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Data Management and Operations Division

Phase 3 User Documentation

ESO Science Data Products Standard

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CHANGE RECORD

ISSUE	DATE	SECTION/PARA. AFFECTED	REASON/INITIATION DOCUMENTS/REMARKS
1	27.11.2010	All	EDP standard initialised to support the ESO Public Surveys Phase 3 Workshop, ESO Garching, 30.11.2010.
2	07.03.2011	2.1	Keyword ASSOM*i* added.
		3.2.1, 3.2.2	NJITTER, DIT, NDIT changed to *optional* for the VISTA deep tile and deep pawprint image.
		3.2.3	List of header keywords refers to the VISTA *deep* stripes image (added to caption).
		3.2.4	*Mandatory* keyword PHOTSYS added for source lists.
		2.8	Optional keywords added to describe the sky coverage in terms of footprint coordinates.
		3.2.5	Data format definition for multi-band source lists added.
		3	Subsections restructured.
3	22/05/2012	All	Document re-structured in view of additional format standards for catalogues, VST imaging, spectra. VISTA/VIRCAM, started previously in §3.8.1, now §3.2
		1.3	Recommendation added to avoid adding new HIERARCH keywords.
		2.1	Convention for multi-valued PROG_ID keyword added
		2.4, 3	Requirements for processing provenance detailed/expanded.
		3	RA, DEC keywords required.
		3.1	Added.
		3.2.1	Comment for PHOTZP given in the header example for the VISTA tile image corrected.
		3.3	Added.
		Appendix A	Added.
4	17/09/2012	All	Title of the document changed. Purpose & scope extended to SDP. New entries to the list of reference documents.
		2.1	Updated OBJECT definition.
		2.11	Added keywords for spectroscopic observations.

		2.2 4, 5 Appendix B	List of PRODCATG values extended. Added new section on spectroscopic data products before the section on science catalogue data. Added.
5	11/01/2012	3.3 Table 1 2.1 2.10, 2.1 2.13 Front page Table 2 Table 3 3.1.4 2.5 2.7 List of references	Data format definition for OmegaCAM imaging added. Added entries to OBSTECH list of values. Added a footnote for the definition of the TELESCOP keyword. Moved the DIT definition to the list of primary keywords and added a footnote. Added TL_ID keyword. Changed name of the releaser. Removed MOSPECTRUM Added the gain map as a new category of ancillary file. Added. Added keyword definitions for readout noise and median weight. Added reference to Table 9. Added reference to SADT.

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Purpose and 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.[1] SDPs are produced by 1) principal investigators of ESO observing programmes, and 2) ESO pipelines as part of the quality control (QC) process or from specific, dedicated, re-processing projects for homogenous raw data sets. SDPs delivered as part of the ESO public survey process or large programs are also referred to as External Data Products (EDPs); SDPs produced by ESO internal pipelines and QC process are also labelled Internal Data Products (IDPs).

To ensure the successful integration of SDPs into the 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.

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.

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 instrument and type of data product.
The procedures and tools that support the data provider in validating the compliancy of data products with the SDP standards are discussed in the ESO Phase 3 User Guide to the Data Submission Process [AD1] (see below).

The target audience consists of 1) principal investigators and their collaborators who return reduced data products resulting from 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.

[1] See http://www.eso.org/sci/observing/phase3 for the main entry point to the ESO Phase 3.

List of Applicable Documents

[AD1] ESO Phase 3 User Guide to the Data Submission Process, Doc. No.: GEN-SPE-ESO-33000-5336, Issue 2, Date: 09.03.2011
http://www.eso.org/sci/observing/phase3/p3userguide.pdf

[AD2] Definition of the Flexible Image Transport System (FITS), FITS Standard Version 3.0, 2008 July 10, FITS Working Group Commission 5: Documentation and Astronomical Data International Astronomical Union,
http://fits.gsfc.nasa.gov/iaufwg/

[AD3] ESO Data Interface Control Document, Doc. No.: GEN-SPE-ESO-19400-0794, Issue: 5, Date: 8 July 2011

List of Reference Documents

[RD1] Calabretta & Greisen, 2002, Astronomy & Astrophysics, 395, 1077-1122

[RD2] The UCD1+ controlled vocabulary, Version 1.23, IVOA Recommendation 02 April 2007,
http://www.ivoa.net/Documents/latest/UCDlist.html

[RD3] IVOA Spectrum Data Model, Version 1.1 - IVOA Recommendation 20 November 2011
http://www.ivoa.net/Documents/SpectrumDM/20111120/REC-SpectrumDM-1.1-20111120.pdf

[RD4] An IVOA Standard for Unified Content Descriptors Version 1.10 – IVOA Recommandation 19 August 2005
http://www.ivoa.net/Documents/REC/UCD/UCD-20050812.pdf

[RD5] ESO Survey Telescopes – Survey Area Definition Tool SADT cookbook, Doc. No.: VLT-MAN-ESO-19200-5168, Issue 1.4, Date: 16.08.2011

Overview

This document starts by defining the general data format requirements for Science Data Products to be submitted through Phase 3 (§1). Section 2 contains the definitions of all keywords applicable in the context of SDPs. The details may be skipped on a first reading. The following sections define the ESO/SDP standard in terms of the mandatory and optional FITS keywords to be used for the characterization of Phase 3 data products according to data product type, starting with imaging (§3) (§3.2 applies to the VISTA public imaging surveys), then spectroscopy (§3.3), and finally science catalogues (§5). Here, the reader may directly jump to the section of interest, hence concentrate on the relevant subsections according to the data to be submitted. After having studied these parts the Phase 3 user will understand the data format structure, specific calibration and characterization requirements and the list of required FITS keywords.

To specify required and optional FITS header keywords, the following style is used throughout this document. *Mandatory* header keywords are typeset in bold face, for example:

```
NAXIS1   =                     %d / Length of data axis 1
```

Optional header keywords, in contrast, are typeset in normal face, for example:

```
CSYER1   =                     %f / Systematic error
```

The format strings `%c`, `%d`, `%f`, and `%s` correspond to the data types boolean, integer number, floating point number, and character string, respectively.

The *Phase 3 Release Validator*[3] is a java-based tool to be run locally on your system before uploading the data to ESO. It helps verifying the formal compliance of the data release with respect to the required standard. Throughout this document you will find the green tick mark symbol displayed next to each data format requirements that is checked by the validator.

Requirements marked by the red tick mark symbol can be checked only after the data have been completely submitted to ESO and the PI has closed the release. Then, the Phase 3 *release content validation* takes place at ESO.

1 General requirements

1.1 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 [AD2].
Furthermore, the data format must comply with the specifications published in the ESO Data Interface Control Document [AD3], 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.

Image data compression

Integer format imaging data may be submitted in compressed FITS format using the Rice compression algorithm as implemented in the *fpack* utility (http://heasarc.gsfc.nasa.gov/fitsio/fpack/), which provides lossless data compression (a.k.a. tile compression).

[3] Go to http://www.eso.org/sci/observing/phase3/validator.html to find more information about the Phase 3 validator and to download the tool.

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.

Unsupported formats

The tiled-table convention for compressing FITS binary tables (http://fits.gsfc.nasa.gov/tiletable.pdf) is not supported by the Phase 3 infrastructure.

1.2 Filenames

Maximum filename size

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

Uniqueness of filenames

✓ Filenames must be unique within a given Phase 3 data release 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 organize the data of a release, the data provider needs to make sure that there are no files having the same file name (in different directories of course).
With regard to updating releases it means that a new version of any file must have a name different from the old version.

Filename suffixes

Filename extensions are generally in lower case (`.fits`, `.tar`, `.jpg` etc.)

✓ 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, compressed (using *fpack*)

1.3 Propagation of original keywords

Science Data Products can be considered at the top of the hierarchy of data products in terms of processing level, and their metadata values must be obtained from the information present in the lower level products. Therefore, it is generally requested for proper archive ingestion that SDPs carry over keyword information from the original raw observational data as elaborated in the next sections. Furthermore, it is recommended to preserve as much of the original information about the observation as possible. If the product was generated based on a single raw science file, the original keywords can be propagated in a one-to-one fashion. However, the hierarchical products from the DPR category, like HIERARCH ESO DPR CATG, are an exception. Actually, science data products shall not contain keywords from the DPR category [AD3]. The value of the keyword DPR TECH is normally propagated to the keyword OBSTECH in the product tile (see section 2.1). If the product is based on more than one raw science file, the keywords of the raw file, which had been acquired first in terms of `MJD-OBS`, can be propagated to the product. However, keywords that do not apply to the data product as a whole should not be propagated.
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.

2 Keywords for Science Data Products

2.1 Primary SDP keywords

Primary SDP keywords go into the primary HDU of the FITS file (if not compressed). Please refer to sections §2 ff. for the applicability of these keywords depending on the specific observational technique, type of data product, and possibly the instrument.

Type[4]	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	ESO Telescope designation. To be adopted from the original data[5].
(S)	INSTRUME	Instrument name. To be adopted from the original data.
(S)	FILTER FILTER*i*	Filter name. To be adopted from the appropriate keyword of the raw data, e.g. HIERARCH ESO INS FILT1 NAME 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 shall be set to FILTER = 'MULTI', and the individual filter names shall be stored in keywords FILTER*i* where *i* is a sequential number starting from 1, without leading zeros.
(S)	OBJECT	Should be set to the target designation as given by the Principal Investigator, for instance OBJECT = 'NGC3603'. For spectroscopic public surveys, the value of the OBJECT keyword shall be set to the survey source identifier, which shall be unique within the survey.
(R)	RA DEC	Equatorial coordinates in decimal degrees (J2000). Image/tile centre[6], barycentre of image arrays in MEF format; spectroscopic target position[7]; centre of the survey field in case of catalogues.
(R)	EQUINOX	Standard FK5 (years). EQUINOX is mandatory if the reference frame is FK5 or FK4. EQUINOX = 2000.0 is tolerated for the ICRS coordinate reference frame.
(S)	RADECSYS	Coordinate reference frame. Preferentially ICRS or FK5.
(R)	DIT	Detector integration time[8], if uniform for all exposures included in this product.

[4] The capital letters I, L, R, and S indicate the keyword's data type integer number, boolean, floating point number, and string type, respectively.
[5] OmegaCAM represents an exception in which TELESCOP cannot be propagated directly because the raw data contains inconsistent values for the TELESCOP keyword (see also section 3.3).
[6] 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).
[7] Estimates like the center of the slit or the telescope pointing positions shall not be used.
[8] 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[4]	Keyword	Description
(R)	EXPTIME	Total integration time per pixel (in seconds). For an imaging data product resulting from the co-addition of multiple exposures pointing at the same sky position (with a tolerance given by a small fraction of the instrumental field of view), EXPTIME should represent the total integration time per pixel obtained in the centre of the image. If the product has been constructed from exposures whose positions were offset from each other in order to sample a region of the sky being larger than the instrumental FOV then the total integration time may vary across the image array. In this case EXPTIME should be set to the nominal total integration time obtained in at least 50% of the image array taking into account the chosen offset pattern. Note that EXPTIME as given in the original raw data almost never represents the proper number of EXPTIME for the product, specifically if detector sub-integrations are involved.
(R)	TEXPTIME	Arithmetic sum of the integration time of all exposures included in this product (in seconds). Note that an exposure's integration time is DIT*NDIT if sub-integrations are involved.
(R)	MJD-OBS	Specifies the start of the observation in terms of the modified Julian date; the start of the earliest observation if the data product results from the combination of multiple observations. To be adopted from the original data.
(R)	MJD-END	Specifies the end of the observation; the end of the latest observation if the data product results from the combination of multiple observations.
(S)	PROG_ID PROGID*i*	The identification code assigned to each observing run by the Observing Programme Committee (OPC) in the format *PPP.C-NNNN(R)*. Normally, PROG_ID should be copied from the keyword HIERARCH ESO OBS PROG ID of the original data. If more than one, the value shall be PROG_ID = MULTI, and the individual programme IDs shall be stored in keywords PROGID*i*, where *i* is an integer index between 1 and 99, with no leading zeros.
(I)	OBID*i*	Set of Observation block 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. If the product includes data from *n* observations, OBID*i* with index *i* running from 1 to *n* should be provided. On the contrary, a given Observation block ID must be listed in all the products that are based on this observation.
(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. The exact definition of an epoch, particularly the associated time scale, depends on the scientific goals and is at the discretion of the programme P.I. The VISTA public survey programmes UltraVISTA, VIDEO and VVV are expected to deliver multi-epoch data products.
(L)	SINGLEXP	TRUE if resulting from single exposure.

Type[4]	Keyword	Description
(I)	NCOMBINE	Number of raw science data files that were combined to generate this data product. Calibration data files do not contribute to this count.
(S)	OBSTECH	Technique used during the observation according to Table 1. OBSTECH can each take more than one value; it is recommended to limit the number of entries to at most three. The values should be separated with commas, with no blank spaces. This provides the means to describe a wide range of observations. If more than one value is present, the entries should as a rule follow the ''general-to-specific'' order. Normally, OBSTECH should be adopted from the keyword HIERARCH ESO DPR TECH of the original data.
(S)	FLUXCAL	FLUXCAL characterises the quality of the flux calibration in terms of two possible values: 'ABSOLUTE' or 'UNCALIBRATED'. For imaging data, it certifies the validity of PHOTZP if set to 'ABSOLUTE', otherwise 'UNCALIBRATED'. 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 (http://doi.org) be included in the value string when available.

Table 1: Examples of principal values (first group) and qualifiers (second group) for keyword OBSTECH describing the technique of observation.

Value	Explanation
IMAGE	any picture
SPECTRUM	single-order spectrum
ECHELLE	cross-dispersed spectrum
MOS	observation with spectra of several objects
MXU	observation with spectra of several objects using a pre-manufactured mask
IFU	Integral Field Unit observation
POLARIMETRY	polarimetric exposure
CORONOGRAPHY	coronography exposure
INTERFEROMETRY	coherent exposure with more than one telescope beam
ABSORPTION-CELL	absorption lines included (e.g. Iodine cell)
FABRY-PEROT	exposure using Fabry-Perot technique
WOLLASTON	Wollaston polarimetry
WIRE_GRID	Wire grid polarimetry
DIRECT	qualifier indicating direct imaging/spectroscopy
CHOPPING	exposure utilising M2 chopping
NODDING	exposure utilising telescope nodding
CHOPNOD	exposure utilising both chopping and nodding

DITHER	A sequence of N exposures with offsets that are sufficiently large to bridge the largest gaps between the CCDs in the detector mosaic.
JITTER	Exposure utilising source jittering technique.
OFFSET	A sequence of N exposures with almost full flexibility of offsets.
STARE	A sequence of N exposures of exactly the same part of the sky. No offsets are done.

2.2 *Data product category*

Type	**Keyword**	**Description**
(S)	PRODCATG	Defines the data product category in terms of one of the predefined values listed in Table 2.

Table 2: Pre-defined values for the keyword PRODCATG

PRODCATG	**Data format**	**Characteristics**
`SCIENCE.IMAGE`	Single image	Single image stored in the primary HDU.
`SCIENCE.MEFIMAGE`	MEF image	Multiple images stored in multi-extension FITS format (MEF).
`SCIENCE.SRCTBL`	Source list	FITS binary table resulting from the detection of sources on an image (both single image or MEF image, including merged multi-band source lists).
`SCIENCE.SPECTRUM`	1D spectrum	Single target one-dimensional spectrum and its associated data. In the 1D spectrum binary table format.
`SCIENCE.CATALOG`	Scientific catalogue (single file format)	Single FITS binary table. Normally, the final product of a survey programme.
`SCIENCE.MCATALOG`	Scientific catalogue (multi-file format)	Metadata definitions for a catalogue submitted in a tile-by-tile fashion, i.e. partitioned in multiple FITS binary tables
`SCIENCE.CATALOGTILE`	Scientific catalogue (multi-file format)	Data file for a catalogue submitted in a tile-by-tile fashion, i.e. partitioned in multiple FITS binary tables

2.3 Science products and associated ancillary data

The ESO Archive is directly searchable for science data products using the respective query forms 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.
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.

Ancillary data products are defined in the FITS header of the corresponding science data product in terms of the following indexed keywords.

Type[9]	Keyword	Description
(S)	ASSON*i*	The list of files associated to this data product. *i* is a sequential number starting from 1. If *n* files are associated to the product, the indexed keywords ASSON*i* and ASSOC*i* should appear *n* times (*i*=1,…,*n*).
(S)	ASSOC*i*	Specifies the product category of the associated file given by ASSON*i* according to Table 3.
(S)	ASSOM*i*	Specifies the md5sum of the associated file given by ASSON*i*. Applies to non-FITS files only.

Guidelines

- Each ancillary file must be associated to at least one science file.
- An associated FITS file like a weightmap cannot contain other associations in turn, i.e. nested associations are not supported.
- In case ancillary data products are in FITS format, they shall *not* contain the header keyword PRODCATG. Instead, the category should be defined by the keywords ASSOC* of the referencing science data product.

Table 3: Examples for categories of associated ancillary files given by the indexed keyword ASSOC*i*.

Category	Description
ANCILLARY.GAINMAP	The gain map specifies for each pixel the number of electrons that contributed to the pixel value in an image. See section 3.1.4 for a detailed description.
ANCILLARY.WEIGHTMAP	Weight map describing 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. The weight map should be a FITS file having the same structure, i.e. number of FITS extensions, if

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

	any, and dimensions as the FITS file that contains the image data array.
ANCILLARY.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 PS or PDF formats may be considered.

2.4 Processing Provenance

2.4.1 PROV keywords

Type	Keyword	Description
(S)	PROV*i*	Processing provenance in terms of the list of science files originating this data product. *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 original raw data or (intermediate) 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.fits'. Data products may be referenced by their ARCFILE name, or, alternatively, by their ORIGFILE name supposed that they belong to the same Phase 3 data collection as the referencing product file. ARCFILE and ORIGFILE references should not be mixed within the same file.

Guidelines

- PROV*i* keywords must reside in the primary HDU of the FITS file;
- PROV*i* records represent pointers to files rather than pointers to FITS extensions, i.e. there is no trailing extension number in square brackets (see also the examples below);
- 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 the first data release and then the originating images afterwards in the second release.[10]
- If the processing provenance exceeds 999 records, then it is required to record the complete list of files in one dedicated FITS binary table (BINTABLE) extension instead of using header keywords (cf. §2.4.2). The header should not contain any PROV*i* keyword in this case to avoid ambiguity.

Example 1: The shallow H-band survey image (16 seconds effective exposure time, part of VVV survey Data Release 1, archived under ADP.2011-06-24T14:56:11.033) originates from 12 raw science data files (6 pawprints with 2 jitter positions each) identified by their ARCFILE names.

```
PROV1   = 'VCAM.2010-03-27T08:58:58.083.fits' / Originating raw science file
PROV2   = 'VCAM.2010-03-27T08:59:10.530.fits' / Originating raw science file
PROV3   = 'VCAM.2010-03-27T08:59:24.541.fits' / Originating raw science file
PROV4   = 'VCAM.2010-03-27T08:59:36.978.fits' / Originating raw science file
PROV5   = 'VCAM.2010-03-27T08:59:51.043.fits' / Originating raw science file
PROV6   = 'VCAM.2010-03-27T09:00:03.446.fits' / Originating raw science file
```

[10] Except for the initial submission of catalogue data resulting from VISTA public surveys (May/June 2012), which is expected to comprise more data than the corresponding first ESO data releases of 2011. Therefore, it is acceptable in this case to set PROV*i* to ORIGFILE of the Phase 3 files even if they are to be submitted later.

```
PROV7    = 'VCAM.2010-03-27T09:00:18.266.fits' / Originating raw science file
PROV8    = 'VCAM.2010-03-27T09:00:30.706.fits' / Originating raw science file
PROV9    = 'VCAM.2010-03-27T09:00:44.764.fits' / Originating raw science file
PROV10   = 'VCAM.2010-03-27T09:00:58.834.fits' / Originating raw science file
PROV11   = 'VCAM.2010-03-27T09:01:12.852.fits' / Originating raw science file
PROV12   = 'VCAM.2010-03-27T09:01:25.349.fits' / Originating raw science file
```

Example 2: The 60-seconds Ks-band image (belonging to the VHS survey, DR1, archived as ADP.2011-10-01T03:24:40.897) was produced by co-addition of six reduced pawprint images, which are referenced in terms of their ORIGFILE names. Both tiles and reduced pawprints belong to the VHS data collection, DR1.

```
PROV1    = 'v20100524_00479_st.fits.fz' / Originating science product file
PROV2    = 'v20100524_00481_st.fits.fz' / Originating science product file
PROV3    = 'v20100524_00483_st.fits.fz' / Originating science product file
PROV4    = 'v20100524_00485_st.fits.fz' / Originating science product file
PROV5    = 'v20100524_00487_st.fits.fz' / Originating science product file
PROV6    = 'v20100524_00489_st.fits.fz' / Originating science product file
```

Example 3: The multi-band source list (belonging to the VMC survey, DR1, archived as ADP.2011-09-22T15:44:47.833) was extracted from the 3 survey images in Y, J and Ks bands as recorded in terms of their ORIGFILE names. Both, source list and reduced images belong to the same data collection.

```
PROV1    = 'vmc_er1_05h36-069d27_y_image_684806.fits.fz' /Originating image file
PROV2    = 'vmc_er1_05h36-069d27_j_image_684837.fits.fz' /Originating image file
PROV3    = 'vmc_er1_05h36-069d27_ks_image_684857.fits.fz'/Originating image file
```

2.4.2 Provenance extension

If the processing provenance exceeds 999 records, it is required to record the complete list of files in one dedicated FITS binary table extension instead of using header keywords. This scheme is aimed at very deep NIR observations, typically imaging, in which several thousand raw files are co-added ('stacked') to obtain the final result. The header should 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:

```
PROVXTN                        T / TRUE if proc. provenance recorded in FITS extn.
```

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 the product has been generated from. The requirements and guidelines for the definition of provenance records listed in the previous section (§2.4.1) apply here as well.

FITS header definition for the Phase 3 provenance extension:

```
XTENSION= 'BINTABLE'           / FITS Extension first keyword
EXTNAME = 'PHASE3PROVENANCE'   / Defines Phase 3 processing provenance
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   = 'A35'                    / Data format of field 1
CHECKSUM=                        %s / HDU checksum
DATASUM =                        %s / Data unit checksum
END
```

2.5 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 [AD3], 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 spectroscopic data, for which units of the data arrays are specified via the TUNIT*i* keywords instead.
(R)	DATAMIN	Specifies the minimum valid physical value across the pixel array in units defined by BUNIT.
(R)	DATAMAX	Specifies the maximum valid physical value across the pixel array in units defined by BUNIT.
(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 normalized 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 CCDs.
(R)	EFFRON	Specifies the median over all pixels of the effective readout noise. The effective readout 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.

2.6 World coordinate system keywords

Type	Keyword	Description
(R)	CRVAL*i*	Coordinate value at reference pixel of axis *i*.
(R)	CRPIX*i*	Reference pixel in axis *i*.

(S)	CTYPE*i*	Pixel coordinate system of axis *i*.
(S)	CUNIT*i*	Specifies the unit of the coordinate transformation. For celestial coordinate systems the default unit is "degree", i.e., CUNIT1 = 'deg' and CUNIT2 = 'deg'.
(R)	CD*i_j*	Transformation matrix element.
(R)	CDELT*i*	Alternative for the CD*i_j* matrix representation. Deprecated for images.
(R)	CSYER*i*	Systematic error in axis *i* (unit given by CUNIT*i*, usually degree).
(R)	CRDER*i*	Random error in axis *i* (unit given by CUNIT*i*, usually degree). CRDER1 and CRDER2 may be set both to 1/√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
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
EQUINOX =                2000. / Standard FK5 (years)
RADECSYS= 'ICRS    '           / Coordinate reference frame
```

2.7 Specific image characterization

Type	**Keyword**	**Description**
(S)	IMATYPE	Specific image type, according to Table 7 and Table 9.
(L)	ISAMP	Flag to indicate if the imaging data represents multiple disconnected regions, i.e. a *sampling* of the sky (ISAMP='T'), or one *contiguous* fraction of the sky (ISAMP='F' or unset).
(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.

2.8 Spatial coverage of a data product

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[11]. 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.
(R)	FPDE*ia*	Footprint's Declination in degrees (J2000).
(R)	SKYSQDEG	Actual total sky coverage of the image or catalogue in units of square degrees.

2.9 Image photometric zeropoint

Type	Keyword	Description
(R)	PHOTZP	Photometric zeropoint that relates the pixel data to total magnitudes (MAG) according to the equation MAG=-2.5*log(data)+PHOTZP, i.e. any applicable scaling with exposure time should be absorbed into PHOTZP.
(R)	PHOTZPER	Optional keyword to indicate the (1 sigma) uncertainty of the photometric zeropoint PHOTZP.
(S)	PHOTSYS	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.

2.10 Near-infrared VISTA 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.

NIR image data products qualify for the keywords listed above 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.

[11] 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 connects back to the first. In order to avoid ambiguities in direction, vertices need to be less than 180° apart in both coordinates.

2.11 Spectroscopic observations

Type	Keyword	Description
(S)	SPECSYS	The frame of reference for spectral coordinates. The list of recognised values are taken from [AD2] and are reproduced below for convenience.
(L)	EXT_OBJ	The value of that 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	TRUE indicates that the flux data represent the total source flux 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. It applies to spectroscopic data having FLUXCAL = 'ABSOLUTE'.
(R)	FLUXERR	Fractional uncertainty of the flux [%].
(S)	DISPELEM	The name of the main dispersive element. The value of that keyword shall be propagated from the value of the original HIERARCH ESO INS keyword. See table below for more details per instrument.
(R)	WAVELMIN	The minimum wavelength in nanometers [nm] covered by this spectrum, e.g. WAVELMIN = CRVAL1+(0.5-CRPIX1)*CDELT1. For spectral data in FITS tabular form where no WCS apply, it corresponds to the value of the first spectral bin.
(R)	WAVELMAX	The maximum wavelength in nanometers [nm] covered by this spectrum, e.g. WAVELMAX = CRVAL1+(NAXIS1+0.5-CRPIX1)*CDELT1. For spectral data in FITS tabular form where no WCS apply, it corresponds to the value of the last spectral bin, that is the NELEM-th bin.
(R)	LAMRMS	The root-mean-square (RMS) of the residuals of the wavelength solution along the wavelength axis [nm].
(R)	LAMNLIN	The number of arc lines used in the fit of the wavelength solution.
(R)	SPEC_BIN	The average spectral coordinate bin size. 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.
(R)	SPEC_SYE	Systematic error in spectral coordinate [nm], applicable to the case when the WCS is not used.

For convenience, we quote here the list of SPECSYS values taken from [AD2]:

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

Examples of possible values for the DISPELEM keyword:

Instrument	Mode	ESO HIERARCH Keyword	Possible values
GIRAFFE	IFU, MOS	INS GRAT NAME	HR, LR
UVES	ECHELLE	INS GRAT2 NAME	CD#1, CD#2, CD#3, CD#4
SOFI	SPECTRUM	INS OPTI2 NAME	GR, GB, HR
EFOSC2	SPECTRUM	INS GRIS1 NAME	GR# followed by a number
VIMOS	MOS	INS GRIS4 NAME	LR_blue, LR_red, MR, HR_blue, HR_orange, HR_red

2.12 Data quality parameters

Type	Keyword	Description
(R)	ABMAGLIM	5-sigma limiting AB magnitude. The quoted magnitude should refer to the total flux of a point source.
(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).
(R)	PSF_FWHM	Spatial resolution (arcsec). Quality parameter measured from the image. Average size of the point spread function expressed as the full width at half maximum in arcseconds.
(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.
(R)	SNR	Average 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.
(R)	SPEC_RES	Average spectral resolution as determined for this spectrum. The spectral resolution is dimensionless (lambda / Δ lambda) and shall be estimated by measuring the FWHM of the ARC-lamp emission lines at different wavelengths along the dispersion axis.

2.13 ESO public imaging surveys

The definition of the survey layout in terms of the tiling of the sky region to be covered includes the responsibility to define the coordinates and one unique identifier for each survey tile and to propagate this information consistently throughout all the survey products like images and source lists.

For VISTA public surveys the tiling of the sky has been defined at the beginning of the preparation of observations using the Survey Area Definition Tool (SADT) [RD5]. The respective coordinates identifying each survey tile on the sky in terms of RA, DEC and PA, are given in the original (i.e. raw) observational data by the following header keywords.

```
HIERARCH ESO OCS SADT TILE RA = 180121.456 / Tile RA [HHMMSS.TTT]
HIERARCH ESO OCS SADT TILE DEC = -312956.4 / Tile Declination [DDMMSS.TTT]
HIERARCH ESO OCS SADT TILE OFFANGLE = 60.598 / Tile rotator offset angle [deg]
```

Alternative ways of tiling the sky, e.g. for the OmegaCAM public surveys may be used.

For public surveys it is required that the survey tile coordinates are propagated to the resulting data products like tile images and source lists.

Type	Keyword	Description
(S)	TL_ID	Tile identifier, unique within the Public Survey.
(R)	TL_RA	Right Ascension of the center of the ideal tile as defined using either the Survey Area Definition Tool [HHMMSS.TTT] or an alternative preparation tool.
(R)	TL_DEC	Declination of the center of the ideal tile as defined using the Survey Area Definition Tool [DDMMSS.TTT] or an alternative preparation tool.
(R)	TL_OFFAN	Tile rotator offset angle as defined using the Survey Area Definition Tool (in degrees) or an alternative preparation tool. Note: Orientation on the sky, opposite sign convention than the position angle on the sky.
(L)	M_TILE	TRUE if data covers more than one survey tile.
(S)	EPS_REG	ESO public survey region name; to be specified for survey programmes targeting multiple regions like the VIDEO survey.

2.14 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.
Keywords that are reserved to record certain information related to the ESO archival process are listed in . If these keywords exist in the header of the submitted data, their content may 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.

Table 4: List of reserved header keywords

Type	Keyword	Description
(S)	ARCFILE	Provides the name under which the file is stored in the ESO science archive.
(S)	CHECKSUM	Provides a Cyclic Redundant Check (CRC) calculation for each HDU. It uses the ASCII encoded 1's complement algorithm.
(S)	DATASUM	Data unit checksum.
(S)	ORIGFILE	Records the original file name, as assigned at the instrument workstation; for EDPs ORIGFILE records the filename as given by the data provider.

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
```

2.15 Science catalogues

This section provides a summary of keywords to define science catalogues, particularly the catalogues resulting from ESO Public Survey including multi-colour photometric source catalogues, multi-epoch

photometry (a.k.a. light curves), catalogues of variables, proper motion catalogues, and target catalogues for spectroscopic surveys. Furthermore, these keywords apply to all ESO observing programmes delivering their final results in tabular form, for example galaxy redshift catalogues or catalogues of stellar properties and chemical abundances.
Please consult §3.3 for detailed keyword definitions and instructions for their application in the context of different types of scientific catalogues.

Type	**Keyword**	**Description**
(S)	TTYPE*i*	Name of the parameter.
(S)	TFORM*i*	Data format string.
(S)	TCOMM*i*	Verbal description.
(S)	TUCD*i*	Unified content descriptor.
(S)	TDISP*i*	Recommended display format.
(S)	TUNIT*i*	Physical units and scale.
(S)	TUTYP*i*	Pointer to a concept expressed in a VO data model.
(R)	TDMIN*i*	Minimum valid physical value.
(R)	TDMAX*i*	Maximum valid physical value.
(I)	TNULL*i*	Undefined value for data type B, I, J or K.
(L)	TINDX*i*	TRUE if database index is defined or required.
(L)	TPRIC*i*	TRUE for principal catalogue columns.
(S)	TXLNK*i*	Defines a data link if set to CATALOG, ARCFILE or ORIGFILE.
(S)	TXP3C*i*	Defines the target of this data link in terms of the Phase 3 collection name.
(S)	TXP3R*i*	Defines the target of this data link in terms of the Phase 3 release number.
(S)	TXCTY*i*	Defines the name of the target column of this catalogue data link in terms of its TTYPE*i*.

2.16 User-provided keywords

Normally, for a given SDP, the keywords defined herein just form a subset of keywords characterizing the data; in fact, the data provider is encouraged to include further keywords to characterize the data in more detail, to a level that seems to be adequate from the scientific point of view.
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 §2.
When adding further keywords to the FITS header, data providers are strongly encouraged to use 8-character FITS standard keywords instead of HIERARCH keywords. Note that lower case characters shall not be used for keyword names according to [AD2], §4.1.2.1 therein.

3 Imaging data products

3.1 Generic image data format

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 §3.2.4 and §3.3, respectively.

To specify required and optional FITS header keywords, the following style is used throughout this document. *Mandatory* header keywords are typeset in bold face, for example:

```
NAXIS1   =                    %d / Length of data axis 1
```

Optional header keywords, in contrast, are typeset in normal face, for example:

```
CSYER1   =                    %f / Systematic error
```

The format strings `%c`, `%d`, `%f`, and `%s` correspond to the data types boolean, integer number, floating point number, and character string, respectively.

Table 5: FITS header for the generic image data format

```
SIMPLE   =                     T / Standard FITS format (NOST-100-2.0)
BITPIX   =                    %d / 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
EXTEND   =                     T / Extensions may be present
BZERO    =                    %f / real = fits-value*BSCALE+BZERO
BSCALE   =                    %f / real = fits-value*BSCALE+BZERO
BUNIT    =                    %s / Physical unit of array values
BLANK    =                    %d / Value used for NULL pixels
ORIGIN   = 'ESO-PARANAL'         / European Southern Observatory
DATE     =                    %s / Date the file was written
DATAMAX  =                    %f / Maximum pixel value
DATAMIN  =                    %f / Minimal pixel value
TELESCOP=                     %s / ESO Telescope designation
INSTRUME=                     %s / Instrument name
FILTER   =                    %s / Filter name
OBJECT   =                    %s / Target designation
RA       =                    %f / Image centre (J2000.0)
DEC      =                    %f / Image centre (J2000.0)
EQUINOX  =                  %.0f / Standard FK5 (years)
RADECSYS=                     %s / Coordinate reference frame
EXPTIME  =                    %f / Total integration time per pixel (s)
TEXPTIME=                     %f / Total integration time of all exposures (s)
MJD-OBS  =                  %.8f / Start of observations (days)
MJD-END  =                  %.8f / End of observations (days)
DATE-OBS=                     %s / Date the observation was started (UTC)
TIMESYS  = 'UTC     '            / Time system used
PROG_ID  =                  %20s / ESO programme identification
M_EPOCH  =                    %c / TRUE if resulting from multiple epochs
NCOMBINE=                     %d / # of combined raw science data files
PROVi    =                    %s / Originating science file
OBSTECH  =                    %s / Technique of observation
PRODCATG= 'SCIENCE.IMAGE'        / Data product category
IMATYPE  =                    %s / Specific image type
ISAMP    =                    %c / TRUE if image represents partially sampled sky
FLUXCAL  = 'ABSOLUTE'            / Certifies the validity of PHOTZP
```

```
CRVAL1  =                     %f / Coordinate value at ref pixel
CRVAL2  =                     %f / Coordinate value at ref pixel
CRPIX1  =                     %f / Ref pixel in X
CRPIX2  =                     %f / Ref pixel in Y
CTYPE1  =                     %s / pixel coordinate system
CTYPE2  =                     %s / pixel coordinate system
CUNIT1  =                     %s / Unit of coordinate transformation
CUNIT2  =                     %s / Unit of coordinate transformation
CD1_1   =                     %f / Transformation matrix element
CD1_2   =                     %f / Transformation matrix element
CD2_1   =                     %f / Transformation matrix element
CD2_2   =                     %f / Transformation matrix element
CSYER1  =                     %f / Systematic error
CSYER2  =                     %f / Systematic error
CRDER1  =                     %f / Random error
CRDER2  =                     %f / Random error
PHOTZP  =                     %f / Photometric zeropoint MAG=-2.5*log(data)+PHOTZP
PHOTZPER=                     %f / Uncertainty on PHOTZP
PHOTSYS =                     %s / Photometric system VEGA or AB
GAIN    =                     %f / Number of electrons per data unit
ABMAGLIM=                     %f / 5-sigma limiting AB magnitude for point sources
ABMAGSAT=                     %f / Saturation limit for point sources (AB mags)
PSF_FWHM=                     %f / Spatial resolution (arcsec)
ELLIPTIC=                     %f / Average ellipticity of point sources
PROCSOFT=                     %s / Data reduction software/system with version no.
REFERENC=                     %s / Bibliographic reference
ASSONi  =                     %s / Name of associated file
ASSOCi  =                     %s / Category of associated file
CHECKSUM=                     %s / HDU checksum
DATASUM =                     %s / Data unit checksum
COMMENT
END
```

3.1.1 Astrometry

Celestial coordinates shall be assigned to image pixels using the FITS convention for world coordinates (Calabretta & Greisen, 2002, Astronomy & Astrophysics, 395, 1077-1122) [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).

3.1.2 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 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 normalized with respect to Vega, or using the AB photometric system (Oke & Gunn, 1983).
It is recommended to provide an estimate of the uncertainty of the photometric/flux calibration quantifying the total error budget including all possible systematics, e.g. the illumination effect unless it has been corrected for.

3.1.3 Weight maps

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. In this case it is required to provide the statistical significance of each pixel in terms of a number that is proportional to the inverse variance of the background signal, i.e. not including the Poisson noise of sources. This additional data array is often called weight map or confidence map. It has the same dimensions as the image array and can be submitted as an associated data product with product category declared in the header of the science file as follows:

```
ASSOC1   = 'ANCILLARY.WEIGHTMAP'/ Associated weight map image
ASSON1   =                    %s / Name of associated file
```

3.1.4 Gain maps

Due to the mosaic nature of some products, computing an average gain value captured in a single GAIN keyword would not reflect the reality and it is more useful to compute a gain map instead. The gain map specifies for each pixel the number of electrons that contributed to the pixel value in 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 s_p in that image is:

s_p = sqrt(gainmap(x,y) * i(x,y)) in electrons, and

s_p = sqrt(i(x,y) / gainmap(x,y)) in data units.

Note that for background subtracted images, s_p 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 * t_{exp} * F(x,y)

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

$gainmap_c(x,y) = \sum_i gainmap_i(x,y)$)

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 and can be submitted as an associated data product with product category declared in the header of the science file as follows:

```
ASSOC1   = 'ANCILLARY.GAINMAP'   / Associated gain map image
ASSON1   =                    %s / Name of associated file
```

3.1.5 Further guidelines

- 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 imaging data the ESO filter designation must be recorded in the data product.
- Required image **quality parameters**: RMS astrometric accuracy, flux uncertainty, limiting magnitude (AB), saturation limit, PSF width and ellipticity.
- For the temporal characterization: each image must record the time of observation in terms of the Julian date. This basically requires properly propagating this information from the raw data to the final product.

3.2 VISTA/VIRCAM

Overview

Table 6 gives an overview of the specific VISTA/VIRCAM data product types and their characteristics. The corresponding header keyword settings are listed in Table 7. The *footprint shape* specifies the sky coverage of the imaging data as given by the combination of the instrumental design and the observing strategy. For VISTA the three footprint shapes, “Pawprint”, “Vertical stripes”, and “Tile”, cover the variety of products resulting from the ESO public survey programmes. The attribute “deep” in the product description indicates if the data product is based on multiple observations. The flag ISAMP indicates if the imaging data represents multiple disconnected regions, i.e. a *sampling* of the sky (ISAMP=‘T’), or one *contiguous* fraction of the sky (ISAMP=‘F’ or unset). The flag SINGLEXP indicates if the product is the result of one single exposure. The column labeled “Source list” indicates the potential availability of source tables extracted from the imaging products. Specific data formats are defined for single-band sources lists and multi-band source lists in §3.2.4 and 3.2.5, respectively.

Table 6: Overview of VISTA data product types and their characteristics

Data product description	VISTA footprint shape	Single/ multiple OBs	Sampled/ contiguous sky	Number of disconnected regions sampled	Source list
VISTA tile	Tile	Single	contiguous	1	✓
VISTA deep tile	Tile	Multi	contiguous	1	✓
VISTA pawprint	Pawprint	Single	sampled	16	✓
VISTA deep pawprint	Pawprint	Multi	sampled	16	✓
VISTA stripes[12]	Vertical stripes	Single	sampled	4	✓
VISTA deep stripes	Vertical stripes	Multi	sampled	4	✓
VISTA single exposure[13]	Pawprint	Single	sampled	16	n/a

[12] The ultra deep part of the UltraVISTA public imaging survey is expected to result in *stripes* as data products.
[13] Single exposures acquired with VISTA are usually not considered final data products, which is why this product type will be insignificant in view of VISTA public survey deliveries.

Table 7: Summary of VISTA data product formats and corresponding keyword settings

Data product description	PRODCATG	IMATYPE	ISAMP	SINGLEXP
VISTA tile VISTA deep tile	SCIENCE.IMAGE	TILE	F	F
VISTA pawprint VISTA deep pawprint	SCIENCE.MEFIMAGE	PAWPRINT	T	F
VISTA stripes VISTA deep stripes	SCIENCE.MEFIMAGE	VSTRIPES	T	F
VISTA single exposure	SCIENCE.MEFIMAGE	PAWPRINT	T	T
VISTA tile's source list VISTA deep tile's source list	SCIENCE.SRCTBL	TILE	F	F
VISTA pawprint's source list VISTA deep pawprint's source list	SCIENCE.SRCTBL	PAWPRINT	T	F
VISTA stripes's source list VISTA deep stripes's source list	SCIENCE.SRCTBL	VSTRIPES	T	F

3.2.1 VISTA tile image

The VISTA tile is the basic building block of VISTA public surveys. The tile is a filled area of sky fully sampled (filling in the gaps in a pawprint) by combining multiple pawprints. 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 camera pixels. An observation executed with the VISTA/VIRCAM template "VIRCAM_img_obs_tile6" results in a tile as data product.

The VISTA tile image comes in two flavours to distinguish whether data have been combined from one or from multiple observations. The "normal" VISTA tile is based on a single observation, which has to be identified by the keyword OBID1. If the original data, which has been combined to form the final tile, was obtained in more than one observation block, the data product is termed VISTA *deep* tile image, and the complete set of original observations should be listed using the indexed keyword OBID*i*. The presence of the keyword OBID2 indicates the multi-OB character, i.e. the fact that the respective data product forms a deep tile image.

The VISTA tile stores the data array in the FITS file's primary HDU. The VISTA tile requires a number of specific keywords related to data acquisition, data quality and public surveys as listed below.

List of header keywords specific to the VISTA tile image including the VISTA deep tile image

```
TELESCOP= 'ESO-VISTA'           / ESO Telescope designation
INSTRUME= 'VIRCAM  '            / Instrument name
OBSTECH = 'IMAGE,JITTER'        / Technique of observation
PRODCATG= 'SCIENCE.IMAGE'       / Data product category
IMATYPE = 'TILE'                / Specific image type
```

Comprehensive list of header keywords for the VISTA tile

```
SIMPLE  =                    T / Standard FITS format (NOST-100-2.0)
BITPIX  =                   %d / 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
EXTEND  =                    T / Extensions may be present
BZERO   =                   %f / real = fits-value*BSCALE+BZERO
BSCALE  =                   %f / real = fits-value*BSCALE+BZERO
BUNIT   =                   %s / Physical unit of array values
BLANK   =                   %d / Value used for NULL pixels
ORIGIN  = 'ESO-PARANAL'        / European Southern Observatory
DATE    =                   %s / Date the file was written
DATAMAX =                   %f / Maximum pixel value
DATAMIN =                   %f / Minimal pixel value
TELESCOP= 'ESO-VISTA'          / ESO Telescope designation
INSTRUME= 'VIRCAM  '           / Instrument name
FILTER  =                   %s / Filter name
OBJECT  =                   %s / Target designation
RA      =                   %f / Image centre (J2000.0)
DEC     =                   %f / Image centre (J2000.0)
EQUINOX =                 %.0f / Standard FK5 (years)
RADECSYS=                   %s / Coordinate reference frame
EXPTIME =                   %f / Total integration time per pixel (s)
TEXPTIME=                   %f / Total integration time of all exposures (s)
MJD-OBS =                 %.8f / Start of observations (days)
MJD-END =                 %.8f / End of observations (days)
DATE-OBS=                   %s / Date the observation was started (UTC)
TIMESYS = 'UTC     '           / Time system used
PROG_ID =                 %20s / ESO programme identification
OBID1   =                   %d / Observation block ID
M_EPOCH =                   %c / TRUE if resulting from multiple epochs
NCOMBINE=                   %d / # of combined raw science data files
PROV1   =                   %s / Originating science file
PROV2   =                   %s / Originating science file
PROV3   =                   %s / Originating science file
OBSTECH = 'IMAGE,JITTER'       / Technique of observation
PRODCATG= 'SCIENCE.IMAGE'      / Data product category
IMATYPE = 'TILE'               / Specific image type
FLUXCAL = 'ABSOLUTE'           / Certifies the validity of PHOTZP
CRVAL1  =                   %f / Coordinate value at ref pixel
CRVAL2  =                   %f / Coordinate value at ref pixel
CRPIX1  =                   %f / Ref pixel in X
CRPIX2  =                   %f / Ref pixel in Y
CTYPE1  =                   %s / pixel coordinate system
CTYPE2  =                   %s / pixel coordinate system
CUNIT1  =                   %s / Unit of coordinate transformation
CUNIT2  =                   %s / Unit of coordinate transformation
CD1_1   =                   %f / Transformation matrix element
CD1_2   =                   %f / Transformation matrix element
CD2_1   =                   %f / Transformation matrix element
CD2_2   =                   %f / Transformation matrix element
CSYER1  =                   %f / Systematic error
CSYER2  =                   %f / Systematic error
CRDER1  =                   %f / Random error
CRDER2  =                   %f / Random error
PHOTZP  =                   %f / Photometric zeropoint MAG=-2.5*log(data)+PHOTZP
PHOTZPER=                   %f / Uncertainty on PHOTZP
PHOTSYS =                   %s / Photometric system VEGA or AB
GAIN    =                   %f / Number of electrons per data unit
ABMAGLIM=                   %f / 5-sigma limiting AB magnitude for point sources
ABMAGSAT=                   %f / Saturation limit for point sources (AB mags)
PSF_FWHM=                   %f / Spatial resolution (arcsec)
ELLIPTIC=                   %f / Average ellipticity of point sources
PROCSOFT=                   %s / Data reduction software/system with version no.
REFERENC=                   %s / Bibliographic reference
ASSON1  =                   %s / Name of associated file
ASSOC1  =                   %s / Category of associated file
ASSON2  =                   %s / Name of associated file
ASSOC2  =                   %s / Category of associated file
TL_RA   =                   %f / Tile RA [HHMMSS.TTT]
TL_DEC  =                   %f / Tile Declination [DDMMSS.TTT]
TL_OFFAN=                   %f / Tile rotator offset angle [deg]
EPS_REG =                   %s / ESO public survey region name
```

```
NJITTER =                     %d / Number of jitter positions
NOFFSETS=                     %d / Number of offset positions
NUSTEP  =                     %d / Number of microstep positions
DIT     =                     %f / Integration Time
NDIT    =                     %d / Number of sub-Integrations
CHECKSUM=                     %s / HDU checksum
DATASUM =                     %s / Data unit checksum
COMMENT
END
```

Comprehensive list of header keywords for the VISTA deep tile image

```
SIMPLE  =                      T / Standard FITS format (NOST-100-2.0)
BITPIX  =                     %d / 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
EXTEND  =                      T / Extensions may be present
BZERO   =                     %f / real = fits-value*BSCALE+BZERO
BSCALE  =                     %f / real = fits-value*BSCALE+BZERO
BUNIT   =                     %s / Physical unit of array values
BLANK   =                     %d / Value used for NULL pixels
ORIGIN  = 'ESO-PARANAL'          / European Southern Observatory
DATE    =                     %s / Date the file was written
DATAMAX =                     %f / Maximum pixel value
DATAMIN =                     %f / Minimal pixel value
TELESCOP= 'ESO-VISTA'            / ESO Telescope designation
INSTRUME= 'VIRCAM  '             / Instrument name
FILTER  =                     %s / Filter name
OBJECT  =                     %s / Target designation
RA      =                     %f / Image centre (J2000.0)
DEC     =                     %f / Image centre (J2000.0)
EQUINOX =                   %.0f / Standard FK5 (years)
RADECSYS=                     %s / Coordinate reference frame
EXPTIME =                     %f / Total integration time per pixel (s)
TEXPTIME=                     %f / Total integration time of all exposures (s)
MJD-OBS =                   %.8f / Start of observations (days)
MJD-END =                   %.8f / End of observations (days)
DATE-OBS=                     %s / Date the observation was started (UTC)
TIMESYS = 'UTC     '             / Time system used
PROG_ID =                   %20s / ESO programme identification
OBID1   =                     %d / Observation block ID
OBID2   =                     %d / Observation block ID
OBIDn   =                     %d / Observation block ID
M_EPOCH =                     %c / TRUE if resulting from multiple epochs
NCOMBINE=                     %d / # of combined raw science data files
PROV1   =                     %s / Originating science file
PROV2   =                     %s / Originating science file
PROV3   =                     %s / Originating science file
OBSTECH = 'IMAGE,JITTER'         / Technique of observation
PRODCATG= 'SCIENCE.IMAGE'        / Data product category
IMATYPE = 'TILE'                 / Specific image type
FLUXCAL = 'ABSOLUTE'             / Certifies the validity of PHOTZP
CRVAL1  =                     %f / Coordinate value at ref pixel
CRVAL2  =                     %f / Coordinate value at ref pixel
CRPIX1  =                     %f / Ref pixel in X
CRPIX2  =                     %f / Ref pixel in Y
CTYPE1  =                     %s / pixel coordinate system
CTYPE2  =                     %s / pixel coordinate system
CUNIT1  =                     %s / Unit of coordinate transformation
CUNIT2  =                     %s / Unit of coordinate transformation
CD1_1   =                     %f / Transformation matrix element
CD1_2   =                     %f / Transformation matrix element
CD2_1   =                     %f / Transformation matrix element
CD2_2   =                     %f / Transformation matrix element
CSYER1  =                     %f / Systematic error
CSYER2  =                     %f / Systematic error
CRDER1  =                     %f / Random error
CRDER2  =                     %f / Random error
```

```
PHOTZP   =                    %f / Photometric zeropoint MAG=-2.5*log(data)+PHOTZP
PHOTZPER=                     %f / Uncertainty on PHOTZP
PHOTSYS =                     %s / Photometric system VEGA or AB
GAIN     =                    %f / Number of electrons per data unit
ABMAGLIM=                     %f / 5-sigma limiting AB magnitude for point sources
ABMAGSAT=                     %f / Saturation limit for point sources (AB mags)
PSF_FWHM=                     %f / Spatial resolution (arcsec)
ELLIPTIC=                     %f / Average ellipticity of point sources
PROCSOFT=                     %s / Data reduction software/system with version no.
REFERENC=                     %s / Bibliographic reference
ASSON1   =                    %s / Name of associated file
ASSOC1   =                    %s / Category of associated file
TL_RA    =                    %f / Tile RA [HHMMSS.TTT]
TL_DEC   =                    %f / Tile Declination [DDMMSS.TTT]
TL_OFFAN=                     %f / Tile rotator offset angle [deg]
EPS_REG =                     %s / ESO public survey region name
NJITTER =                     %d / Number of jitter positions
NOFFSETS=                     %d / Number of offset positions
NUSTEP   =                    %d / Number of microstep positions
DIT      =                    %f / Integration Time
NDIT     =                    %d / Number of sub-Integrations
CHECKSUM=                     %s / HDU checksum
DATASUM =                     %s / Data unit checksum
COMMENT
END
```

Notes regarding keyword definitions

- MJD-OBS should be set to MJD-OBS of the first exposure contributing to this data product.
- MJD-END—the end of observations can be obtained in an approximate fashion using MJD-OBS of the last exposure contributing to this data product and adding the total exposure time of this exposure, i.e. MJD-END = MJD-OBS+(DIT*NDIT)/86400 in which MJD-OBS, DIT and NDIT refer to the last exposure.
- EXPTIME—for a VISTA tile being filled using the standard pattern of 6 pointed observations with fixed offsets with NJITTER exposures per pointing, EXPTIME should be set to the product 2*NJITTER*NDIT*DIT. The factor 2 reflects that most of the pixels of the final co-added image receive the contributions of at least two observations except for two narrow stripes along the edges, which receive just 'single' exposure time.
  For a VISTA deep tile image resulting from the co-addition of N_OBS observations, each of them using the standard pattern of 6 pointed observations with fixed offsets with NJITTER exposures per pointing, EXPTIME should be set to the product 2*N_OBS*NJITTER*NDIT*DIT. The factor 2 reflects that most of the pixels of the final co-added image receive the contributions of at least two observations except for two narrow stripes along the edges, which receive just 'single' exposure time.
  If the N_OBS observations do not share the same individual exposure time, i.e. NJITTER, NDIT, and DIT, then EXPTIME should be set to the sum

  $$\sum_{i=1}^{N\_OBS} 2 \times NJITTER(i) \times NDIT(i) \times DIT(i)$$

  If individual exposures were rejected before combination into the tile, EXPTIME should be adjusted accordingly.
- TEXPTIME—for a VISTA tile being filled using the standard pattern of 6 pointed observations with fixed offsets with NJITTER exposures per pointing, TEXPTIME should be set to the product 6*NJITTER*NDIT*DIT. If individual exposures were rejected before combination into the tile, TEXPTIME should be adjusted accordingly.
  For a VISTA deep tile image resulting from the co-addition of N_OBS observations, each of them using the standard pattern of 6 pointed observations with fixed offsets with NJITTER exposures per pointing, EXPTIME should be set to the product 6*N_OBS*NJITTER*NDIT*DIT. If the N_OBS observations do not share the same individual

exposure time, i.e. NJITTER, NDIT, and DIT, then TEXPTIME should be set to the arithmetic sum of 6*NJITTER*NDIT*DIT. If individual exposures were rejected before combination into the tile, TEXPTIME should be adjusted accordingly.

- ASSON1 and ASSOC1 are compulsory for VISTA tiles to associate the respective weight image, also known as confidence map (see §3.1.3). Further instances of the indexed keywords ASSONi and ASSONi may be used to associate more data products if needed.

Header example for the VISTA tile image

```
SIMPLE  =                    T / Standard FITS format (NOST-100-2.0)
BITPIX  =                   32 / Number of bits per data pixel
NAXIS   =                    2 / Number of data axes
NAXIS1  =                12711 / Length of data axis 1
NAXIS2  =                15605 / Length of data axis 2
EXTEND  =                    F / Extensions may be present
BZERO   =                   0. / real = fits-value*BSCALE+BZERO
BSCALE  =           0.17677670 / real = fits-value*BSCALE+BZERO
BUNIT   = 'ADU     '           / Physical unit of array values
ORIGIN  = 'ESO-PARANAL'        / European Southern Observatory
DATE    = '2009-10-19T08:51:39'         / Date the file was written
TELESCOP= 'ESO-VISTA'          / ESO Telescope designation
INSTRUME= 'VIRCAM  '           / Instrument name
FILTER  = 'Z       '           / Filter name
OBJECT  = 'Orion   '           / Target designation
RA      =            84.589675 / Image centre (J2000.0)
DEC     =             -1.66818 / Image centre (J2000.0)
EQUINOX =                2000. / Standard FK5 (years)
RADECSYS= 'FK5     '           / Coordinate reference frame
EXPTIME =                 48.0 / Total integration time per pixel (s)
TEXPTIME=                144.0 / Total integration time of all exposures (s)
MJD-OBS =       55123.36921823 / Start of observations (days)
MJD-END =       55123.37191074 / End of observations (days)
DATE-OBS= '2009-10-19T08:51:40.4482'    / Date the observation was started (UTC)
TIMESYS = 'UTC     '           / Time system used
PROG_ID = '60.A-9285(B)'       / ESO programme identification
OBID1   =               429633 / Observation block ID
M_EPOCH =                    F / TRUE if resulting from multiple epochs
NCOMBINE=                    6 / # of combined raw science data files
PROV1   = 'VCAM.2009-10-19T08:51:40.455.fits' / Originating science file
PROV2   = 'VCAM.2009-10-19T08:52:22.519.fits' / Originating science file
PROV3   = 'VCAM.2009-10-19T08:53:06.147.fits' / Originating science file
PROV4   = 'VCAM.2009-10-19T08:53:48.218.fits' / Originating science file
PROV5   = 'VCAM.2009-10-19T08:54:28.653.fits' / Originating science file
PROV6   = 'VCAM.2009-10-19T08:55:09.089.fits' / Originating science file
OBSTECH = 'IMAGE,JITTER'       / Technique of observation
PRODCATG= 'SCIENCE.IMAGE'      / Data product category
IMATYPE = 'TILE'               / Specific image type
FLUXCAL = 'ABSOLUTE'           / Certifies the validity of PHOTZP
CRVAL1  =   8.452566863325E+01 / Coordinate value at ref pixel
CRVAL2  =  -1.557574307279E+00 / Coordinate value at ref pixel
CRPIX1  =        6.3555000E+03 / Ref pixel in X
CRPIX2  =        7.8025000E+03 / Ref pixel in Y
CTYPE1  = 'RA---TAN'           / pixel coordinate system
CTYPE2  = 'DEC--TAN'           / pixel coordinate system
CD1_1   =       -2.4540050E-05 / Transformation matrix element
CD1_2   =        9.1546004E-05 / Transformation matrix element
CD2_1   =       -9.1547488E-05 / Transformation matrix element
CD2_2   =       -2.4447898E-05 / Transformation matrix element
CRDER1  =            0.0000108 / Random error (degree)
CRDER2  =            0.0000108 / Random error (degree)
PHOTZP  =               23.844 / Photometric zeropoint MAG=-2.5*log(data)+PHOTZP
PHOTZPER=                 0.01 / Uncertainty on PHOTZP
PHOTSYS = 'VEGA    '           / Photometric system VEGA or AB
ABMAGLIM=                22.58 / 5-sigma limiting AB magnitude for point sources
ABMAGSAT=                15.41 / Saturation limit for point sources (AB mags)
PSF_FWHM=                 0.97 / Spatial resolution (arcsec)
ELLIPTIC=           0.05619717 / Average ellipticity of point sources
```

```
PROCSOFT= 'CASU VDFS v1.0'     / Data reduction software/system with version no.
REFERENC= '2010Msngr.139....6A'     / Bibliographic reference
ASSON1  = 'v20091018_00296_st_tl_conf.fits'   / Name of associated file
ASSOC1  = 'ancillary.weightmap'     / Category of associated file
TL_RA   =            53805.976 / Tile RA [HHMMSS.TTT]
TL_DEC  =           -13321.600 / Tile Declination [DDMMSS.TTT]
TL_OFFAN=             -15.0050 / Tile rotator offset angle [deg]
NJITTER =                    1 / Number of jitter positions
NOFFSETS=                    6 / Number of offset positions
NUSTEP  =                    1 / Number of microstep positions
DIT     =            6.0000000 / Integration Time
NDIT    =                    4 / Number of sub-Integrations
CHECKSUM= 'CYMRAEGLLENYDDOL'   / HDU checksum
DATASUM = '1123581321'         / Data unit checksum
END
```

3.2.2 VISTA pawprint image

The 16 non-contiguous images of the sky produced by the VISTA IR camera, with its 16 non-contiguous detector chips 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.

Similar to the VISTA tile, the VISTA pawprint image comes in two flavors to distinguish whether data have been combined from one or from multiple observations. The "normal" VISTA pawprint is based on a single observation, which has to be identified by the keyword OBID1. If the original data, which has been combined to form the final pawprint image, was obtained in more than one observation block, the data product is termed *VISTA deep pawprint image,* and the complete set of original observations should be listed using the indexed keyword OBID*i*. The presence of the keyword OBID2 indicates the multi-OB character, i.e. the fact that the respective data product forms a deep pawprint image. 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.
The data of the VISTA deep pawprint image are stored in 16 image extensions of the multi-extension FITS file.

The VISTA pawprint image requires a number of specific keywords related to data acquisition, data quality and public surveys as listed below.

List of header keywords specific to the VISTA pawprint image

```
TELESCOP= 'ESO-VISTA'          / ESO Telescope designation
INSTRUME= 'VIRCAM  '           / Instrument name
OBSTECH = 'IMAGE,JITTER'       / Technique of observation
PRODCATG= 'SCIENCE.MEFIMAGE'   / Data product category
IMATYPE = 'PAWPRINT'           / Specific image type
ISAMP   =                    T / TRUE if image represents partially sampled sky
```

Comprehensive list of header keywords for the VISTA pawprint in the primary HDU

```
SIMPLE  =                    T / Standard FITS format (NOST-100-2.0)
BITPIX  =                    8 / Number of bits per data pixel
NAXIS   =                    0 / Number of data axes
EXTEND  =                    T / Extensions may be present
ORIGIN  = 'ESO-PARANAL'        / European Southern Observatory
DATE    =                   %s / Date the file was written
TELESCOP= 'ESO-VISTA'          / ESO Telescope designation
```

```
INSTRUME= 'VIRCAM  '            / Instrument name
FILTER   =                   %s / Filter name
OBJECT   =                   %s / Target designation
RA       =                   %f / Image centre (J2000.0)
DEC      =                   %f / Image centre (J2000.0)
EQUINOX  =                 %.0f / Standard FK5 (years)
RADECSYS=                    %s / Coordinate reference frame
EXPTIME  =                   %f / Total integration time per pixel (s)
TEXPTIME=                    %f / Total integration time of all exposures (s)
MJD-OBS  =                 %.8f / Start of observations (days)
MJD-END  =                 %.8f / End of observations (days)
DATE-OBS=                    %s / Date the observation was started (UTC)
TIMESYS  = 'UTC     '            / Time system used
PROG_ID  =                 %20s / ESO programme identification
OBID1    =                   %d / Observation block ID
M_EPOCH  =                   %c / TRUE if resulting from multiple epochs
SINGLEXP=                    %c / TRUE if resulting from single exposure
NCOMBINE=                    %d / # of combined raw science data files
PROV1    =                   %s / Originating science file
PROV2    =                   %s / Originating science file
PROV3    =                   %s / Originating science file
OBSTECH  = 'IMAGE,JITTER'        / Technique of observation
PRODCATG= 'SCIENCE.MEFIMAGE'     / Data product category
IMATYPE  = 'PAWPRINT'            / Specific image type
ISAMP    =                    T / TRUE if image represents partially sampled sky
FLUXCAL  = 'ABSOLUTE'            / Certifies the validity of PHOTZP
PROCSOFT=                    %s / Data reduction software/system with version no.
REFERENC=                    %s / Bibliographic reference
ASSON1   =                   %s / Name of associated file
ASSOC1   =                   %s / Category of associated file
ASSON2   =                   %s / Name of associated file
ASSOC2   =                   %s / Category of associated file
TL_RA    =                   %f / Tile RA [HHMMSS.TTT]
TL_DEC   =                   %f / Tile Declination [DDMMSS.TTT]
TL_OFFAN=                    %f / Tile rotator offset angle [deg]
EPS_REG  =                   %s / ESO public survey region name
NJITTER  =                   %d / Number of jitter positions
NOFFSETS=                    %d / Number of offset positions
NUSTEP   =                   %d / Number of microstep positions
DIT      =                   %f / Integration Time
NDIT     =                   %d / Number of sub-Integrations
CHECKSUM=                    %s / HDU checksum
DATASUM  =                   %s / Data unit checksum
COMMENT
END
```

Comprehensive list of header keywords for the VISTA pawprint[14] in the image extensions.

```
XTENSION= 'IMAGE   '            / FITS Extension first keyword
BITPIX   =                   %d / 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
EXTNAME  =                   %s / FITS Extension name
INHERIT  =                    T / Primary header keywords are inherited
BZERO    =                   %f / real = fits-value*BSCALE+BZERO
BSCALE   =                   %f / real = fits-value*BSCALE+BZERO
BUNIT    =                   %s / Physical unit of array values
BLANK    =                   %d / Value used for NULL pixels
DATAMAX  =                   %f / Maximum pixel value
DATAMIN  =                   %f / Minimal pixel value
CRVAL1   =                   %f / Coordinate value at ref pixel
CRVAL2   =                   %f / Coordinate value at ref pixel
CRPIX1   =                   %f / Ref pixel in X
```

[14] Applicable to the VISTA deep pawprint image in the same way.

```
CRPIX2  =                    %f / Ref pixel in Y
CTYPE1  =                    %s / pixel coordinate system
CTYPE2  =                    %s / pixel coordinate system
CUNIT1  =                    %s / Unit of coordinate transformation
CUNIT2  =                    %s / Unit of coordinate transformation
CD1_1   =                    %f / Transformation matrix element
CD1_2   =                    %f / Transformation matrix element
CD2_1   =                    %f / Transformation matrix element
CD2_2   =                    %f / Transformation matrix element
CSYER1  =                    %f / Systematic error
CSYER2  =                    %f / Systematic error
CRDER1  =                    %f / Random error
CRDER2  =                    %f / Random error
PHOTZP  =                    %f / Photometric zeropoint MAG=-2.5*log(data)+PHOTZP
PHOTZPER=                    %f / Uncertainty on PHOTZP
PHOTSYS =                    %s / Photometric system VEGA or AB
GAIN    =                    %f / Number of electrons per data unit
ABMAGLIM=                    %f / 5-sigma limiting AB magnitude for point sources
ABMAGSAT=                    %f / Saturation limit for point sources (AB mags)
PSF_FWHM=                    %f / Spatial resolution (arcsec)
ELLIPTIC=                    %f / Average ellipticity of point sources
CHECKSUM=                    %s / HDU checksum
DATASUM =                    %s / Data unit checksum
END
```

Comprehensive list of header keywords for the VISTA deep pawprint in the primary HDU

```
SIMPLE  =                     T / Standard FITS format (NOST-100-2.0)
BITPIX  =                     8 / Number of bits per data pixel
NAXIS   =                     0 / Number of data axes
EXTEND  =                     T / Extensions may be present
ORIGIN  = 'ESO-PARANAL'         / European Southern Observatory
DATE    =                    %s / Date the file was written
TELESCOP= 'ESO-VISTA'           / ESO Telescope designation
INSTRUME= 'VIRCAM  '            / Instrument name
FILTER  =                    %s / Filter name
OBJECT  =                    %s / Target designation
RA      =                    %f / Image centre (J2000.0)
DEC     =                    %f / Image centre (J2000.0)
EQUINOX =                  %.0f / Standard FK5 (years)
RADECSYS=                    %s / Coordinate reference frame
EXPTIME =                    %f / Total integration time per pixel (s)
TEXPTIME=                    %f / Total integration time of all exposures (s)
MJD-OBS =                  %.8f / Start of observations (days)
MJD-END =                  %.8f / End of observations (days)
DATE-OBS=                    %s / Date the observation was started (UTC)
TIMESYS = 'UTC     '            / Time system used
PROG_ID =                  %20s / ESO programme identification
OBID1   =                    %d / Observation block ID
OBID2   =                    %d / Observation block ID
OBIDn   =                    %d / Observation block ID
M_EPOCH =                    %c / TRUE if resulting from multiple epochs
NCOMBINE=                    %d / # of combined raw science data files
PROV1   =                    %s / Originating science file
PROV2   =                    %s / Originating science file
PROV3   =                    %s / Originating science file
OBSTECH = 'IMAGE,JITTER'        / Technique of observation
PRODCATG= 'SCIENCE.MEFIMAGE'    / Data product category
IMATYPE = 'PAWPRINT'            / Specific image type
ISAMP   =                     T / TRUE if image represents partially sampled sky
FLUXCAL = 'ABSOLUTE'            / Certifies the validity of PHOTZP
PROCSOFT=                    %s / Data reduction software/system with version no.
REFERENC=                    %s / Bibliographic reference
ASSON1  =                    %s / Name of associated file
ASSOC1  =                    %s / Category of associated file
ASSON2  =                    %s / Name of associated file
ASSOC2  =                    %s / Category of associated file
TL_RA   =                    %f / Tile RA [HHMMSS.TTT]
TL_DEC  =                    %f / Tile Declination [DDMMSS.TTT]
```

```
TL_OFFAN=                    %f / Tile rotator offset angle [deg]
EPS_REG =                    %s / ESO public survey region name
NJITTER =                    %d / Number of jitter positions
NOFFSETS=                    %d / Number of offset positions
NUSTEP  =                    %d / Number of microstep positions
DIT     =                    %f / Integration Time
NDIT    =                    %d / Number of sub-Integrations
CHECKSUM=                    %s / HDU checksum
DATASUM =                    %s / Data unit checksum
COMMENT
END
```

Notes regarding keyword definitions

- MJD-OBS should be set to MJD-OBS of the first exposure contributing to this data product.
- MJD-END—the end of observations can be obtained in an approximate fashion using MJD-OBS of the last exposure contributing to this data product and adding the total exposure time of this exposure, i.e. MJD-END = MJD-OBS+(DIT*NDIT)/86400 in which MJD-OBS, DIT and NDIT refer to the last exposure.
- EXPTIME—for a VISTA pawprint being the result of NJITTER exposures, EXPTIME should be set to the product NJITTER*NDIT*DIT. If individual exposures were rejected before combination into the pawprint image, EXPTIME should be adjusted accordingly.
  For a VISTA deep pawprint image resulting from the co-addition of N_OBS observations, each of them consisting of NJITTER exposures, EXPTIME should be set to the product N_OBS*NJITTER*NDIT*DIT. If the N_OBS observations do not share the same individual exposure time, i.e. NJITTER, NDIT, and DIT, then EXPTIME should be computed by direct summing of the individual exposure times. If individual exposures were rejected before combination into the pawprint image, EXPTIME should be adjusted accordingly.
- TEXPTIME should equal EXPTIME for the VISTA pawprint image (including the deep pawprint).
- SINGLEXP—must be set TRUE if the pawprint image results from one single exposure. Otherwise, SINGLEXP does not have to be included.
- ASSON1 and ASSOC1 are compulsory for the VISTA pawprint to associate the respective weight image, also known as confidence map (see §3.1.3). Further instances of the indexed keywords ASSONi and ASSONi may be used to associate more data products if needed.

3.2.3 VISTA stripes image

The *VISTA stripes image* consists of 4 vertical stripes sampling a total of about 0.73 square degrees of the 1° by 1.5° patch of one VISTA tile. The VISTA stripes image results from the co-addition of 3 pointed observations vertically offset by ca. 1/3 of the detector size. The dedicated VIRCAM/VISTA template “VIRCAM_img_obs_tile3” allows preparing the respective sequence within a single observation. The data of the VISTA stripes image are stored in 4 image extensions of a multi-extension FITS file.

The stripes image is the baseline layout for the ultra deep part of the UltraVISTA public imaging survey. According to the observing strategy chosen for this particular programme, the VISTA stripes image will consist of 3 OBs each at least, corresponding to the 3 pointing positions. Following the terminology introduced earlier for VISTA tiles and pawprints resulting from multiple OBs, the respective UltraVISTA products are called *deep* stripes image. The FITS header templates listed below apply to the VISTA deep stripes image. It is not foreseen that VISTA public imaging programmes deliver the stripes image resulting from a single OB.

List of header keywords specific to the VISTA stripes image

```
TELESCOP= 'ESO-VISTA'            / ESO Telescope designation
INSTRUME= 'VIRCAM  '             / Instrument name
OBSTECH = 'IMAGE,JITTER'         / Technique of observation
PRODCATG= 'SCIENCE.MEFIMAGE'     / Data product category
IMATYPE = 'VSTRIPES'             / Specific image type
ISAMP   =                      T / TRUE if image represents partially sampled sky
```

Comprehensive list of header keywords for the VISTA deep stripes image in the primary HDU

```
SIMPLE  =                      T / Standard FITS format (NOST-100-2.0)
BITPIX  =                      8 / Number of bits per data pixel
NAXIS   =                      0 / Number of data axes
EXTEND  =                      T / Extensions may be present
ORIGIN  = 'ESO-PARANAL'          / European Southern Observatory
DATE    =                     %s / Date the file was written
TELESCOP= 'ESO-VISTA'            / ESO Telescope designation
INSTRUME= 'VIRCAM  '             / Instrument name
FILTER  =                     %s / Filter name
OBJECT  =                     %s / Target designation
RA      =                     %f / Image centre (J2000.0)
DEC     =                     %f / Image centre (J2000.0)
EQUINOX =                   %.0f / Standard FK5 (years)
RADECSYS=                     %s / Coordinate reference frame
EXPTIME =                     %f / Total integration time per pixel (s)
TEXPTIME=                     %f / Total integration time of all exposures (s)
MJD-OBS =                   %.8f / Start of observations (days)
MJD-END =                   %.8f / End of observations (days)
DATE-OBS=                     %s / Date the observation was started (UTC)
TIMESYS = 'UTC     '             / Time system used
PROG_ID =                   %20s / ESO programme identification
OBID1   =                     %d / Observation block ID
OBID2   =                     %d / Observation block ID
OBIDn   =                     %d / Observation block ID
M_EPOCH =                     %c / TRUE if resulting from multiple epochs
NCOMBINE=                     %d / # of combined raw science data files
PROV1   =                     %s / Originating science file
PROV2   =                     %s / Originating science file
PROV3   =                     %s / Originating science file
OBSTECH = 'IMAGE,JITTER'         / Technique of observation
PRODCATG= 'SCIENCE.MEFIMAGE'     / Data product category
IMATYPE = 'VSTRIPES'             / Specific image type
ISAMP   =                      T / TRUE if image represents partially sampled sky
FLUXCAL = 'ABSOLUTE'             / Certifies the validity of PHOTZP
PROCSOFT=                     %s / Data reduction software/system with version no.
REFERENC=                     %s / Bibliographic reference
ASSON1  =                     %s / Name of associated file
ASSOC1  =                     %s / Category of associated file
ASSON2  =                     %s / Name of associated file
ASSOC2  =                     %s / Category of associated file
TL_RA   =                     %f / Tile RA [HHMMSS.TTT]
TL_DEC  =                     %f / Tile Declination [DDMMSS.TTT]
TL_OFFAN=                     %f / Tile rotator offset angle [deg]
EPS_REG =                     %s / ESO public survey region name
NJITTER =                     %d / Number of jitter positions
NOFFSETS=                     %d / Number of offset positions
NUSTEP  =                     %d / Number of microstep positions
DIT     =                     %f / Integration Time
NDIT    =                     %d / Number of sub-Integrations
CHECKSUM=                     %s / HDU checksum
DATASUM =                     %s / Data unit checksum
COMMENT
END
```

Comprehensive list of header keywords for the VISTA (deep) stripes image in the image extensions

```
XTENSION= 'IMAGE   '            / FITS Extension first keyword
BITPIX  =                    %d / 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
EXTNAME =                    %s / FITS Extension name
INHERIT =                     T / Primary header keywords are inherited
BZERO   =                    %f / real = fits-value*BSCALE+BZERO
BSCALE  =                    %f / real = fits-value*BSCALE+BZERO
BUNIT   =                    %s / Physical unit of array values
BLANK   =                    %d / Value used for NULL pixels
DATAMAX =                    %f / Maximum pixel value
DATAMIN =                    %f / Minimal pixel value
CRVAL1  =                    %f / Coordinate value at ref pixel
CRVAL2  =                    %f / Coordinate value at ref pixel
CRPIX1  =                    %f / Ref pixel in X
CRPIX2  =                    %f / Ref pixel in Y
CTYPE1  =                    %s / pixel coordinate system
CTYPE2  =                    %s / pixel coordinate system
CUNIT1  =                    %s / Unit of coordinate transformation
CUNIT2  =                    %s / Unit of coordinate transformation
CD1_1   =                    %f / Transformation matrix element
CD1_2   =                    %f / Transformation matrix element
CD2_1   =                    %f / Transformation matrix element
CD2_2   =                    %f / Transformation matrix element
CSYER1  =                    %f / Systematic error
CSYER2  =                    %f / Systematic error
CRDER1  =                    %f / Random error
CRDER2  =                    %f / Random error
PHOTZP  =                    %f / Photometric zeropoint MAG=-2.5*log(data)+PHOTZP
PHOTZPER=                    %f / Uncertainty on PHOTZP
PHOTSYS =                    %s / Photometric system VEGA or AB
GAIN    =                    %f / Number of electrons per data unit
ABMAGLIM=                    %f / 5-sigma limiting AB magnitude for point sources
ABMAGSAT=                    %f / Saturation limit for point sources (AB mags)
PSF_FWHM=                    %f / Spatial resolution (arcsec)
ELLIPTIC=                    %f / Average ellipticity of point sources
CHECKSUM=                    %s / HDU checksum
DATASUM =                    %s / Data unit checksum
END
```

Notes regarding keyword definitions

- MJD-OBS should be set to MJD-OBS of the first exposure contributing to this data product.
- MJD-END—the end of observations can be obtained in an approximate fashion using MJD-OBS of the last exposure contributing to this data product and adding the total exposure time of this exposure, i.e. MJD-END = MJD-OBS+(DIT*NDIT)/86400 in which MJD-OBS, DIT and NDIT refer to the last exposure.
- EXPTIME—for a VISTA deep stripes image resulting from the co-addition of 3 deep pawprint images offset by ca. 1/3 of the detector size, having total exposure time T_{exp} each, EXPTIME should be set to $2*T_{exp}$.
- TEXPTIME—for the example given above TEXPTIME should be set to $3*T_{exp}$.
- ASSON1 and ASSOC1 are compulsory for VISTA pawprint to associate the respective weight image, also known as confidence map (see §3.1.3). Further instances of the indexed keywords ASSONi and ASSONi may be used to associate more data products if needed.

3.2.4 VISTA source list

The VISTA source list provides the file format for the tabular data of sources extracted from VISTA imaging data products. Typically the VISTA source list is pipeline-produced, using the nightly calibrations and is delivered on an image-by-image basis.
The single-band source catalogue extracted from one VISTA tile is the prototypical example but a VISTA source list may origin from other images types like the VISTA pawprint as well. Any VISTA source list is necessarily associated to its originating image due to its processing provenance.
The VISTA 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.
The VISTA source list adopts a number of keywords that characterize the originating imaging observation to facilitate direct archive queries.

List of header keywords specific to the VISTA source list

```
TELESCOP= 'ESO-VISTA'           / ESO Telescope designation
INSTRUME= 'VIRCAM  '            / Instrument name
OBSTECH = 'IMAGE,JITTER'        / Technique of observation
PRODCATG= 'SCIENCE.SRCTBL'      / Data product category
IMATYPE =                    %s / Specific image type
ISAMP   =                    %c / TRUE if image represents partially sampled sky
```

Comprehensive list of header keywords for the VISTA source list in the primary HDU

```
SIMPLE  =                     T / Standard FITS format (NOST-100-2.0)
BITPIX  =                     8 / Number of bits per data pixel
NAXIS   =                     0 / Number of data axes
EXTEND  =                     T / Extensions may be present
ORIGIN  = 'ESO-PARANAL'         / European Southern Observatory
DATE    =                    %s / Date the file was written
TELESCOP= 'ESO-VISTA'           / ESO Telescope designation
INSTRUME= 'VIRCAM  '            / Instrument name
FILTER  =                    %s / Filter name
OBJECT  =                    %s / Target designation
RA      =                    %f / Image centre (J2000.0)
DEC     =                    %f / Image centre (J2000.0)
EQUINOX =                  %.0f / Standard FK5 (years)
RADECSYS=                    %s / Coordinate reference frame
EXPTIME =                    %f / Total integration time per pixel (s)
TEXPTIME=                    %f / Total integration time of all exposures (s)
MJD-OBS =                  %.8f / Start of observations (days)
MJD-END =                  %.8f / End of observations (days)
DATE-OBS=                    %s / Date the observation was started (UTC)
TIMESYS = 'UTC     '            / Time system used
PROG_ID =                  %20s / ESO programme identification
OBID1   =                    %d / Observation block ID
OBID2   =                    %d / Observation block ID
OBIDn   =                    %d / Observation block ID
M_EPOCH =                    %c / TRUE if resulting from multiple epochs
SINGLEXP=                    %c / TRUE if resulting from single exposure
PROV1   =                    %s / Originating science file
PROV2   =                    %s / Originating science file
PROV3   =                    %s / Originating science file
OBSTECH = 'IMAGE,JITTER'        / Technique of observation
PRODCATG= 'SCIENCE.SRCTBL'      / Data product category
IMATYPE =                    %s / Specific image type
ISAMP   =                    %c / TRUE if image represents partially sampled sky
PROCSOFT=                    %s / Data reduction software/system with version no.
REFERENC=                    %s / Bibliographic reference
ASSON1  =                    %s / Name of associated file
ASSOC1  =                    %s / Category of associated file
TL_RA   =                    %f / Tile RA [HHMMSS.TTT]
```

```
TL_DEC   =                   %f / Tile Declination [DDMMSS.TTT]
TL_OFFAN=                    %f / Tile rotator offset angle [deg]
EPS_REG =                    %s / ESO public survey region name
CHECKSUM=                    %s / HDU checksum
DATASUM =                    %s / Data unit checksum
COMMENT
END
```

Comprehensive list of header keywords for the VISTA source list in the binary table extensions

```
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
TTYPEi  =                    %s / Label for field i
TFORMi  =                    %s / Data format of field i
TUNITi  =                    %s / Physical unit of field i
EXTNAME =                    %s / FITS Extension name
INHERIT =                     T / Primary header keywords are inherited
NXOUT   =                    %d / Length of image data axis 1
NYOUT   =                    %d / Length of image data axis 2
TCRVL3  =                    %f / Coordinate value at ref pixel
TCRVL5  =                    %f / Coordinate value at ref pixel
TCRPX3  =                    %f / Ref pixel in X
TCRPX5  =                    %f / Ref pixel in Y
TCTYP3  =                    %s / Pixel coordinate system
TCTYP5  =                    %s / Pixel coordinate system
TC3_3   =                    %f / Transformation matrix element
TC3_5   =                    %f / Transformation matrix element
TC5_3   =                    %f / Transformation matrix element
TC5_5   =                    %f / Transformation matrix element
FPRA1   =                    %f / Footprint (J2000.0)
FPDE1   =                    %f / Footprint (J2000.0)
FPRA2   =                    %f / Footprint (J2000.0)
FPDE2   =                    %f / Footprint (J2000.0)
FPRA3   =                    %f / Footprint (J2000.0)
FPDE3   =                    %f / Footprint (J2000.0)
FPRA4   =                    %f / Footprint (J2000.0)
FPDE4   =                    %f / Footprint (J2000.0)
PHOTSYS =                    %s / Photometric system VEGA or AB
ABMAGLIM=                    %f / 5-sigma limiting AB magnitude for point sources
ABMAGSAT=                    %f / Saturation limit for point sources (AB mags)
PSF_FWHM=                    %f / Spatial resolution (arcsec)
ELLIPTIC=                    %f / Average ellipticity of point sources
CHECKSUM=                    %s / HDU checksum
DATASUM =                    %s / Data unit checksum
END
```

Notes regarding keyword definitions

- IMATYPE and ISAMP characterize the VISTA image type from which sources have been extracted as specified in Table 7. ISAMP must be set to 'T' (true) if IMATYPE is 'PAWPRINT' or 'VSTRIPES'.
- The keywords that characterize the observation at large, namely ORIGIN, TELESCOP, INSTRUME, FILTER, OBJECT, EQUINOX, RADECSYS, EXPTIME, TEXPTIME, MJD-OBS, MJD-END, PROG_ID, OBIDi, M_EPOCH, SINGLEXP, OBSTECH, IMATYPE, ISAMP, REFERENC, TL_RA, TL_DEC, TL_OFFAN, EPS_REG, should be adopted from the original image from which the sources were extracted.
- PROV1—reference to the image data product from which this source list was extracted. Provided that image and source list are being released through the same data collection,

PROV1 has to be set to the filename of the image under which it is submitted or it can refer to the filename in the preceding data release. At the time of archiving the data, the system will substitute the filenames with unique ESO archive identifiers. If the image has been submitted to and archived by ESO at an earlier time and it is not part of the preceding data release, PROV1 has to be set to the ESO archive identifier, which has been assigned to the respective file at the time of archiving.

3.2.5 VISTA multi-band source list

This section specifies the content and data format for lists of tabulated sources, which are produced on a tile-by-tile basis by combining the data obtained through different filters, subsequently denoted *multi-band source lists*[15]. All the six VISTA public imaging surveys have planned to deliver products of this type every six months as per ESO public survey policies (cf. http://www.eso.org/sci/observing/phase3/policies_eps).

Characteristics

- The multi-band source list results from the combination of imaging data acquired in two or more spectral bands defined by the instrument's filter set.
- Source lists are produced in a tile-by-tile fashion. Therefore, each one is uniquely associated with its originating VISTA tile on the sky.
- Multi-band source lists are typically based on the calibrations obtained in the single night. Of course, this does not preclude multi-band source lists based on a global calibration, if it is available.
- Fluxes and magnitudes should be aperture-matched, i.e. a correction should be applied to compensate PSF variations across the different bands.
- Each multi-band source list should include the source position in equatorial coordinates with respect to the standard equinox of J2000.0 in decimal degrees (i.e., ICRS position or FK5-based system).
- Each multi-band source list must have one column that uniquely identifies each source within the respective file or FITS extension. The source identifier may be defined in compliance to the IAU Recommendations for Nomenclature using a pattern like <Acronym> J<HHMMSS.ss+DDMMSS.s>, for example "VHS J123456.78+001234.5".
- Variable sources should be flagged in the multi-band source list using a dedicated Boolean column named "VARFLAG".
- The sky coverage, or footprint, of the multi-band source list should be defined in terms of the N vertices of a geodesic polygon using equatorial coordinates (J2000).
- For each band the approximate limiting magnitude should be provided to characterize the data product. Usually this information can be adopted from the respective single-band source list.
- Depending on the adopted data reduction strategy multi-band source lists can be produced from one or more of the following types of VISTA imaging data products: VISTA tile image, pawprint image, and stripes image, VISTA (single-band) source list.

List of header keywords defining the VISTA multi-band source list

```
TELESCOP= 'ESO-VISTA'            / ESO Telescope designation
INSTRUME= 'VIRCAM  '             / Instrument name
FILTER  = 'MULTI   '             / Band-merged data product
OBSTECH = 'IMAGE,JITTER'         / Technique of observation
PRODCATG= 'SCIENCE.SRCTBL'       / Data product category
IMATYPE =                     %s / Specific image type
ISAMP   =                     %c / TRUE if image represents partially sampled sky
```

[15] The term *source list* was chosen in contrast to the survey *source catalogues*, 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. The survey catalogues represent part of the annual survey data releases, as described in the ESO policies for data product delivery, see http://www.eso.org/sci/observing/phase3/policies_eps.

Comprehensive list of header keywords for the VISTA multi-band source list in the primary HDU

```
SIMPLE  =                    T / Standard FITS format (NOST-100-2.0)
BITPIX  =                    8 / Number of bits per data pixel
NAXIS   =                    0 / Number of data axes
EXTEND  =                    T / Extensions may be present
ORIGIN  = 'ESO-PARANAL'        / European Southern Observatory
DATE    =                   %s / Date the file was written
TELESCOP= 'ESO-VISTA'          / ESO Telescope designation
INSTRUME= 'VIRCAM  '           / Instrument name
FILTER  = 'MULTI   '           / Band-merged data product
FILTER1 =                   %s / Filter name
FILTER2 =                   %s / Filter name
FILTER3 =                   %s / Filter name
OBJECT  =                   %s / Target designation
RA      =                   %f / Image centre (J2000.0)
DEC     =                   %f / Image centre (J2000.0)
EQUINOX =                 %.0f / Standard FK5 (years)
RADECSYS=                   %s / Coordinate reference frame
MJD-OBS =                 %.8f / Start of observations (days)
MJD-END =                 %.8f / End of observations (days)
DATE-OBS=                   %s / Date the observation was started (UTC)
TIMESYS = 'UTC     '           / Time system used
PROG_ID =                 %20s / ESO programme identification
OBID1   =                   %d / Observation block ID
OBID2   =                   %d / Observation block ID
OBIDn   =                   %d / Observation block ID
M_EPOCH =                   %c / TRUE if resulting from multiple epochs
PROV1   =                   %s / Originating science file
PROV2   =                   %s / Originating science file
PROV3   =                   %s / Originating science file
OBSTECH = 'IMAGE,JITTER'       / Technique of observation
PRODCATG= 'SCIENCE.SRCTBL'     / Data product category
APMATCHD=                   %c / TRUE if fluxes are aperture-matched
IMATYPE =                   %s / Specific image type
ISAMP   =                   %c / TRUE if image represents partially sampled sky
PROCSOFT=                   %s / Data reduction software/system with version no.
REFERENC=                   %s / Bibliographic reference
ASSON1  =                   %s / Name of associated file
ASSOC1  =                   %s / Category of associated file
TL_RA   =                   %f / Tile RA [HHMMSS.TTT]
TL_DEC  =                   %f / Tile Declination [DDMMSS.TTT]
TL_OFFAN=                   %f / Tile rotator offset angle [deg]
EPS_REG =                   %s / ESO public survey region name
CHECKSUM=                   %s / HDU checksum
DATASUM =                   %s / Data unit checksum
COMMENT
END
```

Comprehensive list of header keywords for the VISTA multi-band source list in the binary table extensions

```
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
TTYPEi  =                   %s / Label for field i
TFORMi  =                   %s / Data format of field i
TUNITi  =                   %s / Physical unit of field i
EXTNAME =                   %s / FITS Extension name
INHERIT =                    T / Primary header keywords are inherited
FPRA1   =                   %f / Footprint (J2000.0)
FPDE1   =                   %f / Footprint (J2000.0)
```

```
FPRA2   =                   %f / Footprint (J2000.0)
FPDE2   =                   %f / Footprint (J2000.0)
FPRA3   =                   %f / Footprint (J2000.0)
FPDE3   =                   %f / Footprint (J2000.0)
FPRA4   =                   %f / Footprint (J2000.0)
FPDE4   =                   %f / Footprint (J2000.0)
PHOTSYS =                   %s / Photometric system VEGA or AB
MAGLIM1 =                   %f / 5-sigma limiting AB magnitude for point sources
MAGLIM2 =                   %f / 5-sigma limiting AB magnitude for point sources
MAGLIM3 =                   %f / 5-sigma limiting AB magnitude for point sources
CHECKSUM=                   %s / HDU checksum
DATASUM =                   %s / Data unit checksum
END
```

Notes regarding the tabular data format

- If an upper limit is reported instead of a flux estimate for a source, this case should be clearly marked e.g. by setting a flag in a dedicated column of the table.
- Missing data can be represented by the special null value, IEEE NaN for floating point data or using the TNULL*i* keyword in case of integer data.

Notes regarding keyword definitions

- The keywords that characterize the observation at large, namely ORIGIN, TELESCOP, INSTRUME, FILTER*i*, OBJECT, EQUINOX, RADECSYS, MJD-OBS, MJD-END, PROG_ID, OBIDi, M_EPOCH, SINGLEXP, OBSTECH, IMATYPE, ISAMP, REFERENC, TL_RA, TL_DEC, TL_OFFAN, EPS_REG, should be adopted from the respective keywords of the images from which the sources were extracted.
- FILTER*i*—(distinct) list of spectral bands using FILTER names of the original imaging products.
- MJD-OBS should be set to the minimum MJD-OBS of the original images including all bands, and, similarly, MJD-END should be set to the maximum MJD-END of the original images including all bands.
- PROV*i*—list of precursor products, normally images, based on which this source list was generated. Note that PROV*i* cannot be validated if it points to a file that is not included in the ESO archive system. Therefore, it is necessary that the PROV*i* refer to product files already being archived in the ESO archive or to files being submitted simultaneously with the referencing product.
- PHOTSYS—specifies the photometric system for the magnitudes reported in the binary table. PHOTSYS does *not* apply to the MAGLIM*i* keywords, whose values have to be given in the AB photometric system invariably.

3.3 OmegaCAM

Overview

Scientific observations with OmegaCAM are performed using templates that differ in the kind of offsets (DITHER, JITTER, OFFSET, or STARE) that are used between exposures, and in the final data product. Table 8 gives an overview of the specific OmegaCAM data product types and their characteristics. The corresponding header keyword settings are listed in Table 9. The *footprint shape* specifies the sky coverage of the imaging data as given by the combination of the instrumental design and the observing strategy. For OmegaCAM the two footprint shapes, “Pawprint”, and “Tile”, cover the variety of products resulting from the ESO public survey programmes and are further described in §3.3.1 and §3.3.2. The attribute “deep” in the product description indicates if the data product is based on multiple observations. The flag ISAMP indicates if the imaging data represents multiple disconnected regions, i.e. a *sampling* of the sky (ISAMP=‘T’), or one *contiguous* fraction of the sky (ISAMP=‘F’ or unset). The flag SINGLEXP indicates if the product is the result of one single exposure or not. The column labelled “Source list” indicates the potential availability of source tables extracted from the imaging products. Specific data formats are defined for source lists in §3.3.3.

Table 8: Overview of OmegaCAM data product types and their characteristics

Data product description	OmegaCAM footprint shape	Single/ multiple OBs	Sampled/ contiguous sky	Number of disconnected regions sampled	Source list
OmegaCAM tile	Tile	Single	contiguous	1	✓
OmegaCAM deep tile	Tile	Multi	contiguous	1	✓
OmegaCAM pawprint	Pawprint	Single	sampled	32	✓
OmegaCAM single exposure	Pawprint	Single	sampled	32	n/a

Table 9: Summary of OmegaCAM data product formats and corresponding keyword settings

Data product description	PRODCATG	IMATYPE	ISAMP	SINGLEXP
OmegaCAM (deep) tile	SCIENCE.IMAGE	TILE	F	F
OmegaCAM pawprint	SCIENCE.MEFIMAGE	PAWPRINT	T	F
OmegaCAM single exposure	SCIENCE.MEFIMAGE	PAWPRINT	T	T
OmegaCAM tile’s source list	SCIENCE.SRCTBL	TILE	F	F
OmegaCAM pawprint’s source list	SCIENCE.SRCTBL	PAWPRINT	T	F

3.3.1 OmegaCAM Tile

The OmegaCAM tile is the basic building block of VST public surveys. The tile is a full field, stacked 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 and it has the detector gaps filled in by executing the observation using the DITHER offset mode.
The purpose of dithering is to remove the imprint of inter-CCD gaps in the detector mosaic. Offsets are taken that are sufficiently large for these gaps to fall on different parts of the sky in each exposure. Co-addition of the images then gives as homogeneous an exposure as possible. For N exposures it is unavoidable that some parts of the image will have been seen in at most N-2 exposures. An observation executed using a dither sequence with the OmegaCAM template “OMEGACAM_img_obs_dither” results in a tile as data product.

The OmegaCAM tile image comes in two flavours to distinguish whether data have been combined from one or multiple observations. The “normal” OmegaCAM tile is based on a single observation, which has to be identified by the keyword OB ID1. If the original data, which has been combined to form a final tile, was obtained in more than one observation block, the data product is termed OmegaCAM *deep* tile image, and the complete set of original observations should be listed using the indexed keyword OB ID*i*. The presence of the keyword OB ID2 indicates the multi-OB character, i.e. the fact that the respective data product forms a deep tile image.

The OmegaCAM tile stores the data array in the FITS file's primary HDU. The OmegaCAM tile requires a number of specific keywords related to data acquisition, data quality and public surveys as listed below.

List of header keywords specific to the OmegaCAM tile image

```
TELESCOP= 'ESO-VST'              / ESO Telescope designation
INSTRUME= 'OMEGACAM'             / Instrument name
OBSTECH = 'IMAGE,DITHER'         / Technique of observation
PRODCATG= 'SCIENCE.IMAGE'        / Data product category
IMATYPE = 'TILE'                 / Specific image type
```

Comprehensive list of header keywords for the OmegaCAM tile image

```
SIMPLE  =                    T / Standard FITS format (NOST-100-2.0)
BITPIX  =                   %d / 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
EXTEND  =                    T / Extensions may be present
BZERO   =                   %f / real = fits-value*BSCALE+BZERO
BSCALE  =                   %f / real = fits-value*BSCALE+BZERO
BUNIT   =                   %s / Physical unit of array values
BLANK   =                   %d / Value used for NULL pixels
ORIGIN  = 'ESO-PARANAL'        / European Southern Observatory
DATE    =                   %s / Date the file was written
DATAMAX =                   %f / Maximum pixel value
DATAMIN =                   %f / Minimal pixel value
TELESCOP= 'ESO-VST'            / ESO Telescope designation
INSTRUME= 'OMEGACAM'           / Instrument name
FILTER  =                   %s / Filter name
OBJECT  =                   %s / Target designation
RA      =                   %f / Image centre (J2000.0)
DEC     =                   %f / Image centre (J2000.0)
EQUINOX =                 %.0f / Standard FK5 (years)
RADECSYS=                   %s / Coordinate reference frame
EXPTIME =                   %f / Total integration time per pixel (s)
TEXPTIME=                   %f / Total integration time of all exposures (s)
MJD-OBS =                 %.8f / Start of observations (days)
MJD-END =                 %.8f / End of observations (days)
DATE-OBS=                   %s / Date the observation was started (UTC)
TIMESYS = 'UTC     '           / Time system used
PROG_ID =                 %20s / ESO programme identification
OBID1   =                   %d / Observation block ID
M_EPOCH =                   %c / TRUE if resulting from multiple epochs
NCOMBINE=                   %d / # of combined raw science data files
PROV1   =                   %s / Originating science file
PROV2   =                   %s / Originating science file
PROV3   =                   %s / Originating science file
OBSTECH = 'IMAGE,DITHER'       / Technique of observation
PRODCATG= 'SCIENCE.IMAGE'      / Data product category
IMATYPE = 'TILE'               / Specific image type
FLUXCAL = 'ABSOLUTE'           / Certifies the validity of PHOTZP
CRVAL1  =                   %f / Coordinate value at ref pixel
CRVAL2  =                   %f / Coordinate value at ref pixel
CRPIX1  =                   %f / Ref pixel in X
CRPIX2  =                   %f / Ref pixel in Y
CTYPE1  =                   %s / pixel coordinate system
CTYPE2  =                   %s / pixel coordinate system
CUNIT1  =                   %s / Unit of coordinate transformation
CUNIT2  =                   %s / Unit of coordinate transformation
CD1_1   =                   %f / Transformation matrix element
```

```
CD1_2    =                    %f / Transformation matrix element
CD2_1    =                    %f / Transformation matrix element
CD2_2    =                    %f / Transformation matrix element
CSYER1   =                    %f / Systematic error
CSYER2   =                    %f / Systematic error
CRDER1   =                    %f / Random error
CRDER2   =                    %f / Random error
PHOTZP   =                    %f / Photometric zeropoint MAG=-2.5*log(data)+PHOTZP
PHOTZPER=                     %f / Uncertainty on PHOTZP
PHOTSYS =                     %s / Photometric system VEGA or AB
DETRON   =                    %f / Detector readout noise
EFFRON   =                    %f / Median effective readout noise
WEIGHT   =                    %f / Median weight
ABMAGLIM=                     %f / 5-sigma limiting AB magnitude for point sources
ABMAGSAT=                     %f / Saturation limit for point sources (AB mags)
PSF_FWHM=                     %f / Spatial resolution (arcsec)
ELLIPTIC=                     %f / Average ellipticity of point sources
PROCSOFT=                     %s / Data reduction software/system with version no.
REFERENC=                     %s / Bibliographic reference
ASSON1   =                    %s / Name of associated file
ASSOC1   ='ANCILLARY.WEIGHTMAP' / Category of associated file
ASSON2   =                    %s / Name of associated file
ASSOC2   =                    %s / Category of associated file
TL_RA    =                    %f / Tile RA [HHMMSS.TTT]
TL_DEC   =                    %f / Tile Declination [DDMMSS.TTT]
TL_OFFAN=                     %f / Tile rotator offset angle [deg]
TL_ID    =                    %s / Unique tile identifier within the survey
EPS_REG =                     %s / ESO public survey region name
NDITHER =                     %d / Number of dither positions
DIT      =                    %f / Integration Time
CHECKSUM=                     %s / HDU checksum
DATASUM =                     %s / Data unit checksum
COMMENT
END
```

Notes regarding keyword definitions

- The TELESCOP value should not be propagated directly from the raw data to the science product but should be set to 'ESO-VST' instead.
- MJD-OBS should be set to MJD-OBS of the first exposure contributing to this data product.
- MJD-END—the end of observations can be obtained in an approximate fashion using MJD-OBS of the last exposure contributing to this data product and adding the total exposure time of this exposure, i.e. MJD-END = MJD-OBS+DIT/86400 in which MJD-OBS and DIT refer to the last exposure in the image co-addition.
- TEXPTIME—for an OmegaCAM tile being the result of one observation performing offsets in between NEXP exposures, TEXPTIME should be set to NEXP*DIT.
  For an OmegaCAM deep tile resulting from the co-addition of N_OBS observations with NEXP exposures per observation, TEXPTIME should be set to the product N_OBS*NEXP*DIT.
  If individual exposures were rejected before combination into the tile, TEXPTIME should be adjusted accordingly.
- EXPTIME should be set to TEXPTIME. This is true for the vast majority of pixels, but not all.
- NCOMBINE should be set to the number of raw science data files that were combined to generate the tile image. It can be obtained from the keyword HIERARCH ESO TPL NEXP of the original data. For a deep tile resulting from the co-addition of N_OBS observations with NEXP exposures per observation, NCOMBINE should be set to N_OBS*NEXP. If individual exposures were rejected before combination into the tile, NCOMBINE should be adjusted accordingly.
- EPS_REG shall be specified for survey programmes targeting multiple regions. For KIDS, it shall be set to KIDS-N, KIDS-S, or KIDS-Wide-i. For ATLAS, it shall be set to ATLAS-N or ATLAS-S.
- The TL_* keywords shall refer to the attributes of the ideal tile as defined using either the Survey Area Definition Tool or an alternative preparation tool.

- ASSON1 and ASSOC1 are compulsory for OmegaCAM tiles to associate the respective weight image, also known as confidence map (see §3.1.3).
- ASSON2 and ASSOC2 are recommended for OmegaCAM tiles to associate the respective gain map (see §3.1.4).
- Further instances of the indexed keywords ASSONi and ASSONi may be used to associate more data products if needed.

3.3.2 OmegaCAM Pawprint

The 32 non-contiguous images of the sky produced by the OmegaCAM camera, with its 32 non-contiguous detector chips 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 degree of the detector 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.

The OmegaCAM pawprint image requires a number of specific keywords related to data acquisition, data quality and public surveys as listed below.

List of header keywords specific to the OmegaCAM pawprint image

```
TELESCOP= 'ESO-VST'              / ESO Telescope designation
INSTRUME= 'OMEGACAM'             / Instrument name
OBSTECH =                     %s / Technique of observation
PRODCATG= 'SCIENCE.IMAGE'        / Data product category
IMATYPE = 'PAWPRINT'             / Specific image type
ISAMP   =                      T / TRUE if image represents partially sampled sky
```

Comprehensive list of header keywords for the OmegaCAM pawprint in the primary HDU

```
SIMPLE  =                      T / Standard FITS format (NOST-100-2.0)
BITPIX  =                     %d / 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
EXTEND  =                      T / Extensions may be present
BZERO   =                     %f / real = fits-value*BSCALE+BZERO
BSCALE  =                     %f / real = fits-value*BSCALE+BZERO
BUNIT   =                     %s / Physical unit of array values
BLANK   =                     %d / Value used for NULL pixels
ORIGIN  = 'ESO-PARANAL'          / European Southern Observatory
DATE    =                     %s / Date the file was written
DATAMAX =                     %f / Maximum pixel value
DATAMIN =                     %f / Minimal pixel value
TELESCOP= 'ESO-VST'              / ESO Telescope designation
INSTRUME= 'OMEGACAM'             / Instrument name
FILTER  =                     %s / Filter name
OBJECT  =                     %s / Target designation
RA      =                     %f / Image centre (J2000.0)
DEC     =                     %f / Image centre (J2000.0)
EQUINOX =                   %.0f / Standard FK5 (years)
RADECSYS=                     %s / Coordinate reference frame
EXPTIME =                     %f / Total integration time per pixel (s)
TEXPTIME=                     %f / Total integration time of all exposures (s)
MJD-OBS =                   %.8f / Start of observations (days)
MJD-END =                   %.8f / End of observations (days)
DATE-OBS=                     %s / Date the observation was started (UTC)
```

```
TIMESYS = 'UTC     '             / Time system used
PROG_ID =                   %20s / ESO programme identification
OBID1   =                     %d / Observation block ID
M_EPOCH =                     %c / TRUE if resulting from multiple epochs
SINGLEXP=                     %c / TRUE if resulting from single exposure
NCOMBINE=                     %d / # of combined raw science data files
PROV1   =                     %s / Originating science file
PROV2   =                     %s / Originating science file
PROV3   =                     %s / Originating science file
OBSTECH =                     %s / Technique of observation
PRODCATG= 'SCIENCE.IMAGE'        / Data product category
IMATYPE = 'PAWPRINT'             / Specific image type
ISAMP   =                      T / TRUE if image represents partially sampled sky
FLUXCAL = 'ABSOLUTE'             / Certifies the validity of PHOTZP
PROCSOFT=                     %s / Data reduction software/system with version no.
REFERENC=                     %s / Bibliographic reference
ASSON1  =                     %s / Name of associated file
ASSOC1  ='ANCILLARY.WEIGHTMAP'   / Category of associated file
ASSON2  =                     %s / Name of associated file
ASSOC2  =                     %s / Category of associated file
TL_RA   =                     %f / Tile RA [HHMMSS.TTT]
TL_DEC  =                     %f / Tile Declination [DDMMSS.TTT]
TL_OFFAN=                     %f / Tile rotator offset angle [deg]
TL_ID   =                     %s / Unique tile identifier within the survey
EPS_REG =                     %s / ESO public survey region name
DIT     =                     %f / Integration Time
CHECKSUM=                     %s / HDU checksum
DATASUM =                     %s / Data unit checksum
COMMENT
END
```

Comprehensive list of header keywords for the OmegaCAM pawprint in the image extensions

```
XTENSION= 'IMAGE   '             / FITS Extension first keyword
BITPIX  =                     %d / 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
EXTNAME =                     %s / FITS Extension name
INHERIT =                      T / Primary header keywords are inherited
BZERO   =                     %f / real = fits-value*BSCALE+BZERO
BSCALE  =                     %f / real = fits-value*BSCALE+BZERO
BUNIT   =                     %s / Physical unit of array values
BLANK   =                     %d / Value used for NULL pixels
DATAMAX =                     %f / Maximum pixel value
DATAMIN =                     %f / Minimal pixel value
CRVAL1  =                     %f / Coordinate value at ref pixel
CRVAL2  =                     %f / Coordinate value at ref pixel
CRPIX1  =                     %f / Ref pixel in X
CRPIX2  =                     %f / Ref pixel in Y
CTYPE1  =                     %s / pixel coordinate system
CTYPE2  =                     %s / pixel coordinate system
CUNIT1  =                     %s / Unit of coordinate transformation
CUNIT2  =                     %s / Unit of coordinate transformation
CD1_1   =                     %f / Transformation matrix element
CD1_2   =                     %f / Transformation matrix element
CD2_1   =                     %f / Transformation matrix element
CD2_2   =                     %f / Transformation matrix element
CSYER1  =                     %f / Systematic error
CSYER2  =                     %f / Systematic error
CRDER1  =                     %f / Random error
CRDER2  =                     %f / Random error
PHOTZP  =                     %f / Photometric zeropoint MAG=-2.5*log(data)+PHOTZP
PHOTZPER=                     %f / Uncertainty on PHOTZP
PHOTSYS =                     %s / Photometric system VEGA or AB
DETRON  =                     %f / Detector readout noise
EFFRON  =                     %f / Median effective readout noise
WEIGHT  =                     %f / Median weight
```

```
ABMAGLIM=                    %f / 5-sigma limiting AB magnitude for point sources
ABMAGSAT=                    %f / Saturation limit for point sources (AB mags)
PSF_FWHM=                    %f / Spatial resolution (arcsec)
ELLIPTIC=                    %f / Average ellipticity of point sources
CHECKSUM=                    %s / HDU checksum
DATASUM =                    %s / Data unit checksum
END
```

Notes regarding keyword definitions

- The TELESCOP value should not be propagated directly from the raw data to the science product but should be set to 'ESO-VST' instead.
- MJD-OBS should be set to MJD-OBS of the first exposure contributing to this data product.
- MJD-END—the end of observations can be obtained in an approximate fashion using MJD-OBS of the last exposure contributing to this data product and adding the total exposure time of this exposure, i.e. MJD-END = MJD-OBS+DIT/86400 in which MJD-OBS and DIT refer to the last exposure in the image co-addition.
- TEXPTIME—for an OmegaCAM pawprint being the result of one observation performing offsets in between NEXP exposures, TEXPTIME should be set to NEXP*DIT.
  For an OmegaCAM deep pawprint resulting from the co-addition of N_OBS observations with NEXP exposures per observation, TEXPTIME should be set to the product N_OBS*NEXP*DIT.
  If individual exposures were rejected before combination into the pawprint, TEXPTIME should be adjusted accordingly.
- EXPTIME should be set to TEXPTIME. This is true for the vast majority of pixels, but not all.
- EPS_REG shall be specified for survey programmes targeting multiple regions. For KIDS, it shall be set to KIDS-N, KIDS-S, or KIDS-Wide-i. For ATLAS, it shall be set to ATLAS-N or ATLAS-S.
- NCOMBINE should be set to the number of raw science data files that were combined to generate the product. It can be obtained from the keyword HIERARCH ESO TPL NEXP of the original data. If individual exposures were rejected before combination into the product, NCOMBINE should be adjusted accordingly.
- SINGLEXP—must be set TRUE if the pawprint results from one single exposure. Otherwise, SINGLEXP does not have to be included.
- The TL_* keywords shall refer to the attributes of the ideal tile as defined using either the Survey Area Definition Tool or an alternative preparation tool.
- ASSON1 and ASSOC1 are compulsory for OmegaCAM pawprints to associate the respective weight image, also known as confidence map (see §3.1.3).
- ASSON2 and ASSOC2 are recommended for OmegaCAM pawprints to associate the respective gain map (see 3.1.4).
- Further instances of the indexed keywords ASSONi and ASSONi may be used to associate more data products if needed.

3.3.3 OmegaCAM source lists

The OmegaCAM source list provides the file format for the tabular data of sources extracted from OmegaCAM imaging data products. Typically the OmegaCAM source list is pipeline-produced, using the nightly calibrations and is delivered on an image-by-image basis.
The required keywords and the format for the OmegaCAM source list is similar to the VISTA source list (with the addition of the TL_ID keyword) hence we refer the reader to §3.2.4 for the detailed specification of the source list.

List of header keywords specific to the OmegaCAM source list

```
TELESCOP= 'ESO-VST'             / ESO Telescope designation
INSTRUME= 'OMEGACAM'            / Instrument name
OBSTECH =                    %s / Technique of observation
PRODCATG= 'SCIENCE.SRCTBL'      / Data product category
```

```
IMATYPE =                     %s / Specific image type
ISAMP   =                     %c / TRUE if image represents partially sampled sky
```

Comprehensive list of header keywords for the OmegaCAM source list in the primary HDU

```
SIMPLE  =                      T / Standard FITS format (NOST-100-2.0)
BITPIX  =                      8 / Number of bits per data pixel
NAXIS   =                      0 / Number of data axes
EXTEND  =                      T / Extensions may be present
ORIGIN  = 'ESO-PARANAL'          / European Southern Observatory
DATE    =                     %s / Date the file was written
TELESCOP= 'ESO-VST'              / ESO Telescope designation
INSTRUME= 'OMEGACAM'             / Instrument name
FILTER  =                     %s / Filter name
OBJECT  =                     %s / Target designation
RA      =                     %f / Image centre (J2000.0)
DEC     =                     %f / Image centre (J2000.0)
EQUINOX =                   %.0f / Standard FK5 (years)
RADECSYS=                     %s / Coordinate reference frame
EXPTIME =                     %f / Total integration time per pixel (s)
TEXPTIME=                     %f / Total integration time of all exposures (s)
MJD-OBS =                   %.8f / Start of observations (days)
MJD-END =                   %.8f / End of observations (days)
DATE-OBS=                     %s / Date the observation was started (UTC)
TIMESYS = 'UTC      '            / Time system used
PROG_ID =                   %20s / ESO programme identification
OBID1   =                     %d / Observation block ID
OBID2   =                     %d / Observation block ID
OBIDn   =                     %d / Observation block ID
M_EPOCH =                     %c / TRUE if resulting from multiple epochs
SINGLEXP=                     %c / TRUE if resulting from single exposure
PROV1   =                     %s / Originating science file
PROV2   =                     %s / Originating science file
PROV3   =                     %s / Originating science file
OBSTECH =                     %s / Technique of observation
PRODCATG= 'SCIENCE.SRCTBL'       / Data product category
IMATYPE =                     %s / Specific image type
ISAMP   =                     %c / TRUE if image represents partially sampled sky
PROCSOFT=                     %s / Data reduction software/system with version no.
REFERENC=                     %s / Bibliographic reference
ASSON1  =                     %s / Name of associated file
ASSOC1  =                     %s / Category of associated file
TL_RA   =                     %f / Tile RA [HHMMSS.TTT]
TL_DEC  =                     %f / Tile Declination [DDMMSS.TTT]
TL_OFFAN=                     %f / Tile rotator offset angle [deg]
TL_ID   =                     %s / Unique tile identifier within the survey
EPS_REG =                     %s / ESO public survey region name
CHECKSUM=                     %s / HDU checksum
DATASUM =                     %s / Data unit checksum
COMMENT
END
```

Comprehensive list of header keywords for the OmegaCAM source list in the binary table extensions

```
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
TTYPEi  =                     %s / Label for field i
TFORMi  =                     %s / Data format of field i
TUNITi  =                     %s / Physical unit of field i
EXTNAME =                     %s / FITS Extension name
INHERIT =                      T / Primary header keywords are inherited
```

```
NXOUT    =                    %d / Length of image data axis 1
NYOUT    =                    %d / Length of image data axis 2
TCRVL3   =                    %f / Coordinate value at ref pixel
TCRVL5   =                    %f / Coordinate value at ref pixel
TCRPX3   =                    %f / Ref pixel in X
TCRPX5   =                    %f / Ref pixel in Y
TCTYP3   =                    %s / Pixel coordinate system
TCTYP5   =                    %s / Pixel coordinate system
TC3_3    =                    %f / Transformation matrix element
TC3_5    =                    %f / Transformation matrix element
TC5_3    =                    %f / Transformation matrix element
TC5_5    =                    %f / Transformation matrix element
FPRA1    =                    %f / Footprint (J2000.0)
FPDE1    =                    %f / Footprint (J2000.0)
FPRA2    =                    %f / Footprint (J2000.0)
FPDE2    =                    %f / Footprint (J2000.0)
FPRA3    =                    %f / Footprint (J2000.0)
FPDE3    =                    %f / Footprint (J2000.0)
FPRA4    =                    %f / Footprint (J2000.0)
FPDE4    =                    %f / Footprint (J2000.0)
PHOTSYS =                     %s / Photometric system VEGA or AB
ABMAGLIM=                     %f / 5-sigma limiting AB magnitude for point sources
ABMAGSAT=                     %f / Saturation limit for point sources (AB mags)
PSF_FWHM=                     %f / Spatial resolution (arcsec)
ELLIPTIC=                     %f / Average ellipticity of point sources
CHECKSUM=                     %s / HDU checksum
DATASUM =                     %s / Data unit checksum
END
```

Notes regarding keyword definitions

- IMATYPE and ISAMP characterize the OmegaCAM image type from which sources have been extracted as specified in Table 7. ISAMP must be set to 'T' (true) if IMATYPE is 'PAWPRINT'.
- The keywords that characterize the observation at large, namely ORIGIN, TELESCOP, INSTRUME, FILTER, OBJECT, EQUINOX, RADECSYS, EXPTIME, TEXPTIME, MJD-OBS, MJD-END, PROG_ID, OBIDi, M_EPOCH, SINGLEXP, OBSTECH, IMATYPE, ISAMP, REFERENC, TL_RA, TL_DEC, TL_OFFAN, TL_ID, EPS_REG, should be adopted from the original image from which the sources were extracted.

4 Spectroscopic data products

4.1 Spectral calibration

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 monotonically increasing steps from TDMIN to TDMAX.
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/cm^2/A.

4.2 Single object: 1D spectrum binary table format

In the case of a single object, its 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 FITS file, for instance sky background-subtracted spectrum, error spectrum, data quality, best fitted model for the continuum.

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 spectrum binary table format is thus 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. To ensure compliancy with the VO standard, the keywords listed in Table 10 shall be present in the extension header.

Table 10: Keywords specific to the single object 1D spectrum in the binary table format

Type	Keyword	Description
(S)	VOCLASS	The data model name and version: '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 propagated here.
(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]. Should WCS information be available, it can be calculated as CRVAL1+(0.5-CRPIX1+NAXIS1*0.5)*CDELT1. Otherwise, it is set to (WAVELMAX+WAVELMIN)/2.0.
(R)	SPEC_BW	Width of the spectrum in nanometers [nm]. Should WCS information be available, it can be calculated as NAXIS1*CDELT1. Otherwise, it is set to WAVELMAX-WAVELMIN.

Each field of the BINTABLE shall be further described in the extension header as specified in Table 11. Mandatory fields shall be WAVE, FLUX, and ERR, in that particular order. Additional fields may be added to the BINTABLE, provided that at least the values for their type, format, and unit be also provided and described by the PI in the release description. Examples of such additional fields are given in Table 11.

Table 11: Keywords describing the BINTABLE columns in the 1D spectrum binary table format.

Type	Keyword	Description	Allowed values
(I)	TFIELDS	Number of fields (columns) in the binary table.	

(S)	TTYPE*i*	It specifies the content of the *i*-th field of the binary table.	`TTYPE1=WAVE|FREQ|ENER`: The wavelength (or frequency or energy) array. `TTYPE2=FLUX`: The data spectrum: either the sky-background subtracted spectrum or the continuum normalised spectrum. `TTYPE3=ERR`: The error spectrum. `TTYPEi=QUAL`: The quality model represents quality by an integer, with the following meanings: 0 is good data, 1 is data which is 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. Quality defaults to 0, i.e. good data. Bitmasks are not allowed and have to be remapped to independent quality flags. See section 4.6.4 of [RD3] for more details. `TTYPEi=SKYBACK`: The sky spectrum. `TTYPEi=CONTINUUM`: The continuum spectrum.
(S)	TFORM*i*	It specifies the data format of the *i*-th field of the binary table.	See Applicable Document [AD2].
(S)	TUNIT*i*	It specifies the physical unit of the *i*-th field of the binary table.	Please refer to the table in Appendix B for examples of unit values. The value of the TUNIT*i* keyword should conform to the recommendations outlined in the ESO DICD, Chapter 8.
(S)	TUTYP*i*	It specifies the UType of the *i*-th field of the binary table.	The UType is a pointer to a data model element in the IVOA spectrum data model; please refer to [RD3] for a description of this data model.
(S)	TUCD*i*	It specifies the IVOA Unified Content Descriptor (UCD) for the *i*-th field of the binary table.	Please refer to [RD2, RD4] for more details on UCDs.
(R)	TDMINi	Start in spectral coordinate.	Applies to TTYPE1 only.
(R)	TDMAX*i*	Stop in spectral coordinate.	Applies to TTYPE1 only.
(I)	NELEM	Length of the data arrays.	All data arrays in the first row of the binary table shall have the same number of points.

Comprehensive list of primary header keywords for the single object 1D spectrum in the binary table format

```
SIMPLE   =                    T / Standard FITS format (NOST-100-2.0)
BITPIX   =                   %d / Number of bits per data pixel
NAXIS    =                    0 / Number of data axes
EXTEND   =                    T / Extensions may be present
ORIGIN   = 'ESO'                / European Southern Observatory
DATE     =                   %s / Date this file was written
TELESCOP=                    %s / ESO Telescope designation
INSTRUME=                    %s / Instrument name
DISPELEM=                    %s / Dispersive element name
SPECSYS =                    %s / Reference frame for spectral coordinates
OBJECT   =                   %s / Target designation
EXT_OBJ =                    %c / TRUE if extended
RA       =                   %f / [deg] Spectroscopic target position (J2000.0)
DEC      =                   %f / [deg] Spectroscopic target position (J2000.0)
```

```
EQUINOX =                  %.0f / Standard FK5 (years)
RADECSYS=                    %s / Coordinate reference frame
EXPTIME =                    %f / Total integration time per pixel (s)
MJD-OBS =                  %.8f / [d] Start of observations (days)
MJD-END =                  %.8f / [d] End of observations (days)
TIMESYS = 'UTC     '            / Time system used
PROG_ID =                  %20s / ESO programme identification
OBID1   =                    %d / Observation block ID
M_EPOCH =                    %d / TRUE if resulting from multiple epochs
PROV1   =                    %s / Originating science file
PROCSOFT=                    %s / Data reduction software/system with version no.
OBSTECH =                    %s / Technique of observation
PRODCATG= 'SCIENCE.SPECTRUM'    / Data product category
FLUXCAL=                     %s / Type of flux calibration
CONTNORM=                    %c / TRUE if normalised to the continuum
WAVELMIN=                    %s / [nm] Minimum wavelength
WAVELMAX=                    %s / [nm] Maximum wavelength
SPEC_BIN=                    %f / Wavelength bin size
SPEC_ERR=                    %f / Statistical error in spectral coordinate
SPEC_SYE=                    %f / Systematic error in spectral coordinate
LAMNLIN =                    %d / Nb of arc lines used in the fit of the wavel. solution
LAMRMS  =                    %f / RMS of the residuals of the wavel. solution
TOT_FLUX=                    %c / TRUE if photometric conditions and all src flux is captured
FLUXERR =                    %f / Uncertainty in flux scale (%)
NCOMBINE=                    %d / # of combined raw science data files
REFERENC=                    %s / Bibliographic reference
ASSON1  =                    %s / Name of associated file
ASSOC1  =                    %s / Category of associated file
ASSOM1  =                    %s / md5sum of ASSON1 (applies to non-FITS)
ASSON2  =                    %s / Name of associated file
ASSOC2  =                    %s / Category of associated file
ASSOM2  =                    %s / md5sum of ASSON2 (applies to non-FITS)
SNR     =                    %f / Average signal to noise ratio per pixel
SPEC_RES=                    %f / [nm] Reference spectral resolution (FWHM)
CHECKSUM=                    %s / HDU checksum
DATASUM =                    %s / Data unit checksum
COMMENT
END
```

Comprehensive list of extension header keywords for the single object 1D spectrum in the binary table format

```
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
VOCLASS = 'SPECTRUM V1.0'       / VO Data Model
VOPUB   = 'ESO/SAF'             / VO Publishing Authority
TITLE   =                    %s / Dataset title
OBJECT  =                    %s / Target designation
RA      =                    %f / [deg] Spectroscopic target position (J2000.0)
DEC     =                    %f / [deg] Spectroscopic target position (J2000.0)
APERTURE=                    %f / [deg] Aperture diameter
TELAPSE =                    %f / [s] Total elapsed time
TMID    =                    %f / [d] MJD mid exposure
SPEC_VAL=                    %f / [nm] Mean Wavelength
SPEC_BW =                    %f / [nm] Bandpass Width Wmax - Wmin
TFIELDS =                    %d / Number of fields in each row
NELEM   =                    %d / Length of the data arrays
TTYPE1  =                    %s / Label for field 1
TUTYP1  = 'Spectrum.Data.SpectralAxis.Value'
TFORM1  =                    %s / Data format of field1
TUNIT1  =                    %s / Physical unit of field1
TUCD1   =                    %s / UCD of field 1
TDMIN1  =                    %f / Start in spectral coord.
TDMAX1  =                    %f / Stop in spectral coord.
TTYPE2  = 'FLUX'                / Label for field 2
```

```
TUTYP2  = 'Spectrum.Data.FluxAxis.Value'
TFORM2  =                    %s / Data format of field 2
TUNIT2  =                    %s / Physical unit of field 2
TUCD2   =                    %s / UCD of field 2
TTYPE3  = 'ERR'                 / Label for field 3
TUTYP3  = 'Spectrum.Data.FluxAxis.Accuracy.StatError'
TFORM3  =                    %s / Data format of field 3
TUNIT3  =                    %s / Physical unit of field 3
TUCD3   =                    %s / UCD of field 3
TTYPE4  = 'QUAL'                / Content of field 4
TUTYP4  =                    %s / UType of field 4
TFORM4  =                    %s / Data format of field 4
TUNIT4  = ''                    / Unit of field 4
TUCD4   =                    %s / UCD of field 4
TTYPE5  = 'SKYBACK'             / Content of field 5
TUTYP5  =                    %s / UType of field 5
TFORM5  =                    %s / Data format of field 5
TUNIT5  =                    %s / Unit of field 5
TUCD5   =                    %s / UCD of field 5
TTYPE6  = 'CONTINUUM'           / Content of field 6
TUTYP6  =                    %s / UType of field 6
TFORM6  =                    %s / Data format of field 6
TUNIT6  =                    %s / Unit of field 6
TUCD6   =                    %s / UCD of field 6
EXTNAME =                    %s / FITS Extension name
INHERIT =                     T / Primary header keywords are inherited
CHECKSUM=                    %s / HDU checksum
DATASUM =                    %s / Data unit checksum
END
```

Notes regarding keyword definitions

- Given that the optional fields (e.g. QUAL, SKYBACK, CONTINUUM) are not always applicable to all data products, the order of their indexing is left up to the data provider. The order adopted on the above comprehensive list of extension header keywords is thus for illustrative purposes only.
- Instances of the indexed keywords ASSONi, ASSONi and ASSOMi may be used to associate e.g. spectrum previews in PNG format with the 1D spectra in FITS format. Those spectrum previews may be showing for instance the position of key emission lines.
- Processing provenance (PROV*i* keyword) is required to monitor the progress of public surveys.
- Quantities that are dimensionless should have their TUNIT*i* keyword set to an empty string.
- Net and total FLUX are distinguished by the `src.net` adjective for TUCD2.
- Please refer to the table in Appendix B for a list of possible TUNIT and TUCD values for the FLUX field.
- If the data is normalized to the continuum (keyword CONTNORM is set to 'T'), TUCD2 shall be suffixed with `arith.ratio` and the value of the TUNIT2 keyword shall be set to an empty string to signify that it is dimensionless.
- UTypes are case-insensitive.
- The UType for CONTINUUM is not defined in the IVOA [RD3], hence the corresponding TUTYPE*i* keyword shall be omitted.
- The value of EXTNAME must be unique within a file.
- There may be at most one SKYBACK field present.
- For data that are not normalized to the continuum, the TUCD and TUNIT of the SKYBACK field shall be the same as for the FLUX field.
- To ensure VO compliancy, the RA, DEC, and OBJECT keywords (and their values) shall be duplicated from the primary header to the extension header.

Example of field characterisation for a flux calibrated spectrum:

```
TTYPE1  = 'WAVE'                / Label for field 1
TUTYP1  = 'Spectrum.Data.SpectralAxis.Value'
```

```
TUNIT1  = 'angstrom'           / Physical unit of field 1
TUCD1   = 'em.wl   '           / UCD of field 1
TTYPE2  = 'FLUX'               / Label for field 2
TUTYP2  = 'Spectrum.Data.FluxAxis.Value'
TUNIT2  = 'erg cm**(-2) s**(-1) angstrom**(-1)'
TUCD2   = 'phot.flux.density;em.wl;src.net'
TTYPE3  = 'ERR'                / Label for field 3
TUTYP3  = 'Spectrum.Data.FluxAxis.Accuracy.StatError'
TUNIT3  = 'erg cm**(-2) s**(-1) angstrom**(-1)'
TUCD3   = 'stat.error;phot.flux.density'
TTYPE4  = 'QUAL'                / Label for field 4
TUTYP4  = 'Spectrum.Data.FluxAxis.Quality'
TUNIT4  = ''                   / Physical unit of field 4
TUCD4   = 'meta.code.qual'     / UCD of field 4
TTYPE5  = 'SKYBACK'            / Label for field 5
TUTYP5  = 'Spectrum.Data.BackgroundModel.Value'
TUNIT5  = 'erg cm**(-2) s**(-1) angstrom**(-1)'
TUCD5   = 'phot.flux.density;em.wl'
TTYPE6  = 'CONTINUUM'          / Label for field 6
TUNIT6  = 'erg cm**(-2) s**(-1) angstrom**(-1) arcsec**(-2)'
TUCD6   = 'phot.flux.density;em.wl;spect.continuum'
```

5 Science catalogue data

The ESO/SDP catalogue data format supports the submission of astronomical catalogues and similar scientific data in tabular format using the Phase 3 process. It applies to catalogues produced by ESO Public Surveys and other ESO observing programmes including multi-colour photometric source catalogues, multi-epoch photometry (a.k.a. light curves), catalogues of variables, proper motion catalogues, target catalogues for spectroscopic surveys, galaxy redshift catalogues, catalogues of stellar properties and chemical abundances.

5.1 Format specifications

5.1.1 Simple catalogue format

This format applies for example to the scientific source catalogues resulting from deep surveys like the VIDEO and the UltraVISTA programmes. It is also 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 a total size up to 2 GB (gigabytes).

Large survey catalogues exceeding this limit shall be submitted in a tile-by-tile fashion using the multi-file catalogue format (§5.1.2). The single file catalogue format does not apply to the scientific source catalogues resulting from large-area surveys like VHS, VIKING, VVV, VMC, or the VST public survey programmes; please refer to the title-by-tile submission scheme in these cases.

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

Required and optional FITS header keywords for the simple catalogue format are defined in **Table** 13.

At submission the release directory on the Phase 3 FTP server just contains the catalogue FITS file and the release description (PDF file).

Table 13: FITS header of the single-file catalogue data format

```
SIMPLE  =                    T / Standard FITS format (NOST-100-2.0)
BITPIX  =                   %d / Number of bits per data pixel
NAXIS   =                    0 / Number of data axes
EXTEND  =                    T / Extensions may be present
ORIGIN  = 'ESO-PARANAL'        / European Southern Observatory
DATE    =                   %s / Date the file was written
TELESCOP=                   %s / ESO Telescope designation
INSTRUME=                   %s / Instrument name
FILTER  =                   %s / Filter name
FILTERi =                   %s / Filter name
OBJECT  =                   %s / Target designation
RA      =                   %f / Field centre (J2000.0)
DEC     =                   %f / Field centre (J2000.0)
EQUINOX =                 %.0f / Standard FK5 (years)
RADECSYS=                   %s / Coordinate reference frame
MJD-OBS =                 %.8f / Start of observations (days)
MJD-END =                 %.8f / End of observations (days)
DATE-OBS=                   %s / Date the observation was started (UTC)
TIMESYS = 'UTC     '           / Time system used
PROG_ID =                 %20s / ESO programme identification
PROGIDi =                 %20s / ESO programme identification
PROVi   =                   %s / Originating science file
OBSTECH =                   %s / Technique of observation
PRODCATG= 'SCIENCE.CATALOG'    / Data product category
REFERENC=                   %s / Bibliographic reference
ABMAGLIM=                   %f / 5-sigma limiting AB magnitude for point sources
MAGLIMi =                   %f / 5-sigma limiting AB magnitude for point sources
SKYSQDEG=                   %f / Sky coverage in units of square degrees
FPRAi   =                   %f / Footprint (J2000.0)
FPDEi   =                   %f / Footprint (J2000.0)
CHECKSUM=                   %s / HDU checksum
DATASUM =                   %s / Data unit checksum
END
====> xtension 1
XTENSION= 'BINTABLE'           / FITS Extension first keyword
EXTNAME = 'PHASE3CATALOG'      / FITS Extension name
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
TTYPEi  =                   %s / Label for field i
TFORMi  =                   %s / Data format of field i
TCOMMi  =                   %s / Description for field i
TDISPi  =                   %s / Display format for field i
TUNITi  =                   %s / Physical unit of field i
TUCDi   =                   %s / Unified content descriptor of field i
TUTYPi  =                   %s / Utype of field i
TDMINi  =                   %f / Minimum valid physical value of field i
TDMAXi  =                   %f / Maximum valid physical value of field i
TINDXi  =                   %c / TRUE if database index exists for field i
TPRICi  =                   %c / TRUE if field i represents principal parameter
TXLNKi  =                   %s / Type of data link represented by field i
TXP3Ci  =                   %s / Data link target collection name
TXP3Ri  =                   %d / Data link target release number
```

```
TXCTYi   =                    %s / Data link target catalogue’s TTYPE
CHECKSUM=                     %s / HDU checksum
DATASUM =                     %s / Data unit checksum
END
```

5.1.1.1 *Specific guidelines for survey catalogues*

For UltraVISTA and VIDEO the characterization of each survey catalogue in terms of coverage and flux limit using the following keywords is mandatory.

```
FILTERi =                     %s / Filter name
PHOTSYS =                     %s / Photometric system VEGA or AB
MAGLIMi =                     %f / 5-sigma limiting AB magnitude for point sources
SKYSQDEG=                     %f / Sky coverage in units of square degrees
FPRAi   =                     %f / Footprint (J2000.0)
FPDEi   =                     %f / Footprint (J2000.0)
EPS_REG =                     %s / ESO public survey region name
```

5.1.1.2 *Catalogue Revisions*

The policies for ESO public surveys foresee that new data is released once per year. According to the progress of observations a new catalogue data release may exceed the previous one in terms of survey area, depth, spectral coverage (i.e. number of different filters), or a combination thereof.
To release a revised version of a simple catalogue, the new FITS file that replaces the previous data altogether is submitted via Phase 3 as a *superseding* release of the same data collection. The name and title of the catalogue remains unchanged while the version number is automatically incremented by one.
Other release options (“updating or complementing”) do not apply to simple catalogues.

5.1.2 Multi-file catalogues format for large catalogues

This format applies to large-area survey programmes, which produce extensive scientific catalogues in excess of the 2 GB volume limit, namely VHS, VIKING, VVV, VMC, VST-Atlas, KIDS, and VPHAS+.
The multi-file catalogue format supports the data preparation and submission of large survey catalogues in a tile-by-tile fashion. The catalogue data are submitted in the form of multiple FITS files, each of them corresponding to one survey tile as defined during Phase 2. Then, the data files will be automatically concatenated during archive ingestion to appear as one single catalogue unit in the ESO Catalogue Facility.
Using the multi-file format each survey catalogue consists of one metadata file and *N* (>1) associated catalogue data files. 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 (Table 14), but usually does not contain data, i.e., the binary table may have zero rows.

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 (Table 15).

✓ The multi-file catalogue format supports catalogue data files with a total size up to 2 GB (gigabytes).

✓ The keyword EXTNAME = 'PHASE3CATALOG' identifies the FITS extension that contains the catalogue (meta)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*) and data types (TFORM*i*) consistent with the definition provided in the metadata file. The other column-related keywords do not need to be repeated.

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 the data in overlapping image areas.

Table 14: FITS header of the metadata file in multi-file catalogue format

```
SIMPLE  =                    T / Standard FITS format (NOST-100-2.0)
BITPIX  =                   %d / Number of bits per data pixel
NAXIS   =                    0 / Number of data axes
EXTEND  =                    T / Extensions may be present
ORIGIN  = 'ESO-PARANAL'        / European Southern Observatory
DATE    =                   %s / Date the file was written
TELESCOP=                   %s / ESO Telescope designation
INSTRUME=                   %s / Instrument name
FILTER  =                   %s / Filter name
FILTERi =                   %s / Filter name
OBJECT  =                   %s / Target designation
RA      =                   %f / Field centre (J2000.0)
DEC     =                   %f / Field centre (J2000.0)
EQUINOX =                 %.0f / Standard FK5 (years)
RADECSYS=                   %s / Coordinate reference frame
MJD-OBS =                 %.8f / Start of observations (days)
MJD-END =                 %.8f / End of observations (days)
DATE-OBS=                   %s / Date the observation was started (UTC)
TIMESYS = 'UTC     '           / Time system used
PROG_ID =                 %20s / ESO programme identification
PROGIDi =                 %20s / ESO programme identification
OBSTECH =                   %s / Technique of observation
PRODCATG= 'SCIENCE.MCATALOG'   / Data product category
REFERENC=                   %s / Bibliographic reference
ABMAGLIM=                   %f / 5-sigma limiting AB magnitude for point sources
MAGLIMi =                   %f / 5-sigma limiting AB magnitude for point sources
SKYSQDEG=                   %f / Sky coverage in units of square degrees
FPRAi   =                   %f / Footprint (J2000.0)
FPDEi   =                   %f / Footprint (J2000.0)
CHECKSUM=                   %s / HDU checksum
DATASUM =                   %s / Data unit checksum
END
====> xtension 1
XTENSION= 'BINTABLE'           / FITS Extension first keyword
EXTNAME = 'PHASE3CATALOG'      / FITS Extension name
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
TTYPEi  =                   %s / Label for field i
TFORMi  =                   %s / Data format of field i
```

```
TCOMMi   =                    %s / Description for field i
TDISPi   =                    %s / Display format for field i
TUNITi   =                    %s / Physical unit of field i
TUCDi    =                    %s / Unified content descriptor of field i
TUTYPi   =                    %s / Utype of field i
TDMINi   =                    %f / Minimum valid physical value of field i
TDMAXi   =                    %f / Maximum valid physical value of field i
TINDXi   =                    %c / TRUE if database index exists for field i
TPRICi   =                    %c / TRUE if field i represents principal parameter
TXLNKi   =                    %s / Type of data link represented by field i
TXP3Ci   =                    %s / Data link target collection name
TXP3Ri   =                    %d / Data link target release number
TXCTYi   =                    %s / Data link target catalogue's TTYPE
CHECKSUM=                     %s / HDU checksum
DATASUM =                     %s / Data unit checksum
END
```

Table 15: FITS header of the catalogue data file in multi-file catalogue format

```
SIMPLE   =                     T / Standard FITS format (NOST-100-2.0)
BITPIX   =                    %d / Number of bits per data pixel
NAXIS    =                     0 / Number of data axes
EXTEND   =                     T / Extensions may be present
ORIGIN   = 'ESO-PARANAL'         / European Southern Observatory
DATE     =                    %s / Date the file was written
TELESCOP=                     %s / ESO Telescope designation
INSTRUME=                     %s / Instrument name
FILTER   =                    %s / Filter name
FILTERi  =                    %s / Filter name
OBJECT   =                    %s / Survey field/tile designation
RA       =                    %f / Survey field/tile centre (J2000.0)
DEC      =                    %f / Survey field/tile centre (J2000.0)
EQUINOX  =                  %.0f / Standard FK5 (years)
RADECSYS=                     %s / Coordinate reference frame
MJD-OBS  =                  %.8f / Start of observations (days)
MJD-END  =                  %.8f / End of observations (days)
DATE-OBS=                     %s / Date the observation was started (UTC)
TIMESYS  = 'UTC     '            / Time system used
PROG_ID  =                  %20s / ESO programme identification
PROGIDi  =                  %20s / ESO programme identification
PROVi    =                    %s / Originating science file
OBSTECH  =                    %s / Technique of observation
PRODCATG= 'SCIENCE.CATALOGTILE'  / Data product category
REFERENC=                     %s / Bibliographic reference
ABMAGLIM=                     %f / 5-sigma limiting AB magnitude for point sources
MAGLIMi  =                    %f / 5-sigma limiting AB magnitude for point sources
SKYSQDEG=                     %f / Sky coverage in units of square degrees
FPRAi    =                    %f / Footprint (J2000.0)
FPDEi    =                    %f / Footprint (J2000.0)
CHECKSUM=                     %s / HDU checksum
DATASUM =                     %s / Data unit checksum
END
====> xtension 1
XTENSION= 'BINTABLE'             / FITS Extension first keyword
EXTNAME  = 'PHASE3CATALOG'       / FITS Extension name
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
TTYPEi  =                    %s / Label for field i
TFORMi  =                    %s / Data format of field i
CHECKSUM=                    %s / HDU checksum
DATASUM =                    %s / Data unit checksum
END
```

The processing provenance (PROV*i*) 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.

5.1.2.1 Specific guidelines for survey catalogues

For VHS, VIKING, VVV, VMC, VST-Atlas, KIDS, and VPHAS+ the characterization of each survey catalogue in terms of flux limit per filter and total sky coverage is mandatory. They must be defined in the metadata file:

```
FILTERi =                    %s / Filter name
PHOTSYS =                    %s / Photometric system VEGA or AB
MAGLIMi =                    %f / 5-sigma limiting AB magnitude for point sources
SKYSQDEG=                    %f / Sky coverage in units of square degrees
EPS_REG =                    %s / ESO public survey region name
```

5.1.2.2 Incremental Catalogue Data Releases

Using the multi-file catalogue format in combination with the tile-by-tile delivery scheme supports incremental catalogue data releases for large-area surveys, i.e. annual data releases corresponding to their observational progress in terms of surveyed sky area. Each incremental data release adds new data to the previously released catalogue without the need to resubmit the previous data all over again. However, to avoid degeneracy in the resulting combined source catalogue careful planning and bookkeeping of the content of the tiles delivered by the survey team is required.

Incremental releases are setup using the Phase 3 release manager by creating an *"updating or complementing"* release for the same data collection that has been defined for the initial release of this catalogue.

✓ For consistency reasons, the catalogue data to be submitted as incremental release must follow exactly the same column definitions as given in the first release.

✓ At the time of submission the release directory on the Phase 3 FTP server should contain *N* catalogue data files (according to the number of tiles), the catalogue metadata file, and the release description (PDF file).

Note that the global catalogue parameters defined in the metadata file, like MJD-OBS, MJD-END, SKYSQDEG, always refer to the entire catalogue resulting from joining the data of the incremental release with the initial release.

After the initial release the catalogue structure is essentially frozen. Therefore, the incremental release scheme is **incompatible** with the aim of adding new catalogue parameters (i.e. a new column) or otherwise changing the column definitions. In this case the *"superseding"* release scheme is the appropriate choice.

5.1.3 Column definitions

Each catalogue parameter is defined in terms of the following keywords indexed with *i* between 1 and 999 without leading zero.

Type	Keyword	Description
(S)	TTYPE*i*	Name of the parameter. Every column of the catalogue shall be assigned a concise, unique, case-insensitive name. E.g., 'KMAG' and 'Kmag' should be 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 A, page 71, *must not* be used as column names. Because of the case-insensitive interpretation, this means for instance that both 'DEC' and 'Dec' are invalid.
(S)	TFORM*i*	Data format string according to Table 16. Note in particular the constraint that numerical data must be scalar.
(S)	TCOMM*i*	Verbal description (68 characters max).
(S)	TUCD*i*	Unified content descriptor according to the UCD1+ controlled vocabulary to describe astronomical data quantities, version 1.23, IVOA 02 April 2007, http://www.ivoa.net/Documents/latest/UCDlist.html [RD2, RD4]. CDS provides and maintains tools that help data providers to assign UCD1+ to astronomical measurements, see: http://cdsweb.u-strasbg.fr/UCD/tools.htx
(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 17.
(S)	TUNIT*i*	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 [AD3], Chapter 8. Please also refer to [AD2], Sect. 4.3, for further guidance.
(S)	TUTYP*i*	Description of the catalogue column content in terms of a pointer to a concept expressed in a VO data model (optional).
(R)	TDMIN*i*	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.
(L)	TINDX*i*	Setting this flag (TRUE) signifies that this parameter is considered important for searching and defining subsamples of the data. Based on this input a database index may be defined for this parameter to make database queries efficient.
(L)	TPRIC*i*	Setting this flag (TRUE) defines the set of principal catalogue columns, which may be displayed by default. In addition, a data access service may return the set of principal catalogue columns unless the user has requested otherwise.

(S)	TXLNK*i*	If this column represents a data link, this keyword should be set to one of the string values 'CATALOG', 'ARCFILE' or 'ORIGFILE' to indicate the type of link. See §5.2.2.1 for instructions how to define data links.
(S)	TXP3C*i*	Defines the target of this data link in terms of the Phase 3 collection name.
(S)	TXP3R*i*	Defines the target of this data link in terms of the Phase 3 release number.
(S)	TXCTY*i*	Defines the name of the target column of this catalogue data link in terms of its TTYPE*i*.

5.1.3.1 Data types

✓ The data types supported for science catalogues are listed in Table 16. The provider of catalogue data selects a format appropriate to the form, range of values, and accuracy of the data.

✓ Note that vector-valued fields must be expanded into scalars before catalogue submission. It means for instance that the definition TFORM*i*='5E' is not supported and must be transformed into 5 separate columns, each one having TFORM*i*='E' (or, equivalently '1E').

✓ Empty catalogue columns (where the repeat count specified in the value of the TFORM*i* keyword of the header is 0) are not permitted.

Table 16: Supported data types for science catalogues

TFORM*i*	**Description**	**8-bit Bytes**
L	Logical	1
*n*A	String of *n* characters	*n*
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 17: Valid TDISP*i* format values in BINTABLE extensions for catalogues

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

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.

5.1.3.2 *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* should not be used in the header definition and the Phase 3 validator raises an error if one of these keywords is present.

5.1.3.3 *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 18. 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.

Table 18: Representation of the special NULL value

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.

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

5.1.3.4 *Unique identifier constraint*

Each catalogue 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 should 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 tiles. The unique identifier must not assume the special NULL value.

See §5.2.1.1 for the application of this concept in the context of source catalogues.

5.2 *Catalogue types*

5.2.1 Astronomical source catalogue

The source catalogue represents the high-level – often the final – data product of every astronomical survey including the nine ESO public imaging surveys currently running at the ESO/VISTA and VST facilities. The source catalogue normally contains *exactly one* entry for each source that has been detected and characterized 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.
Following the guidelines for catalogue data preparation ensures both, smooth ingestion into the ESO Archive and, subsequently, efficient access and data exploitation by the community.

5.2.1.1 *Unique source identifier*

Every source catalogue must have a unique source identifier, defined according to the IAU recommendations for nomenclature using the schema[16]

```
<prefix> J<hhmmss.s±ddmmss.s>
```

or, alternatively,

```
<prefix> J<hhmmss.ss±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.

Table 19: Example of the source catalogue with source identifiers.

SOURCE_ID	RAJ2000	DEJ2000	GAUSSIAN_SIGMA	ELLIPTICITY	…
VHS 130248.6-621027.1					
VHS 130248.9-621027.4					
VHS 130250.1-621011.1					
…					

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
```

5.2.1.2 *Equatorial coordinates (J2000)*

✓ Every source catalogue must contain at least 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 '            /
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
```

[16] See also the "Specifications concerning designations for astronomical radiation sources outside the solar system" issued by the Task Group on Astronomical Designations of IAU Commission 5 (http://cdsweb.u-strasbg.fr/Dic/iau-spec.html).

5.2.1.3 *Galactic coordinates*

Surveys primarily targeting galactic regions may include galactic coordinates *(l,b)* in addition, 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
```

5.2.1.4 *Example for a colour index*

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
TINDX12 =                    T /
```

5.2.2 Multi-epoch photometric catalogue

The multi-epoch photometric catalogue is aimed at photometric light curves, i.e. time series of source flux measurements obtained in variability studies like the VVV – VISTA Variables in the Via Lactea survey programme. This type of catalogue, which records flux and possibly other parameters as a function of time, is always linked to a source catalogue (§5.2.1) that contains all sources being studied including their equatorial coordinates. In case of VVV the first-epoch multi-colour catalogue may serve this purpose.

Table 20: Example of the multi-epoch catalogue VVV_MPHOT (schematically)

PHOT_ID	SOURCE_ID	MJD	KSMAG	KSERR	…
1000001	VVV 130248.9-621027.4				
1000002	VVV 130248.9-621027.4				
1000003	VVV 130248.9-621027.4				
1000004	VVV 130250.1-621011.1				
1000005	VVV 130250.1-621011.1				
1000006	VVV 130250.1-621011.1				
…					

Table 21: Example of the associated source catalogue VVV_CAT

SOURCE_ID	RAJ2000	DEJ2000	ZMAG1	YMAG1	JMAG1	HMAG1	KSMAG1	…
VVV 130248.9-621027.4								
VVV 130250.1-621011.1								
VVV 130258.6-621027.1								

…								

Table 20 illustrates the structure of the multi-epoch catalogue. Each record consists of the measurements for one source obtained at one epoch. PHOT_ID serves as unique identifier for this catalogue according to §5.1.3.4, using integer sequential numbers in this case. This column has the unified content descriptor **meta.id;meta.main**. SOURCE_ID identifies the astronomical source or object each flux measurement belongs to[17] and establishes the link to the source catalogue (Table 21). This allows to build archive services that query photometric data based on position or other source properties. MJD (modified Julian date) specifies the epoch of observation for each measurement. Other time coordinates, like JD, are possible as well. The parameters KSMAG and KSERR represent the measurement recorded in this example.

To summarize the requirements, the multi-epoch photometric catalogue consists of:

- One record (i.e. catalogue row) per source and epoch;
- One column for the unique identifier of each measurement;
- One column for the source identifier according to the associated source catalogue;
- One column for the time coordinate;
- *N* columns for the measured (photometric) parameters according to the objectives of the scientific programme.
- No time-independent information.

Note: Further results based on the analysis of the light curve data, for instance mean magnitude, indicator for flux variability like amplitude or likelihood of variation, variable type, period, phase etc. are recorded depending on the scientific objectives of the programme in a separate variability catalogue. The "Catalogue of Variables in the Via Lactea" (VVV_VAR) is designed for this purpose.

5.2.2.1 Data link definition

The FITS extension header of the multi-epoch photometric catalogue defines the data link to the source catalogue VVV_CAT using the dedicated keywords TXLNK*i*, TXP3C*i*, TXP3R*i*, and TXCTY*i* associated to the SOURCE_ID column with column number 2 in this case (cf. Table 22). TXLNK*i* has the fixed string value 'CATALOG' to indicate the data link. TXP3C*i* and TXP3R*i* define the Phase 3 catalogue name VVV_CAT and the Phase 3 data release number 1, respectively. TXCTY*i* defines the column in the source catalogue which contains the source identifier, which is also labelled SOURCE_ID in this example.

Table 22: FITS extension header for the multi-epoch photometric catalogue example VVV_MPHOT

```
XTENSION= 'BINTABLE'           / Binary table
BITPIX   =                   8 / Required value
NAXIS    =                   2 / Required value
NAXIS1   =                  38 / Number of bytes per row
NAXIS2   =             8984450 / Number of rows
PCOUNT   =                   0 / Normally 0 (no varying arrays)
GCOUNT   =                   1 / Required value
TFIELDS  =                   4 / Number of columns in table
EXTNAME  = 'PHASE3CATALOG'     /
TTYPE1   = 'PHOT_ID '          /
TFORM1   = 'J       '          /
TCOMM1   = 'Photometric data point identifier (running number)' /
TUCD1    = 'meta.id;meta.main'  /
TPRIC1   =                   T /
TTYPE2   = 'SOURCE_ID'         / Label
TFORM2   = '22A     '          / Data format
```

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

```
TCOMM2   = 'VVV source identifier (catalogue data link)' / Description
TUCD2    = 'meta.id'             / Unified content descriptor
TXLNK2   = 'CATALOG'             / Data link type
TXP3C2   = 'VVV_CAT'             / Data link to Phase 3 catalogue VVV_CAT
TXP3R2   =                     1 / Data link release number of VVV_CAT
TXCTY2   = 'SOURCE_ID'           / Data link catalogue's TTYPE
TTYPE3   = 'MJD      '           /
TFORM3   = 'D        '           /
TCOMM3   = 'Date of observations' /
TDISP3   = 'F12.6    '           /
TUNIT3   = 'days     '           /
TUCD3    = 'time.epoch'          /
TINDX3   =                     T /
TTYPE4   = 'KSMAG   '            /
TFORM4   = 'E        '           /
TCOMM4   = 'Ks magnitude'        /
TUNIT4   = 'mag      '           /
TUCD4    = 'phot.mag;em.IR.K'    /
TINDX4   =                     T /
TPRIC4   =                     T /
TTYPE5   = 'KSERR   '            /
TFORM5   = 'E        '           /
TCOMM5   = 'Error of Ks magnitude' /
TUNIT5   = 'mag      '           /
TUCD5    = 'stat.error;phot.mag;em.IR.K' /
TINDX5   =                     F /
TPRIC5   =                     F /
CHECKSUM= 'IGaKJESKIEYKIEYK'     / HDU checksum
DATASUM = '3598906350'           / data unit checksum
END
```

5.2.3 Catalogue of variables

The catalogue of variables, which results from variability studies like the VVV – VISTA Variables in the Via Lactea survey programme 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.

Furthermore, given that the catalogue of variables represents a subtype of the source catalogue (§5.2.1), the requirements specified therein apply as well, meaning that the catalogue must include the unique source identifier and equatorial (J2000) coordinates.

5.2.3.1 Subsamples

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. The formalism is the same as for the multi-epoch photometric catalogue (§5.2.2), for instance

```
TTYPE2   = 'SOURCE_ID'           / Label
TFORM2   = '22A      '           / Data format
TCOMM2   = 'VVV source identifier (catalogue data link)' / Description
TUCD2    = 'meta.id'             / Unified content descriptor
TXLNK2   = 'CATALOG'             / Data link type
TXP3C2   = 'VVV_CAT'             / Data link to Phase 3 catalogue VVV_CAT
TXP3R2   =                     1 / Data link release number of VVV_CAT
TXCTY2   = 'SOURCE_ID'           / Data link catalogue's TTYPE
```

assuming that the catalogue of variables has the source identifier defined in column #2, referring to the multi-colour catalogue named VVV_CAT with release number 1.

5.3 Instructions for catalogue submission

5.3.1 Phase 3 data collection and release

The Phase 3 process for catalogues relies on the same concepts of data collection and data release as the submission and release for other types of data like images or spectra. The Phase 3 Release Manager is the tool to manage these entities.[18]
Each catalogue is represented by one and only one Phase 3 data collection. Therefore, for each new catalogue to be submitted, a dedicated Phase 3 data collection must be defined using the Phase 3 Release Manager. In this step, the data provider is prompted to enter name and title of the data collection, which refers to the catalogue in this case.
Subsequent submissions extending or revising an existing catalogue need to be submitted as a further data release to the same data collection to ensure consistent management of versions including the proper automatic tagging.

5.3.2 Catalogue name

The catalogue name is identical to the Phase 3 data collection name. This name is a string identifier, which must be defined as Phase 3 data collection name by the data provider before starting the first data submission. This determines the corresponding directory on the Phase 3 FTP server where the data then need to be transferred to. The name cannot be modified later. The catalogue name is used to define catalogue data links (see, e.g., §5.2.2.1).

The catalogue name is a character string composed of upper-case letters (A–Z), digits (0–9), and the underscore ('_', decimal 95, hexadecimal 5F) character. Spaces are not allowed. The string should have between 5 and 20 characters. Specifically, the string shall match the (Perl) regular expression: ^[A-Z_][A-Z0-9_]{4,19}$. This constraint is validated by the system when a new Phase 3 data collection is created using the Release Manager.

Because the catalogue/collection name is employed as unique identifier in the context of the Phase 3 system, not just in the context of your Phase 3 programme, names should be sufficiently specific. Therefore, for instance, the name VIDEO_CDFS_CAT should be preferred over just CDFS_CAT. It is generally a good idea to prepend the catalogue/collection name with the (abbreviated) programme name.

Subsequent versions of a given catalogue share the same name, i.e. the combination of catalogue name and catalogue version number (see below) uniquely identifies each catalogue instance stored in the ESO archive. For this reason the catalogue name, and Phase 3 data collection name in general, should not contain a number indicating its version. See Table 23 for examples.

Table 23: Overview of Phase 3 catalogue data deliveries from the ESO/VISTA public survey programmes

Name	**Title**	**Content**
UVISTA_DEEP_CAT	Deep Near-Infrared Catalogue of the COSMOS Field	Aperture-matched source catalogue in YJHKs and NB118 based on the deep stacked images.

[18] http://www.eso.org/rm

UVISTA_UDEEP_CAT	Ultra-deep Near-Infrared Catalogue of the COSMOS Field	Aperture-matched source catalogue in the YJHKs and NB118 based on the stacked images of the ultra-deep part of the survey.
VIKING_CAT	VIKING J-Band Selected ZYJHKs Source Catalogue	Merged multi-band source catalogue with aperture-matched photometry in ZYJHKs for all objects selected and defined in J-band.
VMC_CAT	VISTA Magellanic Survey YJKs Source Catalogue	Homogeneous epoch-merged and band-merged master source catalogue in YJKs
VMC_VAR	VISTA Magellanic Survey Catalogue of Variables	Mean magnitude, amplitude/likelihood of variation (when possible), variable type (i.e. RR Lyrae stars, Cepheids, late-type giants, eclipsing binaries).
VMC_MPHOT	VISTA Magellanic Survey Multi-Epoch Photometry	Homogeneous catalogue of multi-epoch photometric data points listing the measured magnitude as a function of source ID and time of observation (also known as light curve).
VVV_CAT	ZYJHKs Catalogue in the Via Lactea	Homogeneous source catalogue with aperture-matched photometry on the whole survey area (bulge and plane region) based on the first-epoch data.
VVV_VAR	Catalogue of Variables in the Via Lactea	Mean magnitude, amplitude/likelihood of variation (when possible), variable type (i.e. RR Lyrae stars, Cepheids, late-type giants, eclipsing binaries).
VVV_MPHOT	Multi-Epoch Ks-Band Photometry in the Via Lactea	One homogeneous catalogue of multi-epoch Ks photometry in the VVV bulge and plane region.
VHS_DES_CAT	VHS-DES Source Catalogue	Merged multi-band source catalogue with aperture-matched photometry in JHKs.
VHS_ATLAS_CAT	VHS-ATLAS Source Catalogue	Merged multi-band source catalogue with aperture-matched photometry in YJHKs.
VHS_GPS_CAT	VHS-GPS Source Catalogue	Merged multi-band source catalogue with aperture-matched photometry in J and Ks.
VIDEO_ELIAS_CAT	Deep ZYJHKs Catalogue of the ELIAS-S1 field	Combined multi-band source catalogue with aperture-matched photometry in ZYJHKs based on the deep (i.e. stacked) images.
VIDEO_XMM_CAT	Deep ZYJHKs Catalogue of the XMM-LSS field	Combined multi-band source catalogue with aperture-matched photometry in ZYJHKs based on the deep (i.e. stacked) images.
VIDEO_CDFS_CAT	Deep ZYJHKs Catalogue of the Chandra Deep Field South	Combined multi-band source catalogue with aperture-matched photometry in ZYJHKs based on the deep (i.e. stacked) images.

5.3.3 Catalogue Title

The catalogue title is identical to the Phase 3 data collection title. Analogous to the name, the title for the Phase 3 data collection is defined by the data provider before starting the first data submission.

The title allows for a brief significant text description of the content with a maximum length of 68 characters. It is used for display purposes in the context of the entire ESO Science Archive, not just in the context of your Phase 3 programme. Subsequent versions of a given catalogue/collection share the same title (as well as the name). Therefore, the Phase 3 catalogue/collection title should not contain any number indicating the data release version either. The Phase 3 support scientist (ESO/ASG) may modify the PI-provided title of a Phase 3 data collection/catalogue with regard to the overall alignment across the ESO Science Archive.

5.3.4 Catalogue Release number

The catalogue release number is identical to the Phase 3 data release number, sometimes also referred to as "release tag". The Phase 3 Release Manager automatically generates this index, numbering subsequent versions of the catalogue/data collection, when the Phase 3 user creates a new data release.
The catalogue release number is required to define catalogues data links (§5.2.2.1).

Appendix A Sybase IQ Reserved Words

Source of information:
`http://infocenter.sybase.com/help/index.jsp?topic=/com.sybase.infocenter.dc38151.1510/html/iqrefbb/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		

Appendix B Possible 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)