at least 50% of the mapped area. BNOISE corresponds to the PSF smoothed noise level in the optical and infrared regime, which is equivalent to the beam-smoothed RMS noise level (Jy/beam) in case of flux maps, e.g. APEX submillimeter, radio.[16]
(R)	PIXNOISE	Median background pixel-to-pixel noise of the 3D data cube in units of erg.s**(-1).cm**(-2).angstrom**(-1). "Background" here means the region not covered by the object flux, i.e. the estimate does not include the Poissonian noise contributed by the object flux (e.g. mode of the error cube).

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[16] Note: `BNOISE` has a fixed unit (Jy or Jy/beam) independent of `BUNIT`.

(R)	MAGLIM*i*	5-sigma limiting AB magnitude in FILTER*i* for band-merged data products where *i* is a sequential number starting from 1, without leading zeros. The quoted magnitude should refer to the total flux of a point source.
(R)	ABMAGSAT	Saturation limit for point sources (AB magnitude). It corresponds to the total AB magnitude of a point source whose peak flux equals the saturation level of the detector. ABMAGLIM - ABMAGSAT indicates the dynamic range being actually covered by the data.
(R)	PSF_FWHM / SKY_RES	Effective spatial resolution of the data in terms of the FWHM of the profile of an unresolved source (arcsec)[17],[18]. The two keywords PSF_FWHM and SKY_RES express the same concept. PSF_FWHM is used for images and SKY_RES for flux maps and cubes. The SCIENCE.MEFIMAGE format requires PSF_FWHM to be defined separately for each detector, i.e. image extension. The valid range is PSF_FWHM > 0. In case of chip-by-chip processing, it occasionally happens that the PSF_FWHM quality parameter cannot be determined for one of the chips, normally due to the lack of suitable point-like reference objects just in this field. If the PSF_FWHM recorded with the other detectors demonstrates that the overall image quality appears to be ok, the PSF_FWHM value for the problematic detector chip should be set to the special value -1. Note: the PSF_FWHM special value "-1" is not supported for the SCIENCE.IMAGE format i.e. for resampled survey tile images. In case of APEX sub-millimetre maps (SCIENCE.IMAGE.FLUXMAP) SKY_RES is the FWHM effective beam size of the map including the instrumental beam and possible smoothing applied during map synthesis. Median values should be adopted for SKY_RES in case of variations across the survey area. In case of SCIENCE.CUBE.IFS, SKY_RES refers to the associated whitelight broad-band image.
(R)	SKY_RERR	Error of SKY_RES (arcsec), specifies the overall uncertainty in the RMS sense including random and systematic effects.
(R)	ELLIPTIC	Average ellipticity of point sources defined as (1-b/a) with a and b denoting the major and minor axes of the source profile, resp.

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[17] In case of multiple suitable point sources SKY_RES shall be obtained by averaging over individual measurement.

[18] If the image quality cannot be measured directly from the data (normally due to the lack of suitable sources within the FOV), then SKY_RES shall be estimated appropriately, e.g. based on the DIMM seeing, and SKY_RERR must indicate the typically expected deviation with respect to the actual resolution (in the RMS sense).

(R)	SNR	Median(*) signal to noise ratio per pixel, where the signal of the SNR is usually taken to be the continuum level. For spectra with strong emission lines, the level of the sky-background shall be taken. (*)The median is to be computed on all "good" data elements, i.e. excluding any QUAL!=0 data.
(R)	SPEC_RES	Average spectral resolving power (defined as lambda / Δ lambda of the spectrum. SPEC_RES is therefore a dimensionless (floating point) number. It could be estimated by measuring the FWHM of the ARC-lamp emission lines at different wavelengths along the dispersion axis. In case the spectral resolving power varies within the spectral range, SPEC_RES is defined at the central wavelength of the data (WAVELMIN+WAVELMAX)/2. In case of data combination from different IFUs, slices, exposures (e.g. MUSE) the average spectral resolving power should be assigned to SPEC_RES.
(R)	STREHL	Ratio of the intensity at the peak of the light distribution of an on-axis point source to the intensity assuming an ideal optical system limited only by diffraction over the system's aperture. It should be a value between 0 and 1. Possible suggested algorithm: 1. Generate a PSF for the given telescope configuration and observation wavelength. 2. Compute the PSF flux and the PSF peak. 3. Detect the brightest star (if not provided on input). 4. Compute the star peak and the star flux. This step requires a very precise background estimation. A tiny error on the background can have a strong effect on the computed strehl. 5. Compute Strehl = (star_peak/star_flux) / (psf_peak/psf_flux) Limitation: STREHL does not characterise the off-axis image quality.

5.12 Checksums and reserved header keywords

The keywords CHECKSUM and DATASUM shall be included in the submitted data products; they will be used to validate the integrity of the data after transfer to ESO and before archival storage. Improper checksums will prevent successful ingestion into the archive.

Type	Keyword	Description
(S)	CHECKSUM	Provides a Cyclic Redundant Check (CRC) calculation for each HDU. It uses the ASCII encoded 1's complement algorithm. For more details, please refer to the CHECKSUM keyword convention[19].
(S)	DATASUM	Data unit checksum.

We list in the table below some keywords that are reserved to record certain information related to the ESO archival process. If these keywords exist in the header of the submitted data, their content will be overwritten in the course of archival with new information. As a consequence any previous content will get lost. Therefore, the data creator should not use these keywords to deliver any relevant information. If these keywords do not exist in the header of the submitted data, the Phase 3 archiving process will add the kewords to the data headers with the appropriate value.

Type	Keyword	Description
(S)	ARCFILE	Provides the name under which the file is stored in the ESO science archive.
(S)	ORIGFILE	ORIGFILE records the filename as given by the data provider. ORIGFILE is present in the FITS primary header unit, hence data creators must not add this keyword to any FITS extensions to avoid potential inconsistencies.
(S)	P3ORIG	Records the processing origin of the data ('IDP', 'EDP')

Example of reserved header keywords:

```
ARCFILE = 'ADP.2010-08-19T09:33:11.951.fits' / Archive file name
CHECKSUM= 'CYMRAEGLLENYDDOL'  / HDU checksum
DATASUM = '3141592653'        / Data unit checksum
ORIGFILE= 'FORS1-IMG231.19.fits' / Original file name
P3ORIG  = 'EDP'                / ESO external data product
```

5.13 User provided keywords

Normally, for a given science data product, the keywords defined herein just form a subset of keywords characterising the data; in fact, the data provider is encouraged to include further keywords to characterise the data in more detail, to a level that seems to be adequate from the scientific point of view. For instance, science data products may carry over information from the original raw observational data provided the keywords apply to the data product as a whole. The propagation of keywords should have no bearing on the keywords that are being updated in the course of the data calibration process, e.g. the WCS keywords.

In order to avoid (meta)data inconsistencies the data provider has the responsibility to ensure that user-defined keywords do not conflict with the SDP keywords as defined throughout Section 5. When adding further keywords to the FITS header, data providers are strongly encouraged to use 8-character FITS standard keywords instead of HIERARCH keywords.

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[19] https://fits.gsfc.nasa.gov/registry/checksum.html

Note that lower case characters shall not be used for keyword names according to [AD1], §4.1.2.1 therein.

5.14 Near-Infrared observations

Type	Keyword	Description
(I)	NDIT	Number of sub-integrations, if uniform for all exposures included in this product. To be obtained from the keyword HIERARCH ESO DET NDIT of the original data.
(I)	NJITTER	Number of jitter positions per observation if uniform.
(I)	NOFFSETS	Number of offset positions per observation if uniform.
(I)	NUSTEP	Number of microstep positions per observation if uniform.

5.15 Calibration data taken with science category and off-source raw exposures

It can happen that some calibration data have been acquired with a DPR.CATG = 'SCIENCE'. Those calibration exposures must be excluded from the calculation of the T/EXPTIME, NCOMBINE, MJD-OBS, and MJD-END keyword values. The list of PROVi keywords recording the science files originating the data product must not contain any reference to those calibration files.

Example where this situation happens:
XSHOOTER: the OFFSET frames with DPR.TECH = 'SKY' (even though taken as DPR.CATG = 'SCIENCE') should NOT be taken into account, while the ones with DPR.TECH = 'OBJECT' are the real science data.

Similarly, off-source raw exposures must be excluded from the calculation of the value of the above mentioned keywords and the list of PROVi keywords must not contain any reference to off-source raw exposures.

5.16 Science catalogues

Type	Keyword	Description
(R)	FPRA*ia*	Footprint's RA in degrees (J2000). The footprint is defined in terms of the *N* vertices of a geodesic polygon[20]. In case of 4 vertices, the polygon should be convex. Each vertex is identified by the index *i,* an integer number running from 1 to *N,* without leading zero. If the footprint consists of multiple disjoint regions an alphabetic code *a* in the range A through Z is appended to the keyword to identify each region. For a simply connected footprint the suffix *a* should be blank. 0 ≤ FPRAx < 360
(R)	FPDE*ia*	Footprint's Declination in degrees (J2000). -90 ≤ FPDEx ≤ 90

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[20] The ordered list of vertices should encircle the polygon in a counter-clockwise sense in the conventional equatorial coordinate system with North up and East to the left. The last vertex in the list implicitly connects back to the first. Polygons having an enclosed area that exceeds the area of the hemisphere are not supported.

(R)	SKYSQDEG	Actual total sky coverage of the catalogue in units of square degrees. Applies to catalogues only. In case of a catalogue in the multi-file format (section 12.2.2), the value of the SKYSQDEG for the metadata file shall be less than or equal to the sum of the values of the SKYSQDEG of the individual catalogue files.
(L)	M_EPOCH	TRUE if resulting from a combination of multiple epochs. This flag indicates that the data product includes observations obtained in more than one epoch and applies to multi-epoch catalogues formatted according to section 12.5.1 only.
(L)	APMATCHD	TRUE if the tabulated fluxes, magnitudes, and parameters derived thereof like colours etc. were *aperture-matched* in order to correct for possible PSF variations across different bands.
(S)	TXRGFi	Defines the filename of the target catalogue in terms of the ORIGFILE name.
(S)	TXCTYi	Defines the name of the target column of this catalogue data link in terms of its TTYPEi.
(S)	TXLNKi	If this column represents a data link, this keyword shall be set to one of the string values 'CATALOG', 'ARCFILE' or 'ORIGFILE' to indicate the type of link. See section 12.3 for instructions how to define data links.

5.17 Data from other facilities (not ESO)

Type	Keyword	Description
(L)	NOESODAT	To indicate products originating or containing data from a non-ESO facility, use the dedicated boolean keyword NOESODAT in the primary header.

Projects external to the ESO data flow system may have a few inapplicable keywords which are specific to data taken with ESO telescopes. Examples of such keywords are NCOMBINE, PROG_ID/PROGIDi, OBIDi and PROVi.

In case of data originating from non-ESO facilities, please use the online form https://support.eso.org/ to request further Phase 3 support.

5.18 Column descriptors

The columns of tabular data are described with the following indexed keywords, where i is an integer index between 1 and 999, with no leading zeros. Those column descriptors are used in the context of data formats involving BINTABLE.

Type	Keyword	Description
(I)	TFIELDS	Number of fields (columns) in the binary table. As per the FITS standard, the TFIELDS keyword that specifies the number of fields in each row of the binary table must be the 8th keyword in the FITS extension containing the binary table.
(S)	TTYPEi	It specifies the content of the i-th field of the binary table.
(S)	TFORMi	It specifies the data format of the i-th field of the binary table. For catalogue data: only a subset of data formats are allowed (see Table 6).
(S)	TCOMMi	Verbal description (68 characters max).

(S)	TUNIT*i*	It specifies the physical unit of the *i*-th field of the binary table. The value of the TUNIT*i* keyword should conform to the recommendations outlined in the ESO DICD, Chapter 8 [AD2]. Units and scale in which the physical quantity in this column is expressed. The unit string consists of a (base) unit possibly preceded, with no intervening spaces, by a single character (two for deca) representing scale factors mostly in steps of 10^3. The value of this keyword should conform to the recommendations outlined in the ESO DICD [AD2], chapter 8. Please also refer to [AD1], section 4.3, for further guidance. For quantities having no units of measurement, the TUNIT*i* keyword value shall be set to an empty string.
(S)	TUTYP*i*	Description of the column content in terms of a UType. A UType is a pointer to a concept expressed within a data model. Please refer to [RD3] for a description of this data model. UTypes are case-insensitive.
(S)	TUCD*i*	For the *i*-th field of the binary table, it specifies the IVOA Unified Content Descriptor (UCD) according to the UCD1+ controlled vocabulary to describe astronomical data quantities. Please refer to [RD2] [RD4] for more details on UCDs. A machine-readable list of UCDs is available online at http://ivoa.net/rdf
(S)	TDISP*i*	Recommended format for displaying an ASCII text representation of the contents of this column. The permitted display format codes for each type of data (i.e., character strings, logical, integer, or real) are given in Table 3.
(R)	TDMINi	Floating point number specifying the minimum valid physical value represented in the respective column of the catalogue, exclusive of any special values. Applies to numeric data type columns.
(R)	TDMAX*i*	Floating point number specifying the maximum valid physical value represented in the respective column of the catalogue, exclusive of any special values. Applies to numeric data type columns.
(I)	TNULL*i*	Shall contain the integer that represents an undefined value for data type B, I, J or K. The keyword must not be used in case of any other data type.

Field Value	Data type
A*w*	Character
L*w*	Logical
I*w.m*	Integer
F*w.d*	Floating-point, fixed decimal notation
E*w.d*E*e*	Floating-point, exponential notation
G*w.d*E*e*	General; appears as F if significance not lost, else E.
D*w.d*E*e*	Floating-point, exponential notation

Table 3: Valid TDISP*i* format values in BINTABLE extensions for catalogues

Notes: *w* is the width in characters of displayed values, *m* is the minimum number of digits displayed, *d* is the number of digits to right of decimal, and *e* is number of digits in exponent. The *.m* and E*e* fields are optional.

5.19 Specification of units

Allowed units are specified in ESO Data Interface Control Document [AD2] section 8. It applies to keywords BUNIT, CUNITi, and TUNITi.

6. Imaging products

6.1 Data definition

This section defines the generic format for (astronomical) images, i.e. two-dimensional data arrays recording flux in a given band as a function of celestial coordinates. Higher-level products based on imaging data, namely extracted source lists and catalogues, will be covered in Section 9 and Section 12, respectively.

For instruments with mosaic (multi-chip) imagers, the different detectors should be stored together within the same FITS file as several extensions, and frames from the same OB template should be stacked.

Instrumental signatures are to be removed from the pixel data by applying appropriate data reduction and calibration procedures. Depending on instrument it usually includes overscan and bias subtraction, flatfield correction, correction for (chip-to-chip) gain variations, detector linearity correction, cross talk correction, illumination correction, and correction for pixel scale variation across the field of view. For infrared instruments, sky subtraction shall be applied.

Imaging data need to be characterised in terms of their astrometric registration (WCS), photometric scale (PHOTZP) and dynamic range (ABMAGLIM, ABMAGSAT) in order to qualify as Science Data Product according to the ESO/SDP standard.

Taking into account that the accuracy of these calibrations varies depending on the scientific goals for which the data was obtained, the ESO/SDP standard does not specify a fixed level of accuracy for calibrations but allows to encode their quality using specific keywords, namely CRDERi, CSYERi, and PHOTZPER.

It means in practical terms that the image WCS may be defined based on the information given in the raw data if it is not feasible to register the image with respect to an astrometric reference catalogue. Similarly, the photometric scale and depth of the image data may be estimated based on the nominal instrumental characteristics (default instrumental zero points, exposure time calculator) if photometric standards have not been obtained as part of the observation. The larger uncertainty associated with the estimated photometric properties needs to be expressed by setting PHOTZPER to an appropriate value.

PSF width and image ellipticity must be provided.

For imaging data the ESO filter designation must be recorded in the data product.

For the temporal characterisation, each image must record the time of observation in terms of the modified Julian date. This requires the accurate propagation of the information stored in the raw data to the final product(s).

6.1.1 Astrometry

Celestial coordinates shall be assigned to image pixels using the FITS convention for world coordinates [RD1] in which image distortions should be taken into account if need be. For celestial coordinates the International Celestial Reference System (ICRS) is the preferred standard.

It is recommended to quantify the uncertainties of the astrometric registration using the FITS keywords CSYERi and CRDERi for the systematic and random parts to the error budget, respectively (see below for more details).

6.1.2 Photometry

The flux scale of imaging data should refer to a suitable photometric system. It should be specified either logarithmically in terms of the zero point magnitude or in terms of the linear scaling factor of the flux depending on the usual practice for the type of observation under consideration.

The zero point magnitude can be defined with respect to the Johnson system where fluxes are normalised with respect to Vega, or using the AB photometric system (Oke & Gunn, 1983 [RD7]).

It is recommended to provide an estimate of the uncertainty of the photometric/flux calibration (PHOTZPER) quantifying the total error budget including all possible systematics, e.g. the illumination effect unless it has been corrected for.

6.2 Data format

Imaging products can refer to either single images (see section 6.2.1) or image mosaics (see section 6.2.2). An overview of the different data formats supported in the case of imaging data is given in Table 4.

Number N of science image arrays per file	Location of the error / quality / confidence / background maps	FITS format	PRODCATG SCIENCE.*	ASSOC ANCILLARY.* mechanism *for the maps*	HDUCLASn and complementary keywords mechanism	Document section
One single image (N=1)	Separate FITS files	Simple FITS (data in primary HDU)	IMAGE	yes	Not Allowed	6.2.1.1
One single image (N=1)	FITS extensions (same file)	Multi-extension FITS (MEF)	IMAGE	N/A	yes	6.2.1.2
Image mosaic (N>1)	Separate FITS files	Multi-extension FITS (MEF)	MEFIMAGE	yes	N/A	6.2.2

Table 4: overview of supported data formats for imaging data

6.2.1 Single or tile image

A single image (also known as a tile image, PRODCATG='SCIENCE.IMAGE'), is a filled area of sky fully sampled. It can originate either from exposures taken with a single detector or from the combination of multiple pawprints[21] thus filling in the gaps among the detectors.

In the case of VISTA, because of the detector spacing the minimum number of pointed observations (with fixed offsets) required for reasonably uniform coverage is 6, which would expose each piece of sky, except for the edges of the tile, on at least 2 detector pixels. An observation executed with the VISTA/VIRCAM template "VIRCAM_img_obs_tile6" results in a tile as data product. The tile is the basic building block of e.g. the VISTA public surveys.

Similarly, OmegaCAM tile is the basic building block of VST public surveys. The tile is a fully sampled image consisting of the co-addition of a number of dithered exposures (generally four or five). It is a single image, slightly larger than one square degree. An observation executed using a dither sequence with the OmegaCAM template "OMEGACAM_img_obs_dither" results in a tile as data product.

A single image and its error and quality information can be packaged in two different formats, which are described below. Note that even though single images can be provided in different formats, they still share the same PRODCATG value, namely 'SCIENCE.IMAGE'.

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[21] A pawprint is a mosaiced image of the focal plane with significant gaps among the detectors.

6.2.1.1 Associated file format

A single image in the "associated file format" stores the science data array in the primary HDU of the main FITS file which has PRODCATG='SCIENCE.IMAGE'. Its error, quality and confidence maps are provided as associated distinct FITS files characterised by the presence in their primary header of the keyword PRODCATG with the values 'ANCILLARY.RMSMAP', 'ANCILLARY.MASK', and 'ANCILLARY.WEIGHTMAP', respectively. Other types of ancillary data may be associated as separate files.

Required and optional FITS header keywords for a single image in the „associated file format" are listed in Table 8.

6.2.1.2 Multi-Extension File (MEF) format

A single image in the "MEF format" stores both the science data array and its error, quality, confidence and background information into one single FITS file, as multiple extensions. The primary HDU shall not contain any data. Other types of ancillary data may be associated as separate files.

The main requirements for the encoding of information are listed below, more details can be found in [RD6].

1. Science, background, error, data quality and confidence information shall be stored in different HDUs of the same FITS file using the scheme of referencing keywords according to [RD6].
2. It is recommended to associate pixel-by-pixel error with the science data image, and it is optional to associate data quality information with the science data image. If the data quality extension is missing, the bad pixel status should be encoded as *NaN* values in the data, error and confidence extensions.
3. Each HDU with data must be identified via EXTNAME.
4. The dimensions and WCS of the error, data quality and confidence units shall be identical to the science unit. For background data, a different WCS is allowed.
5. The primary unit of the FITS file shall not contain data.
6. The order of the extensions (science, error, data quality, confidence, background) is recommended though any other choice is possible.
7. The header shall contain a reference to the format (HDUCLASS) and document (HDUDOC, HDUVERS) describing the classification and to the HDU types (HDUCLAS*) appropriate to that format, see section 5.10.

The headers shall have specific keywords pointing to the complementary information. The values of the SCIDATA, ERRDATA, QUALDATA, CONFDATA, BKGDATA, BKGERR, BKGCONF keywords shall contain the value of the EXTNAME keyword of the appropriate extension. EXTVER should not be used for unique identification of HDUs.

Required and optional FITS header keywords for a single image in the „MEF format" are listed in Table 8.

6.2.2 Image mosaic or pawprint

An image mosaic (also known as a pawprint image), PRODCATG='SCIENCE.MEFIMAGE') refers to a non-contiguous image of the sky pointing produced by the combination of the instrumental design and the observing strategy. The pawprint or footprint shape specifies the detector coverage of the focal plane.

For instance, the 16 non-contiguous images of a sky pointing produced by the VIRCAM camera, with its 16 non-contiguous detectors are termed VISTA pawprint image. The data are stored in 16 image

extensions of the multi-extension FITS file. According to the usual technique of observation in the NIR regime (jitter mode or offset sky), typically, the pawprint is the result of multiple exposures. An observation executed with the VISTA/VIRCAM template "VIRCAM_img_obs_tile1" for example results in a pawprint as data product.

Similarly, the 32 non-contiguous images of a sky pointing produced by the OmegaCAM camera, with its 32 non-contiguous detectors are termed an OmegaCAM pawprint image. The data are stored in 32 image extensions of the multi-extension FITS file. A pawprint is comprised of single or co-added exposures, with some or no fraction of the gaps filled. An observation executed with the OmegaCAM template "OMEGACAM_img_obs_jitter" (to shift cosmetic CCD blemishes to different parts of the sky) or "OMEGACAM_img_obs_stare" (one fixed pointing position) results in a pawprint as data product. An observation executed with the "OMEGACAM_img_obs_offset" always results in practice in a pawprint as data product, although it could in principle result in a tile given that this particular template allows for user-defined offsets in between exposures.

A pawprint image stores the science data arrays as multiple extensions within the main FITS file which has PRODCATG='SCIENCE.MEFIMAGE'. Its error, quality and confidence maps are all provided as associated individual FITS files with PRODCATG='ANCILLARY.RMSMAP', 'ANCILLARY.MASK', and 'ANCILLARY.WEIGHTMAP' respectively. Other types of ancillary data may be associated as separate files.

Required and optional FITS header keywords for a pawprint image in the MEF format are listed in Table 8.

7. Flux maps

7.1 Data definition

This section defines the image data format for fully reduced, astrometrically registered and flux calibrated sky maps, as for example in the submillimeter domain for observations using the bolometer arrays LABOCA and ARTEMIS at the APEX 12-metre telescope.

The image array represents the spectral flux density in units of Jansky per beam or a decimal fraction thereof like milli-Jansky per beam as declared in the BUNIT keyword.

FLUXERR specifies the uncertainty of the absolute flux calibration including all contributing effects, i.e. the instrumental calibration, atmospheric conditions in terms of the precipitable water (PWV) and stability, and the calibration source.

The effective spatial resolution of the flux map, given by the keyword SKY_RES, accounts for the combined effect of the instrumental beam size and any additional smoothing possibly applied to the data during map synthesis.

The uncertainties of the astrometric registration for a flux map are quantified using the FITS WCS keywords CSYERi and CRDERi for the systematic and random parts to the error budget, respectively.

7.2 Data format

Required and optional FITS header keywords for the flux map format are listed in Table 8.

The data array should reside in the primary header data unit (HDU) of the FITS file[22].

7.3 Inapplicable keywords

ABMAGLIM must not be present, use BNOISE instead.

8. Spectroscopic products

8.1 Data definition

This section applies to individual spectra originating from single as well as multi-object spectroscopic observations. Each one-dimensional spectrum shall be stored in the spectrum binary table format. Although that format allows storing multiple science spectra within the same FITS file, we require that each FITS file contain only one science spectrum. Information associated to the science spectrum shall be stored within the same extension as the main science spectrum, for instance sky background-subtracted spectrum, error spectrum, data quality, best fitted model for the continuum. 2D spectral frames may be submitted in addition as associated files (see section 4.2).

The choice of spectral coordinates can be either wavelength, frequency, or energy. The spectral axis of spectral data should be calibrated to proper physical units, e.g. nanometer.

For spectral data in the spectrum binary table format, the wavelength axis shall have values between TDMIN and TDMAX. Different binnings are allowed. The sequence of elements of the wavelength vector for 1D spectra must be in ascending order, i.e. strictly increasing. Same for the frequency and energy vectors.

In case the spectral data have been calibrated to absolute flux density, the flux scale should be given in physical units, e.g. in erg.s**(-1).cm**(-2).angstrom**(-1).

8.2 Data format

The spectrum binary table format is VO-compliant in the sense that it complies to the basic requirements of the VO format [RD3], both in terms of structure and header keyword names and values.

The 1D spectrum is serialised in a binary table as a single record, with as many cells as needed (e.g. one for the wavelength, one for the flux, etc.), each cell containing one array of data points, and with arrays across all cells of equal size. Despite being supported by FITS, the usage of variable length arrays is not allowed in Phase 3, as such format is not well supported by the existing spectral tools. Only standard BINTABLE extensions are allowed; this implies PCOUNT=0 and GCOUNT=1.

The spectrum binary table format is made of one primary header (no data in the primary HDU, that is NAXIS=0) and one single extension. The extension has its own header unit and one BINTABLE with NAXIS=2. The data arrays are stored as vectors in single cells. As a consequence, there shall be only one row in the BINTABLE, that is NAXIS2=1.

Each field of the BINTABLE shall be further described in the extension header as specified in Section 5.18. Mandatory fields shall be the name of the spectral coordinate (WAVE, FREQ, or ENER), FLUX,

---

[22] FITS extensions may be present, e.g. to encode the list of original science data files in terms of a FITS table instead of using a list of indexed header keywords, see section 5.2.2.

and ERR, in that particular order. Additional fields may be added to the BINTABLE (see Table 5 for some examples), in which case the values for their type, format, unit, and UCD (see section 5.18) shall be provided and described by the data provider in the release description document.

TTYPE*i* value	Description
WAVE	The wavelength array
FREQ	The frequency array
ENER	The energy array
FLUX	The data spectrum: either the sky-background subtracted spectrum or the continuum normalised spectrum.
ERR	The error spectrum. It is not allowed to express errors on the flux of a 1D spectrum as a percentage. The values of the error array associated to the flux of a 1d spectrum must be provided in the same units of the values in the flux array.
QUAL	It is an array of integer values with the following encodings: 0 means good data, 1 means bad for an unspecified reason (e.g. no data in the sample interval), and other positive integers greater than 1 may be used to flag data which is bad or dubious for specific reasons. If there is no quality information provided, all values are taken as good data. We encourage the data quality of each pixel to be encoded in terms of the sum of powers of 2, each 'bit' corresponding to a quality condition.
BGFLUX	The sky background spectrum
CONTINUUM	The continuum spectrum
EXPOSURE	The exposure array for e.g. combined spectra of different wavelength coverage.

Table 5: Mandatory (in bold) and optional TTYPE*i* fields for the 1D spectrum binary table format.

Typically (case 1), a 1D spectrum typically has got one array for the spectral coordinate, and one for the flux. Less frequently (case 2, e.g. in case a spectrum has been reduced with different processing recipes), a 1D spectrum may be provided with multiple arrays, e.g. one for the flux computed using recipe A, and another one for the flux computed using recipe B.

The SDP standard supports both cases. In the first case, one must use the IVOA Spectrum data model standard v1.1 to describe the various arrays. In the second case, one must use a different convention, extending the IVOA Spectrum data model v1.1. To distinguish between the two cases, one has to set in the header of the first extension of the spectrum FITS file the VOCLASS keyword to either 'SPECTRUM v1.0' or 'SPECTRUM v2.0'. Then one has to specify the TUTYPn differently in the two cases:

Case 1: a spectrum with a single array for the spectral coordinate, and a single array for the flux.

```
VOCLASS = 'SPECTRUM v1.0'  / VO Data Model
TTYPE1  = 'WAVE    '              / Label for field 1
TTYPE2  = 'FLUX    '              / Label for field 2
TTYPE3  = 'ERR     '              / Label for field 3
TUTYP1  = 'Spectrum.Data.SpectralAxis.Value'
TUTYP2  = 'Spectrum.Data.FluxAxis.Value'
TUTYP3  = 'Spectrum.Data.FluxAxis.Accuracy.StatError'
```

Everything goes as per the IVOA standard v1.1.

Case 2: a spectrum with multiple arrays of the same Utype.

Let's suppose the spectrum contains two flux columns, computed with recipes A and B, and supposed that the submitter names them respectively FLUX_A and FLUX_B. The data submitter has to choose which column contains the flux to be served by default to the community, that is, the flux that a tool will automatically display to the user. Let's suppose that the default flux is FLUX_A. In this case the header looks like this:

```
VOCLASS = 'SPECTRUM v2.0'  / VO Data Model
TTYPE1  = 'WAVE    '          / Label for field 1
TTYPE2  = 'FLUX_A  '          / Label for field 2
TTYPE3  = 'ERR_A   '          / Label for field 3
TTYPE4  = 'FLUX_B  '          / Label for field 4
TTYPE5  = 'ERR_B   '          / Label for field 5
TUTYP1  = 'spec:Data.SpectralAxis.Value'
TUTYP2  = 'spec:Data.FluxAxis.Value'
TUTYP3  = 'spec:Data.FluxAxis.Accuracy.StatError'
TUTYP4  = 'eso:Data.FluxAxis.Value'
TUTYP5  = 'eso:Data.FluxAxis.Accuracy.StatError'
```

Whereby the suffix "spec:" is used to describe the most important/default columns, while "eso:" (or any other choice) is used for the other columns. Also, the TUCDn (see section 5.18) of the main flux and of the main error must be marked with the token 'meta.main', as in:

```
TUCD1   = 'em.wl;obs.atmos'    / em.wl: vacuum, em.wl;obs.atmos: air
TUCD2   = 'phot.flux.density;em.wl;meta.main'
TUCD3   = 'stat.error;phot.flux.density;em.ql;meta.main'
```

Another common case is the case of a data submitter decides to publish as main flux, the spectrum normalised to the continuum, but wants also to store the flux not normalised. In this case, the primary header must contain the header keyword:

```
CONTNORM =          T
```

and the header in the first extension looks like this:

```
VOCLASS = 'SPECTRUM v2.0'  / VO Data Model
TTYPE1  = 'WAVE    '          / Label for field 1
TTYPE2  = 'FLUX_NORM'         / Label for field 2
TTYPE3  = 'ERR_NORM'          / Label for field 3
TTYPE4  = 'FLUX    '          / Label for field 4
TTYPE5  = 'ERR     '          / Label for field 5
TUTYP1  = 'spec:Data.SpectralAxis.Value'
TUTYP2  = 'spec:Data.FluxAxis.Value'
TUTYP3  = 'spec:Data.FluxAxis.Accuracy.StatError'
TUTYP4  = 'eso:Data.FluxAxis.Value'
TUTYP5  = 'eso:Data.FluxAxis.Accuracy.StatError'
TUCD1   = 'em.wl;obs.atmos'   / em.wl: vacuum, em.wl;obs.atmos: air
TUCD2   = 'phot.flux.density;em.wl;arith.ratio;meta.main'
TUCD3   = 'stat.error;phot.flux.density;em.ql;arith.ratio;meta.main'
TUCD4   = 'phot.flux.density;em.wl'
TUCD5   = 'stat.error;phot.flux.density;em.ql'
```

Notice that the UCD [RD2][RD4] reflects the choice of which one is the main flux (and relative error) using the token 'meta.main', and also reflects the fact that a flux is normalised using the UCD token

'arith.ratio' and the value of the TUNIT2 keyword shall be set to an empty string to signify that it is dimensionless and having no units of measurement.

Further required and optional FITS header keywords for the 1D spectrum binary table format are listed in Table 8. Below follow additional specifications regarding those keywords:

Req-1. NELEM: All data arrays in the first row of the binary table shall have the same number of points.

Req-2. Given that the optional fields (e.g. QUAL, BGFLUX, CONTINUUM) are not always applicable to all data products, the order of their indexing is left up to the data provider.

Req-3. Net and total FLUX are distinguished by the 'src.net' adjective for TUCD2 (see section 5.18).

Req-4. Please refer to the table in the Appendix (see section 16) for a list of possible TUNIT and TUCD values for the FLUX field.

Req-5. Within a given FITS file, all EXTNAME keyword values shall be unique.

Req-6. There may be at most one BGFLUX field present.

Req-7. For data that are not normalised to the continuum, the TUCD and TUNIT of the BGFLUX field shall be the same as for the FLUX field.

Req-8. To discriminate wavelength measured in dry air (at standard temperature and pressure) from the wavelength measured in vacuum, TUCD1 (see section 5.18) must be set to 'em.wl;obs.atmos' and 'em.wl', respectively. For improved human readability when browsing the FITS header, it is recommended to add a respective comment to the line defining the TUCD1 keyword.

Req-9. If the flux is telluric corrected, TTYPEi should be set to 'FLUX_TELLURIC'.

Req-10. If TTYPEi = 'EXPOSURE', TUCDi shall be set to 'time.duration;obs.exposure' and TUTYPEi to an empty string ('').

When the spectral axis is given in air wavelength:

```
TTYPE1   = 'WAVE'
TUCD1    = 'em.wl;obs.atmos' / Air wavelength
```

When the spectral axis is given in vacuum wavelength:

```
TTYPE1   = 'WAVE'
TUCD1    = 'em.wl'  / Vacuum wavelength
```

Note: WAVELMIN and WAVELMAX need to be specified in either air or vacuum wavelength consistent with the definition of the spectral axis.

8.3 Inapplicable keywords

- BUNIT shall not be used in the headers of 1D spectroscopic data products. To provide unit and a scaling factor please use the relevant TUNITn keyword(s).

9. Source list products

9.1 Data definition

The source list provides the file format for the tabular data of sources extracted from imaging data products. Typically the source list is pipeline-produced, using the nightly calibrations and is delivered on an image-by-image basis.

The term „source list„ was chosen in contrast to the term "source catalogue", which are data products processed to a higher level where not only bands but also tiles are merged and a global calibration across tiles is required.

Multi-band source lists are not supported.

Any source list is necessarily associated to its originating image due to its processing provenance.

9.2 Data format

The source list is based on the FITS binary table format. Each data array of the originating image gives rise to one binary table extension in the FITS file. Thus, the source list of a VISTA tile contains one single binary table extension while the source list of VISTA pawprint contains 16 binary table extensions. The primary HDU does not contain data.

Required and optional FITS header keywords for the source list format are listed in Table 8.

9.2.1 Propagation of keyword values from the image to the source list

The source list adopts a number of keywords that characterise the originating imaging observation to facilitate direct archive queries. The keywords that characterise the observation at large, namely ORIGIN, TELESCOP, INSTRUME, FILTER, OBJECT, EQUINOX, RADESYS, EXPTIME, TEXPTIME, MJD-OBS, MJD-END, PROG_ID, OBIDi, NCOMBINE, OBSTECH, REFERENC should be adopted from the original image from which the sources were extracted.

Similarly, the FITS header keywords PHOTSYS, ABMAGLIM, ABMAGSAT, PSF_FWHM, and ELLIPTIC shall be defined consistently in images (PRODCATG=SCIENCE.IMAGE/MEFIMAGE) and derived source tables (SCIENCE.SRCTBL).

10. IFS 3D cube products

10.1 Data definition

The data format being defined in this section applies to reduced integral field spectroscopy data, in particular to observations using the VLT instruments ERIS, SPHERE, KMOS, MUSE, SINFONI and XSHOOTER in IFU mode. The science data cube represents the main data type for integral field spectroscopy products.

Herein it is assumed that the data reduction process includes the following steps, though not necessarily in the given sequence: astrometric calibration, calibration of the dispersion axis to physical wavelength scale, removal/correction for instrumental and sky background signal (if applicable), calibration of the detected signal to physical scale (spectral flux density), re-sampling to a regular 3-dimensional grid, signal combination of multiple exposures (if applicable), error propagation in each processing step to obtain a final error estimate for the science data, and propagation of pixel quality information. Telluric correction may be an optional step among the data reduction sequence.

10.2 Data format

The spectral flux density – in physical units as declared in the BUNIT keyword – is stored as 3-dimensional FITS image (called "science data cube" hereafter) with the first two array dimensions NAXIS1/2 representing the projected celestial coordinates and the third dimension NAXIS3 the

spectral coordinate. Celestial and spectral coordinates are encoded following the FITS WCS conventions [RD1] and [RD5], respectively.

The science data cube is stored in a FITS image extension, i.e. the primary HDU shall not contain any data. Error and data quality information, when present, are included as additional extensions within the same FITS file. Other types of ancillary data may be optionally associated as separate files.

Taking into account that science data cubes normally employ the 32- or 64-bit floating-point data format signified by BITPIX = -32 or -64, the use of the BSCALE and BZERO keywords is **not recommended**[23].

Storing several sets of HDUs with associated science data, error and data quality in a single FITS file, though permitted in [RD6], is not supported by the ESO/SDP standard. Only three HDUs are permitted of which one must be the science data and the other two are the error extension and the data quality extension. Other kind of extensions, except for PROVXTN, are currently not supported[24].

The main requirements for the encoding of error and data quality information are listed below, more details can be found in [RD6].

1. Science, error and data quality information shall be stored in different HDUs of the same FITS file using the scheme of referencing keywords according to [RD6].
2. It is recommended to associate pixel-by-pixel error with the science data cube, and it is optional to associate data quality information with the science data cube. If the data quality extension is missing, the bad pixel status should be encoded as *NaN* values in the data and the error extensions.
3. Each HDU with data must be identified via EXTNAME.
4. The dimensions and WCS of the error and data quality units shall be identical to the science unit.
5. The primary unit of the FITS file shall not contain data.
6. The order of the extensions (science, error, data quality) is recommended though any other choice is possible.
7. The header shall contain a reference to the format (HDUCLASS) and document (HDUDOC, HDUVERS) describing the classification and to the HDU types (HDUCLAS*) appropriate to that format, see section 5.10.
8. The headers shall have specific keywords pointing to the complementary information. The values of the SCIDATA, ERRDATA, QUALDATA keywords shall contain the value of the EXTNAME keyword of the appropriate extension. EXTVER should not be used for unique identification of HDUs.

Required and optional FITS header keywords for the IFS cube format are listed in Table 8.

10.3 Inapplicable keywords

SPEC_BIN should not be present, use CD3_3 instead.

---

[23] Expressing the pixel values in units which are not physical (e.g. adu, counts, or similar) with the addition of a zeropoint or scale factor to scale the cube to physical units is explicitly not allowed.
[24] The requirement of one unique science data HDU applies to the main science file but not to the associated ancillary files, which may contain multiple data extensions, referring for example to individual instrument arms, dispersion orders, or exposures.

11. Interferometric products

11.1 Data definition

This section 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. Updates to this document may be required to deal with data from other interferometric instruments at a later stage.

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.

The visibility data are the primary products and are derived from complex visibilities including amplitudes and phases and their derivatives such as squared amplitudes and closure phases.

For each of the main science products, two associated preview files (transfer function OI_VIS2 and OI_T3) have to be provided. Other types of ancillary data may be optionally associated as separate files.

11.2 Data format

Data must be in OIFITS format, and the primary HDU must not contain any data. The format of the main header of the data files follows the OIFITS2 standard [AD4], but includes additional main header keywords suitable for archive services, while the binary extensions format follows the OIFITS1 standard [AD3]. 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 required and optional Phase 3 FITS header keywords for the interferometric products are listed in Table 8. The other keywords required in order to be compliant with OIFITS are not listed in Table 8 and we refer the user to [AD3, AD4] for a detailed list. The following extensions OI_ARRAY, OI_TARGET, OI_WAVELENGTH, OI_VIS2, and OI_T3 and their associated mandatory keywords must be provided (see header example in section 17). Neither keywords nor columns appear in a specific sequence in a table extension.

Below follow additional specifications:
Req-1. CONTENT: It has to be set to 'OIFITS1'.
Req-2. INSMODE: Possible values: 'FREE_H', 'GRISM_H', 'FREE_K', 'GRISM_K'.
Req-3. 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.
Req-4. 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.
Req-5. SPEC_ERR: The error is hardcoded to 0.5% of the wavelength as it corresponds to the dispersion of the 6 baselines.
Req-6. SPEC_SYE: 100 nm for FREE, << 94 nm for GRISM.

12. Catalogue products

12.1 Data definition

The catalogue data format applies to astronomical catalogues (including multi-colour photometric source catalogues, catalogues of variables, proper motion catalogues, target catalogues for spectroscopic surveys, galaxy redshift catalogues, catalogues of stellar properties and chemical abundances) and similar scientific data in tabular format (multi-epoch photometry a.k.a. light curves) produced by ESO Public Surveys and other ESO observing programmes.

A given survey may produce more than one source catalogue. For instance, using different source extraction techniques, optimised according to the type of source, two distinct catalogues can be generated, one which includes point-like sources, another for extended sources.

12.2 Data Format

Required and optional FITS header keywords for the single-file and multi-file catalogue formats are listed in Table 8.

12.2.1 Single-file format

This format applies for example to the scientific source catalogues resulting from programnes covering small patches on the sky (e.g. deep surveys such as UltraVISTA). It is also generally suitable for the target catalogues of spectroscopic public surveys. The entire scientific catalogue is submitted in the form of one single FITS file with the format declaration:

```
PRODCATG = 'SCIENCE.CATALOG' / Data product category
```

in the primary header and the catalogue data being stored in the binary table extension identified by:

```
XTENSION= 'BINTABLE' / FITS Extension first keyword
EXTNAME = 'PHASE3CATALOG' / FITS Extension name
```

The simple catalogue format supports catalogues having less than 50 million records (table rows). Catalogues exceeding this limit or resulting from surveys covering large areas on the sky in a regular pattern (e.g. VHS) shall be submitted in a tile-by-tile fashion using the multi-file catalogue format (section 12.2.2).

The keyword EXTNAME = 'PHASE3CATALOG' identifies the FITS extension that contains the catalogue data. Note that the keywords EXTVER and EXTLEVEL are *not allowed*.

12.2.2 Multi-file format

This format applies to surveys covering large contiguous areas on the sky in a regular pattern (e.g. VHS) or to catalogues that are simply too big for the single-file format, i.e. containing more than 50 million records (table rows) per file (e.g. NGTS). This format may also be applied in the case of catalogues displaying an irregular pattern of coverage, like e.g. target catalogues of spectroscopic observations which cover several well-defined non-contiguous regions (e.g. VANDELS). In that case all targets of a given region should belong to the same tile (though it can be further split if the limit of 50 million records per tile is reached).

The catalogue data are submitted in the form of multiple FITS files, each of them corresponding to one catalogue tile. Then, the data files will be automatically concatenated during archive ingestion into the database used to perform searches on its records.

12.2.2.1 Metadata file

Using the multi-file format each survey catalogue consists of one metadata file (PRODCATG=SCIENCE.MCATALOG) and *N* (>1) logically associated catalogue data files (PRODCATG=SCIENCE.CATALOGTILE). The metadata file, which contains the global definitions for the entire catalogue in the primary header, is declared by

```
PRODCATG = 'SCIENCE.MCATALOG' / Data product category
```

The binary table extension of the metadata file specifies the structure of the catalogue in terms of the complete set of catalogue column definitions (section 5.18) but does not contain data, i.e., the binary table has zero rows.

For the CATALOGTILES to be logically associated to the MCATALOG meta file, the following scheme is used: a second extension of the MCATALOG metadata file includes the list of associated CATALOGTILEs encoded as a dedicated FITS binary table. The table stores the filename (ORIGFILE) of each CATALOGTILE, using one record per CATALOGTILE.

Specifically required FITS header keywords (binary table extension):

```
XTENSION= 'BINTABLE'
BITPIX = 8
NAXIS = 2
NAXIS1 = %d
NAXIS2 = %d
PCOUNT = 0
GCOUNT = 1
TFIELDS = %d
TTYPEi = 'ORIGFILE'
TFORMi = 'nA '
EXTNAME = 'PHASE3FILELIST'
```

NAXIS2 equals the total number of CATALOGTILEs. The table must consist of one single ORIGFILE column at minimum. The table may contain more columns, having TTYPEi different from ORIGFILE, if the data provider intends to record further file parameters of interest.

12.2.2.2 Catalogue data files

The associated catalogue data files have:

```
PRODCATG = 'SCIENCE.CATALOGTILE' / Data product category
```

in the primary header and contain all the catalogue data together with a minimum set of mandatory keywords in their binary table extensions as per Table 8.

The keyword EXTNAME = 'PHASE3CATALOG' identifies the FITS extension that contains the catalogue data. Note that the keywords EXTVER and EXTLEVEL are *not allowed*.

The column definitions in the metadata file apply to all data files of this catalogue. Each catalogue data file must define column labels (TTYPE*i*), data types (TFORM*i*), unified content descriptors (TUCD*i*), units (TUNIT*i*) (see section 5.18) consistent with the definitions provided in the metadata file. The TUNIT*i* keyword shall always be present, even for quantities having no units of measurements, in which case its value shall be set to an empty string.

The value of TFIELDS must be the same for each catalogue file.

To successfully pass Phase 3 validation each catalogue data file must include the indexed keyword TCOMM*i*, one for each catalogue column.

The tile-by-tile submission scheme is no replacement for source merging in the overlapping region of adjacent survey tiles. In practice, the Phase 3 data provider will define the final catalogue tiles (without overlaps) at last after cross-calibration and merging of the data in overlapping image areas.

The processing provenance (encoded in the PROV*i* keywords, in the dedicated FITS file extension or in a dedicated catalogue column) records the list of original science files that were used as input to produce the data of this catalogue file. Normally these are again Phase 3 science data products like images or source lists depending on the details of the reduction strategy.

12.2.2.3   Header keyword values

The values of the keywords applicable to catalogue data (e.g. MJD-OBS, MJD-END, FILTERi – see Table 8 for the complete list) shall characterise the entire catalogue when present in the SCIENCE.MCATALOG metadata file, whereas the values of those keywords shall refer to the characterisation of the individual catalogue data files when present in the SCIENCE.CATALOGTILE products.

12.2.3 Column definitions

Each catalogue parameter is defined in terms of the keywords of section 5.18.

About TTYPE*i*: Every column of the catalogue shall be assigned a concise, unique, case-insensitive name. E.g., 'KMAG' and 'Kmag' are interpreted as the same name. It is required that the character string to be composed only of upper and lower case letters, digits, and the underscore ('_', decimal 95, hexadecimal 5F) character.

The reserved keywords listed in Appendix B (see section 15) *must not* be used as column names. Because of the case-insensitive interpretation, this means for instance that neither 'DEC' nor 'Dec' are supported as column names.

12.2.4 Data format types

The data format types supported for science catalogues are listed in Table 6. The provider of catalogue data selects a format appropriate to the form, range of values, and accuracy of the data.

The value of each TFORMn indexed keyword shall contain a character string of the form rT. The repeat count r is the ASCII representation of a non-negative integer specifying the number of elements in field n. The default value of r is 1; the repeat count need not be present if it has the default value. The data type T specifies the data type of the contents of field n. Only the data types listed in Table 6 are supported. The field types P and Q are not supported.

Empty catalogue columns (where the repeat count specified in the value of the TFORM*i* keyword of the header is 0) are not permitted. The repeat count r must not exceed 1500[25]. With that limitation in mind, numerical arrays can be used for example to encode light curves and one dimensional probability distribution functions.

The end of a data array should be padded with *NaN* in case it has less data points than the repeat count given in TFORM.

TFORM*i*	Description	8-bit Bytes
L	Logical	1
A	Character	1
B	Unsigned 8-Bit Integer (Byte)	1
I	16-Bit Integer	2
J	32-Bit Integer	4
K	64-Bit Integer	8
E	Single Precision Floating-Point	4
D	Double Precision Floating-Point	8

Table 6: Supported data format types for science catalogues

12.2.5 Physical values

Catalogues to be submitted via Phase 3 must directly store the physical values for each parameter without any scaling. The keywords TZERO*i* and TSCAL*i* must not be used in the header definition.

12.2.6 Missing data

Sometimes a measurement could not be obtained for all parameters of a catalogue record, for example drop-outs in a multi-colour photometric catalogue. The fact that information is missing must be represented in the respective catalogue fields using the special NULL value according to Table 7. Entire columns that do not contain any valid data (dummy columns, padding) are not accepted and must be removed from the catalogue before data submission.

TFORM*i*	NULL representation
L	A 0 byte (hexadecimal 00) indicates a NULL value.
*n*A	Null strings are defined by the presence of an ASCII NULL as the first character.
B, I, J, K	Null values are given by the value of the associated TNULL*i* keyword.
E, D	The IEEE *NaN* ("Not a Number") is used to represent null values.

Table 7: Representation of the special NULL value

TNULL must not be used for identifiers whose fields carry the following UCD: TUCDn = 'meta.id;meta.main' (e.g. source_id).

Note that special IEEE values other than *NaN*, e.g. 'Infinity', are not permitted in Phase 3 science catalogue data.

---

[25] This limit is imposed by the current database system configuration. Please contact Phase 3 operations support staff at https://support.eso.org/ prior to submission if your data has more elements per field.

12.2.7 Unique record identifier constraint

Each catalogue[26] has one column that serves as unique identifier for its records and which is indicated by the value of the UCD attribute:

```
TUCDi = 'meta.id;meta.main' / Unified content descriptor
```

The identifier must be of string or integer data type having a minimum data type size to ensure global uniqueness in the context of the entire catalogue. For catalogues in multi-file format it means that the identifier must be unique with respect to the union set of all catalogue files. The unique identifier must not assume the special NULL value.

See section 12.4.1 for the application of this concept in the context of source catalogues.

For multi-epoch catalogues described in section 12.5.1, the combination of two columns shall be unique.

12.2.8 Propagation of keyword values from science files to a catalogue

When FITS keywords are propagated from science files to a catalogue, keyword names and values must be propagated consistently. It means:
- TTYPEi has to be set to the keyword name[27].
- TFORMi has to be defined according to the data type of the keyword (character string => A, numeric integer => I,J, floating point => D,E)
- For each catalog record, the keyword value must be propagated from the science file corresponding to this record.
- Values must be preserved, in case of numbers, within the bounds of the numerical precision.

A common use case are spectroscopic surveys when the OBJECT keyword is propagated from the spectrum file to the spectroscopic catalogue. In the example below:

- spectrum1.fits contains the keyword name/value OBJECT = '19100733-6002595'
- spectrum2.fits contains the keyword name/value OBJECT = '19100732-6002594'

which corresponds to the following catalogue entries:

OBJECT	RA	DECLINATION	VRAD
"19100733-6002595"	287.53054166666175	-60.0498611111101	-12.40915
"19100732-6002594"	287.5304999999952	-60.04983333333232	-2.2271502

with the column definition TTYPE1 = 'OBJECT' and TFORM1 = '16A'.

12.3 Data link definition

It is possible to define a data link between a reference catalogue and a target catalogue. To define the target catalogue of a data link between two catalogues, the TXLNKi, TXRGFi, and TXCTYi keywords are to be specified in the reference catalogue.

---

[26] With the exception of multi-epoch catalogues formatted as per section 12.5.1.
[27] Within the limitations of accepted TTYPEs, for example: DEC cannot be directly propagated to TTYPE. See section 12.2.3 for more information.

- TXLNK*i* has the fixed string value 'CATALOG' to indicate the type of data link.
- TXRGFi (type character string) must declare the filename of the target catalogue in terms of the ORIGFILE name.
- TXCTY*i* defines the column in the target catalogue which contains the unique source identifier.

A typical example is the data link between a variability catalogue (as per section 12.6) and a source catalogue.

Another example is the data link between a multi-epoch catalogue (as per section 12.5.1) and a source catalogue. The multi-epoch catalogue acts as reference catalogue and the source catalogue as target catalogue. The FITS extension header of the multi-epoch catalogue records the data link to the source catalogue using the dedicated keywords TXLNK*i*, TXRGF*i*, and TXCTY*i* associated to the SOURCE_ID column (column TTYPE3 in the example below).

Extension header of the multi-epoch catalogue:

```
TXLNK3 = 'CATALOG ' / Data link type
TXRGF3 = 'vmc_er3_yjks_catMetaData.fits' / Target catalogue
TXCTY3 = 'SOURCE_ID' / Target catalogue's TTYPE
TTYPE3 = 'SOURCE_ID'      /
TFORM3 = 'K'              /
TUNIT3 = ' '              /
TUCD3  = 'meta.id'        /
TCOMM3 = 'UID of this merged detection' /
```

In case the target catalogue is a multi-file catalogue (section 12.2.2), as in the example above, the data link must point to the filename of the meta catalogue file (PRODCATG='SCIENCE.MCATALOG').

In case of a reference catalogue in the multi-file format (see section 12.2.2), the data link has to be defined only in the extension header of the metadata file, and not in each catalogue tile.

12.4 Source catalogue

The source catalogue represents the high-level – often the final – data product of every astronomical survey. The source catalogue normally[28] contains *exactly one* entry for each source that has been detected and characterised during the survey programme, recording its best estimates for position, flux for each passband (i.e. apparent magnitudes), colours, morphology and other parameters depending on the scientific objectives.

12.4.1 Unique source identifier

Every source catalogue must have a unique source identifier.

The object identifier shall be defined either in the form of a character string (TFORM=xA) or a positive, non-zero integer number having 16, 32, or 64 bits (TFORM=I, J, or K).

Example:

```
TTYPE1  = 'SOURCE_ID'
TFORM1  = '30A'
TUCD1   = 'meta.id;meta.main'
```

Alternative TTYPE values are possible.

---

[28] An exception is for example a catalogue containing blended sources.

When defined according to the IAU recommendations for nomenclature[29], please use the following schema:

```
<prefix> J<hhmmss.ss+-ddmmss.s>
```

or, alternatively,

```
<prefix> J<hhmmss.sss+-ddmmss.ss>
```

where prefix denotes the survey programme. The source identifier serves as a reference key and must be recorded in any other catalogue that contains measurements for the given source, including for instance multi-epoch photometric data collections or catalogues of variables.
The source identifier must not assume the special NULL value.

In case of a moving object (e.g. high proper motion), the aim is to have a source identifier (in the catalogue products but also e.g. in spectra as encoded in the OBJECT keyword) that remains the same across different epochs. To achieve this, we recommend setting the source identifier of the object using the coordinates that correspond to the epoch of the first data product of that object submitted in the corresponding Phase 3 collection. That single source identifier is then propagated to any subsequent data products for that object delivered to the ESO Archive via Phase 3.

In case the data provider cannot use the IAU naming convention because of duplication/deblending problems, then please be aware of what follows: sources in the band merged catalogues with duplication/deblending problems should still have a unique identifier.

Survey PIs and data providers are responsible for the definition of source identifiers and their consistent application across different data products and Phase 3 releases.

The unified content descriptor (UCD) meta.id;meta.main shall be set to identify the catalogue column that represents the source identifier as in this example:

```
TTYPE1 = 'SOURCE_ID ' / Label
TFORM1 = '22A ' / Data format
TCOMM1 = 'VHS source designation' / Description
TUCD1  = 'meta.id;meta.main' / Unified content descriptor
```

There is no Phase 3 requirement for a particular column name. The names must comply with the restrictions specified in Section 12.2.3 (see keyword TTYPE*). Long integer type is ok. Here is an example:

```
TTYPE1 = 'SOURCE_ID'
TFORM1 = 'K '
TCOMM1 = 'Unique source identifier'
TUCD1  = 'meta.id;meta.main'
```

12.4.2 Equatorial coordinates (J2000)

Every source catalogue must contain Right Ascension and Declination in decimal degrees (J2000) to specify the celestial position of each source. The two coordinates must be identified in the FITS header by 'pos.eq.ra;meta.main' and 'pos.eq.dec;meta.main' set in the corresponding TUCD*i* keywords, for example:

```
TTYPE2  = 'RAJ2000 '            /
```

---

[29] http://cdsweb.u-strasbg.fr/Dic/iau-spec.html

```
TFORM2  = 'E          '            /
TCOMM2  = 'Right ascension in decimal degrees (J2000)' /
TUNIT2  = 'deg       '            /
TUCD2   = 'pos.eq.ra;meta.main' / Unified content descriptor
TTYPE3  = 'DEJ2000 '             /
TFORM3  = 'E          '            /
TCOMM3  = 'Declination in decimal degrees (J2000)' /
TUNIT3  = 'deg       '            /
TUCD3   = 'pos.eq.dec;meta.main' / Unified content descriptor
```

12.4.3 Galactic coordinates

Surveys primarily targeting galactic regions may include galactic coordinates *(l,b)* in addition to the equatorial ones, for example:

```
TTYPE4  = 'GLON    '            /
TFORM4  = 'E          '            /
TCOMM4  = 'Galactic longitude' /
TUNIT4  = 'deg       '            /
TUCD4   = 'pos.galactic.lon' / Unified content descriptor
TTYPE5  = 'GLAT    '            /
TFORM5  = 'E          '            /
TCOMM5  = 'Galactic latitude'  /
TUNIT5  = 'deg       '            /
TUCD5   = 'pos.galactic.lat' / Unified content descriptor
```

12.4.4 Fluxes and magnitudes

Fluxes and magnitudes must be aperture-matched, i.e. a correction must be applied to compensate PSF variations across the different bands.

12.4.5 Colour indices

Multi-band source catalogues should generally contain colour indices for each source in order to facilitate efficient queries including colour constraints. Each survey team is free to identify suitable colours according to their scientific objectives. The colour definitions should be documented in the data release description associated to each catalogue. Example for the definition of the

J-H colour index in the FITS header of a catalogue file:

```
TTYPE12 = 'J_H     '            /
TFORM12 = 'E          '            /
TCOMM12 = 'J-H colour index'   /
TDISP12 = 'F8.4     '            /
TUNIT12 = 'mag      '            /
TUCD12  = 'phot.color;em.IR.J;em.IR.H' / Unified content descriptor
```

12.4.6 Variable sources

Variable sources must be flagged in the source catalogue in a catalogue column whose TUCDn is set to 'meta.code;src.var', for example:

```
TTYPE1 = 'VARFLAG'
TFORM1 = 'L'
TUCD1  = 'meta.code;src.var'
```

12.4.7 Limiting magnitudes

For each band the approximate limiting magnitude must be provided as FITS header keyword value to characterise photometric catalogues. As explained in section 5.11, it is achieved by using ABMAGLIM for a single band, or MAGLIMi if multiple bands are provided. Usually this information can be adopted from the respective single-band source lists.

12.4.8 Upper limits

If an upper limit is reported instead of a flux estimate for a source in a catalogue, this case must be clearly marked e.g. by setting a flag in a dedicated column of the table.

12.5 Multi-epoch catalogue

Multi-epoch catalogues are data tables to record time-resolved measurements of astronomical object properties such as source flux or sky position. The time resolved measurements can be provided in two possible ways:

- A table whereby each record (i.e. catalogue row) consists of the measurements of one source obtained at one epoch. Time-independent data are provided in a separate source catalogue. For more details, see section 12.5.1.

  or

- A table whereby each record (i.e. catalogue row) consists of the measurements of one source, and where the time-resolved properties are stored in arrays, one element for each epoch, and where also the list of epochs are stored in arrays. Time-independent data are provided in the same table. For more details, see section 12.5.2.

When using arrays in time resolved fields, it is important to keep in mind two limitations: (1) the number of epochs cannot exceed 1500, (2) the ESO catalogue search engines won't be able to set query constraints on specific values stored inside the arrays.

In either case, the time of observation shall be defined according to the intrinsic precision of the time coordinate of the astronomical observation, normally as TTYPE value 'MJD' or 'HJD' using the eight-bytes IEEE floating point number format D. Other time coordinates, like JD, are possible as well. Alternative TTYPE values (i.e. column names) are possible.

Sections 12.4.1 to 12.4.6 apply to the multi-epoch catalogue as well.

12.5.1 Separate table structures for multi-epoch and time-independent data

This format requires one catalogue record per source and time epoch. The combination of the source identifier and time epoch parameters forms a composite key which uniquely identifies a record. The 'meta.main' UCD word is used to tag this composite key, as shown in the example below:

```
TTYPE1  = 'SOURCE_ID'
TFORM1  = '30A'
TUCD1   = 'meta.id;meta.main'
```

```
TTYPE2  = 'MJD'
TFORM2  = 'D'
TUCD2   = 'time.epoch;meta.main'
```

Catalogue columns tagged with meta.main cannot have null value (see Table 7).

Each FITS file belonging to a multi-epoch catalogue formatted as described in the present section, must include in the primary header the keyword M_EPOCH in order to identify the data type:

```
M_EPOCH   = T / TRUE
```

The structure of the multi-epoch cataloque is illustrated below. Each record (i.e. catalogue row) consists of the measurements for one source obtained at one epoch. MJD (modified Julian date) specifies the epoch of observation for each measurement. The parameters KSMAG and KSERR represent the measurement recorded in this example.

SOURCE_ID	MJD	KSMAG	KSERR	...
VVV J125618.07-644449.1	55246.33	14.47	0.01	
VVV J125618.07-644449.1	55254.13	14.33	0.01	
VVV J125618.07-644449.1	55256.22	14.29	0.01	
VVV J125618.27-644535.0	55254.13	16.08	0.07	
VVV J125618.27-644535.0	55256.22	16.03	0.07	
...				

To avoid unnecessary repetitions, time-independent data should be provided in a separate source catalogue which must be linked to the multi-epoch's one. For instance, if the positional information in multi-epoch catalogues is not time resolved, there is no need to include sky coordinates in the multi-epoch table. In this case the multi-epoch catalogue must be linked to a source catalogue (section 12.3) containing sky coordinates for each object. The link between multi-epoch catalogue and source catalogue is optional if the multi-epoch catalogue contains positional coordinates. The link between a multi-epoch catalogue and a source catalogue must be defined in the FITS header of the multi-epoch catalogue as shown in the following example:

```
TXLNK1 = 'CATALOG ' / Data link type
TXRGF1 = 'vmc_er3_yjks_catMetaData.fits' / Target catalogue
TXCTY1 = 'SOURCE_ID' / Target catalogue's TTYPE
```

For referential integrity, if a link exists between multi-epoch catalogue and source catalogue, then it is required that each source being listed in the multi-epoch catalogue must be recorded in the corresponding source catalogue with the exact same (string or numeric) identifier.

TFORM*i* of the object/source identifier in the multi-epoch catalogue and in the source catalogue must be identical.

The unique source identifier in a multi-epoch catalogue identifies the astronomical source each individual measurement belongs to[30], and establishes the link to the source catalogue. The table below illustrates the structure of the source catalogue.

SOURCE_ID	RAJ2000	DEJ2000	ZMAG1	YMAG1	JMAG1	HMAG1	KSMAG1	...
VVV J125618.07-644449.1	194.07533	-64.74698	16.22558	15.77634	17.37570	15.52600	16.05641	
VVV J125618.27-644535.0	194.07614	-64.75972	17.82400	17.30961		16.48619		
...								

---

[30] The definition of unique source identifiers and their consistent application across different catalogues belongs to the responsibilities of the PI of the programme.

This allows to build archive services that query time-series data based on position or other source properties.

12.5.2 Unique table structure for multi-epoch and time-independent data

With respect to the previous section 12.5.1, this section provides an alternative way to format multi-epoch science catalogue data, and requires one catalogue record per source. Multi-epoch data are included and stored along with single-epoch and time-independent data in one unique table structure, using arrays of values to convey the time resolved measurements.

Multi-epoch data, such as photometric flux or astrometric position, and the associated time epochs are stored in single table cells as arrays of values (TFORM repeat count >1). Epochs must be listed in time sequence.

There must be at least two table fields having TFORMi repeat count >1 and ≤1500 (section 12.2.4): one table field containing the array of time epoch values and one more field for the array of measurements.

The multi-epoch catalogue may be split across multiple files following the scheme in section 12.2.2.

The structure of the multi-epoch catalogue is illustrated below:

SOURCE_ID	RAJ2000	DEJ2000	...	MJD	KSMAG	KSERR	...
VVV J125618.07-644449.1	194.07533	-64.74698	...	55246.33, 55254.13, 55256.22	14.47, 14.33, 14.29	0.01, 0.01, 0.01	...
VVV J125618.27-644535.0	194.07614	-64.75972	...	55254.13, 55256.22, NaN	16.08, 16.03, NaN	0.07, 0.07, NaN	...
...							

Each record (i.e. catalogue row) consists of the measurements for one source obtained at all epochs. MJD (modified Julian date) specifies the epoch of observation for each measurement. The parameters KSMAG and KSERR represent the measurements recorded in this example.

Related fields (e.g. MJD, KSMAG, KSERR) must have identical number of array elements (same repeat count for the TFORM keyword), as shown in the FITS header example below.

```
TTYPE1  = 'SOURCE_ID'
TFORM1  = '30A'
TUCD1   = 'meta.id;meta.main'

TTYPE4  = 'MJD'
TFORM4  = '3D'
TUCD4   = 'time.epoch'

TTYPE5  = 'KSMAG'
TFORM5  = '3D'
TUCD5   = 'phot.mag;em.IR.K'

TTYPE6  = 'KSERR'
TFORM5  = '3D'
TUCD5   = 'stat.error;phot.mag;em.IR.K'
```

It is not required that any two sources share the same epochs or the same number of epochs. The end of an array should be padded with *NaN* for time series of sources having less data points than the repeat count given in TFORM.

The epoch array shall not contain any *NaN* values, unless referring to the *NaN* padding at the end of the time series. When no measurement is available for a reported epoch, the corresponding array element carries the value *NaN*.

12.6 Variability catalogue

The catalogue of variables is primarily defined by its specific content, e.g. mean magnitude, indicator for flux variability like amplitude or likelihood of variation, variable type, period, phase, etc. The PI is responsible for the exact definition of these parameters, driven by the scientific objective of the programme. Phase 3 requires that these parameters definitions be documented, formally in terms of FITS keywords (TTYPE*i*, TCOMM*i*, TUCD*i*, etc.), and informally in the data release description.

If the catalogue of variables contains a subset of sources published in another Phase 3 source catalogue, then this link should be made explicit using the data link keywords (section 12.3).

Sections 12.4.1 to 12.4.6 apply to the variability catalogue as well.

13. Required, recommended, and optional FITS header keywords per PRODCATG

In order to identify the list of required, recommended, and optional FITS keywords for the characterisation of Phase 3 science data products according to the data product category, please refer to the Table 8 below.

Mandatory keywords consist of the keyword name (a string) and its value. The keyword value is either a string, a number, or a boolean. A number is either a float or an integer.
Whenever the value of a keyword is of type 'string', it cannot be empty (unless specified otherwise, e.g. under certain conditions for REFERENC and TUNIT – see the footnotes to the Table 8). An empty string is defined as a string with zero characters.
For keywords of type 'float' or 'integer', the value shall be within the allowed range as specified in the keyword dictionary (section 5).

Legend:

M	Keyword mandatory.
Meso	Keyword mandatory for ESO files.
Mapp	Keyword mandatory where applicable, refer to the table footnotes for more information.
R	Keyword recommended; it means applicable unless you have a good reason to not use it.
NotAlw	Keyword not allowed: the Phase 3 system will reject the file.
O	It makes sense to provide the value, but it is optional.
N/A	Keyword not applicable, i.e. it is not relevant in the context of the PRODCATG (or it is computed by the Phase 3 system) but it is tolerated, that is it is not checked by our system.

The background of the cell represents the location of the keyword in the FITS file. Example:

M	White background: keyword mandatory in the primary header.
M	Grey background: keyword mandatory in the extension header.

Table 8: Matrix of required, recommended and optional keywords per PRODCATG

	PRODCATG vs SCIENCE.* keyword	IMAGE (single associated file format)	IMAGE (single) MEF format	MEFIMAGE (mosaic) MEF format	IMAGE.FLUXMAP	SPECTRUM	CUBE.IFS	VISIBILITY	SRCTBL	MCATALOG	CATALOGTILE	CATALOG
1	PRODCATG	M	M	M	M	M	M	M	M	M	M	M
2	ASSOCi	Mapp[31]	Mapp[31]	Mapp[31]	Mapp[31]	Mapp[31]	Mapp[31]	Mapp[31]	Mapp[31]	N/A	Mapp[31]	Mapp[31]
3	ASSONi	Mapp[32]	Mapp[32]	Mapp[32]	M[33]	Mapp[32]	M[34]	Mapp[32]	Mapp[32]	N/A	Mapp[32]	Mapp[32]
4	ASSOMi	Mapp[31]	Mapp[31]	Mapp[31]	Mapp[31]	Mapp[31]	Mapp[31]	Mapp[31]	Mapp[31]	N/A	Mapp[31]	Mapp[31]
5	ORIGIN	M	M	M	M	M	M	M	M	M	M	M
6	TELESCOP TELESCi	M	M	M	M	M	M	M	M	M	M	M
7	INSTRUME INSTRi	M	M	M	M	M	M	M	M	M	M	M
8	FILTER FILTERi	M	M	M	M	N/A	N/A	N/A	M	Mapp[35]	Mapp[35]	Mapp[35]
9	OBJECT	M	M	M	M	M M	M	M	M	M	M	M
10	RA DEC	M	M	M	M	M M	M	M	M	N/A	M	Mapp[36]
11	EQUINOX	Mapp[37]	Mapp[37]	Mapp[37]	Mapp[37]	Mapp[37]	Mapp[37]	Mapp[37]	Mapp[37]	N/A	Mapp[37]	Mapp[37, 36]
12	RADESYS	M	M	M	M	M	M	M	M	N/A	M	Mapp[36]
13	TIMESYS	Mapp[38]	Mapp[38]	Mapp[38]	Mapp[38]	Mapp[38]	Mapp[38]	Mapp[38]	Mapp[38]	Mapp[38]	Mapp[38]	Mapp[38]
14	EXPTIME	M	M	M	M	M	M	M	M	N/A	N/A	N/A
15	TEXPTIME	M	M	M	M	M	M	M	M	N/A	N/A	N/A
16	MJD-OBS	M	M	M	M	M	M	M	M	M	M	M
17	MJD-END	M	M	M	M	M	M	M	M	M	M	M
18	PROG_ID PROGIDi	Meso	Meso	Meso	Meso	Meso	Meso	Meso	Meso	Meso	Meso	Meso
19	OBIDi	Meso	Meso	Meso	Meso	Meso	Meso	Meso	Meso	Meso	Meso	Meso
20	NCOMBINE	Meso	Meso	Meso	Meso	Meso	Meso	Meso	Meso	N/A	N/A	N/A
21	OBSTECH	M	M	M	M	M	M	M	M	Mapp[39]	Mapp[39]	Mapp[39]
22	FLUXCAL	M	M	M	M	M	M	N/A	N/A	N/A	N/A	N/A
23	PROCSOFT	M	M	M	M	M	M	M	M	M	M	M
24	REFERENC	M[40]	M[40]	M[40]	M[40]	M[40]	M[40]	M[40]	M[40]	M[40]	M[40]	M[40]
25	PROVi PROVXTN	Meso	Meso	Meso	Meso	Meso	Meso	Meso	Meso	N/A	Meso	Meso
26	BUNIT	M	M	M	M	NotAlw	M	N/A	N/A	N/A	N/A	N/A
27	GAIN	O	O	O	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
28	DETRON	O	O	O	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
29	EFFRON	O	O	O	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
30	WEIGHT	O	O	O	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
31	CRVALi	M	M	M	M	N/A	M	N/A	N/A	N/A	N/A	N/A

[31] Mandatory for the cases where ancillary files are provided in a non-FITS format.

[32] Mandatory for the cases where ancillary files are provided in association with the scientific data.

[33] The flux map must always be associated with the RMS noise map, or the SNR map, or both.

[34] The IFS 3D cube must always be associated with the white-light image. The white-light image must be delivered using the ASSONi/ASSOCi mechanism.

[35] Applicable to photometric catalogues as well as APEX catalogues.

[36] There can be cases where that keyword does not apply, for instance in the case of target catalogues of spectroscopic surveys, e.g. PESSTO where no appropriate RA/DEC value can be defined to characterise the catalogue as a whole.

[37] If RADESYS='FK5', EQUINOX=2000.0 is mandatory. If RADESYS = 'ICRS', EQUINOX is tolerated and its value needs to be 2000.0.

[38] Must be present if the system used is other than UTC.

[39] Does not apply to catalogues for which no unique value of OBSTECH can be identified.

[40] If a refereed publication is not available at the time of the data release going public, the value can be left to an empty string.

	PRODCATG SCIENCE.* keyword (vs)	IMAGE (single) associated file format	IMAGE (single) MEF format	MEFIMAGE (mosaic) MEF format	IMAGE.FLUXMAP	SPECTRUM	CUBE.IFS	VISIBILITY	SRCTBL	MCATALOG	CATALOGTILE	CATALOG
32	CRPIXi	M	M	M	M	N/A	M	N/A	N/A	N/A	N/A	N/A
33	CTYPEi	M	M	M	M	N/A	M	N/A	N/A	N/A	N/A	N/A
34	CUNITi	M	M	M	M	N/A	M	N/A	N/A	N/A	N/A	N/A
35	CDi_j	M	M	M	M	NotAlw	M	N/A	N/A	N/A	N/A	N/A
36	CSYERi	R	R	R	R	N/A	R	N/A	N/A	N/A	N/A	N/A
37	CRDERi	R	R	R	R	N/A	R	N/A	N/A	N/A	N/A	N/A
38	PHOTZP	M	M	M	N/A	N/A	N/A	N/A	Mapp[41]	N/A	N/A	N/A
39	PHOTZPER	R	R	R	N/A	N/A	N/A	N/A	R	N/A	N/A	N/A
40	PHOTSYS	M	M	M	N/A	N/A	N/A	N/A	M	M	M	M
41	SPECSYS	N/A	N/A	N/A	N/A	M	M	M	N/A	N/A	N/A	N/A
42	EXT_OBJ	N/A	N/A	N/A	N/A	Mapp[42]	N/A	N/A	N/A	N/A	N/A	N/A
43	CONTNORM	N/A	N/A	N/A	N/A	M	N/A	N/A	N/A	N/A	N/A	N/A
44	TOT_FLUX	N/A	N/A	N/A	N/A	M	N/A	N/A	N/A	N/A	N/A	N/A
45	FLUXERR	N/A	N/A	N/A	M	M[43]	N/A	N/A	N/A	N/A	N/A	N/A
46	WAVELMIN	N/A	N/A	N/A	M	M	M	M	N/A	Mapp[44]	Mapp[44]	Mapp[44]
47	WAVELMAX	N/A	N/A	N/A	M	M	M	M	N/A	Mapp[44]	Mapp[44]	Mapp[44]
48	LAMRMS	N/A	N/A	N/A	N/A	O	N/A	N/A	N/A	N/A	N/A	N/A
49	LAMNLIN	N/A	N/A	N/A	N/A	O	N/A	N/A	N/A	N/A	N/A	N/A
50	SPEC_BIN	N/A	N/A	N/A	N/A	M	NotAlw	N/A	N/A	N/A	N/A	N/A
51	SPEC_ERR	N/A	N/A	N/A	N/A	R	N/A	M	N/A	N/A	N/A	N/A
52	SPEC_SYE	N/A	N/A	N/A	N/A	R	N/A	M	N/A	N/A	N/A	N/A
53	RA_ERR	NotAlw	NotAlw	NotAlw	NotAlw	R	NotAlw	N/A	N/A	N/A	N/A	N/A
54	DEC_ERR	NotAlw	NotAlw	NotAlw	NotAlw	R	NotAlw	N/A	N/A	N/A	N/A	N/A
55	NELEM	N/A	N/A	N/A	N/A	M	N/A	N/A	N/A	N/A	N/A	N/A
56	VOCLASS	N/A	N/A	N/A	N/A	M	N/A	N/A	N/A	N/A	N/A	N/A
57	VOPUB	N/A	N/A	N/A	N/A	M	N/A	N/A	N/A	N/A	N/A	N/A
58	TITLE	N/A	N/A	N/A	N/A	M	N/A	N/A	N/A	N/A	N/A	N/A
59	APERTURE	N/A	N/A	N/A	N/A	M	N/A	N/A	N/A	N/A	N/A	N/A
60	TELAPSE	N/A	N/A	N/A	N/A	M	N/A	N/A	N/A	N/A	N/A	N/A
61	TMID	N/A	N/A	N/A	N/A	M	N/A	N/A	N/A	N/A	N/A	N/A
62	SPEC_VAL	N/A	N/A	N/A	N/A	M	N/A	N/A	N/A	N/A	N/A	N/A
63	SPEC_BW	N/A	N/A	N/A	N/A	M	N/A	N/A	N/A	N/A	N/A	N/A
64	BNOISE	N/A	N/A	N/A	N/A	M	N/A	N/A	N/A	N/A	N/A	Mapp[45]
65	MAPMODE	N/A	N/A	N/A	N/A	M	N/A	N/A	N/A	N/A	N/A	Mapp[45]
66	FEBEi	N/A	N/A	N/A	N/A	M	N/A	N/A	N/A	N/A	N/A	Mapp[45]
67	CONTENT	N/A	N/A	N/A	N/A	N/A	N/A	M	N/A	N/A	N/A	N/A
68	INSMODE	N/A	N/A	N/A	N/A	N/A	N/A	M	N/A	N/A	N/A	N/A
69	BASE_MIN	N/A	N/A	N/A	N/A	N/A	N/A	M	N/A	N/A	N/A	N/A
70	BASE_MAX	N/A	N/A	N/A	N/A	N/A	N/A	M	N/A	N/A	N/A	N/A
71	NUM_CHAN	N/A	N/A	N/A	N/A	N/A	N/A	M	N/A	N/A	N/A	N/A

[41] Mandatory depending on whether fluxes or magnitudes are provided in the source list.

[42] EXT_OBJ is mandatory for externally submitted data products (e.g. spectroscopic public surveys). EXT_OBJ is not applicable to data processed in an unsupervised way, for which the keyword value cannot be assessed and thus the property is not known.

[43] FLUXERR applies to SCIENCE.SPECTRUM with FLUXCAL='ABSOLUTE'. In case of SCIENCE.SPECTRUM with FLUXCAL = 'UNCALIBRATED', the FLUXERR keyword shall be set to -1. The special value -2 is reserved for the case when the flux error cannot be determined.

[44] Applicable to spectroscopic and APEX catalogues. For photometric catalogues, the value is calculated by the Phase 3 system unless the combination (INSTRi, FILTERi) is not unique, in which case please contact Phase 3 operations support staff at https://support.eso.org/ to assess the correct values of the WAVELMIN/MAX keywords, to be added in the headers.

[45] For APEX catalogues only.

#	PRODCATG SCIENCE.* keyword (vs)	IMAGE (single) associated file format	IMAGE (single) MEF format	MEFIMAGE (mosaic) MEF format	IMAGE.FLUXMAP	SPECTRUM	CUBE.IFS	VISIBILITY	SRCTBL	MCATALOG	CATALOGTILE	CATALOG
72	VIS2ERR	N/A	N/A	N/A	N/A	N/A	N/A	M	N/A	N/A	N/A	N/A
73	T3PHIERR	N/A	N/A	N/A	N/A	N/A	N/A	M	N/A	N/A	N/A	N/A
74	STOKES	Please contact Phase 3 operations support staff at https://support.eso.org/ if you intend to submit polarisation data.										
75	HDUCLASS	N/A	M	N/A	N/A	N/A	M	N/A	N/A	N/A	N/A	N/A
76	HDUCLASi	N/A	M	N/A	N/A	N/A	M	N/A	N/A	N/A	N/A	N/A
77	HDUDOC	N/A	M	N/A	N/A	N/A	M	N/A	N/A	N/A	N/A	N/A
78	HDUVERS	N/A	M	N/A	N/A	N/A	M	N/A	N/A	N/A	N/A	N/A
79	SCIDATA	N/A	Mapp[46]	N/A	N/A	N/A	Mapp[46]	N/A	N/A	N/A	N/A	N/A
80	ERRDATA	N/A	Mapp[46]	N/A	N/A	N/A	Mapp[46]	N/A	N/A	N/A	N/A	N/A
81	QUALDATA	N/A	Mapp[46]	N/A	N/A	N/A	Mapp[46]	N/A	N/A	N/A	N/A	N/A
82	CONFDATA	N/A	Mapp[46]	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
83	BKGDATA	N/A	Mapp[46]	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
84	BKGERR	N/A	Mapp[46]	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
85	BKGCONF	N/A	Mapp[46]	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
86	ABMAGLIM	M	M	M	NotAlw	N/A	M	N/A	M	Mapp[47]	Mapp[47]	Mapp[47]
87	PIXNOISE	N/A	N/A	N/A	N/A	N/A	M	N/A	N/A	N/A	N/A	N/A
88	MAGLIMi	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	Mapp[48]	Mapp[48]	Mapp[48]
89	ABMAGSAT	M	M	M	N/A	N/A	N/A	N/A	M	N/A	N/A	N/A
90	PSF_FWHM	M	M	M	N/A	N/A	N/A	N/A	M	N/A	N/A	N/A
91	ELLIPTIC	M[49]	M[49]	M[49]	N/A	N/A	O	N/A	M[49]	N/A	N/A	N/A
92	SNR	N/A	N/A	N/A	N/A	M	N/A	N/A	N/A	N/A	N/A	N/A
93	SPEC_RES	N/A	N/A	N/A	N/A	M	M	M	N/A	N/A	N/A	N/A
94	SKY_RES	N/A	N/A	N/A	M	N/A	M	N/A	N/A	N/A	N/A	Mapp[45]
95	SKY_RERR	N/A	N/A	N/A	Mapp[50]	N/A	Mapp[50]	N/A	N/A	N/A	N/A	Mapp[50]
96	STREHL	Mapp[51]	Mapp[51]	Mapp[51]	N/A	Mapp[51]	Mapp[51]	N/A	Mapp[51]	N/A	N/A	N/A
97	ARCFILE	Reserved keyword. If present, modified by the Phase 3 system during the archiving process.										
98	CHECKSUM	M	M	M	M	M	M	M	M	M	M	M
99	DATASUM	M	M	M	M	M	M	M	M	M	M	M
100	ORIGFILE	Reserved keyword. If present, modified by the Phase 3 system during the archiving process.										
101	P3ORIG	Reserved keyword. If present, modified by the Phase 3 system during the archiving process.										
102	NDIT	Mapp[52]	Mapp[52]	Mapp[52]	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
103	NJITTER	Mapp[52]	Mapp[52]	Mapp[52]	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
104	NOFFSETS	Mapp[52]	Mapp[52]	Mapp[52]	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
105	NUSTEP	Mapp[52]	Mapp[52]	Mapp[52]	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
106	FPRAia	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	Mapp[53]	M	Mapp[54]

[46] SCIDATA is mandatory for the cases where ancillary extensions are provided in association with the scientific data. ERRDATA / QUALDATA / CONFDATA / BKGDATA / BKGERR / BKGCONF shall be used if the corresponding extension is provided.

[47] For photometric catalogues. And if there is more than one filter, it is not applicable. Use MAGLIMi instead.

[48] For photometric catalogues with more than one filter.

[49] For VIRCAM and OmegaCAM only.

[50] Applicable to the case when SKY_RES is expected to vary within the data collection due to the way it is estimated (see footnote 18).

[51] For AO observations only.

[52] NIR image data products qualify for the keyword if, and only if, all exposures and observations contributing to the given product share the same value for the respective parameter. If, for example, the product has been created from exposures taken with different detector integration time, the keyword DIT should *not* be defined in the FITS header.

[53] Not mandatory in case of complex footprints.

[54] Does not apply to spectroscopic catalogues for which no coverage pattern exists.

	PRODCATG SCIENCE.* keyword (vs)	IMAGE (single) associated file format	IMAGE (single) MEF format	MEFIMAGE (mosaic) MEF format	IMAGE.FLUXMAP	SPECTRUM	CUBE.IFS	VISIBILITY	SRCTBL	MCATALOG	CATALOGTILE	CATALOG
107	FPDEia	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	Mapp[53]	M	Mapp[54]
108	SKYSQDEG	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	M	M	Mapp[54]
109	M_EPOCH	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	Mapp[55]	Mapp[55]	Mapp[55]
110	APMATCHD	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	Mapp[56]	Mapp[56]	Mapp[56]
111	TXLNKi	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	Mapp[57]	Mapp[57,58]	Mapp[57,58]
112	TXRGF	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	Mapp[57]	N/A	Mapp[57]
113	TXCTY	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	Mapp[57]	N/A	Mapp[57]
114	NOESODAT	Mapp[59]	Mapp[59]	Mapp[59]	Mapp[59]	Mapp[59]	Mapp[59]	Mapp[59]	Mapp[59]	Mapp[59]	Mapp[59]	Mapp[59]
115	TFIELDS	N/A	N/A	N/A	N/A	M	N/A	M	M	M	M	M
116	TTYPEi	N/A	N/A	N/A	N/A	M	N/A	M	M	M	M	M
117	TFORMi	N/A	N/A	N/A	N/A	M	N/A	M	M	M	M	M
118	TCOMMi	N/A	N/A	N/A	N/A	O	N/A	O	O	M	M	M
119	TUNITi	N/A	N/A	N/A	N/A	M[61]	N/A	Mapp[60]	Mapp[60]	M[61]	M[61]	M[61]
120	TUTYPi	N/A	N/A	N/A	N/A	M[62]	N/A	N/A	N/A	N/A	N/A	N/A
121	TUCDi	N/A	N/A	N/A	N/A	M	N/A	O	O	M	M	M
122	TDMINi	N/A	N/A	N/A	N/A	Mapp[63]	N/A	O	O	O	O	O
123	TDMAXi	N/A	N/A	N/A	N/A	Mapp[63]	N/A	O	O	O	O	O
124	TNULLi	N/A	N/A	N/A	N/A	N/A	N/A	O	O	Mapp[64]	Mapp[64]	Mapp[64]
125	EXTNAME	Mapp[65]	Mapp[65]	Mapp[65]	Mapp[65]	Mapp[65]	Mapp[65]	Mapp[65]	Mapp[65]	Mapp[65]	Mapp[65]	Mapp[65]
126	TZEROi									NotAlw	NotAlw	NotAlw
127	TSCALi									NotAlw	NotAlw	NotAlw
128	EXTVER									NotAlw	NotAlw	NotAlw
129	EXTLEVEL									NotAlw	NotAlw	NotAlw

14. Appendix A: Optional ancillary products

Data format PRODCATG = ANCILLARY.*	Description	Usually applied to the following SCIENCE.*
2DSPECTRUM	A 2D spectrum denotes the 2D array with one axis oriented along the dispersion direction (calibrated in wavelength), the other axis being the spatial dimension, normally oriented along the slit. Wavelength calibrated and distortion corrected 2D	SPECTRUM

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[55] Applicable to multi-epoch catalogues formatted according to section 12.5.1 only.

[56] For aperture-matched catalogues only.

[57] In case data link is used (see section 12.3).

[58] In case provenance per catalogue record is used (see section 5.2.3).

[59] Applicable to products originating or containing data from a non-ESO facility.

[60] Keyword may be absent for columns representing quantities having no units of measurement, otherwise it must be present.

[61] For quantities having no units of measurement, the value shall be set to an empty string.

[62] In case the UType is not defined in the IVOA document [9] like e.g. for CONTINUUM, the corresponding TUTYPi keyword shall be set to an empty string.

[63] Mandatory for the TTYPE1 array only (start/stop spectral coordinates).

[64] See section 5.18 and section 12.2.6 for applicability.

[65] A specific value is requested in particular cases: 'PHASE3PROVENANCE', 'PHASE3CATALOG', 'PHASE3FILELIST'.

Data format PRODCATG = ANCILLARY.*	Description	Usually applied to the following SCIENCE.*
	spectra can be submitted as associated files of the SCIENCE.SPECTRUM products.	
CUBE.IFS.NO_TELLCORR	A 3D data cube that contains the data calibrated but without the telluric correction.	CUBE.IFS
CUBE.IFS.SKY	A file containing the reconstructed cube for the IFUs that observed the sky.	CUBE.IFS
CUBE.IFS.STD	A 3D data cube of a standard star. FITS data cube with the same dimension as the science data cube.	CUBE.IFS
FEROSTAR	A FEROS TAR file containing various r.FEROS* pipeline product files and a HTML summary page of the reduced products, including plots which may be useful for making a quick evaluation of the data quality. The TAR files contain several types of files, both FITS and non-FITS. *Mostly generated in the case of ESO-processed data.*	SPECTRUM
FILTERED	Filtered image used to optimally extract compact sources. FITS image with the same geometry (NAXIS*i*) and the same physical units (BUNIT) as the flux map.	IMAGE.FLUXMAP
HARPSTAR	The HARPS TAR files contain several types of files, both FITS and non-FITS. *Mostly generated in the case of ESO-processed data.*	SPECTRUM
IMAGE	An image without photometric and astrometric calibration can be submitted as an associated file of a main SCIENCE product (e.g. an acquisition image associated to a SCIENCE.SPECTRUM). The ancillary image may also be accompanied by a set of e.g. error and quality maps as additional extensions within the same FITS file.	SPECTRUM IMAGE CATALOG CUBE.IFS
KMOS.SPECTRUM.TELLURIC	A file containing the 1D telluric correction, and its error, applicable or applied to the KMOS science cubes. *Mostly generated in the case of ESO-processed data.*	CUBE.IFS
MOSSPECTRA	2D image, plus FIBRE_SETUP table extracted, re-binned; all fibers *Mostly generated in the case of ESO-processed data, e.g. GIRAFFE.*	SPECTRUM
MOSSPECTRA.CALSIM	2D image, plus FIBRE_SETUP table, including residual shifts WLRES; origin: attached exposures, same OB *Mostly generated in the case of ESO-processed data, e.g. GIRAFFE.*	SPECTRUM
MOSSPECTRA.PREVIEW	Spectral overview *Mostly generated in the case of ESO-processed data, e.g. GIRAFFE.*	SPECTRUM
MOSSPECTRA.SKY	2D image, plus FIBRE_SETUP table *Mostly generated in the case of ESO-processed data, e.g. GIRAFFE.*	SPECTRUM
PIXELCOUNTMAP	In the context of co-adding multiple exposures, the pixel count map records the variation of the number of contributing exposures of 2D image mosaic and 3D IFU data cubes per pixel and per spaxel, respectively. If the contributing exposures have different exposure times, the pixel count map does not apply, and the exposure map should be associated instead. The pixel count map is a 2D FITS image associated to the main science data as an ancillary file. It shares the dimensions (AXIS1, AXIS2), WCS definitions and number of image extensions (if any) with the 2D image mosaics, or, in case of	IMAGE MEFIMAGE CUBE.IFS

Data format PRODCATG = ANCILLARY.*	Description	Usually applied to the following SCIENCE.*
	3D IFU data cubes, the pixel count map inherits the dimensions and WCS definition of the first two axis of the data cube (AXIS1, AXIS2, etc). The pixel count map encodes the total number of contributing exposures per pixel/spaxel as integer number (BUNIT = ' ' / dimensionless) using 16 bits (BITPIX = 16, see FITS standard). The pixel count map is constrained to integer values >0 for data pixels/spaxels representing a valid signal, or value=0 for void pixels/spaxels. Note: It is recommended to set the values of void spaxels in the science data to *NaN*. BLANK or any other special value are not allowed in the pixel count map.	
MUSE.PIXTABLE_REDUCED	Intermediate product compatible with the MUSE data reduction pipeline. PRO.CATG = PIXTABLE_REDUCED Intermediate pipeline products may be provided to allow regenerating the final science data cube using customised processing parameters for the respective data reduction recipes. Starting data reprocessing from intermediate products is more convenient than repeating the entire processing chain from the beginning, i.e. by starting from the raw data.	CUBE.IFS
PREVIEW	Preview of the data product normally using one of the common graphics file formats such as JPEG, PNG, GIF, etc. For image data products the preview usually consists of an appropriately downscaled version of the image. For spectra the preview typically consists of a line plot for which the PNG, PS or PDF formats may be considered. Those spectrum previews may be showing for instance the position of key emission lines. For PIONIER data, the preview consists of a PDF plot of the transfer function (TF) for each spectra, i.e. the squared visibility amplitude measured on calibrators, corrected for their angular diameter.	SCIENCE.*
README	*Mostly generated in the case of ESO-processed data.*	SCIENCE.*
RESMAP	Map of residuals after removal of sources. FITS image with the same geometry (NAXIS*i*) and the same physical units (BUNIT) as the flux map.	IMAGE.FLUXMAP
RMSMAP	RMS noise map. FITS image with the same geometry (NAXIS*i*) and the same physical units (BUNIT) as the flux map.	IMAGE.FLUXMAP IMAGE
SNRMAP	The signal-to-noise ratio (SNR) map is equal to the arithmetic ratio of flux map and noise map. FITS image with the same geometry (NAXIS*i*) as the flux map. The SNR map is dimensionless, i.e. BUNIT should be set to a blank string.	IMAGE.FLUXMAP IMAGE
SPECTRUM	Signal, error, and SNR Format: For AMAZE, it is ascii.	SPECTRUM
SPECTRUM.TELLURIC	Telluric spectrum	SPECTRUM
SRCMASK	Sextractor source mask file. FITS image with the same geometry (NAXIS*i*) as the flux map.	IMAGE.FLUXMAP
SRCTBL	Catalogue of sources directly detected in the map image. Format: ASCII list For high-level source catalogues resulting from a survey project, please adopt the SCIENCE.CATALOG format instead (section 12).	IMAGE.FLUXMAP
TAR	A TAR file	SCIENCE.*

Data format PRODCATG = ANCILLARY.*	Description	Usually applied to the following SCIENCE.*
VARMAP	Variance map	IMAGE MEFIMAGE

Table 9: List of optional ancillary product categories

15. Appendix B: Sybase IQ reserved words

Source of information:
http://infocenter.sybase.com/help/index.jsp?topic=/com.sybase.infocenter.dc38151.1510/html/iqref bb/Alhakeywords.htm

SQL reserved words			
active	add	all	algorithm
alter	and	any	append
as	asc	auto	backup
begin	between	bigint	binary
bit	bottom	break	by
calibrate	calibration	call	cancel
capability	cascade	case	cast
certificate	char	char_convert	character
check	checkpoint	checksum	clientport
close	columns	comment	commit
committed	comparisons	computes	conflict
connect	constraint	contains	continue
convert	create	cross	cube
current	current_timestamp	current_user	cursor
date	dbspace	dbspacename	deallocate
debug	dec	decimal	declare
decoupled	decrypted	default	delay
delete	deleting	density	desc
deterministic	disable	distinct	do
double	drop	dynamic	elements
else	elseif	enable	encapsulated

encrypted	end	endif	escape
except	exception	exclude	exec
execute	existing	exists	explicit
express	externlogin	fastfirstrow	fetch
first	float	following	for
force	foreign	forward	from
full	gb	goto	grant
group	grouping	having	hidden
history	holdlock	identified	if
in	inactive	index	index_lparen
inner	inout	input	insensitive
insert	inserting	install	instead
int	integer	integrated	intersect
into	iq	is	isolation
jdk	join	kb	key
lateral	left	like	lock
logging	login	long	mb
match	membership	message	mode
modify	namespace	natural	new
no	noholdlock	nolock	not
notify	null	numeric	of
off	on	open	optimization
option	options	or	order
others	out	outer	over
pages	paglock	partial	partition
passthrough	password	plan	preceding
precision	prepare	primary	print
privileges	proc	procedure	proxy
publication	raiserror	range	raw

readcommitted	readonly	readpast	readtext
readuncommitted	readwrite	real	recursive
reference	references	release	relocate
remote	remove	rename	reorganize
repeatable	repeatableread	reserve	resizing
resource	restore	restrict	return
revoke	right	rollback	rollup
root	row	rowlock	rows
save	savepoint	schedule	scroll
secure	select	sensitive	serializable
service	session	set	setuser
share	smallint	soapaction	some
space	sqlcode	sqlstate	start
stop	subtrans	subtransaction	synchronize
syntax_error	table	tablock	tablockx
tb	temporary	then	ties
time	timestamp	tinyint	to
top	tran	transaction	transactional
transfer	tries	trigger	truncate
tsequal	unbounded	uncommitted	union
unique	uniqueidentifier	unknown	unsigned
update	updating	updlock	url
user	utc	using	validate
values	varbinary	varchar	variable
varying	virtual	view	wait
waitfor	web	when	where
while	window	with	withauto
with_cube	with_lparen	with_rollup	within
word	work	writeserver	writetext

xlock	xml

16. Appendix C: FLUX UCD1+ and unit values

Table 3 of [RD3] is reproduced below for convenience:

Table 3: Flux Value options

Field	UCD1+	Meaning	Unit (OGIP style)
FluxAxis.ucd	phot.flux.density;em.wl	Flux density per unit wave.	erg cm**(-2) s**(-1) angstrom**(-1), W m**(-2) m**(-1), keV cm**(-2) s**(-1) angstrom**(-1)
FluxAxis.ucd	phot.flux.density;em.freq	Flux density per unit freq.	erg cm**(-2) s**(-1) Hz**(-1), Jy, W m**(-2) Hz**(-1)
FluxAxis.ucd	phot.flux.density;em.energy	Flux density per energy interval	keV cm**(-2) s**(-1) kev**(-1)
FluxAxis.ucd	phot.flux.density;em.energy; meta.number	Photons per unit area, time, energy	photon cm**(-2) s**(-1) keV**(-1)
FluxAxis.ucd	phot.flux.density;em.wl	Flux density per log wave interval ($\nu F(\nu)$)	Jy Hz
FluxAxis.ucd	phot.flux.density.sb;em.wl	Surface brightness per unit wavelength	erg cm**(-2) s**(-1) angstrom**(-1) arcsec**(-2)
FluxAxis.ucd	phot.flux.density.sb;em.freq	Surface brightness per unit frequency	Jy sr**(-1)
FluxAxis.ucd	phot.count	Counts in spectral channel	count
FluxAxis.ucd	arith.rate;phot.count	Count rate in spectral channel	count/s
FluxAxis.ucd	arith.ratio;phot.flux.density	Flux ratio of two spectra	-
FluxAxis.ucd	phys.luminosity;em.wl	Luminosity per unit wave	erg s**(-1) angstrom**(-1), W/m
FluxAxis.ucd	phys.luminosity;em.freq	Luminosity per unit freq	erg s**(-1) Hz**(-1), W/Hz
FluxAxis.ucd	phys.luminosity;em.energy	Luminosity per unit energy	erg s**(-1) keV**(-1)
FluxAxis.ucd	phys.luminosity;em.energy	Luminosity per log frequency	erg s**(-1), W
FluxAxis.ucd	phys.energy.density	Radiation energy density per unit volume, per unit wave etc.	erg cm**(-3), J m**(-3)
FluxAxis.ucd	phot.fluence;em.wl	Photon number flux per unit wave.	photon cm**(-2) s**(-1) angstrom**(-1)
FluxAxis.ucd	phot.flux.density;em.wl; phys.polarization	Polarized flux per unit wavelength	erg cm**(-2) s**(-1) angstrom**(-1)
FluxAxis.ucd	phys.polarization	Polarized fraction vs spectral coord	(dimensionless)
FluxAxis.ucd	phys.luminosity; phys.angArea;em.wl	Flux per unit solid angle (at source)	erg cm**(-2) s**(-1) sr**(-1) angstrom**(-1)
FluxAxis.ucd	phot.antennaTemp	Antenna temperature	K
FluxAxis.ucd	phot.flux.density; phys.temperature	Brightness temperature	K
FluxAxis.ucd	phot.mag	Magnitude in defined band	mag
FluxAxis.ucd	phot.mag	AB (spectrophotometric) magnitude	mag
FluxAxis.ucd	phot.flux.density;instr.beam	Flux per resolution element (e.g. Jy/beam)	Jy/beam
FluxAxis.ucd	phot.mag.sb	Surface brightness in magnitudes	mag arcsec**(-2)
FluxAxis.ucd	phys.transmission	Filter transmission, 0.0 to 1.0	(dimensionless)
FluxAxis.ucd	phys.area;phys.transmission	Effective area	cm**2
FluxAxis.ucd	phot.flux.density;em.wl; spect.continuum	Continuum only	erg cm**(-2) s**(-1) angstrom**(-1) arcsec**(-2)

17. Appendix D: FITS header examples

For each PRODCATG, a list of header examples can be found online at
https://www.eso.org/sci/observing/phase3/faq.html
The header examples are for illustrative pourposes only and are not binding. For a list of required and optional FITS header keywords for a given product category, please refer to Table 8.

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