METIS

Mid-infrared
E-ELT Imager and
Spectrograph

Data Reduction Library Design

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1 INTRODUCTION

1.1 Scope

This document describes the design of the data reduction software for the Mid-infrared E-ELT Imager and Spectrograph (METIS), one of the instruments for the Extremely Large Telescope (ELT). It builds upon the Data Reduction Library Specifications document [AD1] presented for Preliminary Design Review (PDR) and supersedes that document for Final Design Review (FDR).

1.2 Applicable documents

[AD1] *METIS Data Reduction Library Specifications*. E-SPE-AST-MET-1001. Version 2-0. 2019-11-22.

[AD2] *METIS Operational Concept Description*. E-PLA-MPIA-MET-1057. Version 4-0. 2022-08-26.

[AD3] *Data Interface Control Document*. ESO-044156. Version 6. 2016-06-21.

[AD4] *ESO Science Data Products Standard*. ESO-044286. Version 6. 2020-06-15.

[AD5] *Dataflow for ESO Observatories Deliverables Standard*. ESO-037611. Version 4. 2020-03-02. ESO.

1.3 Reference documents

[RD1] *METIS Data Reduction Library Validation and Test Plan*. E-PLA-AST-MET-1007. Version 1-0. 2023-09-18.

[RD2] *PIP Verification Control Document*. E-VCD-AST-MET-1003. Version 2-0. 2019-03-09.

[RD3] *METIS Coordinate system definition*. E-SPE-NOVA-MET-1090. Version 3-0. 2021-08-16.

[RD4] *METIS Data Interface Definition*. E-LIS-KUL-MET-1002. Version 2-0. 2022-08-01.

[RD5] *METIS Template Manual*. E-MAN-MPIA-MET-1058. Version 2-0. 2022-08-08.

[RD6] *METIS Calibration Plan*. E-PLA-NOVA-MET-1066. Version 4-0. 2022-08-05.

[RD7] *Atmospheric Differential Dispersion in METIS*. E-TNT-MPIA-MET-1002. Version 1-0. 2019-03-02.

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[RD16] *MOLECFIT Pipeline User Manual*. VLT-MAN-ESO-19550-5772. Version 4.2. 2021-02-08.

[RD17] *MOLECFIT Pipeline User Manual*. VLT-MAN-ESO-19550-5772. Version 4.1. 2021-02-08. ESO.

[RD18] *HDRL Pipeline Developer Manual*. ESO-299492. Version 1.5.0. 2022-06-01.

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[RD24] *METIS calibration error budget*. E-SPE-NOVA-MET-1291. Version 2-0.

[RD25] *“METIS meets MATISSE” detector meeting*. E-MIN-CEA-MET-1005. Version 0.1. 2017-05-23.

[RD26] *VISIR Pipeline User Manual*. VLT-MAN-ESO-19500-3852. Version 1.7. 2016-09-21.

[RD27] *MATISSE Data Reduction Library Design*. ESO-255410, VLT-TRE-MAT-15860-9305. Version 3. 2017-05-24.

[RD28] *X-Shooter Pipeline User Manual*. VLT-MAN-ESO-14650-4840. Version 12.19. 2018-08-06.

[RD29] S. Hunziker et al. “PCA-based approach for subtracting thermal background emission in high-contrast imaging data”. In: *Astron. & Astroph.* 611 (Mar. 2018), A23.

[RD30] *METIS data rates*. E-LIS-NOVA-MET-1161. Version 4-0. 2022-09-15.

[RD31] *HEEPS end-to-end simulator documentation*. E-TNT-ULG-MET-1032. Version 1-0. 2022-08-04.

[RD32] *METIS Work Packages*. E-LIS-NOVA-MET-0013. Version 6-0. 2021-12-22.

[RD33] *METIS Product Breakdown Structure*. E-LIS-NOVA-MET-0035. Version 7-0. 2022-08-08.

1.4 Acronyms

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

ADC Atmospheric Dispersion Corrector

ADI Angular Differential Imaging

ADU Analogue-Digital-Unit

AIT Assembly Integration and Test

AO Adaptive Optics

CRIRES CRyogenic high-resolution InfraRed Echelle Spectrograph

CPL Common Pipeline Library

DPR Data Products

DRL	Data Reduction Library
DRS	Data Reduction Software
EDPS	ESO Data Processing System
ELFN	Excess Low Frequency Noise
ELT	Extremely Large Telescope
ESO	European Southern Observatory
FDR	Final Design Review
FITS	Flexible Image Transport System
FWHM	Full Width Half Maximum
HCI	High-Contrast Imaging
HDRL	High-Level Data-Reduction Library
HITRAN	HIgh-resolution TRANsmission molecular absorption database
HST	Hubble-Space-Telescope
ICS	Instrument Control System
IAU	International Astronomical Union
IFU	Integral Field Unit
IMG	Imaging Mode
IRTF	NASA Infrared Telescope Facility
JWST	James-Webb-Space-Telescope
KMOS	K-band Multi Object Spectrograph
LHATPRO	Low Humidity And Temperature Profiling microwave RadiOmeter
LSF	Line Spread Function
LMS	L/M band Spectrograph Subsystem
LSS	Long-Slit Spectroscopy
METIS	Mid-infrared E-ELT Imager and Spectrograph
MIR	Mid-Infrared
OB	Observation Block
PAE	Preliminary Acceptance Europe
PDR	Preliminary Design Review

PSF Point Spread Function

PWV Precipitable Water Vapour

QC Quality Control

QCL Quantum Cascade Laser

RSRF Relative Spectral Response Function

SNR Signal-to-Noise Ratio

SCAO Single Conjugate Adaptive Optics

SDP Science Data Product

SOF Set-of-Files

STD Standard star

TSS Telluric Standard Star

WFS Wave Front Sensor

WFS-FS Wave Front Sensor Field Selector

VISIR VLT Imager and Spectrometer for mid Infrared

WCU Warm Calibration Unit

1.5 Requirements

The following table connects the requirements (Polarion-links) to the relevant place in this document. Only those pipeline subsystem requirements are listed for which this document provides evidence to verify the requirement in question. See [RD1] for information about their verification. The full set of evidence for all PIP requirements is traced in [RD2]

Requirements marked with ⋆ are commented on individually below the table.

Table 1: Requirements compliance

Req. ID	Requirement Title	Section
METIS-5945	DRS for science-grade data reduction	6
METIS-5989	ADI post-processing	6.7
METIS-5997	Detector linearity characterisation	6.1.1
METIS-6058	Data reduction package	6
METIS-6059	DRS for Quick-Look and Operational Data QC	6
METIS-6060	Interactive data reduction system	6
METIS-6061	Reduced simulated data products	3.5

Req. ID	Requirement Title	Section
METIS-6062	Software Assurance Requirements	12
METIS-6063	Master dark frames	6.1.2
METIS-6070	METIS coordinate systems definition	3.1
METIS-6072	Parallel observing mode IMG-LM and LMS	4.5.3
METIS-6073	LMS Spectral Resolution	11.3.3
METIS-6074	Wavelength calibration	6.4.5, 6.5.5 6.6.1
METIS-6075	Burst mode data rates	10.10
METIS-6077	Operational use cases	⋆
METIS-6080	FITS format and meta-data of generated data	3.5
METIS-6081	FITS keywords	3.1
METIS-6082	Data products conformity to ESO standards	3.5
METIS-6084	Low-resolution slit spectroscopy	6.4, 6.5
METIS-6085	Background subtraction in IMG-LM with dedicated sky observations	6.2.3
METIS-6086	Background subtraction in IMG-LM from dithered images	6.2.3
METIS-6087	Distortion/plate-scale calibration	6.2.7, 6.3.6
METIS-6088	Distortion correction	6.3.4, 6.2.5
METIS-6089	Masked region of the N-band detector	6.3.2
METIS-6090	Masked region of the IMG_LM detector	6.2.2
METIS-6091	Telluric calibration recipe	6.4.8, 6.5.9
METIS-6093	Format and content of the raw data	3.1
METIS-6094	Background subtraction in chopping-nodding mode	6.3.2
METIS-6096	LM-band imaging flatfield	6.2.1
METIS-6098	N-band imaging flatfield	6.3.1
METIS-6104	IMG-LM data products	6.2.5, 6.2.6
METIS-6105	IMG-N data products	6.3.4, 6.3.5
METIS-6112	SPEC-LM data products	6.4
METIS-6113	SPEC-N data products	6.5
METIS-6131	LMS data products	6.6.4
METIS-6265	LMS straylight	6.6.4
METIS-6309	Masked regions of the LMS detectors	6.6.4
METIS-6681	Error propagation	10.7
METIS-6698	Characterisation and correction of relative spectral response function	6.4.3, 6.5.3, 6.6.2
METIS-6733	Auxiliary Parameters in Data Products	3.5
METIS-6923	QC parameters for permanent monitoring	11
METIS-7244	Parallel observing mode IMG-LM and IMG-N	4.5.1

Req. ID	Requirement Title	Section
METIS-7245	Parallel observing mode LSS-LM and LSS-N	4.5.2
METIS-9145	Persistence Correction	6.1.3
METIS-9150	Calibration of atmospheric dispersion correction and slit losses	6.8.3
METIS-9151	Fringing correction	6.8.4
METIS-9212	IMG-LM_(RA/C)VC data products	6.7.1
METIS-9213	IMG-LM_APP data products	6.7.2
METIS-9214	IMG-N_CVC data products	6.7.1
METIS-9215	LMS_(RA/C)VC data products	6.7.3
METIS-9216	LMS_APP data products	6.7.3
METIS-9355	Code documentation	7
METIS-9626	AO Telemetry in Science Data Products	3.5
METIS-9627	Data provenance	3.5
METIS-10300	Wavelength-to-pixel calibration uncertainty during AIT	6.4.5, 6.6.1

Notes on individual requirements:

METIS-6077 refers to the operational use cases *observation*, *calibration* and *maintenance*. As such, there is no single point in this document to point to for verification evidence. The recipes in Chapter 6 cover all of these use cases.

2 Instrument Modes and Configurations

The following table lists the instrument modes for METIS [AD2]. All of these modes will be supported by the data reduction pipeline, where horizontal lines delimit groups of modes that can be reduced with the same set of recipes. Recipes for post-calibration processing may be available for individual modes within a group (e.g. Angular Differential Imaging (ADI) post-processing for HCI modes, Section 6.7).

Exposures or sequences of exposures can be taken in pupil-tracking mode or in field-tracking mode. In the first case, the derotator keeps the pupil fixed with respect to the detector pixel rows and columns, while the field rotates. In the second case, the field is kept fixed, while the pupil rotates. For the pipeline, this has consequences when it comes to combining several exposures. In pupil-tracking mode, images have to be rotated in software before they can be stacked to improve signal to noise in scientific data products.

Table 2: The five main observing modes of METIS. The acronyms stand for: **CVC** – Classical Vortex Coronagraph; **RAVC** – Ring-apodized Vortex Coronagraph; **APP** – Apodized Phase Plate; N/A – not applicable.; **P/T** – pupil tracking; **F/T** – field tracking.

Observing Mode	**Instrument Configuration**						**Code**
	Subsystem	**Band**	**IFS Setting**	**HCI Mask**	**P/T**	**F/T**	
Direct Imaging	IMG	L, M	N/A	N/A	•	•	IMG_LM
	IMG	N	N/A	N/A	•	•	IMG_N
High Contrast Imaging	IMG	L, M	N/A	RAVC/CVC	•		IMG_LM_(RA/C)VC
			N/A	APP	•		IMG_LM_APP
	IMG	N	N/A	CVC	•		IMG_N_CVC
Longslit spectroscopy	IMG	L, M	N/A	N/A		•	SPEC_LM
	IMG	N	N/A	N/A		•	SPEC_N_LOW
IFU spectroscopy	IFU	L, M	full IFU field	N/A	•	•	IFU_nominal
	IFU	L, M	extended $\Delta\lambda = 300\,\mathrm{nm}$	N/A	•	•	IFU_extended
IFU + HCI spectroscopy	IFU	L, M	full IFU field	APP	•		IFU_nominal_APP
				RAVC/CVC	•		IFU_nominal_(RA/C)VC
	IFU	L, M	extended $\Delta\lambda = 300\,\mathrm{nm}$	APP	•		IFU_extended_APP
				RAVC/CVC	•		IFU_extended_(RA/C)VC

3 Instrument Data Description

METIS data uses the FITS format for both raw and product data files. Raw frames are the unprocessed output of METIS instrument observations, while product frames are the result of pipeline processing.

All data files can be classified on the basis of sets of keywords stored in the FITS headers. Association of raw frames to calibration files is achieved by comparing keyword values.

3.1 Raw data format

All raw data files produced by METIS will be in FITS format and follow ESO standards (METIS-6081, METIS-6093), in particular as laid out in [AD3].

Data from the different subsystems (LM imager/spectrograph, N imager/spectrograph, LM IFU) are always stored in separate files. When more than one subsystem is recording data simultaneously, then more than one FITS file is created by one observing template.

The IFU integral-field spectrograph consists of four chips, hence the FITS file will consist of an empty primary data unit, whose header holds information pertaining to the exposure as a whole, and four extension units that hold the data from the four chips along with information pertaining to each chip. Even though the LM and N imagers are single-chip sub-instruments, the imaging data will still appear in an extension HDU, because this ensures the data format is equivalent to the IFU mode. The primary HDU will therefore only contain headers for all raw data.

A template may produce several exposures, each of which consists of NDIT subexposures (DITs). The exact definition of what constitutes an "exposure" or which and how many DITs will be save in a FITS file, are still under discussion. The goal will be for a file to contain the "smallest calibratable subset" of DITs, for instance one cycle of the chopping patters, or data taken in one nod position. Keeping files small in this way allows the pipeline to process data even for cases where observing blocks are only partially executed.

Where applicable, all the DITs belonging to an exposure may be saved in a 3D-cube format. This is described in more detail for the various observing modes in the following sections.

The raw data should include World Coordinate Systems based on the telescope pointing, derotator angle and the design characteristics of the telescope and instrument. Instrument-internal coordinates (e.g. angles of movable components inside METIS) will follow the definition in [RD3] (METIS-6070).

The list of these FITS header keywords used by METIS is kept in [RD4] and the list of keys used by the DRS is kept in App. A. This fulfills METIS-6081 and METIS-6093.

3.1.1 Adaptive Optics Telemetry

A subset of the adaptive optics telemetry will be available in the headers of each raw data product. In particular, the position information of the Wave Front Sensor Field Selector (WFS-FS) mirror will be available, as this is used in various recipes to determine the offset between dither steps.

The full adaptive optics telemetry will be available as a separate raw data product because of its size and complexity. The raw exposure data will contain the `AOFILE` header keyword that contains the value of the `ARCFILE` of the corresponding adaptive optics data product. The full adaptive optics telemetry data will not be processed by the pipeline and the exact file format is therefore beyond the scope of this document.

3.2 LM-band Imager and Spectrograph

The LM-band imager is equipped with a 2k $\times$ 2k HAWAII2RG detector with a pixel scale of 5.47 mas. A number of rows and columns along the edges of the detector will be masked (see Sect. 8.2 of [AD1]).

Grisms in the imager pupil wheel in conjunction with a number of slit masks in the CFO focal plane provide low-resolution spectroscopy covering the entire L and M bands, respectively, with $R \gtrsim 1400$.

The basic templates for LM-band imaging are ([AD2], [RD5]):

- `METIS_img_lm_obs_AutoJitter`
- `METIS_img_lm_obs_GenericOffset`
- `METIS_img_lm_obs_FixedSkyOffset`

Each of these templates moves the target position between exposures, either using the internal (CFO-PP2) chopper or telescope offsets, and takes an exposure at each position, consisting of subintegrations defined by DIT and NDIT. Depending on the setting of a Boolean template parameter (`DET CUBE MODE`), all DITs are stored as layers of 3D cube, or a co-added frame is stored as a 2D image. The 3D cube or 2D image are written out in the first extension HDU of the FITS file for consistency.

When offsetting, the accurate (<1 mas) relative field positioning information will come from the chopper metrology (laser interferometer) and/or the field selector (in the case of nodding offsets).

The header of the FITS file will contain all information that pertains to the exposure. This should include information about the position of the internal chopper (`SEQ.CFO.CHOP.POSANG`, `SEQ.CFO.CHOP.THROW`), the telescope offsets (`SEQ OFFSET1`, `SEQ OFFSET2`) and the characterisation of the observation as `OBJECT` or `SKY` (in `DPR.TYPE`).

Similar considerations apply to the spectroscopic and coronagraphic templates, where pointing offsets are however restricted by the slit or coronagraphic masks.

3.3 N-band Imager and Spectrograph

The N-band imager is equipped with a 2k $\times$ 2k GeoSnap detector with a pixel scale of 6.8 mas. A number of rows and columns along the edges of the detector will be masked.

A grism in the imager pupil wheel in conjunction with a number of slit masks in the CFO focal plane provide low-resolution spectroscopy in the N band with $R \gtrsim 400$.

Subtraction of the thermal background in the N band will be done using chopping up to a few Hertz using the internal chopper and regular nodding using telescope offsets. The basic templates for N imaging are

- `METIS_img_n_obs_AutoChopNod`
- `METIS_img_n_obs_GenericChopNod`

At each nod position, a series of exposures are taken at alternating chop positions. Depending on the setting of the template parameter `DET CUBE MODE`, all exposures are stored as layers of a 3D cube or they are precombined in a 2D image. Another chop cycle is then taken at another nod position, and so on. Whether separate nod positions are stored as individual FITS files or as extension units of a single FITS file remains to be determined. As explained in Sect. 3.1, there is a preference for small FITS files containing minimal calibratable subsets of DITs.

The primary header of the FITS file will contain all information that pertains to the chop cycle or the sequence of chop/nod cycle. The headers of the individual files or extensions will allow unique determination of the chop/nod positions.

3.4 LM-band Integral Field Unit

METIS will contain an image slicing Integral Field Unit (IFU) for high-resolution spectroscopy in L- and M-band ($R \approx 100,000$).

Both the subsystem containing the IFU and the observation mode can be referred to as L/M band Spectrograph Subsystem (LMS). In the context of this document, we prefer to use the term IFU for the mode to prevent confusion with the other LM modes, but occasionally LMS is used as well.

The IFU is equipped with a 2×2 mosaic of HAWAII2RG detectors separated by small gaps. A number of rows and columns along the edges of the detector will be masked (see Sect. 8.2 of [AD1]).

In the nominal mode, the field will be resolved into 28 spatial slices covering a field of view of $0.897 \times 0.577\,\mathrm{arcsec}^2$. The slit width (i.e. the across-slice pixel scale) is 20.7 mas; the along-slice pixel scale is 8.2 mas. Spectrally, the slices span a short wavelength range of width 37 nm and 70 nm, depending on the central wavelength setting, which is selected by rotation of the echelle grating.

The extended mode provides a larger wavelength range coverage at the expense of a reduced field of view. The dispersed two-dimensional image from the pre-disperser is spectrally sliced, resulting in six non-overlapping wavelength subranges (selected by the echelle angle) onto the detector, each with three spatial slices.

The layout of spectra on the detector array in the nominal and extended modes is shown in the left and right panels of Fig. 1, respectively.

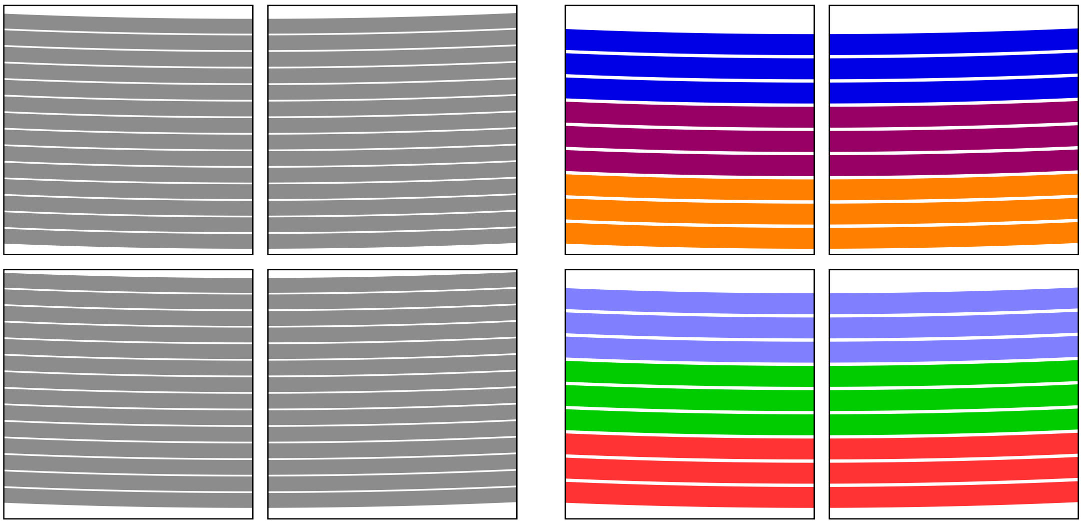


Figure 1: Layout of the IFU detector mosaic in the nominal (left) and extended (right) modes. The dispersion direction is horizontal. In the nominal mode, all 28 slices cover approximately the same wavelength range. In the extended mode, slices marked by the same colour cover the same wavelength ranges, while the wavelength ranges of the six groups of slices each are not contiguous. The position and curvature of the slices are indicative only.

The basic templates for LM integral-field spectroscopy are:

- `METIS_ifu_obs_FixedSkyOffset`
- `METIS_ifu_obs_GenericOffset`

Both templates move the target position between exposures, using the internal chopper or the telescope. At a given position a number of exposures with DIT/NDIT are taken. Depending on the setting of the template parameter `DET CUBE MODE` all the DITs may be stored as layers of a 3D cube (burst mode) or co-added into a 2D image.

As the IFU contains an array of four detectors, there will be four image or cube extensions in the FITS file for one exposure.

The primary header of the FITS file will contain all information that pertains to the exposure. This will include information on the position of the internal chopper, the telescope offsets, and the type of observation (`DPR.TYPE=OBJECT` or `SKY`).

A typical sequence of IFU exposures will go through a series of dispersion grating settings in order to fill gaps in the instantaneous wavelength coverage ("spectral dithering"). Finally, the field will be rotated by 90 degrees and the observing sequence repeated to permit full image reconstruction (cf. Sect. 8.9 of [AD1]). The FITS header information will ensure that the position of each exposure within this complex sequence can be uniquely identified.

3.5 Reduced data format

All data products, both intermediary and final ones, will be provided in FITS format. Final data products will be saved according to [AD4], fulfilling METIS-6061 and METIS-6080.

If there are additional meta-data necessary for archiving, processing, analysis, and distribution, they will be added. METIS-6082.

By default, recipes try to preserve the information of the FITS headers of the input Set-of-Files (SOF) in the output products:

- When the number of (primary) output FITS files is the same as the number of (primary) input FITS files, then relevant FITS header keywords are copied per FITS files. When there is only one output FITS file for a set of input FITS files (e.g. when stacking frames for a `MASTER_DARK_2RG`), then only FITS headers from the first input file are propagated.
- When the output FITS files have the same number of extensions as the input, then the FITS header keywords from each extension are propagated into the output. When there are less extensions in the output (e.g. when reconstructing a cube), then only the headers from the first extension are propagated.
- FITS headers from calibration data is only copied into the data products when appropriate.

This includes the meteorological, astronomical and atmospheric site parameters, fulfilling METIS-6733. The same is true for Adaptive Optics (AO) Telemetry, in particular the reference to the raw data product with the full AO telemetry data, satisfying METIS-9626.

The saving-functions provided by ESO Common Pipeline Library (CPL), given the list of input frames, add this list to the headers of data products, thus providing provenance information in compliance with METIS-9627.

The list of individual data products can be found in Ch. 8.

4 Functional and Workflows Description

The METIS data reduction system runs in different environments and serves various purposes. According to the setting, the following pipeline levels are distinguished [AD5]:

Quality Control Level 0 (QC0): The QC0 pipeline runs automatically in real time on a dedicated pipeline workstation in the instrument control room at the observatory. Its purpose is to analyse every FITS file created by the instrument and produce quality control parameters that allow assessment of whether the observation and instrument performance were within specifications. The appropriate reduction recipe is triggered either when a single FITS file is delivered to the workstation or when a template is finished. The files are classified based on header keywords, grouped and associated to the necessary standard calibration files.

Quality Control Level 1 (QC1): The goal of the QC1 pipeline is to produce certified calibration products from calibration observations as well as to produce QC parameters that are used to check the quality of observations and to monitor observing conditions and instrument health. The QC1 pipeline is run automatically by ESO in Garching. Calibration products and QC parameters are ingested into the ESO Science Archive.

Quality Control Level 2 (QC2): The QC2 pipeline produces Science Data Products compliant with [AD4] as well as QC parameters derived from science exposures. It runs offline in an automatic way and uses the best calibration products for the night of observation (produced by the QC1 pipeline). The QC2 pipeline is run automatically by ESO in Garching. Science data products and QC parameters are ingested into the ESO Science Archive.

Science-Grade Desktop Environment: The pipeline recipes are delivered to the astronomical community to enable users to reduce data in an optimal and interactive way. Recipes can be run from the command line using the `esorex` front-end or in the context of a `Reflex`/ESO Data Processing System (EDPS) workflow. While the desktop recipes are identical to those used in the QC2 pipeline, the user can change recipe parameters to optimise the reduction. Within the `Reflex`/EDPS environment, interactive tools are provided that allow the user to assess the quality of individual reduction steps and to repeat them with different parameters. The products of this pipeline are compliant with [AD4].

The rest of this document describes the recipes primarily from the perspective of the desktop pipeline. The QC0, QC1, QC2 pipelines use the subset of these recipes necessary for the goals described above. Recipes used in the QC0 environment are written such that they can be run in real time, possibly requiring different defaults for processing parameters.

4.1 Required calibrations

Table 3 (taken from [RD6]) lists the main calibration steps that are required for each instrument mode.

Table 3: Overview of required calibrations per instrument mode. The IFU modes refer to both the nominal configuration and to the extended wavelength configuration. From [RD6].

	Dark / Linearity	Flat	Wave	Background subtraction	Telluric	Flux	Distortion	NCPA + PSF	RSRF
IMG_LM	✓	✓	—	Dither	—	✓	✓	—	—
IMG_LM_(RA/C)VC	✓	✓	—	ADI	—	✓	✓	✓	—
IMG_LM_APP	✓	✓	—	Dither + ADI	—	✓	✓	✓	—
SPEC_LM	✓	—	✓	Dither along slit	✓	✓	✓	—	✓
IFU	✓	—	✓	Dither	✓	✓	✓	—	✓
IFU_APP	✓	—	✓	Dither[1] + ADI	✓	✓	✓	✓	✓
IFU_(RA/C)VC	✓	—	✓	ADI	✓	✓	✓	✓	✓
IMG_N	✓	✓	—	chop/nod	—	✓	✓	—	—
IMG_N_CVC	✓	✓	—	three-point chopping	—	✓	—	✓	—
SPEC_N_LOW	✓	—	✓	chop/nod along slit	✓	✓	✓	—	✓

4.2 Imaging in LM and N

The purpose of the pipeline is to correct or remove contributions from the instrument, telescope, and atmosphere and produce science-grade data products. In the case of the METIS imaging modes the main contributions to correct or remove are dark current, flatfield, bad pixels, and, most importantly, thermal background emission from the sky and the telescope. Further effects include persistence, cross-talk, geometric distortions, etc. The final product of the imaging pipeline is one or more image(s) that are flux-calibrated in units of photons/s/pixel against a standard star. Several images can be stacked into a single possibly mosaiced image.

Due to the differences in characteristics between the HAWAII2RG detector used for imaging in the L and M bands and the GeoSnap detector used for the N band, the operational concept for the two imager subsystems are quite different. This induces differences in the way the data have to be reduced.

The GeoSnap detector has more stable gain than AQUARIUS detector, which was still in the baseline at PDR. Chopping is still necessary, albeit at a lower frequency of a few Hz, and a chop/nod technique, which meets the specific ELT requirements (Section 10.4.2), will be employed for background subtraction. As the dark signal is automatically removed when the exposures from the different chop and nod positions are combined no master dark is required for the reduction of science data. The GeoSnap data is also flat fielded.

Observations and reduction of LM band data with the HAWAII2RG detector can proceed as in the near infrared. After dark subtraction and flat-fielding, the background is estimated from a series of dithered science exposures or from exposures on a nearby blank patch of sky.

The association maps for the current designs of the imaging pipelines in LM and N are shown in Figs. 2 and 3, respectively.

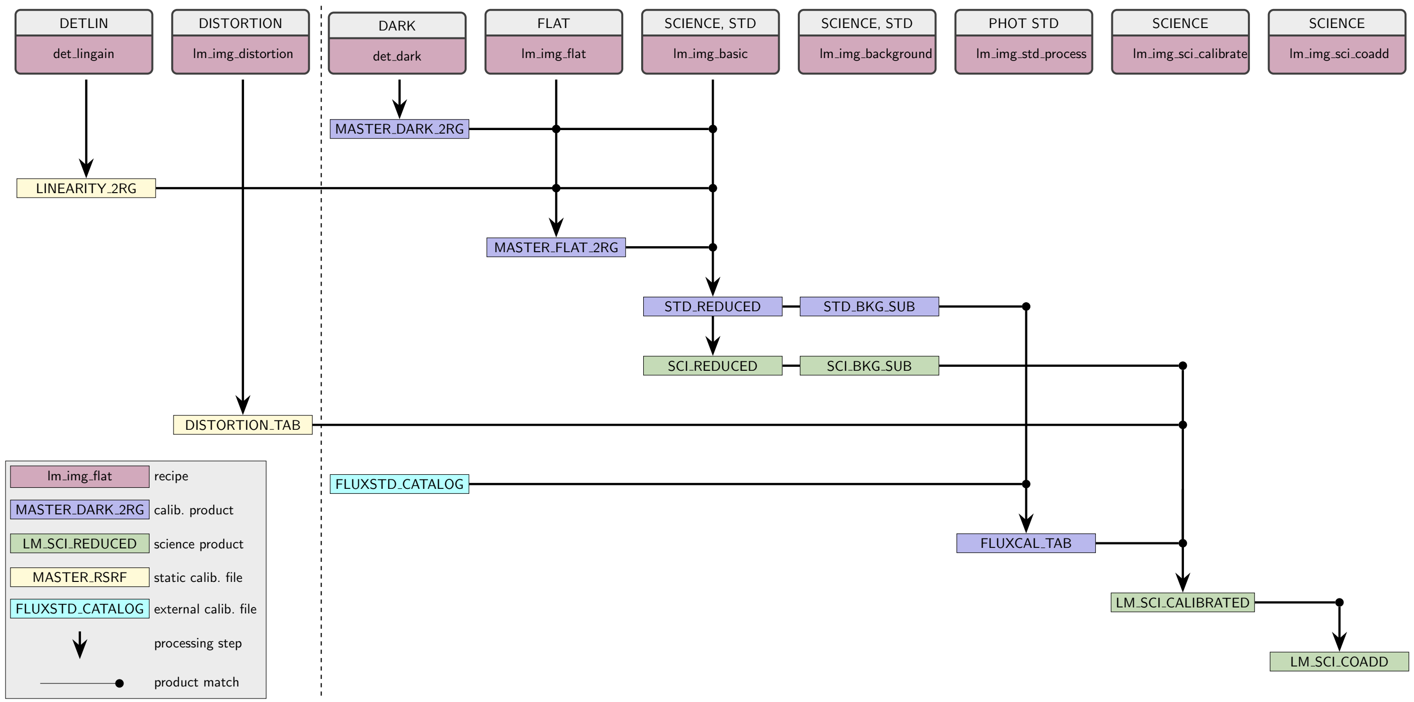


Figure 2: Association map for imaging in the LM band. The figure shows only the primary product created from each recipe; for a full list of products refer to the recipe descriptions in Sect. 6.2. The dashed line separates calibration tasks that are done at AIT or infrequently during operations (left) from daily tasks (right). The prefix " `metis_`" has been omitted from the recipe names to improve clarity. The product names omit " `LM_`".

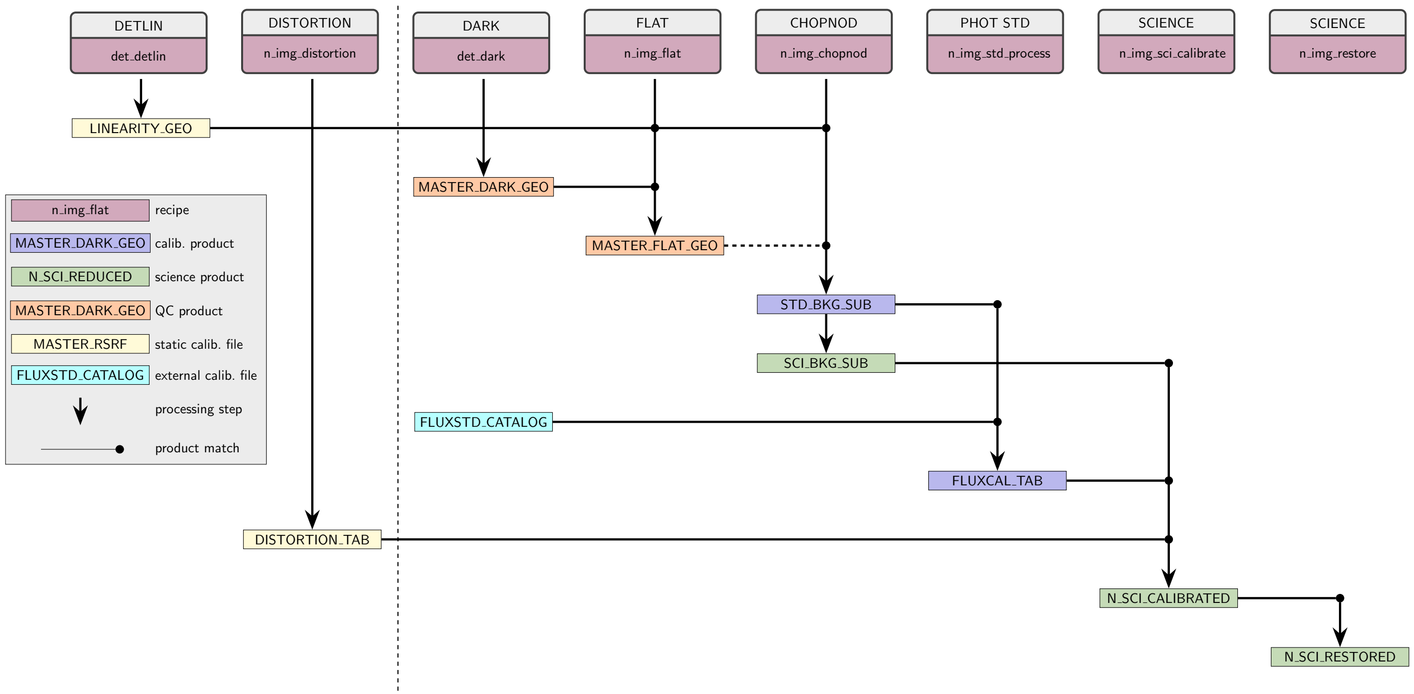


Figure 3: Association map for imaging in the N band. The figure shows only the primary product created from each recipe; for a full list of products refer to the recipe descriptions in Sect. 6.3. The dashed line separates calibration tasks that are done at AIT or infrequently during operations (left) from daily tasks (right). The prefix "`metis_`" has been omitted from the recipe names to improve clarity. The product names omit "`N_`".

4.3 Long-Slit Spectroscopy in L/M- and N-bands

4.3.1 The workflow cascades

The purpose of these workflows is to correct or remove contributions from the instrument, telescope, and atmosphere and generate science-grade data products for the L/M- and N-band Long-Slit Spectroscopy (LSS) mode. Since the Geosnap detector is still not fully characterised, we currently assume basically the same reduction cascade for both spectral ranges LM and N, respectively. The major differences at the time being are the subtraction methods for the sky background (nodding in LM, chop-nodding in N band) and the absence of Warm Calibration Unit (WCU) laser sources in the N-band, which are only available during Assembly Integration and Test (AIT) phase to generate a first guess of the pixel-to-wavelength relation. Therefore the first guess wavelength solution in the N-band will be based on that AIT data. As we assume the instrument to be very stable, that approach should be sufficient for the low-resolution N-band spectroscopy. In the LM range, two fixed-frequency lasers (@3.39µm and @5.26µm) and one tuneable (4.68....4.78µm) are foreseen in the WCU to be taken on daily basis (cf. [RD6]). Although mainly foreseen to be used for the high-resolution spectroscopy IFU mode, we can use these laser sources for the LM-band LSS as well.

Special emphasis has to be drawn to the effects of the Earth's atmosphere in several respects:

- Wavelength calibration: Absorption/emission features are intended to be used for the wavelength calibration. Thus, a good knowledge on / identification of these features is crucial for the accuracy of the wavelength calibration.
- Telluric correction: In the MIR regime telluric absorption is one of the most dominant effects visible in spectra. Modelling approaches like `molecfit` heavily rely on accurate atmospheric input profiles, which represent the actual state and composition of the Earth's atmosphere. This especially applies to the Precipitable Water Vapour (PWV) content since this is the most dominant and most variable species. We also include the classical approach for the telluric correction (i.e. deriving the Earth's atmosphere transmission by means of standard stars) to be able to achieve a good removal of sky emission in case `molecfit` appears to be insufficient.
- Atmospheric dispersion: METIS will have Atmospheric Dispersion Corrector (ADC)s compensating the effect of atmospheric dispersion. However, for technical reasons there are two fixed ADCs per waveband optimized for two distinct airmasses. This means that the compensation is only partially, leading to two practical effects: (a) wavelength-dependent slit losses, and (b) distortions in both, the spatial and the spectral direction (see [RD7] for more details). For both, the pipeline needs to correct for. It is foreseen to determine these slitlosses on yearly basis with a separate calibration task (cf. [RD6]) and create a slit-loss table to be included in the static calibration database.

Figures 5 and 6 show the reduction cascade and the association map for the recipes handling L/M-long-slit spectroscopy data. For the N-band LSS mode the cascade and the data processing table is given in Figs. 7 and 8.

In general, there are four major steps in each of the two cascades:

- **Preparation steps:** This part contains the recipes which are invoked only rarely, e.g. after major instrument interventions, or on monthly/yearly basis to update the static calibration database. These recipes are therefore not shown in the cascade in Figs. 5/6 and 7/8 and the corresponding data processing tables. In case of the LSS pipeline this concerns the creation of the gain maps/linearity checks (see Section 6.1.1), the determination of the throughput as function of the source position in the across-slit direction (cf. Section 6.8.3 and Section "Calibration of slit losses" in Calibration plan [RD6]) and the zero position of the chopping mirror (see Section 6.8.2 and Section "Chopper Home Position" in [RD6] for more details).
- **Basic steps**: The basic steps aim for correcting the detector influence, in particular the correction of the dark (if necessary) and the Relative Spectral Response Function (RSRF). Special cases are the linearity correction and (optionally) the persistence subtraction, which are done consecutively in the individual recipes as first two reduction steps on the corresponding raw data.
- **Calibration/correction steps**: This is the main part which incorporates the order trace detection, distortion, wavelength and absolute flux calibration. In case a dedicated Standard star (STD) star is provided, a transmission curve is created for the telluric correction.
- **Post-calibration steps**: After having calibrated spectra at hand, the last step is the telluric absorption correction with `molecfit`, which is the baseline for the time being. This step is omitted in case the user decided not to use the classic approach with a standard star.

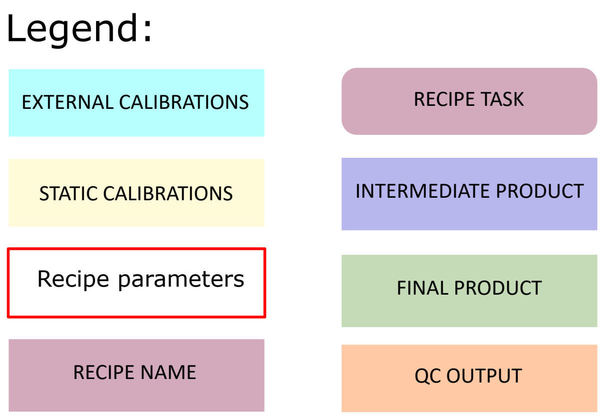


Figure 4: Legend of the coloured boxes in the LSS cascades.

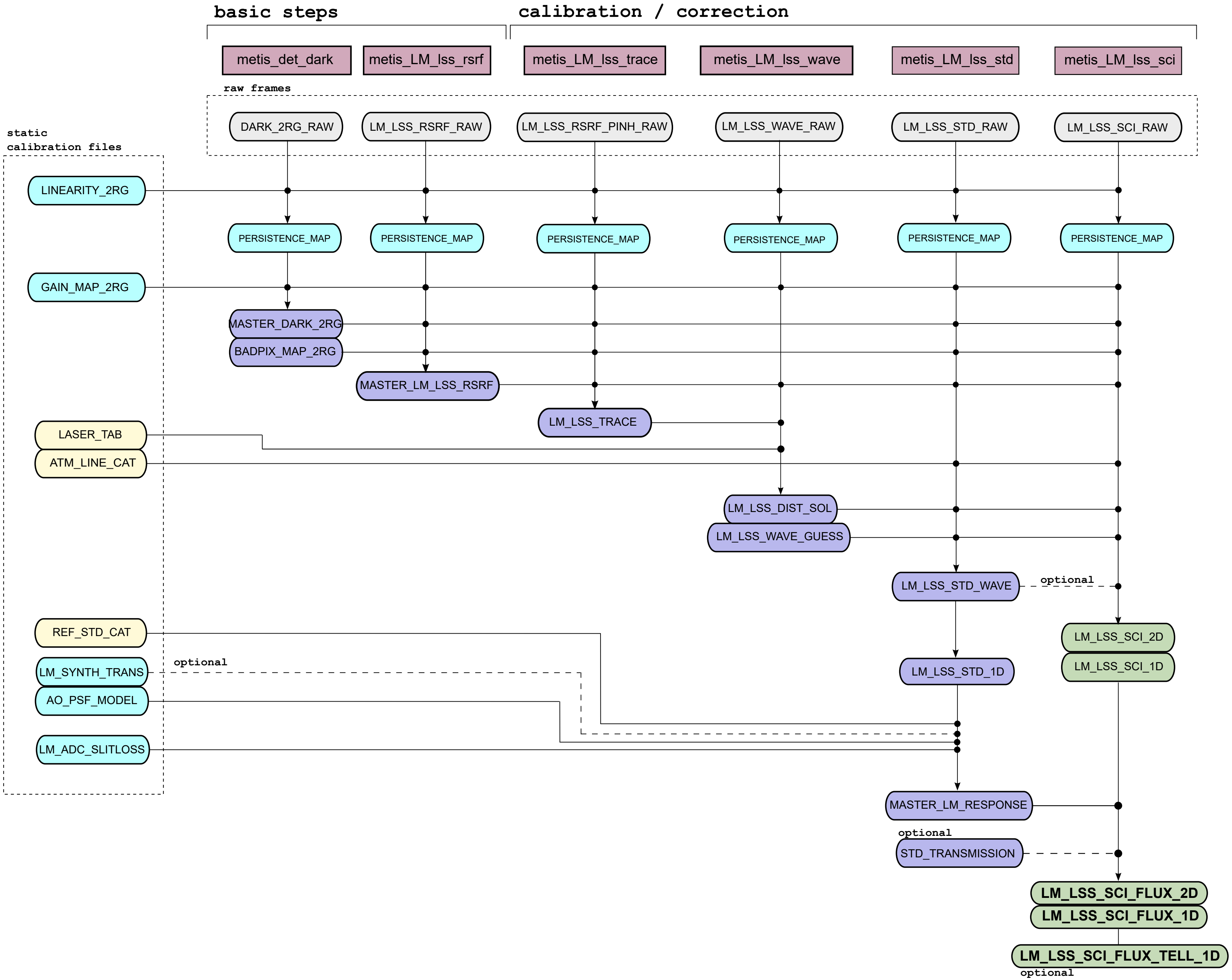


Figure 5: Part 1 of the reduction cascade and association map for long-slit spectroscopy in the LM bands.

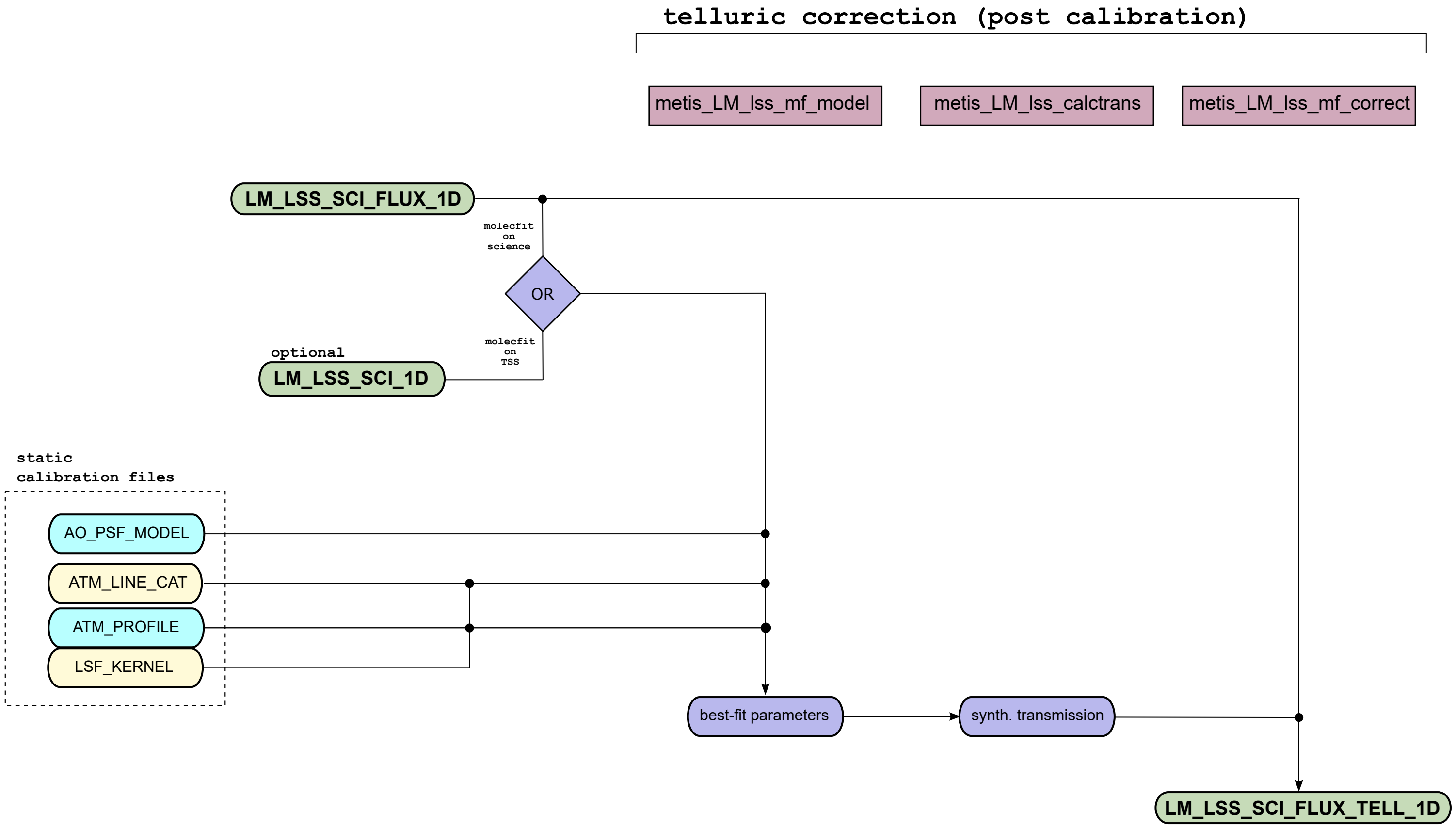


Figure 6: Part 2 of the reduction cascade and association map for long-slit spectroscopy in the LM bands.

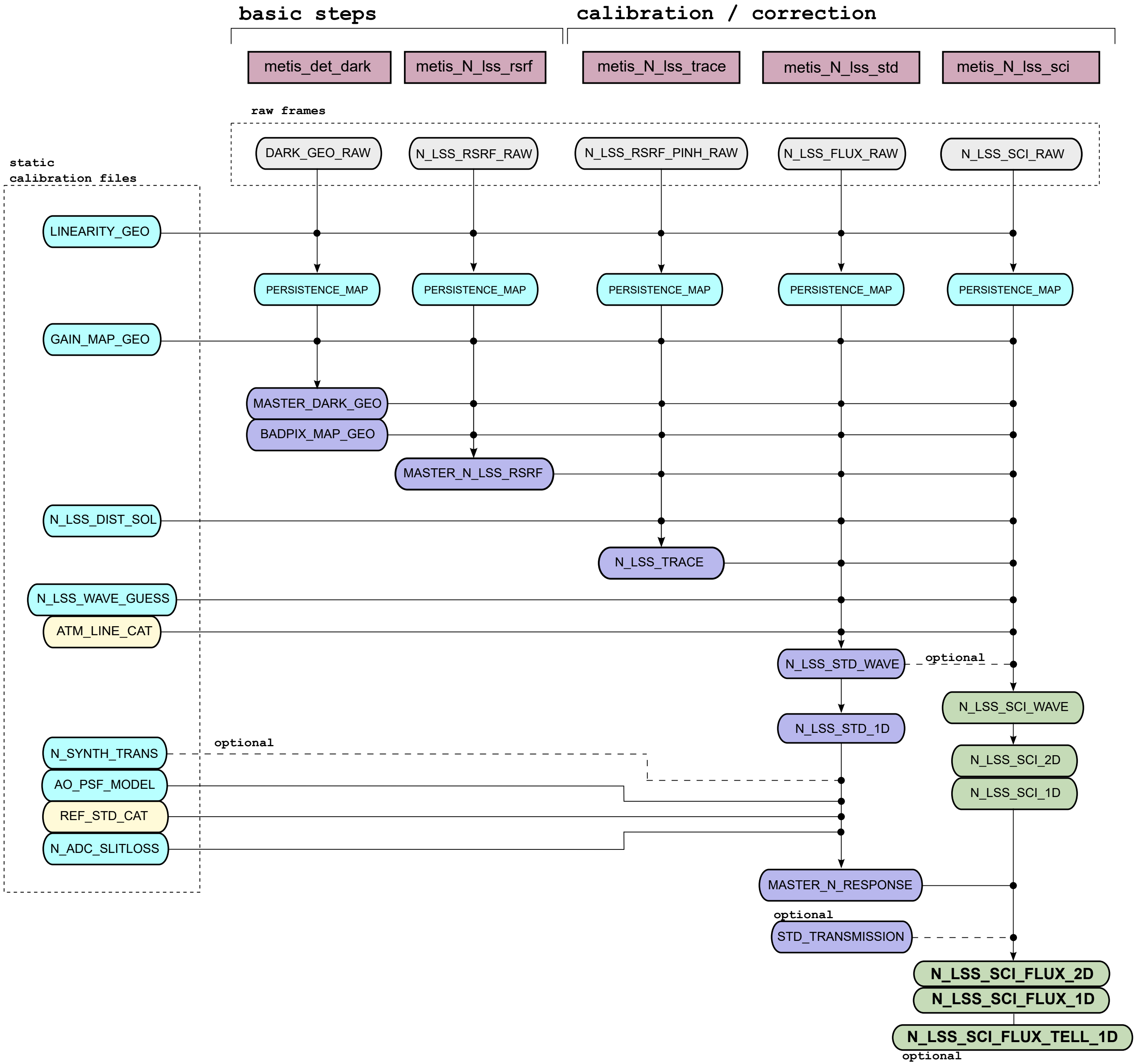


Figure 7: Reduction cascade and association map for long-slit spectroscopy in the N bands.

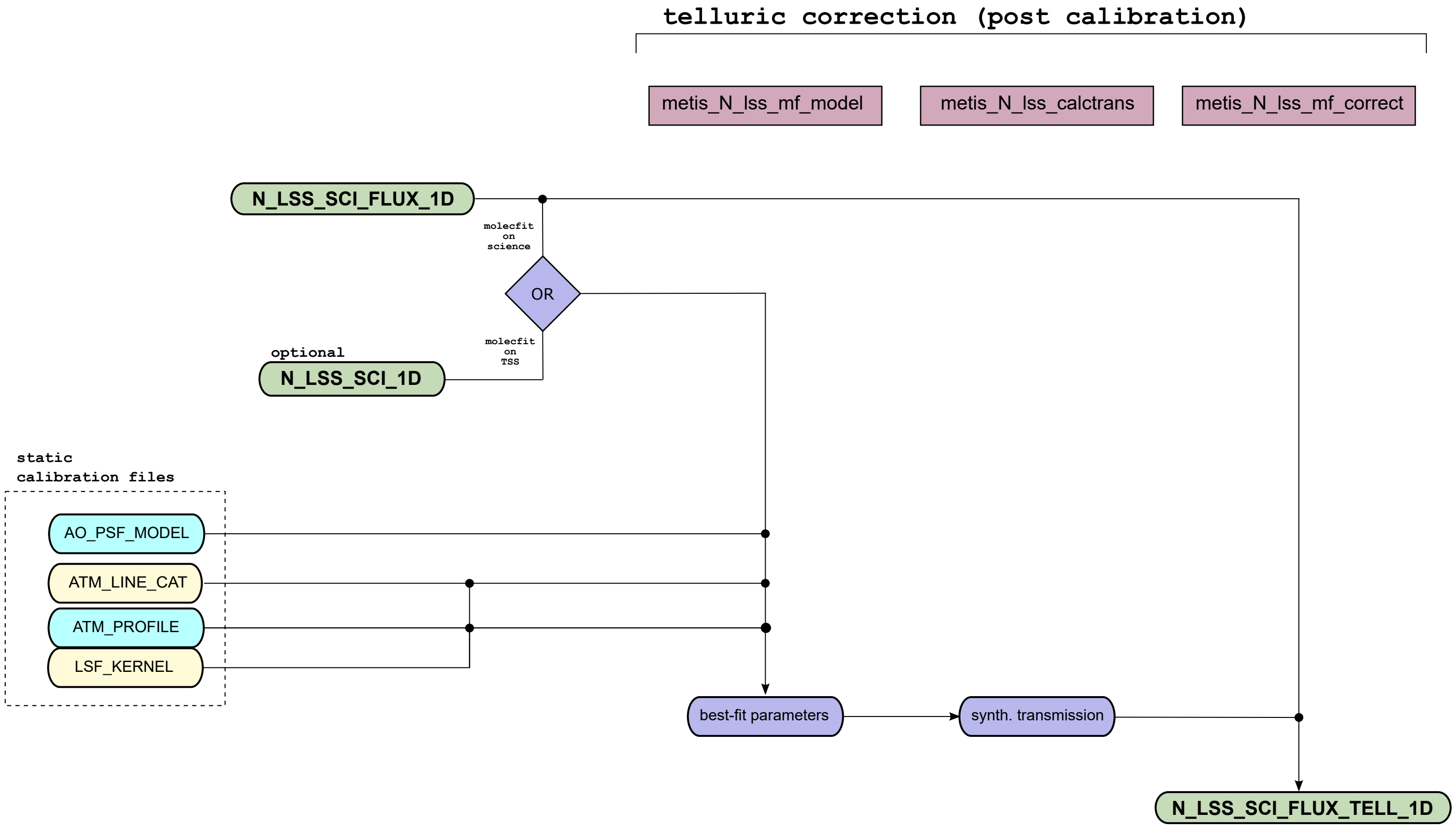


Figure 8: Reduction cascade and association map for long-slit spectroscopy in the N bands.

4.3.2 Static calibration database

The static calibration database comprises several data sets, some are updated from time to time:

- GAIN_MAP_2RG, GAIN_MAP_GEO: These are the detector gain maps of the detectors (2RG=Hawaii2RG, LM-band; GEO=Geosnap, N-band), which are created by the recipe metis_det_lingain (see Section 6.1.1). This recipe is carried out every once in a while (see [RD6]) as we assume the detectors to be fairly stable.
- LINEARITY_2RG, LINEARITY_GEO: These are the coefficients for the correction of the linearity of the individual pixels. Also created by the recipe metis_det_lingain (see Section 6.1.1).
- LASER_TAB: The WCU provides laser sources for the first guess of the wavelength solution. The main laser frequencies are fixed ([RD6]) and given in a static table.
- ATM_LINE_CAT: The main wavelength calibration will be done by means of atmospheric lines, most probably based on the HIgh-resolution TRANsmission molecular absorption database (HITRAN)[2]. They are given in a static catalogue. This database is also required by the telluric correction package molecfit.
- LM_SYNTH_TRANS/N_SYNTH_TRANS: For the determination of the continuum of flux standard stars a rough telluric correction is needed. We intend to also offer the possibility to apply static transmission curves for that purpose for performance reasons. These static transmission curves will be determined during commissioning via molecfit or by means of the ESO SkyCalc Tool[3].
- AO_PSF_MODEL: Due to the broad wings of the Point Spread Function (PSF) there might be a fraction of the flux falling outside the long slits, leading to some losses. Depending on the stability of the AO performance, these losses might be non-constant and maybe need some correction by estimating width of the PSF. One idea is to incorporate a static PSF model, which is scaled by some AO telemetry data. However, many details on that topic are still unclear. We therefore keep it as placeholder for the time being until it is clarified whether such a correction is necessary.
- REF_STD_CAT: Catalogue of standard stars used for the absolute flux calibration and (optionally) the telluric correction. This catalogue contains theoretical models of a set of standard stars (cf. Section 5.1).
- LM_ADC_SLITLOSS/N_ADC_SLITLOSS: It is expected that the fixed positions of the ADC will lead specific slit losses, which also depend on the object's position in the slit. The throughput as function of the across-slit position of the source is determined in the recipes metis_lm_adc_slitloss and metis_n_adc_slitloss (see Section 6.8.3 and [RD6]). As these losses are assumed to be very stable, these recipes will be carried out only rarely.

[2] https://hitran.org/
[3] https://www.eso.org/observing/etc/bin/gen/form?INS.MODE=swspectr+INS.NAME=SKYCALC

- ATM_PROFILE and LSF_KERNEL: The telluric correction package molecfit requires an atmospheric profile incorporating height information of the temperature, pressure and molecular abundances as input. Currently we use a static profile (equatorial equ.atm[4]) as starting point of the fit of the molecular column densities. In addition, a kernel for the Line Spread Function (LSF) is provided. We intend to determine the kernel during commissioning and use this as input. However, it is still unclear in how far the AO influences that kernel. The current baseline is to use the static LSF_KERNEL as starting point for fitting the line spread function.
- N_LSS_DIST_SOL/N_LSS_WAVE_GUESS: First guess solutions of the N-band LSS mode are static due to the absence of laser sources after AIT. As the instrument is expected to be very stable, these calibration files will be created only once and kept static.

4.4 LM IFU: integral-field spectroscopy

In general, the workflow is similar to the LSS mode, except the extensive post-processing stage. The main difference arises from the need to co-add multiple exposures to achieve the full resolution, since pixel scales are different:

- in the along-slice direction, the sampling is sufficient, ie. above the Nyquist rate; at 8.2 mas per pixel;
- in the across-slice direction, the sampling is below the Nyquist rate at 20.7 mas per pixel, and dithering/co-adding of multiple exposures is needed.

The ratio of these resolutions shows that at least three exposures shifted by one third of the pixel size are required. The image is then reconstructed on a square pixel grid of $8.2 \times 8.2 \mathrm{mas}^2$.

The exposures are taken in two perpendicular field rotations, so that full resolution is obtained naturally in the along-slice direction and by dithering in the across-slice direction; in the other sequence of three exposures these directions are essentially swapped.

The association map is shown in Fig. 9.

Two more changes are foreseen in the IFU recipe cascade:

- Allow telluric standard stars to be used, similarly to the LSS workflow, and
- Refactor the recipes such that the common processing steps are in a shared recipe, similarly to the imaging workflows.

[4] https://eodg.atm.ox.ac.uk/RFM/atm/

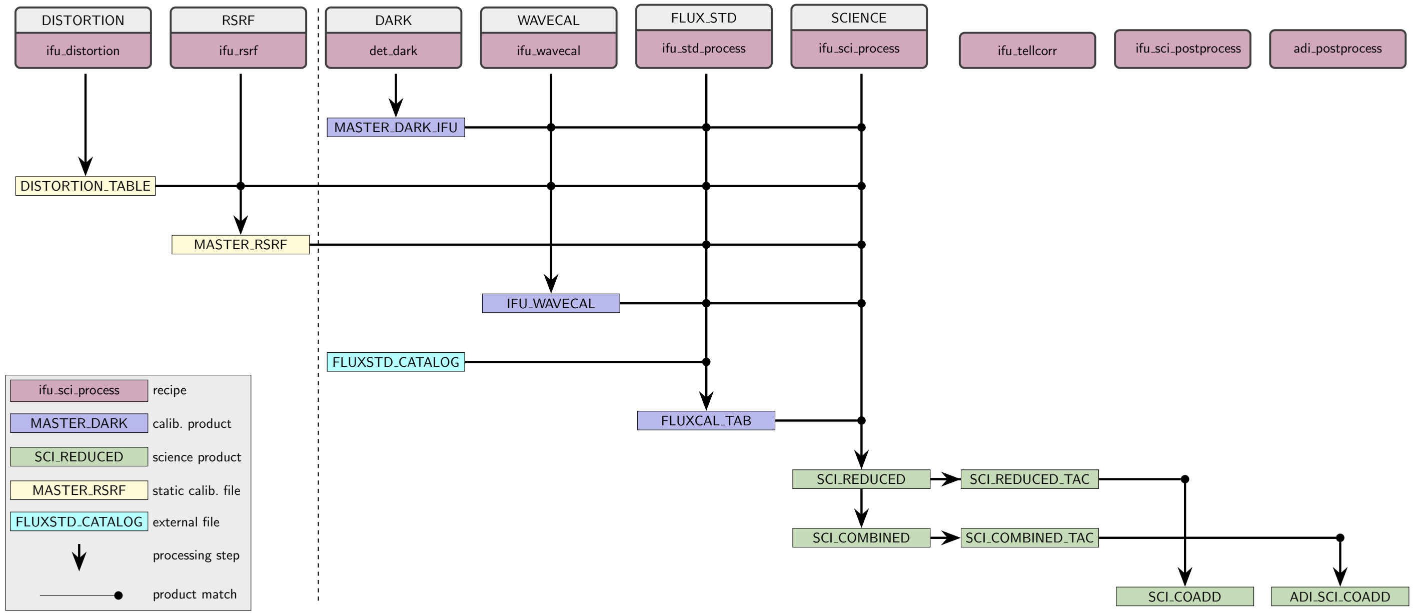


Figure 9: Association map for IFU spectroscopy in L- and M-band. The figure shows only the primary products created by each recipe; for a full list of products refer to the recipe descriptions in Sect. 6.6. The dashed line separates calibration tasks that are done at AIT or infrequently during operations from tasks done daily. The prefix "`metis_`" has been omitted from the recipe names to improve clarity.

4.5 Parallel Observing Modes

There are three parallel observing modes:

- Parallel observing mode IMG-LM and IMG-N (Section 4.5.1)
- Parallel observing mode LSS-LM and LSS-N (Section 4.5.2)
- Parallel observing mode IMG-LM and IFU (Section 4.5.2)

The respective templates corresponding to these modes will produce raw data files that can be processed independently by the relevant workflows. That is, the templates will trigger two different recipe cascades, and there are no specific recipes for any of the parallel observing modes.

4.5.1 Parallel observing mode IMG-LM and IMG-N

There are two specific templates for parallel imaging observations in the LM-band and N-band:

- `METIS_img_lmn_obs_AutoChopNod`
- `METIS_img_lmn_obs_GenericChopNod`

These templates produce two kind of raw images that are processed independently in either the LM-band or N-band imaging workflow. This fulfills METIS-7244.

4.5.2 Parallel observing mode LSS-LM and LSS-N

There is one specific template for parallel LSS observations in the LM-band and N-band:

- `METIS_spec_lmn_obs_AutoChopNodOnSlit`

These templates produce two kind of raw images that are processed independently in either the LM-band or N-band LSS workflow. This fulfills METIS-7245.

4.5.3 Parallel observing mode IMG-LM and IFU

Parallel observing mode IMG-LM and IFU is also needed to perform non-common path pointing and aberration correction in High-Contrast Imaging (HCI) modes: real-time monitoring of non-common path aberrations between the Single Conjugate Adaptive Optics (SCAO) Wave Front Sensor (WFS) and the HCI elements cannot be performed with the IFU due to slicing and sampling issues.

The IFU pickoff optic is a beamsplitter with a transmission of 10% to the LM imager and a reflectivity of 90% to the IFU. LM-band images can therefore be taken in parallel with the IFU exposures, for any of the IFU templates. The LM-band images and IFU exposures are processed independently. This fulfills METIS-6072.

4.6 Workflows

The association matrices described in the previous sections will be converted one-to-one into Reflex or EDPS workflows.

Any interactivity in the workflows is described with the individual recipes.

5 Algorithms / Mathematical description

This section provides a mathematical description for the advanced processing techniques needed to the data reduction library.

5.1 Telluric absorption correction / absolute flux calibration

Due to the dense molecular absorptions arising from the Earth's atmosphere, nearly every Mid-Infrared (MIR) regime spectrum requires a correction for these telluric features. The required atmospheric transmission curve can be achieved either by specific observations of a Telluric Standard Star (TSS) (the "classical" way) or by a modelling approach, e.g. `molecfit`.
As default mode for the telluric correction `molecfit` is foreseen for all modes. For the IFU we assume no major issues, especially as in highly resolved spectra individual line shapes can be fit very well. However, it is to be tested during commissioning, how well that approach works in case of the LSS modes, as only blends of lines are visible in the low-resolution regime. We therefore include also the well-proven classical method by means of a standard star.
In the MIR regime it is possible to use a standard star for both, the telluric correction and the absolute flux calibration, i.e. the conversion of Analogue-Digital-Unit (ADU)s to physical units. This is done by comparing the observed spectrum of a standard star with its reference spectrum as seen without atmospheric and instrument/telescope signatures, facilitating the response function to be determined. This function describes the throughput of the optical system, i.e. the instrumental effect on the flux. In principle this is a standard procedure based on the comparison of an observed spectrum of a spectro-photometric standard star with its flux calibrated model, hence a good model containing intrinsic spectral features as well as absolute fluxes of the individual star is required.
Having such observations at hand, telluric correction and flux calibration can be applied simultaneously as one correction function containing the absolute flux and atmospheric absorptions can be derived, if the standard star is observed directly before/after the science target at the same airmass (ideally in the same direction) assuming the atmosphere has not changed significantly in the meantime. The current calibration plan foresees observations of up to two standard stars for Observation Block (OB)s requiring accurate flux calibration (cf. [RD6], Section 3.8). In that case, this star can be used for the combined purpose. As we do not differ between standard stars for telluric correction and absolute flux calibration refer only to "Standard Stars" (STD) hereafter.
For the time being we assume no significant wavelength-dependent slit-losses e.g. by different performance of the AO in the science and the calibrator observations, which might affect the accuracy of the absolute flux calibration.

5.1.1 Classic approach with a standard star

A STD spectrum is taken ideally directly before/after the science observations near the science target position (or at least at the same airmass) to probe the same pathway through the Earth's atmosphere. The most simplest approach can be described by

$$F_{sci} = F_{0,cal} \cdot (S_{sci}/S_{cal}) \cdot (T_{SkyCalc\_cal}/T_{SkyCalc\_sci}) \quad (1)$$

where S_{sci} and S_{cal} are the measured fluxes (e.g. in [ADU]) of the science target and the standard star and $F_{0,cal}$ is a model of the standard star in physical flux units. Thus, the standard star is used for the flux calibration, i.e. the conversion between ADU and physical units to correct for the total instrumental throughput and the sky transparency. In case there's only a marginal difference in airmass between the science and the calibrator target, the airmass compensation can be achieved with synthetic model spectra of the transmission of the science target $T_{SkyCalc\_sci}$ and the calibrator $T_{SkyCalc\_cal}$, e.g. with the tool `SkyCalc`[5]. Also the latest version of `molecfit` incorporates a routine for the compensation of airmass differences. This approach should be sufficient even for the LSS mode as the wide wavelength range and the low resolving power does not allow to resolve individual telluric lines anyway. The high-resolution mode (IFU) enables one to much better determine telluric features and is therefore less prone to problems arising with `molecfit`.
There are several sources for standard spectra available (cf. also Section 4 in [RD6]):

- Cohen set ([RD8]): Set of 422 stellar model templates, mainly K and M giants. One of the standard sets in MIR.
- The SPEX NASA Infrared Telescope Facility (IRTF) Spectral library[6]: Set of observed stellar spectra (F to M-type, some carbon and S-type stars and L and T dwarfs) in the range 0.8...5.0μm mostly at a resolving power of $R \equiv \lambda/\Delta\lambda \sim 2,000$.
- Phoenix library[7][RD9]: Library of synthetic medium and high resolution spectra between 0.5...5.5μm covering a wide stellar parameter space ($2,300\text{K} \leq T_{\text{eff}} \leq 12,000\text{K}$; $0.0 \leq \log g \leq +6.0$; $-4.0 \leq$[Fe/H]$\leq +1.0$; $0.2 \leq[\alpha/\text{Fe}]\leq +1.2$).
- Flux calibration programme of the James-Webb-Space-Telescope (JWST) ([RD10])
- "van der Bliek" standards ([RD11]): 253 L and M band standards
- Standard star database from `CalSpec`[8]: flux standards for the Hubble-Space-Telescope (HST) system ([RD12])
- L-band fluxes from 55 near-IR standards from the MSSSO system [RD13]
- Standards stars from CRIRES[9] containing high-resolution spectrophotometric observations of 23 stars (L-band)
- UKIRT standard stars[10]

[5] https://www.eso.org/observing/etc/bin/gen/form?INS.MODE=swspectr+INS.NAME=SKYCALC
[6] http://irtfweb.ifa.hawaii.edu/~spex/IRTF_Spectral_Library/
[7] https://phoenix.astro.physik.uni-goettingen.de/
[8] http://www.stsci.edu/hst/observatory/crds/calspec.html
[9] https://www.eso.org/sci/facilities/paranal/instruments/crires/tools.html
[10] http://www.ukirt.hawaii.edu/astronomy/calib/photcal/

The METIS consortium will soon look into that topic and to assemble a set of appropriate STD stars for each observing mode.

5.1.2 Modelling synthetic transmission spectra

In the last years the modelling method for the telluric correction has evolved. It is based on radiative transfer modelling of the Earth's atmosphere. A height model of the Earth's atmosphere containing information of pressure, temperature and the concentration of molecules in combination with a radiative transfer model and a molecular line list is used to calculate a transmission function of the Earth's atmosphere at the time of observations. By fitting specific atmospheric absorption features in the science spectra and varying the input height profile allows to determine the state of the Earth's atmosphere at the time of observation. The best-fit transmission function is finally used for the telluric correction.

In the past years the approach of modelling transmission curves of Earth's atmosphere has made significant progress leading to versatile and mature software packages for the telluric correction. One of these packages is `molecfit`[11] ([RD14, RD15, RD16]). This software is optimised for the ESO framework and ESO instruments and is also foreseen to be used for METIS.

The outcome of the ELT working group meeting of 2021-03-15 was that future instrument pipelines should include dedicated recipes based on the telluric correction `telluriccorr` library [RD17]. This package is based on `molecfit` and will be provided and maintained by European Southern Observatory (ESO). The telluric correction will be performed in three dedicated recipes as post-correction and closely follow the approach as implemented in the K-band Multi Object Spectrograph (KMOS) pipeline. The three steps comprise the fit of the telluric features (e.g. `metis_LM_lss_mf_model` for the LM range), the calculation of the transmission curve (e.g. `metis_LM_lss_mf_calctrans`) and the application of the actual correction (e.g. `metis_LM_lss_mf_correct`). For the determination of the LSF we primarily rely on the possibilities as offered by the `telluricorr/molecfit` package, which is based on a fitting of the LSF by a combination of a boxcar, Gaussian or Lorentzian. On basis of the commissioning data we will establish a parameter set providing a good starting point for the fits.

We also intend to enable the user to include a dedicated line kernel instead, in case a reliable kernel model can be determined with other (external) tools (e.g. a model-based convolution of an internal LSF, the slit-widths and/or an AO component). In addition, also external supplementary meteorological data (e.g. line-of-sight profiles of water vapour measured by an Low Humidity And Temperature Profiling microwave RadiOmeter (LHATPRO) radiometer) can be included if the `telluricorr/molecfit` and/or `skycorr` package offers that possibility.

5.1.3 Approach for METIS

The modelling approach has become the standard way for the telluric correction in several ESO pipelines as it avoids to spend valuable observing time on taking STD spectra. Since the synthetic transmission function is noise-free, it also conserves the Signal-to-Noise Ratio (SNR) of the science spectrum. It is therefore foreseen as default method for the METIS pipeline.

[11] `http://www.eso.org/sci/software/pipelines/skytools/molecfit`

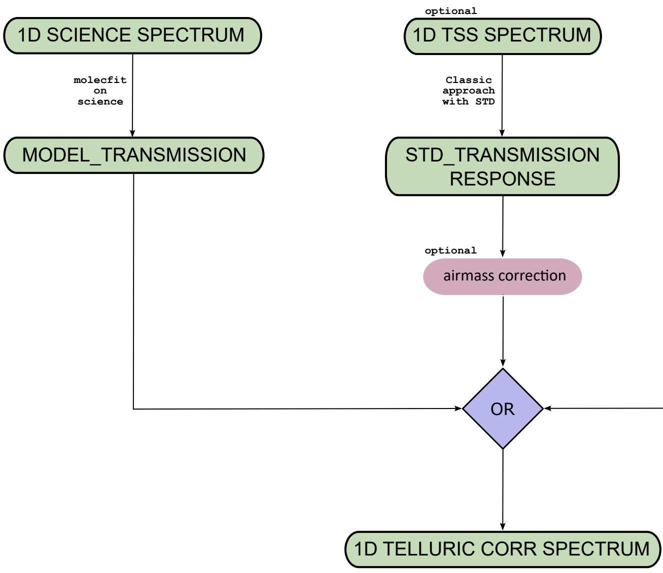


Figure 10: Methods for the telluric correction to be included in the METIS pipeline.

However, there might be situations where the classical way becomes the better option. For example, in case the science object's continuum is too weak to be used for fitting telluric absorption features and not enough sky emission is available, or the low-resolution LSS spectra do not allow to find a good fitting solution due to line blends. In addition, `molecfit` relies on a number of fitting parameters, which might not lead to the best minimum. In particular, the quality of the fit is very sensitive to the incorporated LSF-Kernel, whereas the LSF of a STD spectrum is naturally (almost) identical.
We therefore will include three different approaches for the telluric correction in the METIS pipeline (cf. Fig. 10):

- "*molecfit-on-science*": This is the usual way of using `molecfit`, i.e. the science spectrum ("`1D SCIENCE SPECTRUM`") is used to determine the state of the Earth's atmosphere and to calculate a synthetic transmission (left branch in Fig. 10)
- "classical" approach: The transmission of the Earth's atmosphere is determined in the classical way with the help of a STD as described above (right branch in Fig. 10). In this case, a combined absolute flux calibration / telleuric correction is applied.
- "*molecfit-on-star*": This is a combination of the both methods in the sense that `molecfit` is applied to STD observations, and the resulting synthetic transmission spectrum is used for the telluric correction of the science target (middle branch in Fig. 10)

Additional remarks:
Following the development within the ELT working group "Telluric Correction", the newest release[12] of `molecfit` will contain some new features, which will be used in the METIS pipelines:

[12] https://www.eso.org/sci/software/pipelines/

(a) a routine to correct transmission spectra for airmass. This allows the usage of STD which are at a different airmass than the science target; (b) a method to quantitatively estimate the quality of the telluric correction on the science frames, which will be used for Quality Control (QC); (c) a routine to use the wavelength fit as wavelength calibration for the science observations, i.e. to use telluric features as reference frame. For more details on that new features we refer to the `molecfit` documentation of the upcoming release and the documents in the working group[13].
As mentioned above, `molecfit` will be the default method. It is therefore the users sole responsibility to decide whether a STD is required/desired. However, the selection of the STD should not be arbitrary, but only possible from a provided catalogue.
Please note that the workflow in the recipes processing the STD stars (e.g. `metis_LM_lss_std` or `metis_N_lss_std`) changes when the classical method is chosen. In the `molecfit` case, a telluric correction is applied to the STD spectrum to better determine the response function and only the response is delivered to the science recipes. In case of the classical approach, the response function will also contain the telluric features of the STD, and therefore a telluric correction beforehand is counterproductive.
For the LSS mode of METIS we intend to implement the flux calibration approach as described in the High-Level Data-Reduction Library (HDRL) wherever possible (cf. [RD18]).

5.1.4 Quality control parameters for `molecfit`

To estimate the quality of the telluric correction we follow the approach incorporated with the new `molecfit` version 4.3.1:

- Smoothing the corrected spectrum with a Savitzky-Golay filter[14]
- dividing the corrected spectrum by the smoothed one; This leads to a normalisation to unity and a crude removal of slopes and intrinsic features
- Determine the mean absolute difference of the resulting spectrum, excluding `NaN` values on the user provided spectral ranges (e.g., only spectral ranges with telluric features).

5.2 High-contrast imaging with the apodizing phase plate

LM-band imaging data taken with the apodizing phase plate undergo the same basic reduction as standard imaging data.

1. Locate the positions of the PSFs with respect to each other (dither correction). This is primarily done through the WFS-FS position information. The positions of the PSFs are also measured in the images themselves as a verification.
2. Center the leakage PSF in the frames.
3. Extract the coronagraphic PSFs and combine them into a single cube (see Fig. 11). This combined cube has an almost continuous 360° dark zone with a narrow brighter strip in

[13] https://eso.org/wiki/pub/ELTScience/Telluric_correction/TelluricWG_20230425.pdf
[14] https://en.wikipedia.org/wiki/Savitzky%E2%80%93Golay_filter

between the original 180° dark zones, which is included in the static mask of step 6.

4. Median combine the cube to obtain the reference PSF image.
5. Subtract PSF image from all layers of the cube.
6. Derotate all layers to correct for field rotation, taking into account a static mask to reject noisy border regions of the dark zones.
7. Sum the layers to obtain final image. Intermediate data products are also provided.

Additionally a reduction process where the two PSFs are handled separately also works. This will use the same approach however the mask will cover a larger angular extent.

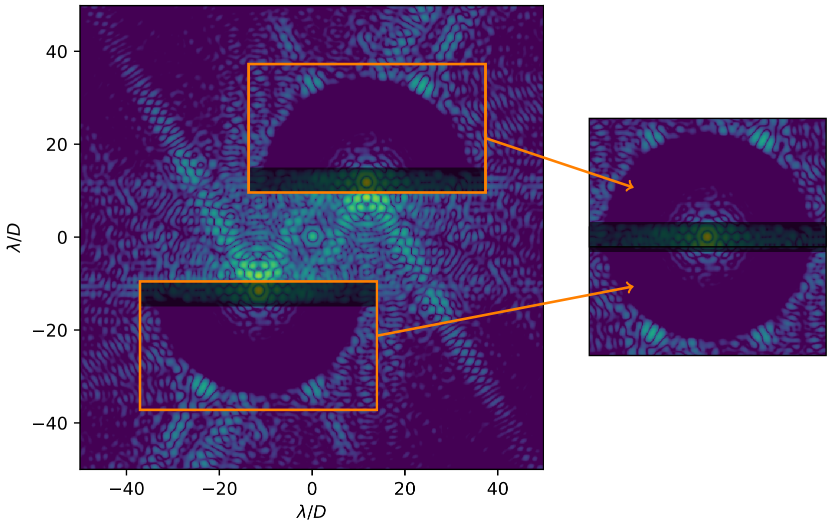


Figure 11: Combination of the coronagraphic PSFs of APP observations into a single PSF with nearly 360° dark zones. The bright horizontal stripes through the peak of the PSF will be masked for ADI post-processing.

5.3 Long-slit spectroscopy mode

5.3.1 Order background contamination removal

Order background contamination may arise from internal straylight probably covering larger areas of the detector. Since it is expected to be low frequency only, its removal can be achieved by a low-order 2D polynomial fit

$$z = (a_0 + a_1x + a_2y + a_3x^2 + a_4x^2y + a_5x^2y^2 + a_6y^2 + a_7xy^2 + a_8xy\ldots) \tag{2}$$

and a subsequent subtraction. The fitting points/regions must be chosen to be outside the LSS order (cf. e.g. Figs 60/61 for simulated data). Whereas these fitting points/regions can be chosen on fairly regular basis due to the straight order geometry in the LSS mode, the degree of the polynomial depends on the actual straylight. This can be determined only during the testing phase when first real data are available. Note that this algorithm will only be implemented in case such a contamination is visible.

5.3.2 Order detection and rectification

The algorithms for order detection and rectification are adopted from [RD19, RD20]. In brief, the selection of pixels that may belong to spectral LSS order is done by first smoothing each column and then selecting pixels above the median of the difference between the original and the smoothed column, i.e. pixel (x,y) is selected if

$$I(x,y) > \bar{I}(x,y) + \mathrm{Median}(I(x,y) - \bar{I}(x,y)). \tag{3}$$

In the following a clustering analysis is performed, which associates connected groups of pixels. This is done scanning rows and columns and identifying neighbouring pixels selected in the previous step as belonging to the same cluster if δx and δy differ by at most 1. As spectral orders may be partitioned into different clusters because of e.g. detector defects, polynomial fits to the clusters are performed and the pairwise extensions of the fits to consecutive clusters are compared to identify which clusters are to be merged according to predefined criteria for the goodness of match. For each order, the detection algorithm yields a polynomial description of order location on the detector (the order center and its edges), an uncertainty estimate for the fitted polynomial, and the first and last columns to be used during spectrum extraction. Order rectification is achieved using the PyReduce algorithm described by [RD20] that can account for both tilt and curvature of the slit image.

5.3.3 Wavelength calibration strategy

The wavelength calibration (i.e. the pixel-to-wavelength relation) of the LSS modes is done in a two-step approach:

- First guess: The first guess is based on laser sources in the WCU and during commissioning. In the LM range, two fixed-frequency lasers (@3.39µm and @5.26µm) and one tuneable (4.68....4.78µm) is foreseen in the WCU to be taken on daily basis (cf. [RD6]). In the N-band, a laser source will only be available during AIT. As we assume the instrument to be very stable, that approach should be sufficient to achieve a first guess solution for the low-resolution N-band spectroscopy.
- For the final calibration atmospheric lines are used in the recipes `metis_LM_lss_sci` and `metis_N_lss_sci`, which are used in the `pyreduce` package as reference frame.
- Optionally: the package `molecfit` in its newest version has a new function implemented, which allows a fine-tuning of the wavelength calibration by means of fitting atmospheric features. It is to be tested during commissioning, whether this step is required.

5.3.4 Object extraction and faint object spectroscopy

The object spectra will be extracted using the optimal extraction described by [RD20] in order to maximized the SNR. Faint objects will lead to additional requirements for the observation and the data reduction. For the target acquisition a blind offset from a reference source might become necessary in case the actual object cannot be detected directly. For the data reduction, manual interaction with the user is expected to be necessary to define the target position along the slit since automatic object detection algorithms (e.g. optimal extraction rely on a certain SNR. This will be implemented as interactive actor in Reflex (or ESO-DPS).

5.4 Miscellanea

5.4.1 Gain

The variance N_c^2 is related to the signal S_c via [RD21, Section 9.1]:

$$N_c^2 = \frac{1}{g} S_c + R_c^2, \tag{4}$$

where g is the gain and R_c the readout noise. All quantities with subscript c are in counts (ADU).

5.4.2 Conversion of wavelengths between vacuum and air regime

Since METIS measures spectral lines inside a vacuum cryostat, it only makes sense that the DRL will use vacuum wavelengths throughout, both for long-slit and IFU spectroscopy. The line lists are an external input to the pipeline, and if needed the wavelengths can be transformed as follows.

For the conversion of λ_{vac} to λ_{air} the International Astronomical Union (IAU) standard formula provided by Donald Morton [RD22] $\lambda_{\text{air}} = \lambda_{\text{vac}}/n$ is used, where

$$\begin{aligned} s &= 10^4/\lambda_{\text{vac}} \\ n &= 1 + 0.0000834254 + \frac{0.02406147}{(130 - s^2)} + \frac{0.00015998}{(38.9 - s^2)} \end{aligned} \tag{5}$$

The reverse transform λ_{air} to λ_{vac} was derived by N. Piskunov[15], being $\lambda_{\text{vac}} = \lambda_{\text{air}} * n$ with

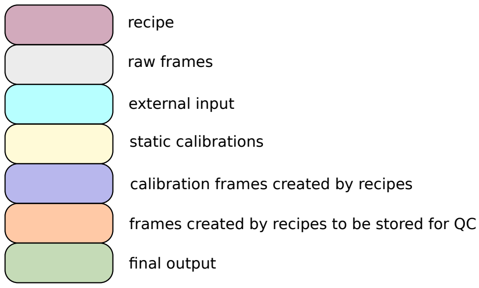
$$\begin{aligned} s &= 10^4/\lambda_{\text{air}} \\ n &= 1 + 0.000083366242 + \frac{0.0240892687}{(130.106592452 - s^2)} + \frac{0.00015997409}{(38.925687933 - s^2)} \end{aligned} \tag{6}$$

[15] https://www.astro.uu.se/valdwiki/Air-to-vacuum%20conversion

6 Pipeline Recipes / CPL Plugins

All functionality of the METIS pipeline is provided through *recipes*, i.e. CPL plugins that run in the contexts that ESO tools provide. The only dependencies are the ESO libraries CPL and HDRL (including their respective dependencies), and the ESO workflow system. This is in accordance with [AD5] and fulfills requirements METIS-6058 and its parts METIS-6059, METIS-6060 and METIS-5945.

Throughout this document we use the following color scheme for the recipe workflows:



6.1 Detector calibration recipes

METIS will have three focal plane detector arrays:

- One 2k × 2k HAWAII2RG detector used for LM-band imaging and slit spectroscopy.
- One 2k × 2k GeoSnap (Teledyne) detector used for N-band imaging and slit spectroscopy.
- An array of four 2k × 2k HAWAII2RG detectors used for LM-band integral-field spectroscopy.

This section lists recipes that calibrate detector characteristics independent of a specific instrument mode. Where `_det` appears in FITS keywords of input or product files, it is taken to mean `_LM`, `_N` or `_IFU` according to the detector array for which data are being processed.

6.1.1 `metis_det_lingain`: Detector linearity and gain determination

The recipe `metis_det_lingain` determines detector (non-)linearity and absolute detector gain from a set of flat-field frames taken with the broad-band lamp over a range of detector exposure times (DITs) and flux levels. The recipe structure will be similar as for `detmon_ir_lg` [RD23]; however, further insight into detector behaviour (in particular of GeoSnap) may necessitate development of more complex procedures.

The linearity curve is given by the measured background level as a function of exposure time for constant illumination. For each pixel the coefficients of a polynomial fit will be recorded in a coefficient cube, which can in turn be used to correct for non-linearity in other recipes. Pixels whose coefficients differ significantly from the majority of pixels will be marked as bad.

Detector gain is typically computed pixelwise as the slope of a linear fit of the variance against the mean (or median) values over a set of frames taken over a range of DITs and illumination levels. For mid-infrared detectors that suffer from Excess Low Frequency Noise (ELFN), e.g. the AQUARIUS detector, this approach does not work. The GeoSnap is not expected to show ELFN, hence gain determination is probably possible.

The set of calibration frames used for this recipes will include exposures with WCU window closed (`LAMP OFF`), which will be used as 'dark' frames that captur thermal emission within the instrument. This is subtracted from all other exposures in the sequence.

This satisfies METIS-5997.

Name:	metis_det_lingain
Purpose:	determine non-linearity and gain of the detectors
Requirements:	METIS-5997
Type:	Calibration
Templates:	METIS_img_lm_cal_DetLin
	METIS_img_n_cal_DetLin
	METIS_ifu_cal_DetLin
Input data:	DETLIN_det_RAW: (set of FLAT,LAMP frames taken with increasing DIT)
	det_WCU_OFF_RAW: (set of internal darks taken at the start of the template)
Algorithm:	Subtract instrument dark (hdrl_imagelist_sub_image).
	Compute mean and variance for each frame.
	Gain is determined as the slope of variance against mean (metis_derive_gain)
	Fit polynomial of value as a function of DIT and illumination level for each pixel (metis_derive_nonlinearity).
	Flag pixels with coefficients significantly different from the mean of all pixels. (hdrl_bpm_fit_compute)
Output data:	GAIN_MAP_det
	LINEARITY_det
	BADPIX_MAP_det
Expected accuracies:	0.5% background subtraction (cf. [RD24])
	0.1% non-linearity measurement (cf. [RD24])
QC1 parameters:	QC LIN GAIN MEAN
	QC LIN GAIN RMS
	QC LIN NUM BADPIX
hdrl functions:	hdrl_imagelist_sub_image
	hdrl_bpm_fit_compute

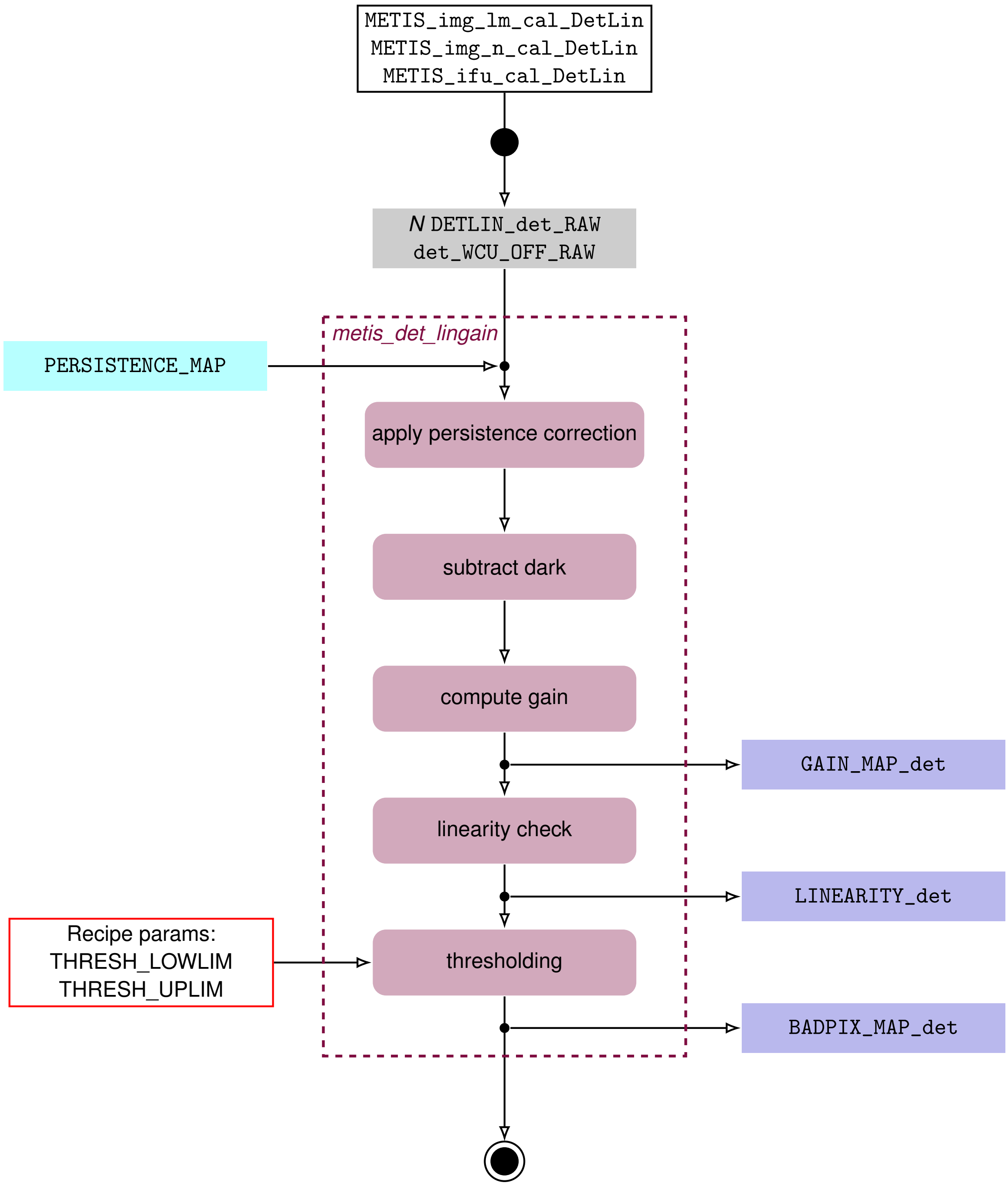


Figure 12: `metis_det_lingain` – determination of linearity and gain of the detectors.

6.1.2 metis_det_dark: Master dark creation

Darks are taken in daytime for all science detectors [RD6]. The data will be classified by detector (e.g. DET.ID and DET.CHIP.ID) and integration time (DET.DIT).[16] There will be "METIS-dark" (with the CLOSED position of the CFO-PP1 wheel) and "Imager-dark" (with the CLOSED position in the subsystem PP1), to be distinguished by header keywords. The former will be used for pipeline processing, the latter for monitoring purposes.

Each set of raw dark frames is processed into a master dark. For the IFU, both raw frames and master dark have four extensions corresponding to the four detectors in the focal-plane array. The recipe also produces bad pixel masks by identifying hot pixels whose dark current differs significantly (by more than $\pm 5\sigma$) from the average over the detector.

This fulfills METIS-6063.

Name:	metis_det_dark
Purpose:	determine the dark current of the detectors
Requirements:	METIS-6063
Type:	Calibration
Templates:	METIS_gen_cal_dark
	METIS_gen_cal_InsDark
Input data:	DARK_det_RAW
	LINEARITY_det
	PERSISTENCE_MAP
Parameters:	Combination method (median, mean, sigclip,...)
	Parameters for combination methods
	Thresholds for deviant-pixel identification
Algorithm:	Group files by detector and DIT, based on header keywords
	Call function metis_determine_dark for each set of files
	call metis_update_dark_mask to flag deviant pixels
Output data:	MASTER_DARK_det
	BADPIX_MAP_det
Expected accuracies:	0.1% (cf. [RD24])
QC1 parameters:	QC DARK MEAN
	QC DARK MEDIAN
	QC DARK RMS

[16] The dark current is not expected to depend on the readout mode of the detectors. Should hardware tests reveal such a dependence, the recipe will be amended to classify on readout mode as well.

	QC DARK NBADPIX
	QC DARK NCOLDPIX
	QC DARK NHOTPIX
hdrl functions:	hdrl_bpm_3d_compute
	hdrl_imagelist_collapse

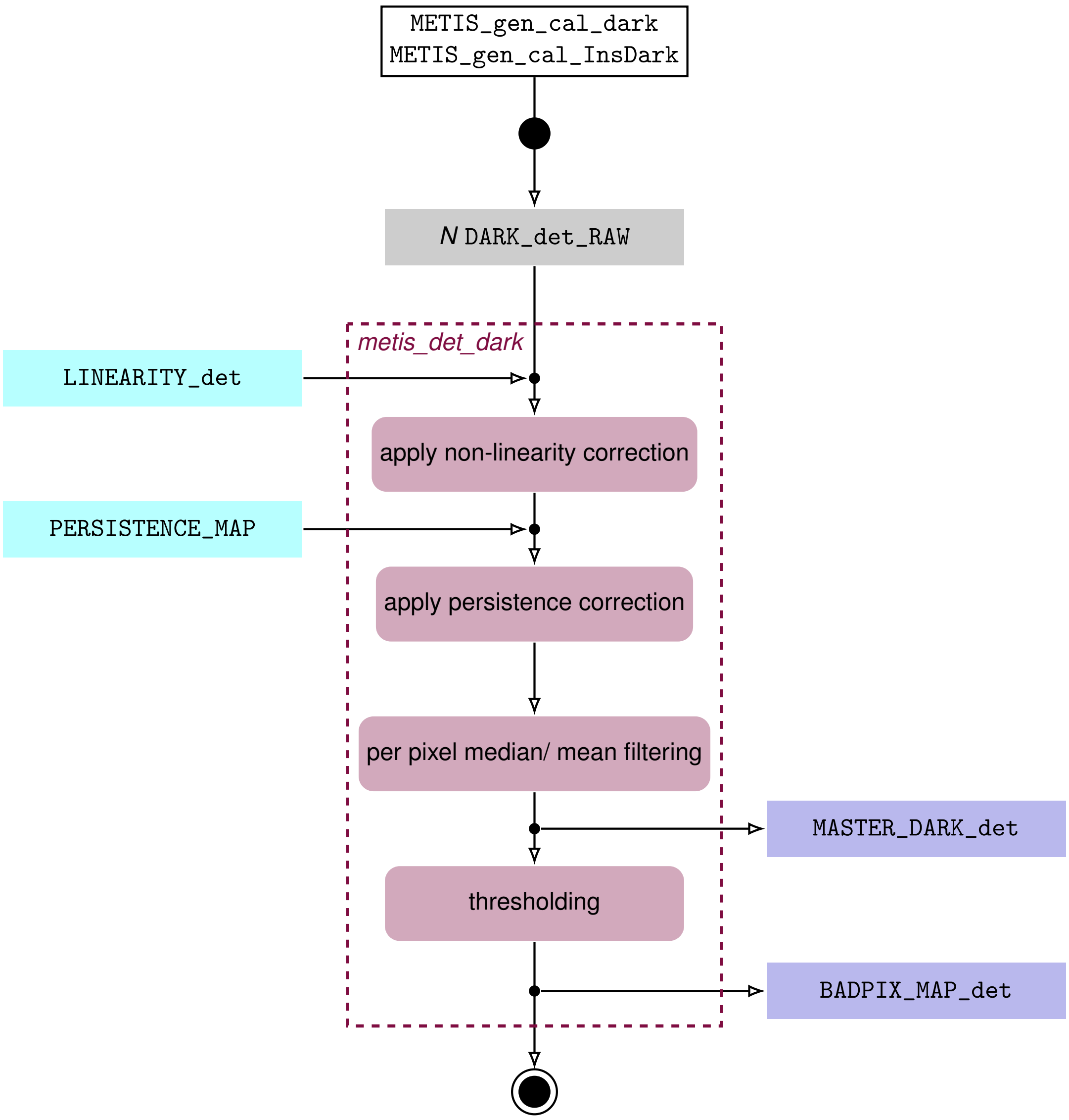


Figure 13: metis_det_dark – creation of master dark and bad pixel maps

6.1.3 metis_det_persistence: Persistence map creation

Infrared detectors are prone to persistence due to charges trapped on a variety of timescales. The correction for a given science or calibration exposure is built from a sequence of exposures preceding the exposure in question. As these may include exposures taken for another proprietary programme, the recipe is run by ESO on data taken from the science archive and its products are again ingested into the archive. The recipe will make use of the HDRL function for the creation of the persistence map, which will be provided by ESO in the future.
We will update this Section as soon as more information is available.

6.2 LM-band imaging recipes

6.2.1 metis_lm_img_flat: Flatfielding

The purpose of the flat-field calibration is to determine pixel-to-pixel gain variations and large scale illumination variations (due to inhomogeneities of optical elements in the telescope or instrument). Calibration frames are obtained either during day time using the black-body lamp of the WCU (internal flats) or by taken images of the twilight sky (twilight flats). Advantages and disadvantages of the two types of flat are discussed in [RD6]. Since the operational concept for twilight flats needs to be refined during commissioning at the telescope, the current recipe design is primarily valid for internal flats.

This recipe creates a master flat for the HAWAII2RG detector (LM-band imaging) from lamp or sky images matched by various setup parameters as detailed below. A set of internal flats includes a number of exposures with `LAMP OFF`, which will be used for dark subtraction. For twilight flats a master dark will be subtracted. The master flat is obtained by the slope of a linear fit of the pixel values against the illumination level of the exposures.

The quality control parameters give various statistics for each input frame (mean, standard deviation, etc.), the standard deviation of the normalised master flat and the number of bad pixels identified by the recipe. If a bad-pixel map is provided on input, it is updated, otherwise a new one is created.

Name:	metis_lm_img_flat
Purpose:	Create master flat field for the LM-band imaging detector.
Requirements:	METIS-6096
Type:	Calibration
Templates:	METIS_img_lm_cal_InternalFlat
	METIS_img_lm_cal_TwilightFlat
Input data:	LM_FLAT_LAMP_RAW
	or LM_FLAT_TWILIGHT_RAW

	MASTER_DARK_2RG (for twilight flats)
	BADPIX_MAP_2RG
Matched keywords:	Detector ID
	Filter ID
	ADC ID
	Flat type (internal or twilight)
Parameters:	Combination method (`mean`, `median`, `sigclip`, ...)
	Parameters for combination methods
	Threshold(s) for deviant-pixel identification
Algorithm:	Call `metis_apply_persistence_correction` to apply the persistence correction
	For internal flats: call `metis_det_dark` with `LAMP OFF` images to create dark frame.
	Subtract internal dark or master dark from flat exposures.
	call `metis_lm_img_flat` to fit slope of pixel values against illumination level. Frames with the same exposure time will be averaged.
	Compute median or average of input frames to improve statistics.
	Call `metis_update_lm_flat_mask` to flag deviant pixels.
Output data:	MASTER_IMG_FLAT_LAMP_LM
	or MASTER_IMG_FLAT_TWILIGHT_LM
	BADPIX_MAP_2RG
Expected accuracies:	0.5% (cf. [RD24])
QC1 parameters:	`QC LM MASTERFLAT RMS`
	`QC LM MASTERFLAT NBADPIX`
	`QC LM FLAT MEAN ##`
	`QC LM FLAT RMS ##`
hdrl functions:	`hdrl_bpm_fit_compute`
	`hdrl_imagelist_collapse`
	`hdrl_imagelist_sub_image`

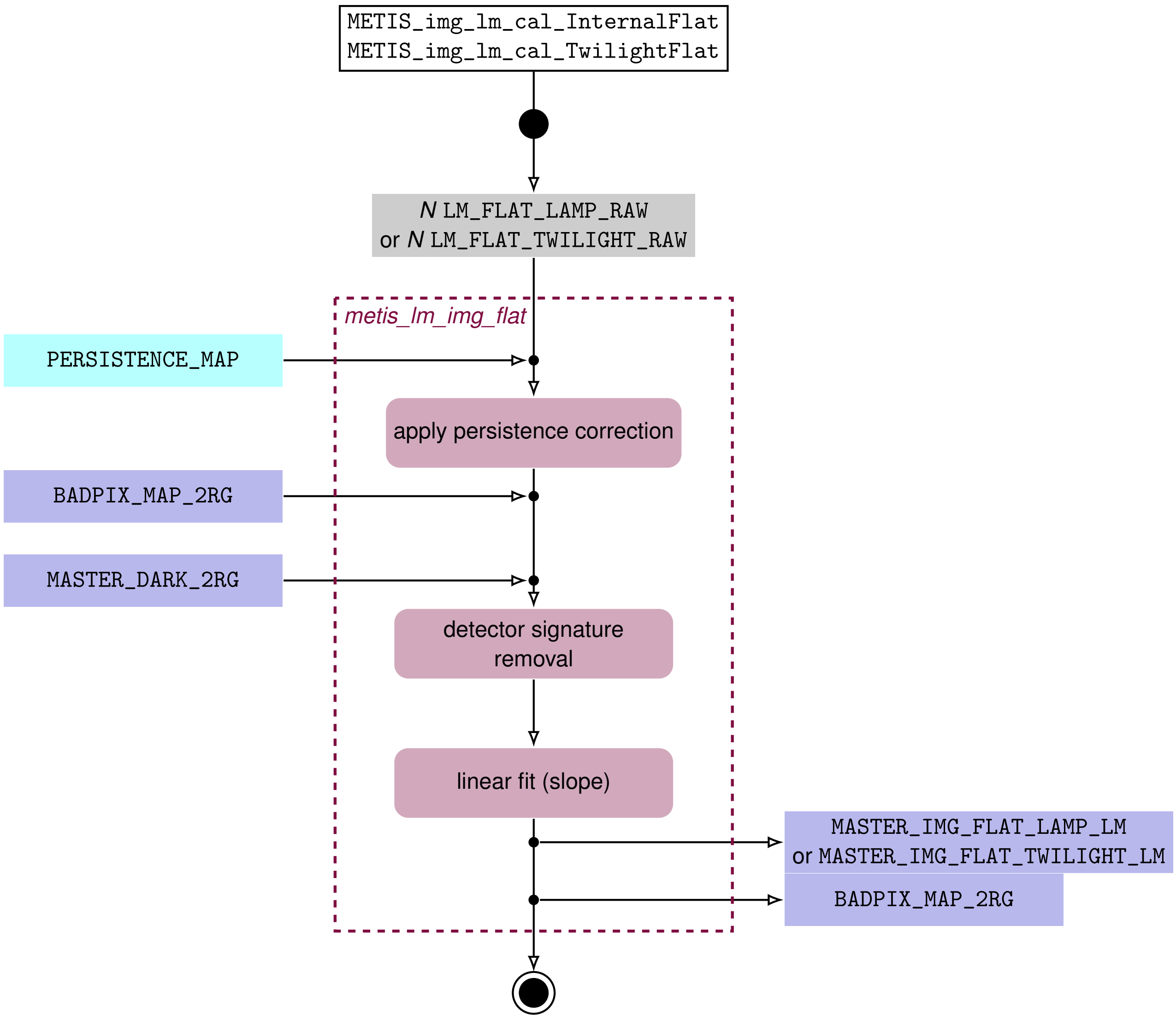


Figure 14: metis_lm_img_flat – creation of IMG_LM master flatfield.

6.2.2 metis_lm_img_basic_reduce: Basic reduction

This recipe performs the basic reduction of raw exposures from the LM-band imager, i.e. dark subtraction, flat fielding and other removing instrumental signals. It is used for both standard and science exposures.

This recipe analyses the masked detector regions for channel offset correction, crosstalk (see [RD25]) and removal of detector artefacts (electronic ghosts). In the horizontal dimension, the masked pixels are used to correct for each channel offset. In the vertical dimension, the masked pixels are used to correct for cross-talk.

Basic statistics of the images can be used to screen for saturation.

Name:	metis_lm_img_basic_reduce
Purpose:	apply basic reduction of images
Requirements:	METIS-6090
Type:	Calibration, Science
Templates:	METIS_img_lm_cal_standard METIS_img_lm_obs_AutoJitter METIS_img_lm_obs_GenericOffset METIS_img_lm_obs_FixedSkyOffset METIS_img_lm_app_obs_FixedOffset METIS_img_lm_vc_obs_FixedSkyOffset METIS_img_lm_cal_psf METIS_img_lmn_obs_AutoChopNod METIS_img_lmn_obs_GenericChopNod METIS_ifu_obs_FixedSkyOffset METIS_ifu_obs_GenericOffset METIS_ifu_ext_obs_FixedSkyOffset METIS_ifu_ext_obs_GenericOffset METIS_ifu_vc_obs_FixedSkyOffset METIS_ifu_ext_vc_obs_FixedSkyOffset METIS_ifu_app_obs_Stare METIS_ifu_ext_app_obs_Stare METIS_ifu_cal_psf
Input data:	LM_IMAGE_SCI_RAW (Dithered images (standard, science) MASTER_DARK_2RG MASTER_IMG_FLAT_LAMP_LM

	or MASTER_IMG_FLAT_TWILIGHT_LM
Matched keywords:	DIT (for dark)
	Filter ID (for flat)
Algorithm:	Remove crosstalk, correct non-linearity
	Analyse and optionally remove masked regions
	Subtract dark, divide by flat
	Remove blank sky pattern
Output data:	LM_SCI_BASIC_REDUCED
	LM_STD_BASIC_REDUCED
QC1 parameters:	QC LM IMG MEDIAN
	QC LM IMG STANDARD DEVIATION
	QC LM IMG PEAK
hdrl functions:	hdrl_imagelist_sub_image
	hdrl_imagelist_div_image

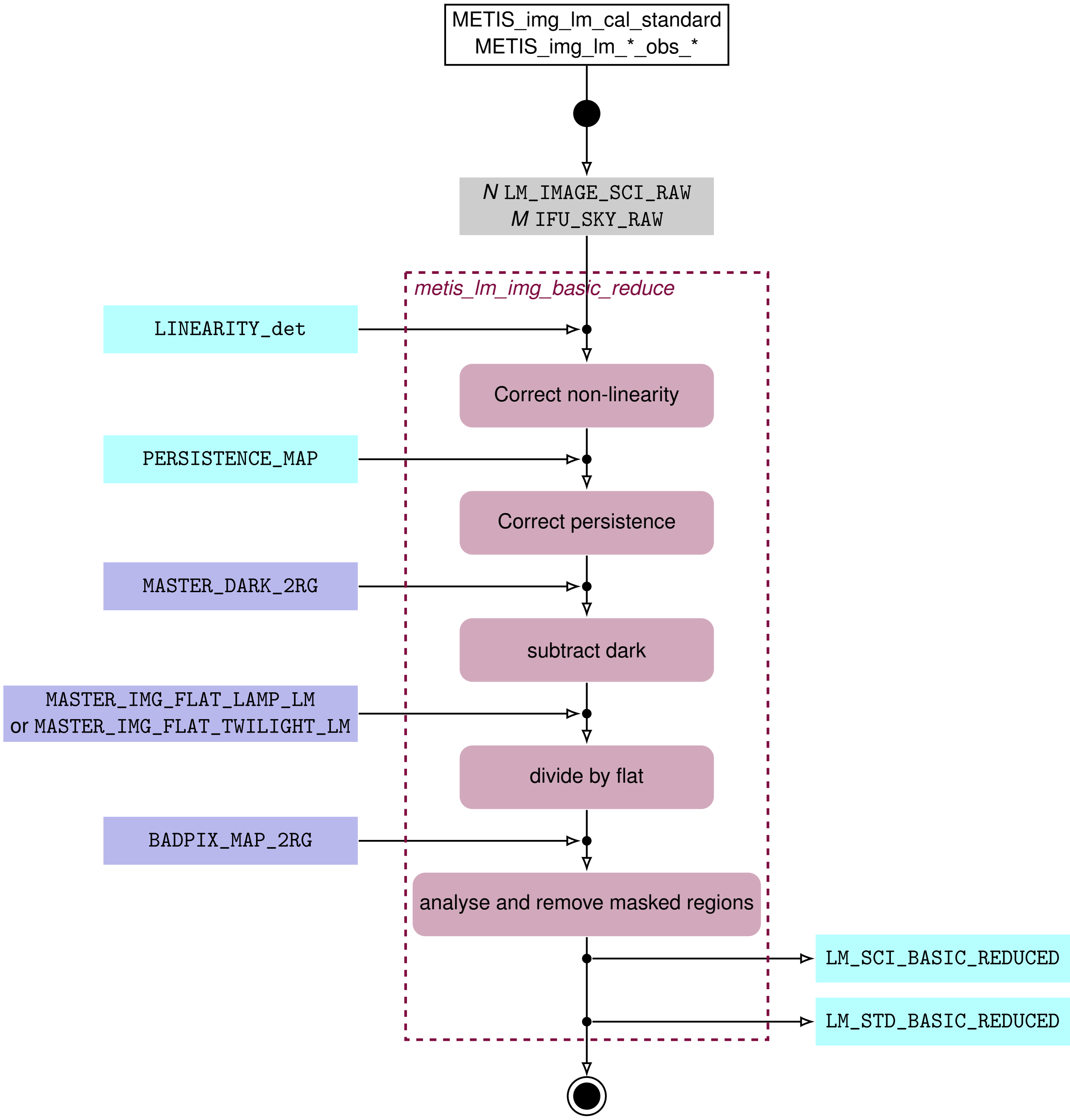


Figure 15: metis_lm_img_basic_reduce – basic reduction of IMG_LM data.

6.2.3 metis_lm_img_background: Background subtraction

This recipe estimates and subtracts the background from LM-band imaging data. Thermal background emission from the atmosphere, telescope and warm parts of the instrument dominate the photon count in mid-infrared observations. Accurate determination and removal of background counts is therefore crucial to make MIR data scientifically usable.

A set of observations will consist of a number of dithered exposures of the field, where the offsets are achieved using the internal chopper of METIS or the with the telescope. For extended objects, the telescope will be used to perform "out-of-field dithering", i.e. observe nearby blank patches of sky interlaced with the target observations. Imaging observations are performed in pupil-tracking mode, hence angular dithering of the field is automatic.

For in-field-dithered exposures, all dithered exposures will be averaged to obtain the background estimate. In order to only average the background contribution, an iterative procedure of object detection and masking will be employed. Averaging will be done using a robust estimator of the mean (e.g. median).

For extended objects, all out-of-field exposures will be averaged (with object rejection) and subtracted off the in-field exposures.

Name:	metis_lm_img_background
Purpose:	estimate and subtract background
Requirements:	METIS-6085 and METIS-6086
Type:	Calibration
Input data:	LM_SCI_BASIC_REDUCED
	LM_STD_BASIC_REDUCED
Matched keywords:	dither position (SKY?
Algorithm:	Average all or SKY exposures with object rejection
	Subtract background
Output data:	LM_SCI_BKG
	LM_STD_BKG
	LM_SCI_BKG_SUBTRACTED
	LM_STD_BKG_SUBTRACTED
	LM_SCI_OBJECT_CAT
	LM_STD_OBJECT_CAT
QC1 parameters:	QC LM IMG BKG MEDIAN
	QC LM IMG BKG MEDIAN DEVIATION
hdrl functions:	hdrl_imagelist_sub_image
	hdrl_imagelist_div_image

hdrl_catalogue_compute

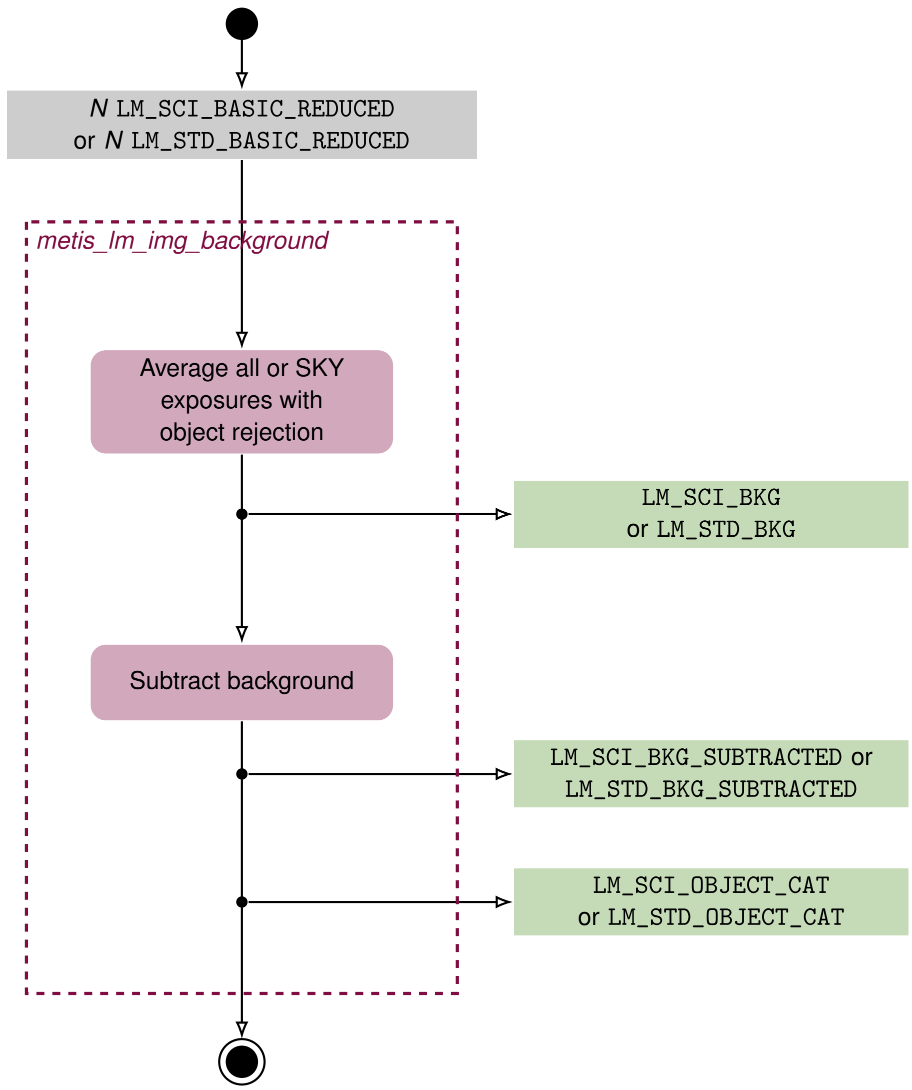


Figure 16: metis_lm_img_background – background estimation and subtraction of dithered IMG_LM data.

6.2.4 metis_lm_img_std_process: Photometric standard analysis

This recipe determines the conversion from ADU to physical units from a set of reduced exposures of a photometric standard star. The flux of the star is measured in each exposure in ADU, normalised to an exposure time of 1 second and averaged over all exposures. In addition, the exposures are stacked (after recentering on the standard star, but without derotation) and the flux is measured in the combined image. Comparison to the tabulated brightness of the star in the observing filter yields the conversion factor from ADU s^{-1} to photons $s^{-1} cm^{-2}$.

QC parameter will include estimates of the sensitivity for the detection of point sources and surface brightness sensitivity following [RD26].

Name:	metis_lm_img_std_process
Purpose:	Determine conversion factor between detector counts and physical source flux
Type:	Calibration
Input data:	LM_STD_BKG_SUBTRACTED
	FLUXSTD_CATALOG (photometric standard catalogue)
Matched keywords:	OBJECT ID
	FILTER ID
Parameters:	None
Algorithm:	Call lm_calculate_std_flux to measure flux in input images
	call hdrl_resample_compute to recenter the images
	call hdrl_imagelist_collapse to stack the images
	call lm_calculate_std_flux on the stacked image to get flux of the star in detector units
	call calculate_std_fluxcal to calculate the conversion factor to physical units
	call calculate_detection_limits to compute measure background noise (std,rms) and compute detection limits
Output data:	LM_STD_COMBINED
	FLUXCAL_TAB
Expected accuracies:	3% (cf. [RD24])
QC1 parameters:	QC LM IMG STD BACKGD RMS
	QC LM STD PEAK CNTS
	QC LM STD APERTURE CNTS
	QC LM STD STREHL

	QC LM STD FLUXCONV
	QC LM STD AIRMASS
	QC LM SENSITIVITY
	QC LM AREA SENSITIVIY
hdrl functions:	hdrl_strehl_compute
	hdrl_catalogue_compute
	hdrl_efficiency_compute
	hdrl_imagelist_collapse

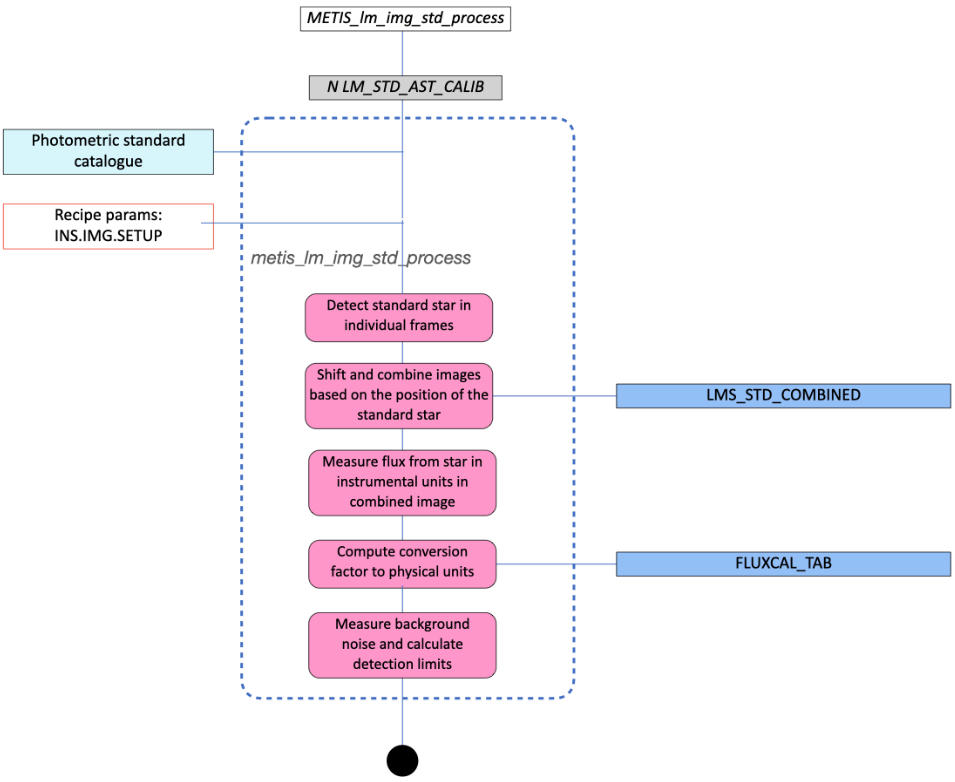


Figure 17: metis_lm_img_std_process – compute conversion between ADU and physical flux units

6.2.5 metis_lm_img_calibrate: Image calibration

This recipe applies the flux calibration to the reduced science images and adds geometric calibration data to the FITS header. The products of this recipe are fully calibrated individual exposures.

Each image is multiplied by the conversion factor such that pixel values are in units of photons per second per centimetre squared. The header of each file receives keyword BUNIT with value 'photon.s**(-1).cm**(-2)'.

LM-band imaging observations will be performed in pupil-tracking mode [AD2], which means that the field rotates from exposure to exposure. The information about the field orientation along with target coordinates, pixel scale and higher-order polynomial distortion coefficients is written to the FITS header. The images are not resampled by this recipe, this is left to metis_lm_img_sci_postprocess.

Name:	metis_lm_img_calibrate
Purpose:	Convert science images to physical units Add distortion information
Type:	Calibration
Templates	None
Input data:	LM_SCI_BKG_SUBTRACTED FLUXCAL_TAB LM_DISTORTION_TABLE
Matched keywords:	Filter ID
Parameters:	None
Algorithm:	call lm_scale_image_flux to Scale image data to ph/s add header information (BUNIT, WCS, etc.)
Output data:	LM_SCI_CALIBRATED
QC1 parameters:	None
hdrl functions:	hdrl_imagelist_mult_scalar

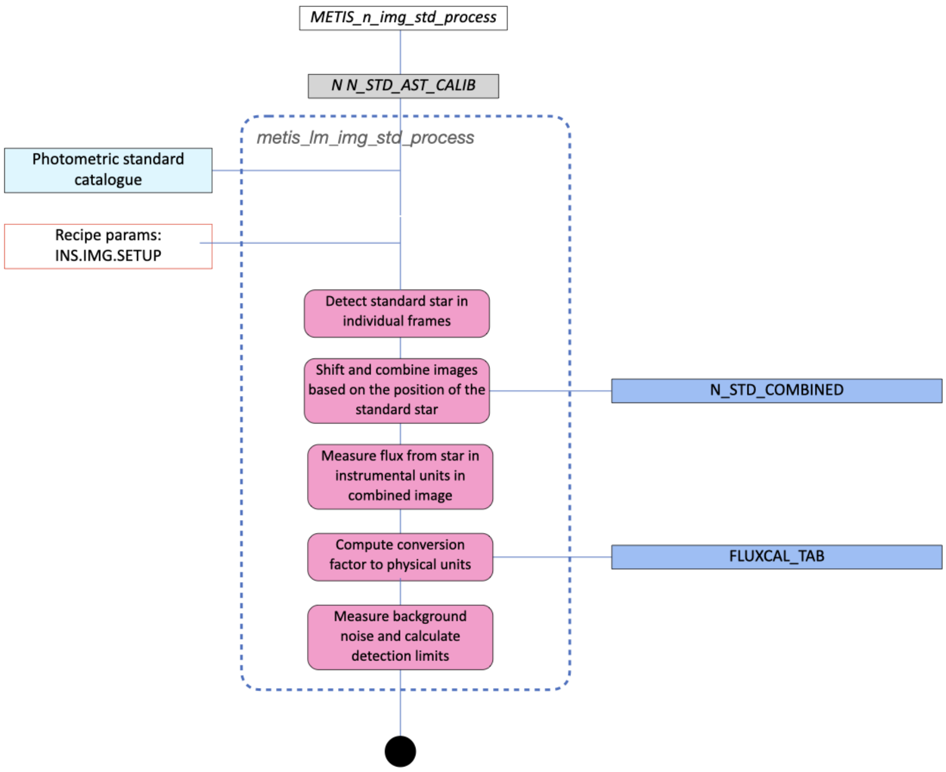


Figure 18: `metis_lm_img_calibrate` – Convert images to physical flux units and update FITS header

6.2.6 metis_lm_img_sci_postprocess: Image post-processing

This recipe coadds a sequence of flux-calibrated, background-subtracted images (possibly from several observing blocks) after resampling the images on a common pixel grid defined by a standard sky projection. The alignment of the images is done through by using the position of the WFS-FS mirror. The number of input images contributing to any pixel in the output image (variable due to offsets and bad pixels) will be documented in a contribution map.

This recipe will only be used in the science-grade pipelines, not at the observatory. The output fulfills the criteria for Science Data Product (SDP)s and is compliant with METIS-6104.

Name:	metis_lm_img_sci_postprocess
Purpose:	Coadd reduced images.
Requirements:	METIS-6104
Templates:	None
Type:	Science
Input data:	LM_SCI_CALIBRATED (Calibrated science images)
	BADPIX_MAP_2RG (Associated bad-pixel maps)
Parameters:	None
Algorithm:	Check and refine WCS of input images by using the WFS-FS data.
	Determine output pixel grid encompassing all input images.
	Call hdrl_resample_compute to recenter the images.
	Call hdrl_imagelist_collapse to stack the images.
Output data:	LM_SCI_COADD (coadded, mosaiced image)
Expected accuracies:	n/a
QC1 parameters:	QC LM SCI NEXPOSURE

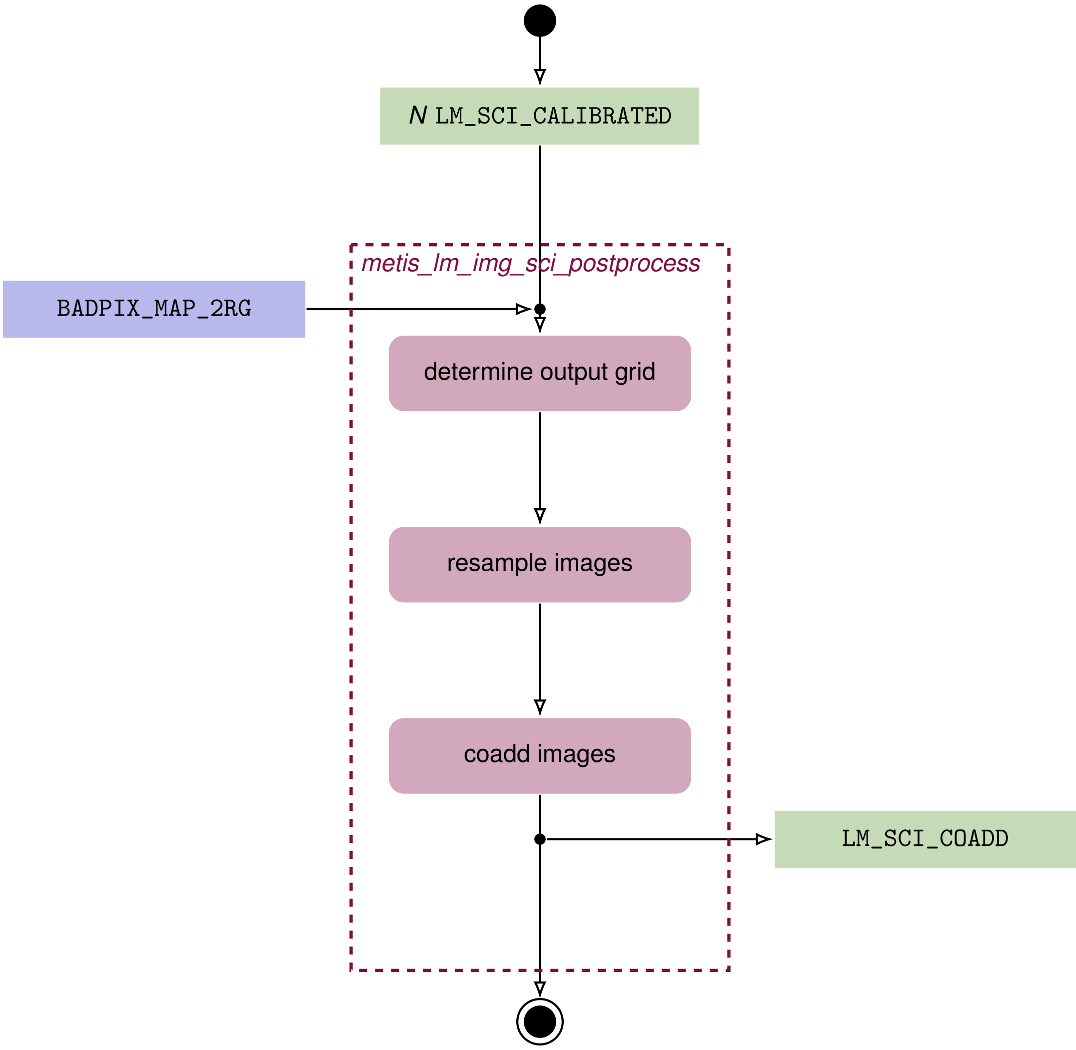


Figure 19: metis_lm_img_sci_postprocess – post-processing (coaddition) of reduced IMG_LM science frames.

6.2.7 metis_lm_img_distortion: Distortion calibration

Calibration of the imaging distortion is done on an image of a pin-hole grid mask located in the WCU. The distortion is described in terms of a polynomial model whose coefficients can be transformed to WCS keywords and applied to any other pipeline product. In addition to the distortion table, a map of pixel scale across the detector will be created.

Name:	metis_lm_img_distortion
Purpose:	Determine optical distortion coefficients for the LM imager.
Requirements:	METIS-6087
Templates:	METIS_img_lm_cal_distortion
Type:	Calibration
Input data:	LM_DISTORTION_RAW (Images of grid mask in WCU-FP2 or CFO-FP2.)
	LM_WCU_OFF_RAW
	PINHOLE_TABLE (Grid of pinhole mask positions)
	BADPIX_MAP_2RG
Parameters:	Parameters for fitting routine
Algorithm:	Subtract background image. (hdrl_imagelist_sub_image)
	Measure location of point source images in frames (hdrl_catalogue_create)
	call fit_distortion to fit polynomial coefficients to deviations from grid positions.
Output data:	LM_DISTORTION_TABLE
	LM_DISTORTION_MAP
	LM_DIST_REDUCED
Expected accuracies:	10^{-3} (cf. [RD24])
QC1 parameters:	QC LM DISTORT RMS
	QC LM DISTORT NSOURCE
hdrl functions:	hdrl_catalogue_create
	hdrl_imagelist_sub_image

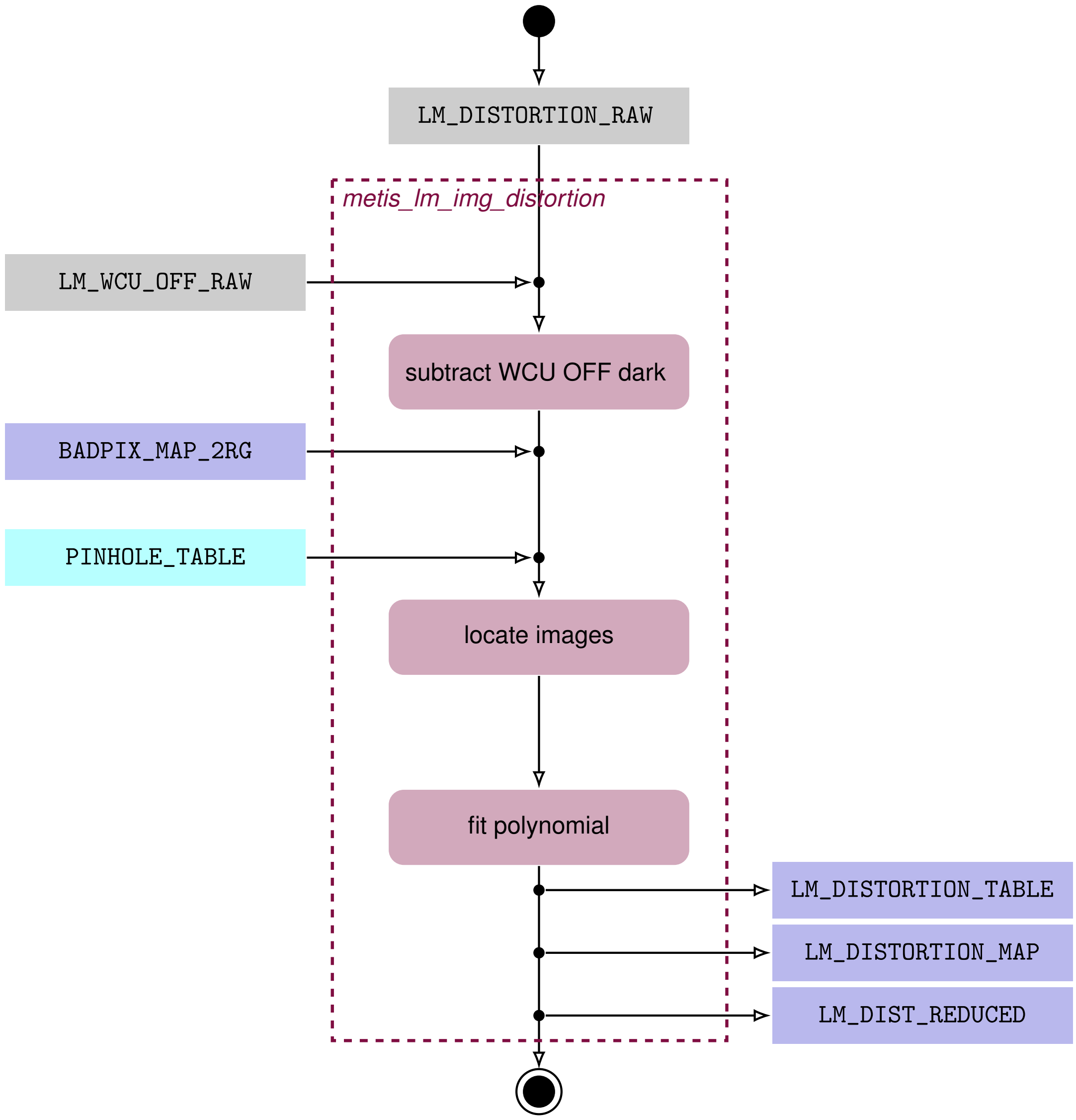


Figure 20: `metis_lm_img_distortion` – LM IMG distortion calibration

6.3 N-band imaging recipes

6.3.1 metis_n_img_flat: Flatfielding

The purpose of the flat-field calibration is to determine pixel-to-pixel gain variations and large scale illumination variations (due to inhomogeneities of optical elements in the telescope or instrument). Calibration frames are obtained either during day time using the black-body lamp of the WCU (internal flats) or by taken images of the twilight sky (twilight flats). Advantages and disadvantages of the two types of flat are discussed in [RD6].

MIR detectors are typically unstable in that they show gain fluctuations on rather short time scales, hence science exposures may have a different flat-field structure from those captured by the calibration flats. The GeoSnap detector is more linear than the H2RG detectors, but should be flat-fielded anyway. N-band flat fields will also be taken for quality control and monitoring purposes.

Since the operational concept for twilight flats needs to be refined during commissioning at the telescope, the current recipe design is primarily valid for internal flats.

This recipe creates a master flat for the GeoSnap detector (N-band imaging) from lamp or sky images matched by various setup parameters as detailed below. A set of internal flats includes a number of exposures with `LAMP OFF`, which will be used for dark subtraction. For twilight flats a master dark will be subtracted. The master flat is obtained by the slope of a linear fit of the pixel values against the illumination level of the exposures.

The quality control parameters give various statistics for each input frame (mean, standard deviation, etc.), the standard deviation of the normalised master flat and the number of bad pixels identified by the recipe. If a bad-pixel map is provided on input, it is updated, otherwise a new one is created.

Name:	metis_n_img_flat
Purpose:	Create master flat field for the N-band imaging detector.
Requirements:	METIS-6098
Type:	Calibration
Templates:	METIS_img_n_cal_InternalFlat
	METIS_img_n_cal_TwilightFlat
Input data:	N_FLAT_LAMP_RAW or N_FLAT_TWILIGHT_RAW
	MASTER_DARK_GEO (for twilight flats)
	BADPIX_MAP_GEO
Matched keywords:	Detector ID
	Filter ID
	ADC ID

	Flat type (internal or twilight)
Parameters:	Combination method (mean, median, sigclip, ...)
	Parameters for combination methods
	Threshold(s) for deviant-pixel identification
Algorithm:	Call metis_apply_persistence_correction to apply the persistence correction
	For internal flats: call metis_det_dark with LAMP OFF images to create dark frame.
	Subtract internal dark or master dark from flat exposures.
	call metis_n_img_flat to fit slope of pixel values against illumination level. Frames with the same exposure time will be averaged.
	Compute median or average of input frames to improve statistics.
	Call metis_update_n_flat_mask to flag deviant pixels.
Output data:	MASTER_IMG_FLAT_LAMP_N or MASTER_IMG_FLAT_TWILIGHT_N
	BADPIX_MAP_GEO
Expected accuracies:	0.5% (cf. [RD24])
QC1 parameters:	QC N MASTERFLAT RMS
	QC N MASTERFLAT NBADPIX
	QC N FLAT MEAN ##
	QC N FLAT RMS ##
hdrl functions:	hdrl_bpm_fit_compute
	hdrl_imagelist_collapse
	hdrl_imagelist_sub_image

6.3.2 metis_n_img_chopnod: Chop-nod combination

This recipe combines a set of exposures taken at all positions of a defined chop-nod pattern and adds/subtracts them into a single chop/nod difference image. Depending on the actual chop-nod pattern, this image will contain one or more positive and negative beams.

The GeoSnap detectors will have a substantial number of bad pixels. The N-band observations therefore require extensive dithering to mitigated bad pixels. The master flat will have to be divided into the chop half-cycle images before the dither correction is applied.

This recipe analyses the masked detector regions for channel offset correction, crosstalk (see [RD25]) and removal of detector artefacts (electronic ghosts). The edges of the N-band detector will be behind a cold mask on all four sides.

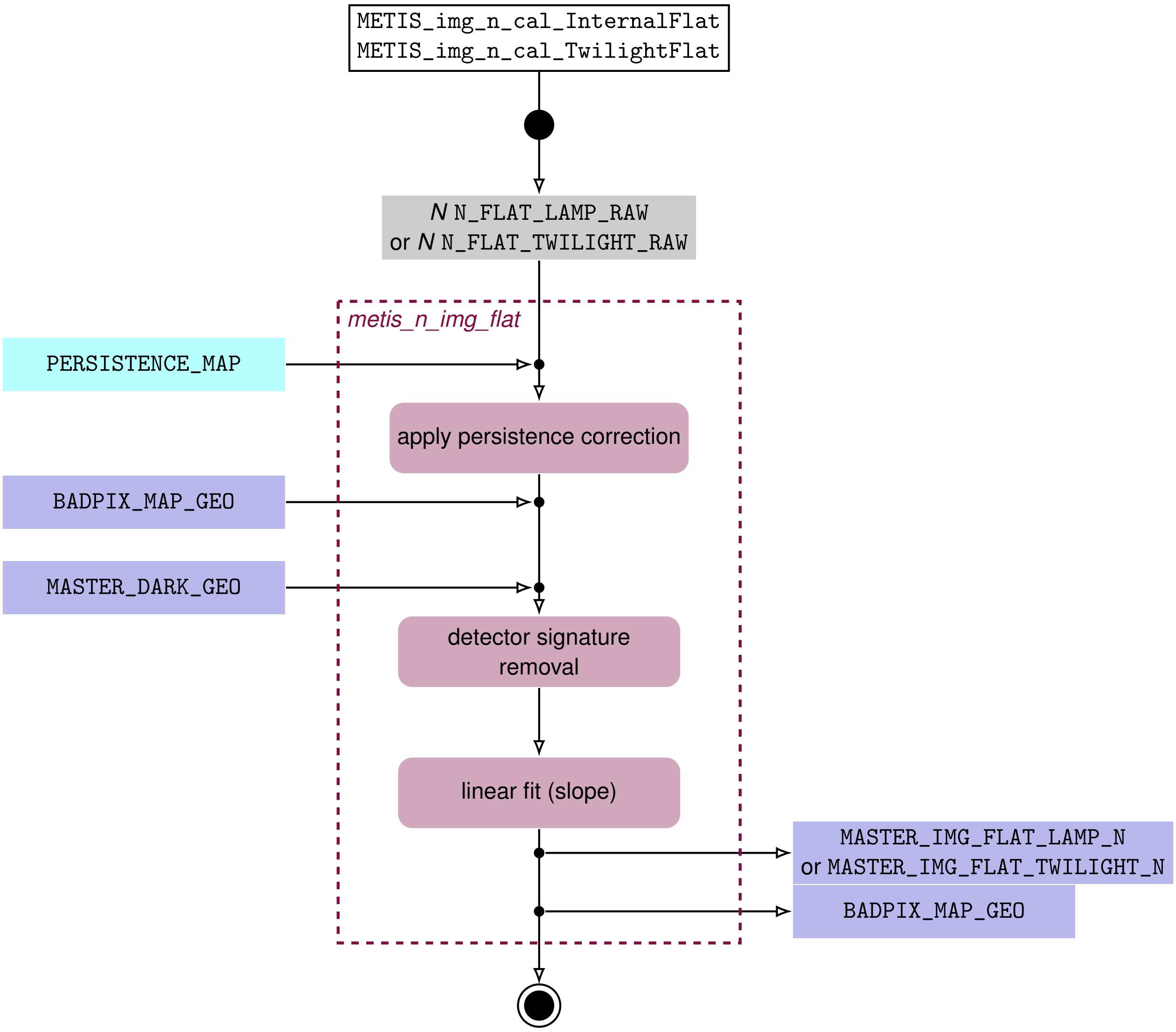


Figure 21: metis_n_img_flat – creation of IMG_N master flatfield

Name:	metis_n_img_chopnod
Purpose:	chop/nod combination of exposures for background subtraction
Requirements:	METIS-6089
Type:	Calibration, Science
Templates:	METIS_img_n_cal_standard METIS_img_n_obs_AutoChopNod METIS_img_n_obs_GenericChopNod METIS_img_n_cvc_obs_AutoChop METIS_img_n_cal_psf METIS_img_lmn_obs_AutoChopNod METIS_img_lmn_obs_GenericChopNod
Input data:	N_IMAGE_SCI_RAW (Chopped/nodded science or standard images) BADPIX_MAP_GEO Bad-pixel map MASTER_IMG_FLAT_LAMP_N or MASTER_IMG_FLAT_TWILIGHT_N
Matched keywords:	Filter ID Chop position Nod position
Parameters:	None
Algorithm:	Analyse and optionally remove masked regions and correct crosstalk and ghosts Add/subtract images to subtract background
Output data:	N_SCI_BKG_SUBTRACTED N_STD_BKG_SUBTRACTED
QC1 parameters:	N IMG PEAK CNTS
hdrl functions:	hdrl_imagelist_collapse

6.3.3 metis_n_img_std_process: Photometric standard analysis

This recipe determines the conversion from ADU to physical units from a chop-nod difference image of a photometric standard star. The flux of the standard star is measured in each of the beams of the chop-nod difference image, averaged and normalised to an exposure time of 1 second. Comparison to the tabulated brightness of the star in the observing filter yields the conversion factor from ADU s^{-1} to photons $s^{-1}\,cm^{-2}$.

QC parameters will include estimates of the sensitivity for the detection of point sources and surface brightness sensitivity following [RD26].

Name:	metis_n_img_std_process
Purpose:	Determine conversion factor between detector counts and physical source flux.
Type:	Calibration
Input data:	N_STD_BKG_SUBTRACTED
	FLUXSTD_CATALOG
Matched keywords:	Object ID
	Filter ID
Parameters:	None
Algorithm:	call n_calculate_std_flux to measure the flux in all beams
	average and normalize flux values
	call calculate_std_fluxcal to calculate conversion factor to physical units
	call calculate_detection_limits to compute measured background noise (std, rms) and compute detection limits
Output data:	FLUXCAL_TAB
Expected accuracies:	3% (cf. [RD24])
QC1 parameters:	QC N STD PEAK CNTS
	QC N STD APERTURE CNTS
	QC N STD STREHL
	QC N STD FLUXCONV
	QC N STD AIRMASS
	QC N SENSITIVITY
	QC N AREA SENSITIVITY
hdrl functions:	hdrl_catalogue_create
	hdrl_strehl_compute

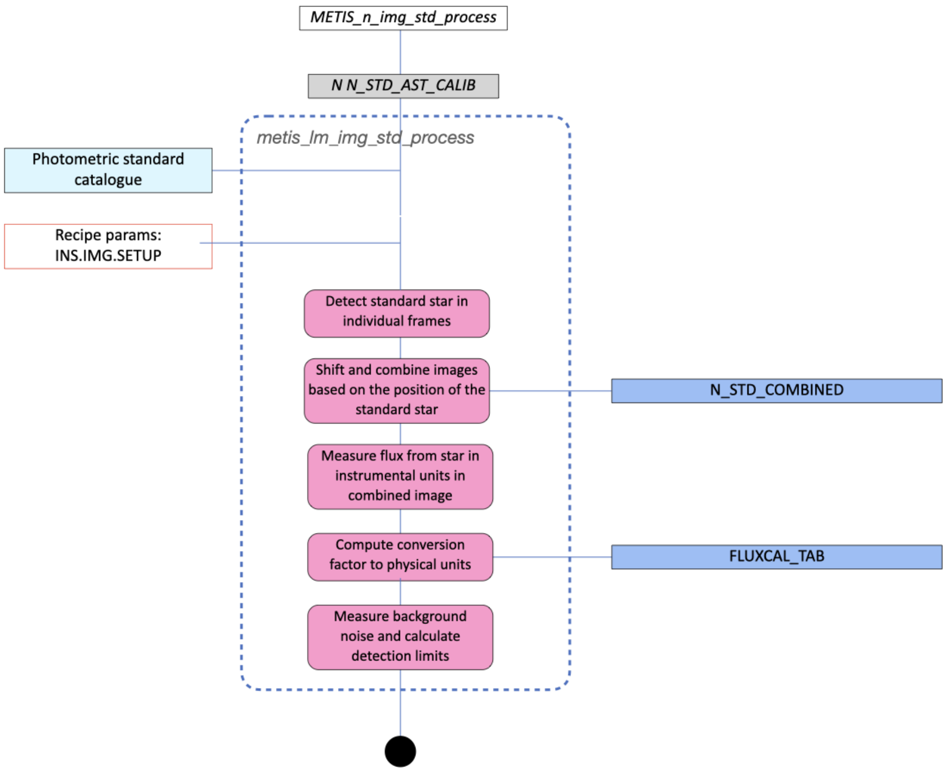


Figure 22: `metis_n_img_std_process` – compute conversion between ADU and physical flux units.

6.3.4 metis_n_img_calibrate: Image calibration

This recipe applies the flux calibration to the chop-nod difference image. A unique geometric calibration is not possible at this point, although one could take one of the beams (e.g. the positive beam in a parallel two-point chop-nod pattern) as reference for a WCS. Distortion information can be added without a reference point as it pertains to the detector/focal plane, not to the field.

The products of this recipe is the fully calibrated chop-nod difference image.

The image is multiplied by the conversion factor such that pixel values are in units of photons per second per centimetre squared. The header receives the keyword BUNIT with value 'photon.s**(-1).cm**(-2)'.

Name:	metis_n_img_calibrate
Purpose:	Convert science image to physical units
	Add distortion information
Type:	Calibration
Templates:	
Input data:	N_SCI_BKG_SUBTRACTED
	FLUXCAL_TAB
	N_DISTORTION_TABLE
Matched keywords:	Filter ID
Parameters:	None
Algorithm:	call n_scale_image_flux to Scale image data to ph/s
	add header information (BUNIT, etc.)
Output data:	N_SCI_CALIBRATED
QC1 parameters:	None

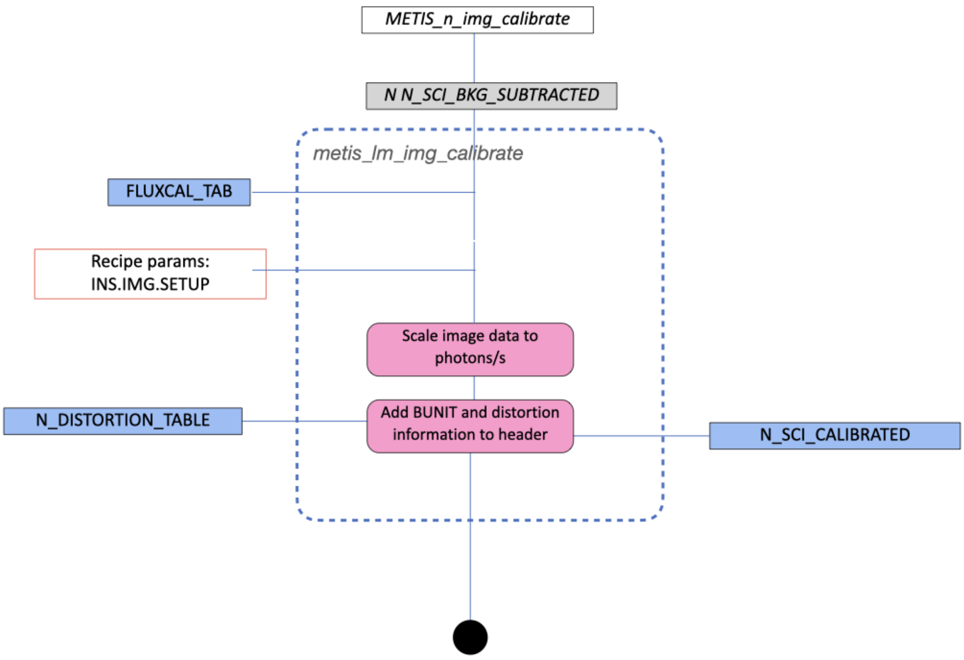


Figure 23: `metis_n_img_calibrate` – convert image to physical flux units and update FITS header

6.3.5 metis_n_img_restore: Image restoration

This recipe attempts to combine the positive and negative beams of the chop-nod difference image into a single positive image of the source. For compact sources with a size smaller than half the distance between the beams, it suffices to cut out small regions around the source images and add the with the appropriate signs to obtain a single image. Extended sources are beyond the scope of the pipeline.

Name:	metis_n_img_restore
Purpose:	Restore a single positive beam from chop-nod difference image
Type:	Science
Input data:	N_SCI_CALIBRATED
Parameters:	size of cutout region
Algorithm:	Call cutout_region to cut regions around beams Add regions with appropriate signs (hdrl_imagelist_collapse)
Output data:	N_SCI_RESTORED
QC1 parameters:	None
hdrl functions:	hdrl_imagelist_collapse

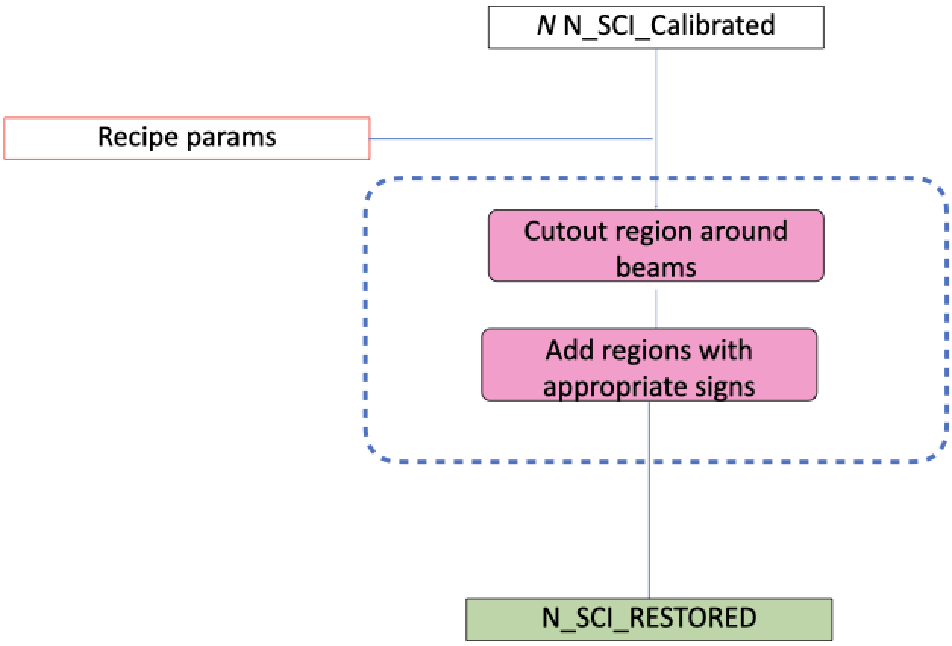


Figure 24: `metis_n_img_restore` – Create a single positive image from chop-nod difference image

6.3.6 metis_n_img_distortion: Distortion calibration

Calibration of the imaging distortion is done on an image of a pin hole mask located in a focal plane within the instrument. The distortion is described in terms of a polynomial model whose coefficients can be transformed to WCS keywords and applied to any other pipeline product. In addition to the distortion table, a map of pixel scale across the detector will be created.

Name:	metis_n_img_distortion
Purpose:	Determine optical distortion coefficients for the N imager.
Templates:	METIS_img_n_cal_distortion
Type:	Calibration
Input data:	N_DISTORTION_RAW (Images of grid mask in WCU-FP2 or CFO-FP2.)
	N_WCU_OFF_RAW
	PINHOLE_TABLE (Grid of pinhole mask positions)
	BADPIX_MAP_GEO
Parameters:	Parameters for fitting routine
Algorithm:	Subtract background image. (hdrl_imagelist_sub_image)
	Measure location of point source images in frames. (hdrl_catalogue_create)
	call fit_distortion to fit polynomial coefficients to deviations from grid positions.
Output data:	N_DISTORTION_TABLE
	N_DISTORTION_MAP
	N_DIST_REDUCED
Expected accuracies:	2×10^{-3} (cf. [RD24])
QC1 parameters:	QC N DISTORT RMS
	QC N DISTORT NSOURCE
hdrl functions:	hdrl_catalogue_create
	hdrl_imagelist_sub_image

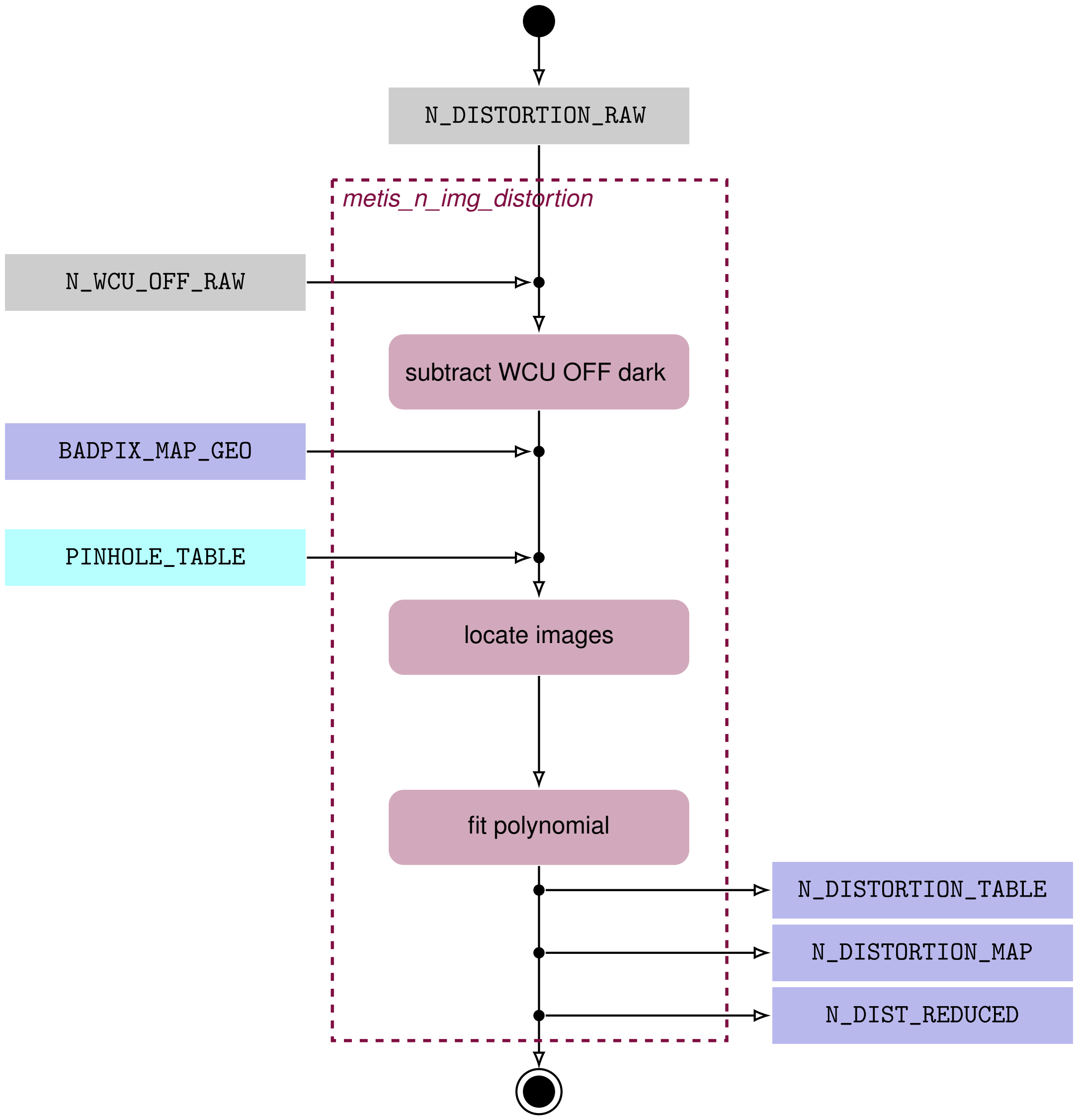


Figure 25: `metis_n_img_distortion` – `IMG_N` distortion calibration

6.4 LM-band long-slit spectroscopy recipes

A draft of the reduction cascade is shown in Figs. 5 and 6The first part aims to update the static calibration database, in particular the creation of the gain map (metis_det_lingain) and the determination of the ADC slitlosses (metis_lm_adc_slitloss). They are executed only when an update is required, e.g. after a major instrument intervention or on yearly basis. The second part comprises the basic calibrations, e.g. the dark correction and the spectroscopic flatfielding via RSRF, followed by the third part, the main calibration steps, incorporating the determination of the first guess wavelength solution by means of the laser sources in the WCU and the determination of the response curve for the flux calibration. Subsequently, the main reduction is conducted, which applies the previously created master calibration files to the science frames. Both, the standard star and the science observations are wavelength calibrated with the help of the atmospheric lines visible in the respective spectra. Therefore the main step of the wavelength calibration is carried out in the recipes metis_LM_lss_std and metis_LM_lss_sci. Finally, the telluric absorption correction is applied using the modelling approach with molecfit. Optionally, the telluric correction can be done with a telluric standard star.

Note that the list of QC parameters in the recipe descriptions will be extended whenever necessary.

6.4.1 metis_det_lingain and metis_det_dark: Linearity/Gain

These recipes aim for detector-specific calibrations and are therefore the same as in the imaging pipeline. Common detector calibrations are described in Section 6.1.

6.4.2 metis_LM_adc_slitloss: Slit loss determination

The recipe metis_LM_adc_slitloss aims to determine the slit losses induced by the fixed ADC positions as function of the object position across the slit. The recipe aims to create a table with slitlosses (LM_ADC_SLITLOSS), which is added to the static database and used in the recipes metis_LM_lss_std. This recipe is to be carried out only when an update of the database is needed. The algorithm and the workflow of the recipe to determine the slit-losses is given in Section 6.8.3, more information can be found in Section "Calibration of slit-losses" in the Calibration Plan [RD6].

6.4.3 metis_LM_lss_rsrf: Flatfielding

The recipe metis_LM_lss_rsrf aims to create a spectroscopic master flatfield for determining the pixel-to-pixel sensitivity and to enable the order location algorithm (metis_LM_lss_trace).

Name:	`metis_LM_lss_rsrf`
Purpose:	Spectroscopic flatfielding with RSRF
Type:	Calibration
Requirements:	METIS-6084, METIS-3291, METIS-9099
Templates:	`METIS_spec_lm_cal_rsrf`

Input data:	$N\times$ `LM_LSS_RSRF_RAW`
	`PERSISTENCE_MAP`
	`LINEARITY_2RG`
	`GAIN_MAP_2RG`
	`BADPIX_MAP_2RG`
	`MASTER_DARK_2RG`

Parameters:	exposure time, spectral setup (L or M band)
Algorithm:	subtract master WCU "OFF" frame from illumination frame (done on individual images) median/mean filtering of subtracted images division by blackbody spectrum normalisation to achieve RSRF
Output data:	`MASTER_LM_LSS_RSRF` (`PRO.CATG=MASTER_LM_LSS_RSRF`): master flatfield/RSRF `MEDIAN_LM_LSS_RSRF_IMG`: median map (QC) `MEAN_LM_LSS_RSRF_IMG`: mean map (QC)
Expected accuracies:	3% (cf. [RD6] and [RD24])
QC1 parameters:	`QC LM LSS RSRF MEAN LEVEL`: Mean level of the RSRF `QC LM LSS RSRF MEDIAN LEVEL`: Median level of the RSRF `QC LM LSS RSRF INTORDR LEVEL`: Flux level of the interorder background `QC LM LSS RSRF NORM STDEV`: Standard deviation of the normalised RSRF `QC LM LSS RSRF NORM SNR`: SNR of the normalised RSRF

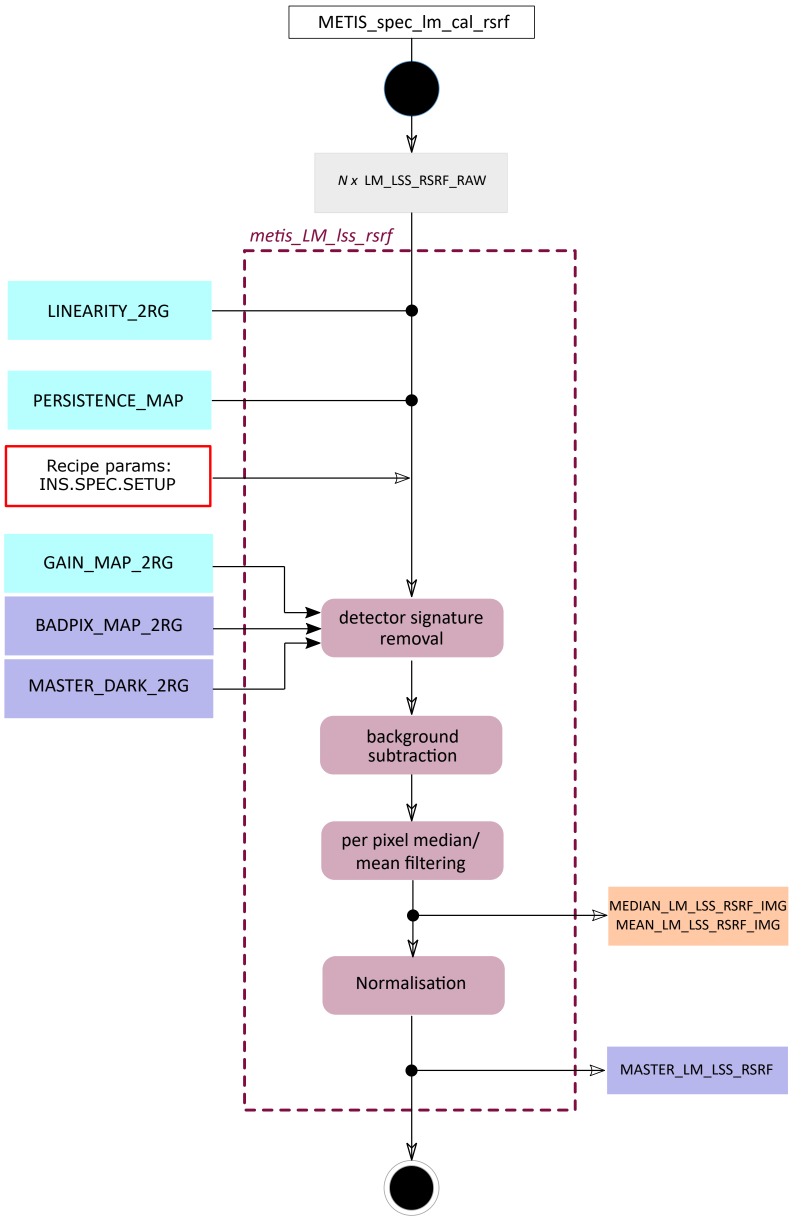


Figure 26: metis_LM_lss_rsrf – Recipe workflow to create the spectroscopic flatfield by means of the RSRF.

6.4.4 metis_LM_lss_trace: Order detection

The recipe metis_LM_lss_trace aims at detecting the order and a polynomial fitting of the order location (see [RD19] and [RD20] for details on the algorithms). The detection and polynomial fitting is based on flatfield frames taken through a pinhole mask, which leads to individual pinhole traces along the entire dispersion direction.

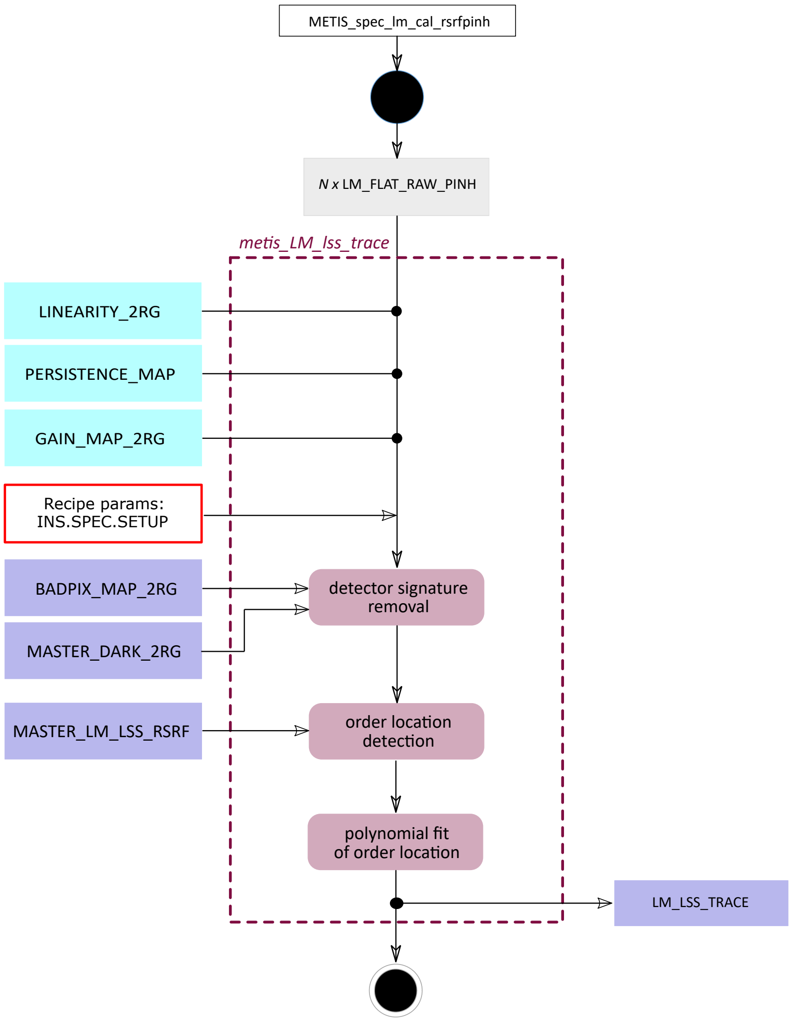


Figure 27: metis_LM_lss_trace – Detection and polynomial fitting of the order location.

Name:	metis_LM_lss_trace
Purpose:	Detection of order location
Type:	Calibration

Requirements:	None
Templates:	METIS_spec_lm_cal_rsrfpinh
Input data:	$N\times$ LM_LSS_RSRF_PINH_RAW PERSISTENCE_MAP LINEARITY_2RG GAIN_MAP_2RG BADPIX_MAP_2RG MASTER_DARK_2RG MASTER_LM_LSS_RSRF
Parameters:	exposure time, spectral setup (L or M band)
Algorithm:	Detection of the order edges Polynomial fitting
Output data:	LM_LSS_TRACE (PRO.CATG=LM_LSS_TRACE): order table
Expected accuracies:	1/10th of a pixel after post-processing (cf. [RD6], R-MET-106, METIS-167, METIS-1371)
QC1 parameters:	QC LM LSS TRACE LPOLYDEG: Degree of the polynomial fit of the left order edge QC LM LSS TRACE LCOEFF<i>: *i*-th coefficient of the polynomial of the left order edge QC LM LSS TRACE RPOLYDEG: Degree of the polynomial fit of the right order edge QC LM LSS TRACE RCOEFF<i>: *i*-th coefficient of the polynomial of the right order edge QC LM LSS TRACE INTORDR LEVEL: Flux level of the interorder background

6.4.5 metis_LM_lss_wave: Wavelength calibration

This recipe aims at determining the first guess of the wavelength calibration on basis of the WCU laser sources (c.f. [RD6]). Therefore the first steps are the removal of the detector signature of the LM_WAVE_RAW frames by applying the master calibration files derived in the previous steps, following by the background subtraction (if needed) and the application of the RSRF. The distortion of the lines (i.e. possible tilt, curvature,...) and the wavelength solution is determined by the algorithm developed by Piskunov et al. ([RD19], [RD20]). The reference frame is defined by the laser line catalogue (LASER_TAB).
This is in compliance with METIS-6074.
Remark: For the N-band there will be laser sources only at AIT available, from which we derive the first guess solution in the same way. Although this solution will eventually be put into the static calibration database, we need a recipe to process the N-band data. This will be done with this recipe.

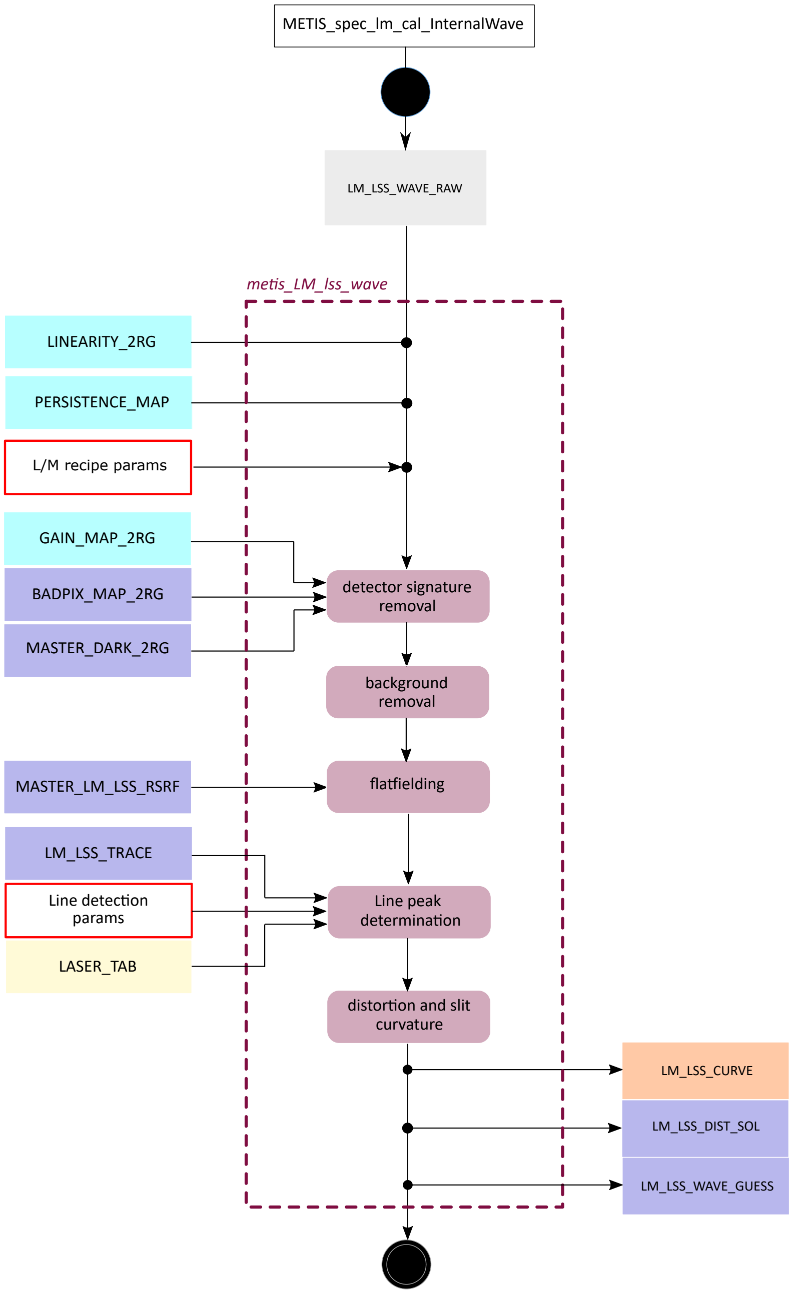


Figure 28: `metis_LM_lss_wave` – Creation of the LM LSS master wavelength correction.

Name:	metis_LM_lss_wave
Purpose:	Wavelength calibration
Type:	Calibration
Requirements:	METIS-6084, METIS-1371, METIS-6074
Templates:	METIS_spec_lm_cal_internalwave,
Input data:	LM_LSS_WAVE_RAW PERSISTENCE_MAP LINEARITY_2RG GAIN_MAP_2RG BADPIX_MAP_2RG MASTER_DARK_2RG MASTER_LM_LSS_RSRF LM_LSS_TRACE LASER_TAB
Parameters:	exposure time, spectral setup (L or M band)
Algorithm:	Application of detector master calibration files Determination and application of the distortion correction Determination of the first guess of the wavelength solution by polynomial fit of the detected laser source lines
Output data:	LM_LSS_CURVE (PRO.CATG=LM_LSS_CURVE): Curvature properties (QC) LM_LSS_DIST_SOL (PRO.CATG=LM_LSS_DIST_SOL): Distortion solution LM_LSS_WAVE_GUESS (PRO.CATG=LM_LSS_WAVE_GUESS): Wavelength first guess
Expected accuracies:	1/10th of a pixel after post-processing (cf. [RD6], R-MET-106, METIS-167, METIS-1371)
QC1 parameters:	QC LM LSS WAVE POLYDEG: Degree of the first guess polynomial QC LM LSS WAVE COEFF<i>: *i*-th coefficient of the polynomial QC LM LSS WAVE NLINES: Number of detected (laser) lines; should be constant QC LM LSS WAVE LINEFWHMAVG: Average of the Full Width Half Maximum (FWHM) of the detected lines (should be widely constant)

`QC LM LSS WAVE INTORDR LEVEL`: Flux level of the interorder background

6.4.6 metis_LM_lss_std: Standard star processing

This recipe aims at processing standard stars used for the absolute flux calibration and (optionally) for the telluric feature removal: As first step the detector master calibration files derived previously are applied followed by the background subtraction, if needed the distortion correction (LM_LSS_DIST_SOL), and the wavelength calibration by means of the first guess solution (LM_LSS_WAVE_GUESS) and the telluric sky lines (c.f. Sect. 8.5 in [AD1]). Then the recipe removes sky background, extracts the standard star spectrum object and collapses the 2D to 1D spectra. In case the STD is used only for the flux calibration, a telluric correction is required to better compare the corresponding model spectrum. This is done by means of the standard star observations itself or (optionally) with a synthetic transmission curve (either a standard curve derived by the ESO Skycalc Tool[17], a standard curve (LM_SYNTH_TRANS) or molecfit. It is on the user's decision whether the standard star is used for the absolute flux calibration only, or also used for the telluric correction of the science target. The response function is then calculated as ratio of the measured 1d-STD spectrum and a detailed model containing absolute flux information.

Please note that the procedure of the STD handling changes when the classical method for the telluric correction is chosen. The reason is that in the response function, also the telluric features of the STD star have to be present to be able to apply a combination of the telluric absorption removal and the conversion towards physical flux units (cf. Section 5.1). In the case of using molecfit, a telluric correction is applied to the STD spectrum to better determine the response function and only the response is delivered to the science recipes. In case of the classical approach with a STD, the response function will also contain the telluric features of the STD, and therefore a telluric correction beforehand is counterproductive.

[17] https://www.eso.org/observing/etc/bin/gen/form?INS.MODE=swspectr+INS.NAME=SKYCALC

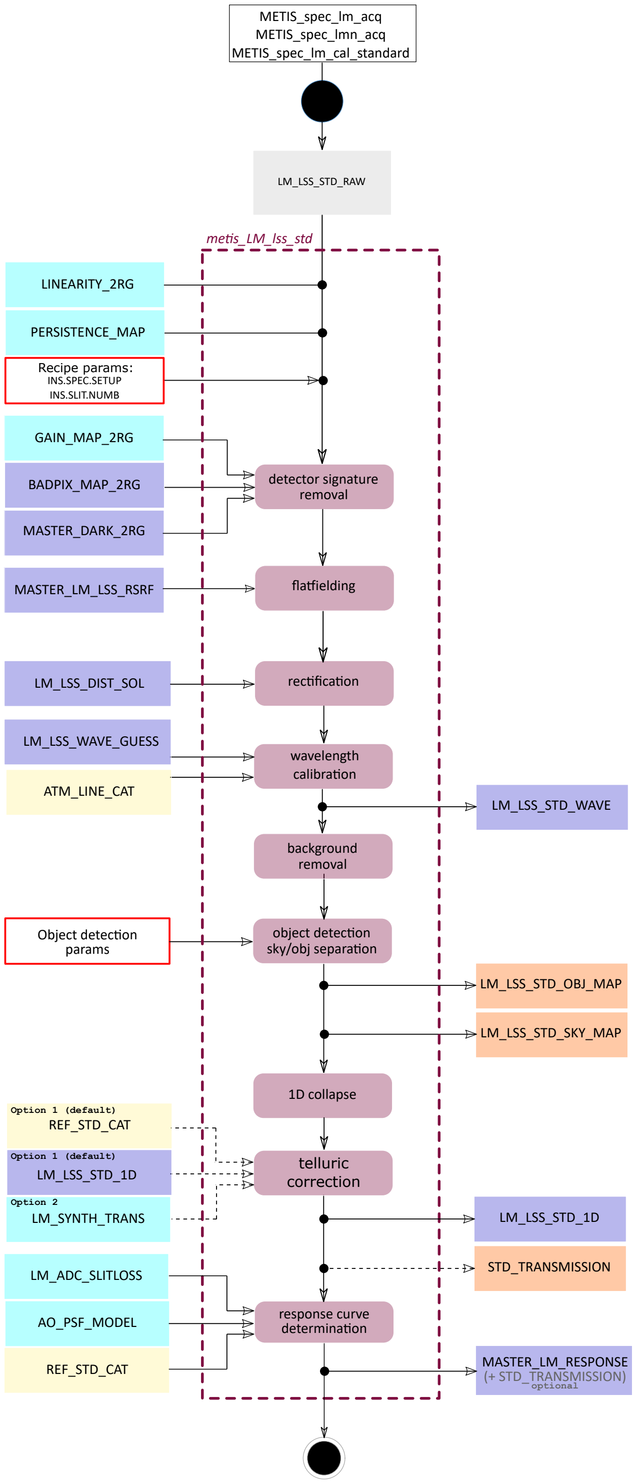


Figure 29: metis_LM_lss_std – Calibration recipe for processing standard stars for (combined) telluric and spectro-photometric calibration.

Name:	metis_LM_lss_std
Purpose:	Flux calibration
Type:	Calibration
Requirements:	METIS-6084, METIS-6074, METIS-2757
Templates:	METIS_spec_lm_acq, METIS_spec_lmn_acq, METIS_spec_lm_cal_standard METIS_spec_lmn_obs_AutoChopNodOnSlit
Input data:	LM_LSS_STD_RAW PERSISTENCE_MAP LINEARITY_2RG GAIN_MAP_2RG BADPIX_MAP_2RG MASTER_DARK_2RG MASTER_LM_LSS_RSRF LM_LSS_DIST_SOL LM_LSS_WAVE_GUESS AO_PSF_MODEL ATM_LINE_CAT LM_ADC_SLITLOSS LM_SYNTH_TRANS REF_STD_CAT
Parameters:	exposure time, spectral setup (L or M band), target information, nodding parameters
Algorithm:	Application of master calibration files Background removal Determination and application of the distortion correction Determination and application of the wavelength solution Identifying/separatiing sky/object pixels Removing sky lines: Creation and Subtraction of 2D sky Collapsing 2D to 1D spectrum, (see Fig. 30) Determination and application of response curve
Output data:	LM_LSS_STD_OBJ_MAP: Pixel map of object pixels (QC) LM_LSS_STD_SKY_MAP: Pixel map of sky pixels (QC)

	LM_LSS_STD_1D: coadded, wavelength calibrated, collapsed 1D spectrum
	LM_LSS_STD_WAVE: Wavelength solution derived from the STD star (optional)
	STD_TRANSMISSION: Transmission function derived by means of the STD (QC)
	MASTER_LM_RESPONSE: response function (optionally including the transmission)
Expected accuracies:	for wavelength: 1/10th of a pixel after post-processing
	(cf. [RD6], R-MET-106, METIS-167, METIS-1371)
	for flux: 10% over an atmospheric band
	$<$ 30% absolute line flux accuracy
	$<$ 5% absolute flux calibration
	(cf. [RD6], R-MET-107, R-MET-82)
QC1 parameters:	QC LM LSS STD BACKGD MEAN: Mean value of background
	QC LM LSS STD BACKGD MEDIAN: Median value of background
	QC LM LSS STD BACKGD STDEV: Standard deviation value of background
	QC LM LSS STD SNR: Signal-to-noise ration of flux standard star spectrum
	QC LM LSS STD NOISELEV: Noise level of flux standard star spectrum
	QC LM LSS STD FWHM: FWHM of flux standard spectrum
	QC LM LSS STD INTORDR LEVEL: Flux level of the interorder background
	QC LM LSS STD AVGLEVEL: Average level of the standard star flux
	QC LM LSS STD WAVECAL DEVMEAN: Mean deviation from the wavelength reference frame
	QC LM LSS STD WAVECAL FWHM: Measured FWHM of lines
	QC LM LSS STD WAVECAL NIDENT: Number of identified lines
	QC LM LSS STD WAVECAL NMATCH: Number of lines matched between catalogue and spectrum
	QC LM LSS STD WAVECAL POLYDEG: Degree of the polynomial

`QC LM LSS STD WAVECAL POLYCOEFF<n>`: *n*-th coefficient of the polynomial

`QC LM LSS STD SNR`: Signal-to-noise ration of flux standard star spectrum

`QC LM LSS STD NOISELEV`: Noise level of flux standard star spectrum

`QC LM LSS STD FWHM`: FWHM of flux standard spectrum

6.4.7 metis_LM_lss_sci: Science reduction

The science calibration recipe comprises the extraction of the object (i.e. separation of object/sky pixels), removing the sky lines, the application of the response curve previously defined, the 2D to 1D collapse and the co-addition. It also applies an absolute flux calibration (optionally with the telluric correction in one step, cf. Section 5.1).

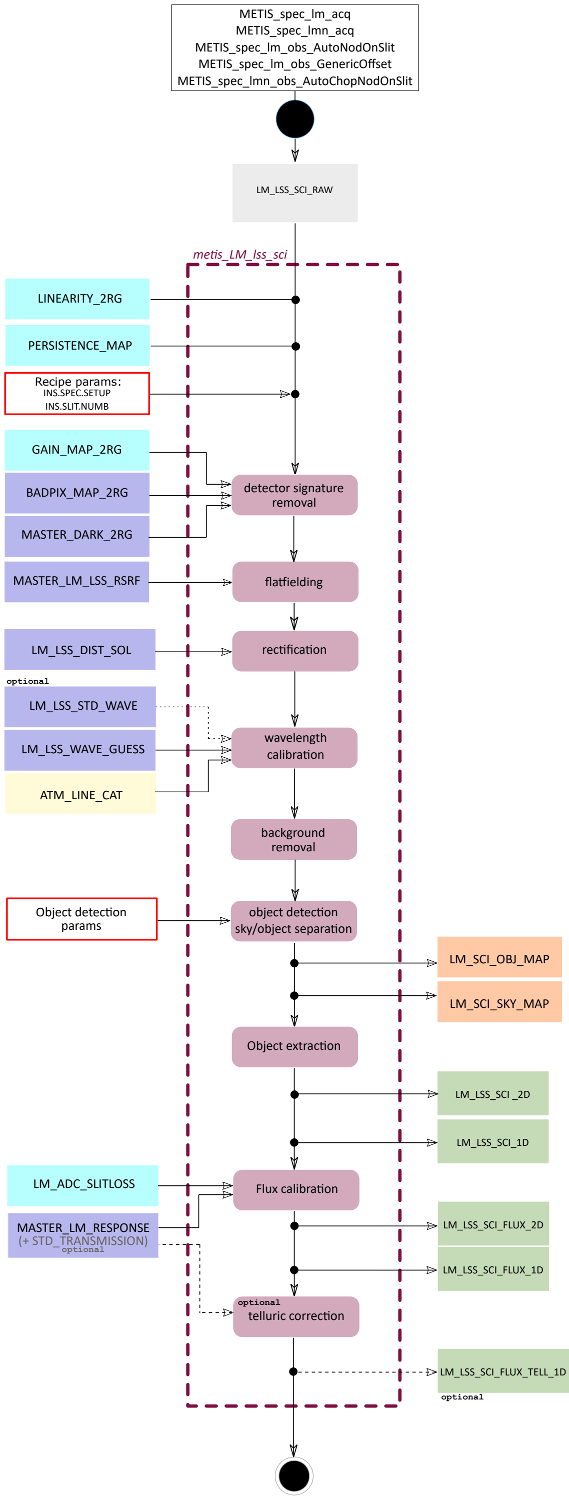


Figure 30: metis_LM_lss_sci – Science reduction recipe.

Name:	metis_LM_lss_sci
Purpose:	Science data calibration
Type:	Science reduction
Requirements:	METIS-6084
Templates:	METIS_spec_lm_acq, METIS_spec_lmn_acq, METIS_spec_lm_obs_AutoNodOnSlit, METIS_spec_lm_obs_GenericOffset METIS_spec_lmn_obs_AutoChopNodOnSlit
Input data:	LM_LSS_SCI_RAW PERSISTENCE_MAP LINEARITY_2RG GAIN_MAP_2RG BADPIX_MAP_2RG MASTER_DARK_2RG MASTER_LM_LSS_RSRF LM_LSS_DIST_SOL LM_LSS_WAVE_GUESS ATM_LINE_CAT LM_ADC_SLITLOSS STD_TRANSMISSION (optional) MASTER_LM_RESPONSE
Parameters:	exposure time, spectral setup (L or M band), target information, nodding parameters
Algorithm:	Application of the detector master calib files wavelength calibration Identifying/separating sky/object pixels Removing sky lines: Creation and Subtraction of 2D sky Coaddition of individual object spectra of one OB Collapsing 2D to 1D spectrum, (see Fig. 30) Application of the response function (flux calibration)
Output data:	LM_LSS_SCI_OBJ_MAP: Pixel map of object pixels (QC) LM_LSS_SCI_SKY_MAP: Pixel map of sky pixels (QC)

	LM_LSS_SCI_2D: coadded, wavelength calibrated 2D spectrum
	(PRO_CATG: LM_LSS_2d_coadd_wavecal)
	LM_LSS_SCI_1D: coadded, wavelength calibrated 1D spectrum
	(PRO_CATG: LM_LSS_1d_coadd_wavecal)
	LM_LSS_SCI_FLUX_2D: coadded, wavelength + flux calibrated 2D spectrum
	(PRO_CATG: LM_LSS_2d_coadd_wavecal)
	LM_LSS_SCI_FLUX_1D: coadded, wavelength + flux 1D spectrum
	(PRO_CATG: LM_LSS_1d_coadd_wavecal)
Expected accuracies:	for wavelength: 1/10th of a pixel after post-processing
	(cf. [RD6], R-MET-106, METIS-167, METIS-1371)
	for flux: 10% over an atmospheric band
	$<$ 30% absolute line flux accuracy
	$<$ 5% absolute flux calibration
	(cf. [RD6], R-MET-107, R-MET-82)
	for optional telluric correction: 10% within an atmospheric band); desired: 2% ([RD6])
QC1 parameters:	QC LM LSS SCI SNR: Signal-to-noise ration of science spectrum
	QC LM LSS SCI NOISELEV: Noise level of science spectrum
	QC LM LSS SCI FLUX SNR: Signal-to-noise ration of flux calibrated science spectrum
	QC LM LSS SCI FLUX NOISELEV: Noise level of flux calibrated science spectrum
	QC LM LSS SCI INTORDR LEVEL: Flux level of the interorder background
	QC LM LSS SCI WAVECAL DEVMEAN: Mean deviation from the wavelength reference frame
	QC LM LSS SCI WAVECAL FWHM: Measured FWHM of lines
	QC LM LSS SCI WAVECAL NIDENT: Number of identified lines
	QC LM LSS SCI WAVECAL NMATCH: Number of lines matched between catalogue and spectrum

`QC LM LSS SCI WAVECAL POLYDEG`: Degree of the wavelength polynomial

`QC LM LSS SCI WAVECAL POLYCOEFF<n>`: *n*-th coefficient of the polynomial

6.4.8 metis_LM_lss_mf_model: Telluric correction

The telluric correction will be done with the package molecfit[18]. It is realised in three individual recipes, metis_LM_lss_mf_model, which calculates the best-fit model, metis_LM_lss_mf_calctrans, which creates a synthetic transmission curve, and metis_LM_lss_mf_correct, which performs the actual telluric correction by means of the synthetic transmission.

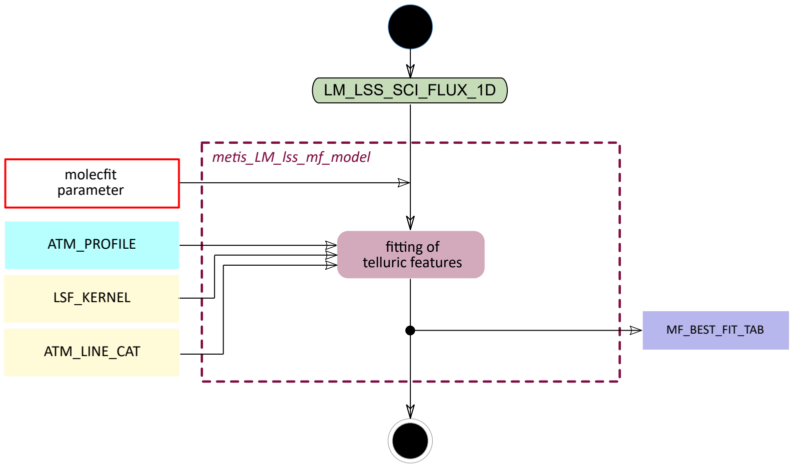


Figure 31: metis_LM_lss_mf_model – Recipe to achieve the best-fit for the calculation of the synthetic transmission curve for the telluric correction.

[18] https://www.eso.org/sci/software/pipelines/molecfit/molecfit-pipe-recipes.html

Name:	metis_LM_lss_mf_model
Purpose:	Achieve the best fit for modelling the transmission curve to be applied as telluric correction
Type:	Post-calibration
Requirements:	METIS-4051, METIS-6091
Templates:	None
Input data:	LM_LSS_SCI_FLUX_1D
	LSF_KERNEL
	ATM_PROFILE
	ATM_LINE_CAT
Parameters:	molecfit parameters (c.f. [RD16])
Algorithm:	Fit of telluric features visible in the science input spectrum
	Determination of best-fit parameter set
Output data:	MF_BEST_FIT_TAB: Table with best-fit parameters
Expected accuracies:	n/a
QC1 parameters:	cf. [RD16]

6.4.9 metis_LM_lss_mf_calctrans: Telluric correction

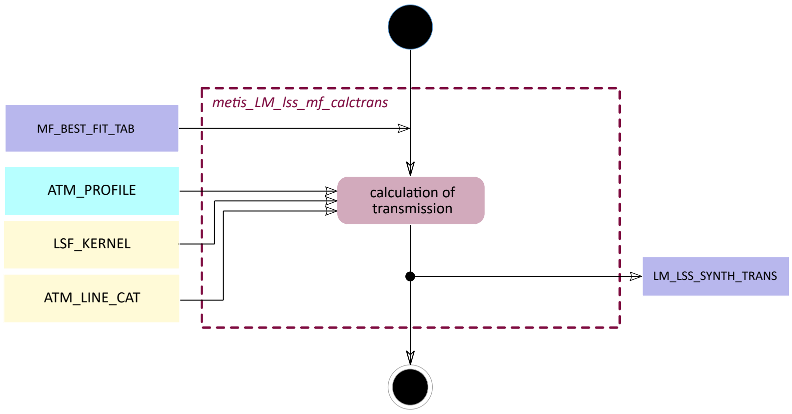


Figure 32: metis_LM_lss_mf_calctrans – Recipe to calculate the synthetic transmission to be applied as telluric correction.

Name:	metis_LM_lss_mf_calctrans
Purpose:	Calculation of the synthetic transmission
Type:	Post-calibration
Requirements:	METIS-4051, METIS-6091
Templates:	None
Input data:	MF_BEST_FIT_TAB: Table with best-fit parameters LSF_KERNEL ATM_PROFILE ATM_LINE_CAT
Parameters:	molecfit parameters (c.f. [RD16])
Algorithm:	Calculate the entire transmission curve by means of the best-fit parameters
Output data:	LM_LSS_SYNTH_TRANS: synth. transmission
Expected accuracies:	n/a
QC1 parameters:	cf. [RD16]

6.4.10 metis_LM_lss_mf_correct: Telluric correction

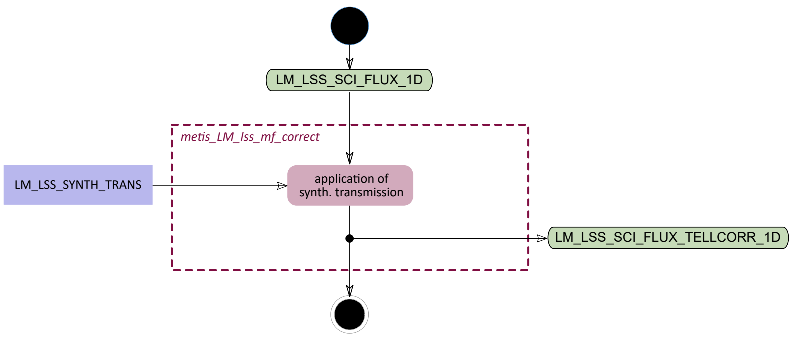


Figure 33: metis_LM_lss_mf_correct – Recipe to apply the telluric correction.

Name:	metis_LM_lss_mf_correct
Purpose:	Apply the synthetic transmission to the science spectra
Type:	Post-calibration
Requirements:	METIS-4051, METIS-6091
Templates:	None
Input data:	LM_LSS_SCI_FLUX_1D LM_LSS_SYNTH_TRANS
Parameters:	None
Algorithm:	Apply telluric correction, i.e. divide the input science spectrum by the synthetic transmission
Output data:	LM_LSS_SCI_FLUX_TELLCORR_1D
Expected accuracies:	Telluric removal must be good enough to reach the required spectro-photometric accuracy (10% within an atmospheric band). Desired: 2% ([RD6])
QC1 parameters:	cf. [RD16]

6.5 N-band long-slit spectroscopy recipes

A draft of the reduction cascade is shown in Figs. 7 and 8.The first part aims to update the static calibration database, in particular the creation of the gain map (metis_det_lingain) and the determination of the ADC slitlosses (metis_n_adc_slitloss). Both are executed only when an update is required, e.g. after a major instrument interention or on yearly basis. The second part comprises the basic calibrations, e.g. the dark correction and the spectroscopic flatfielding via RSRF, followed by the third part, the main calibration steps, incorporating the wavelength calibration (by means of atmospheric lines visible in the respective spectra and the first guess wavelength solution created during AIT) and the determination of the response curve for the flux calibration. Therefore the main step of the wavelength calibration is carried out in the recipes metis_N_lss_std and metis_LM_lss_sci. Finally, the telluric absorption correction is applied using the modelling approach with molecfit. These recipes aim for detector-specific calibrations and are therefore the same as in the imaging pipeline. Common detector calibrations are described in Section 6.1.
Note that the list of QC parameters in the recipe descriptions will be extended whenever necessary.

6.5.1 metis_det_lingain and metis_det_dark: Linearity/Gain

These recipes aim for detector-specific calibrations and are therefore the same as in the imaging pipeline. Common detector calibrations are described in Section 6.1.

6.5.2 metis_N_adc_slitloss: Slit loss determination

The recipe metis_n_adc_slitloss aims to determine the slit losses induced by atmospheric refraction. The recipe aims to create a table with slitlosses (N_ADC_SLITLOSS), which is added to the static database and used in the recipes metis_N_lss_std. This recipe is to be carried out only when an update of the database is needed. The algorithm and the workflow of the recipe to determine the slitlosses is given in Section 6.8.3, more information can be found in Section "Calibration of slit losses" in the Calibration Plan [RD6].

6.5.3 metis_N_lss_rsrf: Flatfielding

The recipe metis_N_lss_rsrf aims to create a spectroscopic master flatfield for determining the pixel-to-pixel sensitivity and to enable the order location algorithm (metis_N_lss_trace).

Name:	metis_N_lss_rsrf
Purpose:	Spectroscopic flatfielding with RSRF
Type:	Calibration

Requirements:	METIS-6084, METIS-3291, METIS-9099
Templates:	METIS_spec_n_cal_rsrf
Input data:	$N\times$ N_LSS_RSRF_RAW PERSISTENCE_MAP LINEARITY_GEO GAIN_MAP_GEO BADPIX_MAP_GEO MASTER_DARK_GEO
Parameters:	exposure time
Algorithm:	subtract master WCU "OFF" frame from illumination frame (done on individual images) median/mean filtering of subtracted images division by blackbody spectrum normalisation to achieve RSRF
Output data:	MASTER_N_LSS_RSRF (PRO.CATG=MASTER_N_LSS_TRSRF): master flatfield/RSRF MEDIAN_N_LSS_RSRF_IMG: median map (QC) MEAN_N_LSS_RSRF_IMG: mean map (QC)
Expected accuracies:	3% (cf. [RD6] and [RD24])
QC1 parameters:	QC N LSS RSRF MEAN LEVEL: Mean level of the RSRF QC N LSS RSRF MEDIAN LEVEL: Median level of the RSRF QC N LSS RSRF INTORDR LEVEL: Flux level of the interorder background QC N LSS RSRF NORM STDEV: Standard deviation of the normalised RSRF QC N LSS RSRF NORM SNR: SNR of the normalised RSRF

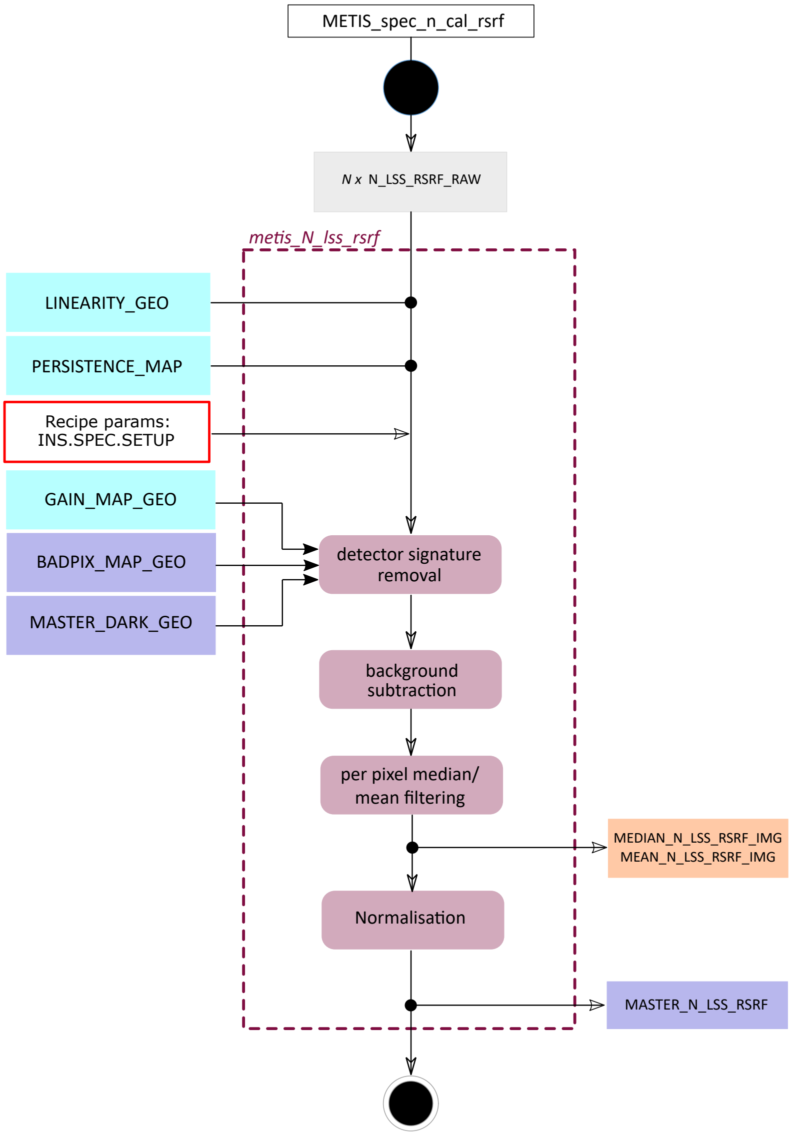


Figure 34: metis_N_lss_rsrf – Spectroscopic faltfielding with RSRF.

6.5.4 metis_N_lss_trace: Order detection

The recipe metis_N_lss_trace aims at detecting the order and a polynomial fitting of the order location (see [RD19] and [RD20] for details on the algorithms). The detection and polynomial fitting is based on flatfield frames taken through a pinhole mask, which leads to individual pinhole traces along the entire dispersion direction.

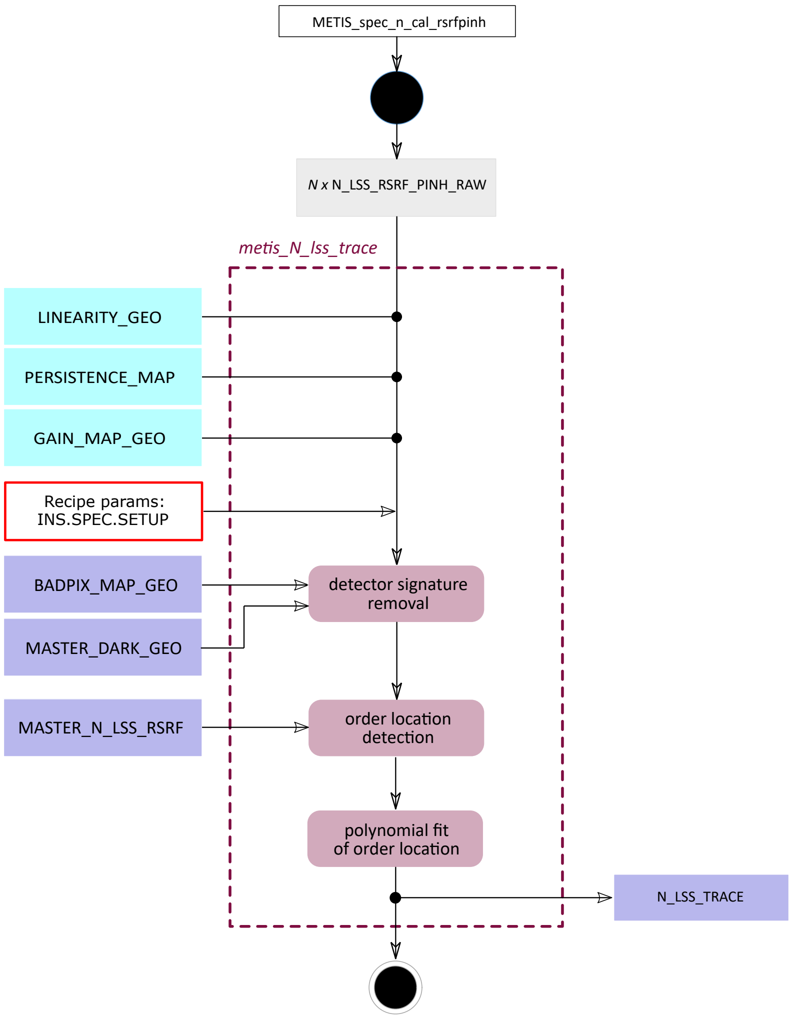


Figure 35: metis_N_lss_trace – Detection and polynomial fitting of the order location.

Name:	metis_N_lss_trace
Purpose:	Detection of order location
Type:	Calibration

Requirements:	None
Templates:	METIS_spec_n_cal_rsrfpinh
Input data:	$N\times$ N_LSS_RSRF_PINH_RAW
	PERSISTENCE_MAP
	LINEARITY_GEO
	GAIN_MAP_GEO
	BADPIX_MAP_GEO
	MASTER_DARK_GEO
	MASTER_N_LSS_RSRF
Parameters:	exposure time
Algorithm:	Detection of the order edges
	Polynomial fitting
Output data:	N_LSS_TRACE (PRO.CATG=N_LSS_TRACE): Polynomial coefficients
Expected accuracies:	1/10th of a pixel after post-processing
	(cf. [RD6], R-MET-106, METIS-167, METIS-1371)
QC1 parameters:	QC N LSS TRACE LPOLYDEG: Degree of the polynomial fit of the left order edge
	QC N LSS TRACE LCOEFF<i>: *i*-th coefficient of the polynomial of the left order edge
	QC N LSS TRACE RPOLYDEG: Degree of the polynomial fit of the right order edge
	QC N LSS TRACE RCOEFF<i>: *i*-th coefficient of the polynomial of the right order edge
	QC N LSS TRACE INTORDR LEVEL: Flux level of the interorder background

6.5.5 metis_N_lss_std: Standard star processing

This recipe aims at processing standard stars used for the absolute flux calibration and (optionally) for the telluric feature removal: As first step the detector master calibration files derived previously are applied followed by the background subtraction, if needed the distortion correction (N_LSS_DIST_SOL), and the wavelength calibration by means of the first guess solution (N_LSS_WAVE_GUESS) and the telluric sky lines (c.f. Sect. 8.5 in [AD1]). Then the recipe removes sky background, extracts the standard star spectrum object and collapses the 2D to 1D spectra. In case the STD is used only for the flux calibration, a telluric correction is required to better compare the corresponding model spectrum. This is done by means of the standard star observations itself or (optionally) with a synthetic transmission curve (either a standard curve derived by the ESO Skycalc Tool[19], a standard curve (N_SYNTH_TRANS) or `molecfit`. It is on the user's decision whether the standard star is used for the absolute flux calibration only, or also used for the telluric correction of the science target. The response function is then calculated as ratio of the measured 1d-STD spectrum and a detailed model containing absolute flux information.

Please note that the procedure of the STD handling changes when the classical method for the telluric correction is chosen. The reason is that in the response function, also the telluric features of the STD star have to be present to be able to apply a combination of the telluric absorption removal and the conversion towards physical flux units (cf. Section 5.1). In the case of using `molecfit`, a telluric correction is applied to the STD spectrum to better determine the response function and only the response is delivered to the science recipes. In case of the classical approach with a STD, the response function will also contain the telluric features of the STD, and therefore a telluric correction beforehand is counterproductive.

[19] https://www.eso.org/observing/etc/bin/gen/form?INS.MODE=swspectr+INS.NAME=SKYCALC

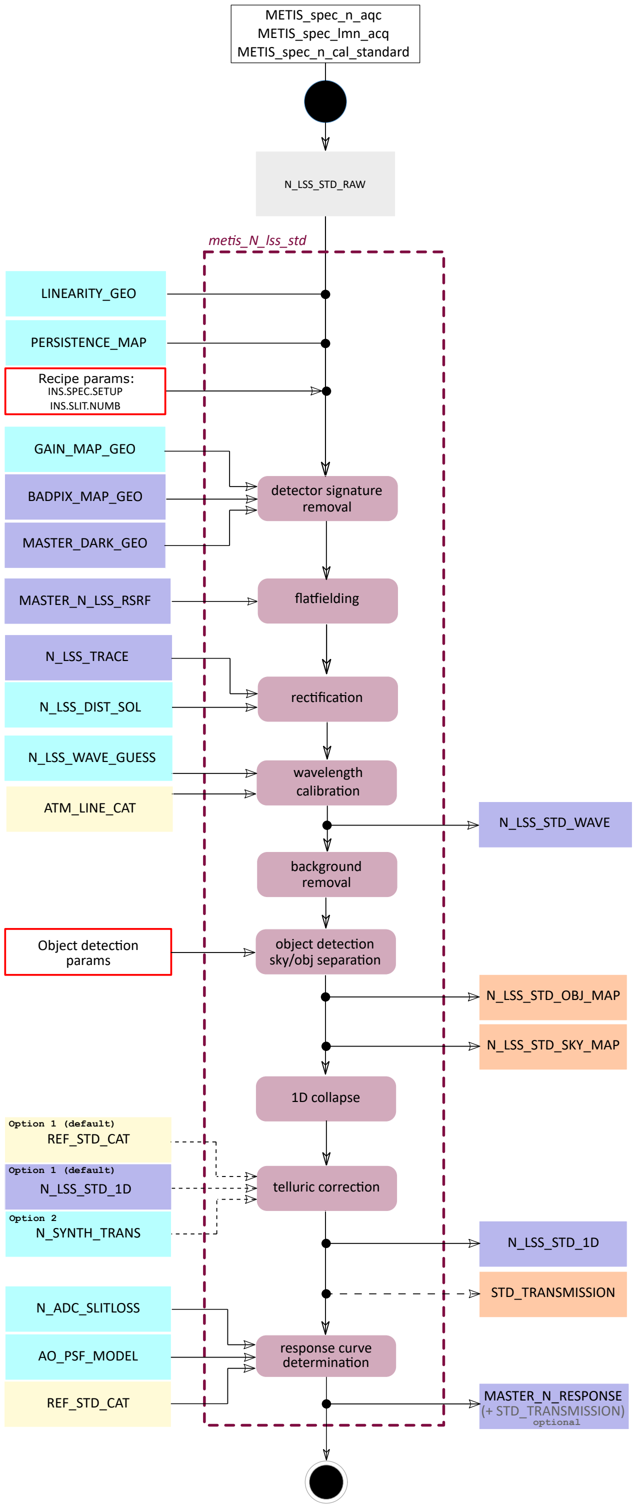


Figure 36: metis_N_lss_std – Standard star calibration recipe.

Name:	metis_N_lss_std
Purpose:	Flux calibration
Type:	Calibration
Requirements:	METIS-6084, METIS-6074, METIS-2757
Templates:	METIS_spec_n_acq, METIS_spec_lmn_acq, METIS_spec_N_cal_standard METIS_spec_lmn_obs_AutoChopNodOnSlit
Input data:	N_LSS_STD_RAW PERSISTENCE_MAP LINEARITY_GEO GAIN_MAP_GEO BADPIX_MAP_GEO MASTER_DARK_GEO MASTER_N_LSS_RSRF N_LSS_TRACE N_LSS_DIST_SOL N_LSS_WAVE_GUESS N_SYNTH_TRANS AO_PSF_MODEL ATM_LINE_CAT N_ADC_SLITLOSS REF_STD_CAT
Parameters:	exposure time, target information, nodding(/chopping parameters
Algorithm:	Application of master calibration files Determination and application of the wavelength solution Background removal Determination and application of the distortion correction Identifying/separatiing sky/object pixels Removing telluric lines Collapsing 2D to 1D spectrum, (see Fig. 37) Determination and application of response curve
Output data:	N_LSS_STD_OBJ_MAP: Pixel map of object pixels (QC)

	N_LSS_STD_SKY_MAP: Pixel map of sky pixels (QC)
	N_LSS_STD_1D : coadded, wavelength calibrated, collapsed 1D spectrum
	STD_TRANSMISSION: Transmission curve derived by menas of the STD star (QC)
	MASTER_N_RESPONSE: response function (optionally including the transmission)
Expected accuracies:	for wavelength: 1/10th of a pixel after post-processing
	(cf. [RD6], R-MET-106, METIS-167, METIS-1371)
	for flux: 10% over an atmospheric band
	$<$ 30% absolute line flux accuracy
	$<$ 5% absolute flux calibration
	(cf. [RD6], R-MET-107, R-MET-82)
QC1 parameters:	QC N LSS STD BACKGD MEAN: Mean value of background
	QC N LSS STD BACKGD MEDIAN: Median value of background
	QC N LSS STD BACKGD STDEV: Standard deviation value of background
	QC N LSS STD SNR: Signal-to-noise ration of flux standard star spectrum
	QC N LSS STD NOISELEV: Noise level of flux standard star spectrum
	QC N LSS STD FWHM: FWHM of flux standard spectrum
	QC N LSS STD INTORDR LEVEL: Flux level of the interorder background
	QC N LSS STD AVGLEVEL: Average level of the standard star flux
	QC N LSS STD WAVECAL DEVMEAN: Mean deviation from the wavelength reference frame
	QC N LSS STD WAVECAL FWHM: Measured FWHM of lines
	QC N LSS STD WAVECAL NIDENT: Number of identified lines
	QC N LSS STD WAVECAL NMATCH: Number of lines matched between catalogue and spectrum
	QC N LSS STD WAVECAL POLYDEG: Degree of the polynomial

QC N LSS STD WAVECAL POLYCOEFF<n>: *n*-th coefficient of the polynomial

QC N LSS STD SNR: Signal-to-noise ration of flux standard star spectrum

QC N LSS STD NOISELEV: Noise level of flux standard star spectrum

QC N LSS STD FWHM: FWHM of flux standard spectrum

6.5.6 metis_N_lss_sci: Science reduction

The science calibration recipe comprises the extraction of the object (i.e. separation of object/sky pixels), removing the sky lines, the application of the response curve previously defined, the 2D to 1D collapse and the co-addition. It also applies an absolute flux calibration (optionally with the telluric correction in one step, cf. Section 5.1).

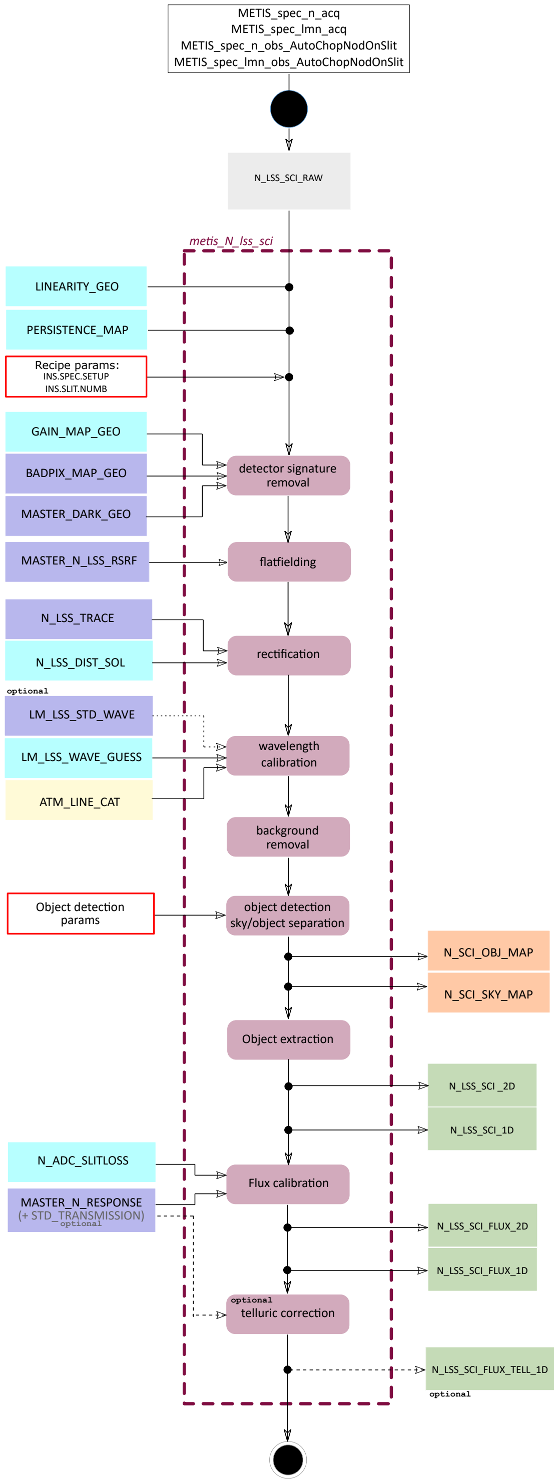


Figure 37: metis_N_lss_sci – Science reduction recipe.

Name:	metis_N_lss_sci
Purpose:	Science data calibration
Type:	Science reduction
Requirements:	METIS-6084
Templates:	METIS_spec_n_acq, METIS_spec_lmn_acq, METIS_spec_n_obs_AutoChopNodOnSlit, METIS_spec_lmn_obs_AutoChopNodOnSlit
Input data:	N_LSS_SCI_RAW PERSISTENCE_MAP LINEARITY_GEO GAIN_MAP_GEO BADPIX_MAP_GEO MASTER_DARK_GEO MASTER_N_LSS_RSRF N_LSS_TRACE N_LSS_DIST_SOL N_LSS_WAVE_GUESS ATM_LINE_CAT N_ADC_SLITLOSS MASTER_N_RESPONSE
Parameters:	exposure time, target information, nodding(/chopping parameters
Algorithm:	Application of the detector master calib files wavelength calibration Identifying/separatiing sky/object pixels Removing sky lines: Creation and Subtraction of 2D sky Coaddition of individual object spectra of one OB Collapsing 2D to 1D spectrum, (see Fig. 37) Application of the response function (flux calibration)
Output data:	N_LSS_SCI_OBJ_MAP: Pixel map of object pixels (QC) N_LSS_SCI_SKY_MAP: Pixel map of sky pixels (QC) N_LSS_SCI_2D: coadded, wavelength calibrated 2D spectrum

	(PRO_CATG: N_LSS_2d_coadd_wavecal) N_LSS_SCI_1D: coadded, wavelength calibrated 1D spectrum (PRO_CATG: N_LSS_1d_coadd_wavecal) N_LSS_SCI_FLUX_2D: coadded, wavelength calibrated 2D spectrum (PRO_CATG: N_LSS_2d_coadd_wavecal) N_LSS_SCI_FLUX_1D: coadded, wavelength 1D spectrum (PRO_CATG: N_LSS_1d_coadd_wavecal)
Expected accuracies:	for wavelength: 1/10th of a pixel after post-processing (cf. [RD6], R-MET-106, METIS-167, METIS-1371) for flux: 10% over an atmospheric band $<$ 30% absolute line flux accuracy $<$ 5% absolute flux calibration (cf. [RD6], R-MET-107, R-MET-82) for optional telluric correction: 10% within an atmospheric band); desired: 2% ([RD6])
QC1 parameters:	QC N LSS SCI SNR: Signal-to-noise ration of science spectrum QC N LSS SCI NOISELEV: Noise level of science spectrum QC N LSS SCI FLUX SNR: Signal-to-noise ration of flux calibrated science spectrum QC N LSS SCI FLUX NOISELEV: Noise level of flux calibrated science spectrum QC N LSS SCI INTORDR LEVEL: Flux level of the interorder background QC N LSS SCI WAVECAL DEVMEAN: Mean deviation from the wavelength reference frame QC N LSS SCI WAVECAL FWHM: Measured FWHM of lines QC N LSS SCI WAVECAL NIDENT: Number of identified lines QC N LSS SCI WAVECAL NMATCH: Number of lines matched between catalogue and spectrum QC N LSS SCI WAVECAL POLYDEG: Degree of the wavelength polynomial QC N LSS SCI WAVECAL POLYCOEFF<n>: n-th coefficient of the polynomial

6.5.7 metis_N_lss_mf_model: Telluric correction

The telluric correction will be done with the package molecfit[20]. It is realised in three individual recipes, metis_N_lss_mf_model, which calculates the best-fit model, metis_N_lss_mf_calctrans, which creates a synthetic transmission curve, and metis_N_lss_mf_correct, which performs the actual telluric correction by means of the synthetic transmission.

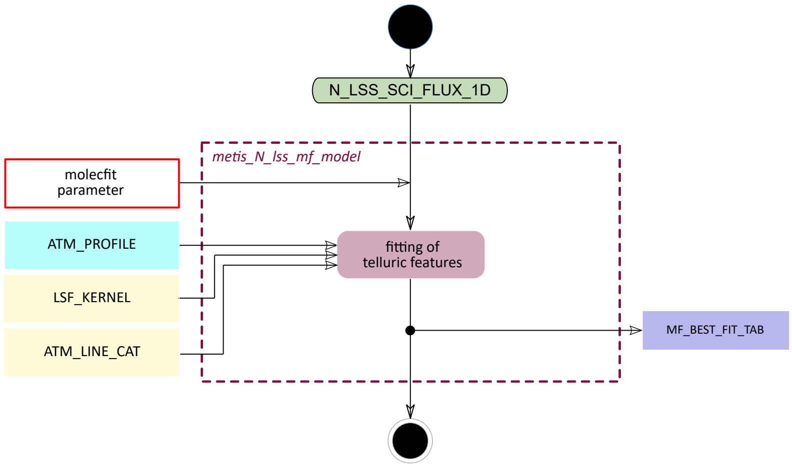


Figure 38: metis_N_lss_mf_model – Recipe to achieve the best-fit for the calculation of the synthetic transmission curve for the telluric correction.

[20] https://www.eso.org/sci/software/pipelines/molecfit/molecfit-pipe-recipes.html

Name:	metis_N_lss_mf_model
Purpose:	Achieve the best fit for modelling the transmission curve to be applied as telluric correction
Type:	Post-calibration
Requirements:	METIS-4051, METIS-6091
Templates:	None
Input data:	N_LSS_SCI_FLUX_1D
	LSF_KERNEL
	ATM_PROFILE
	ATM_LINE_CAT
Parameters:	molecfit parameters (c.f. [RD16])
Algorithm:	Fit of telluric features visible in the science input spectrum
	Determination of best-fit parameter set
Output data:	MF_BEST_FIT_TAB
Expected accuracies:	n/a
QC1 parameters:	cf. [RD16]

6.5.8 metis_N_lss_mf_calctrans: Telluric correction

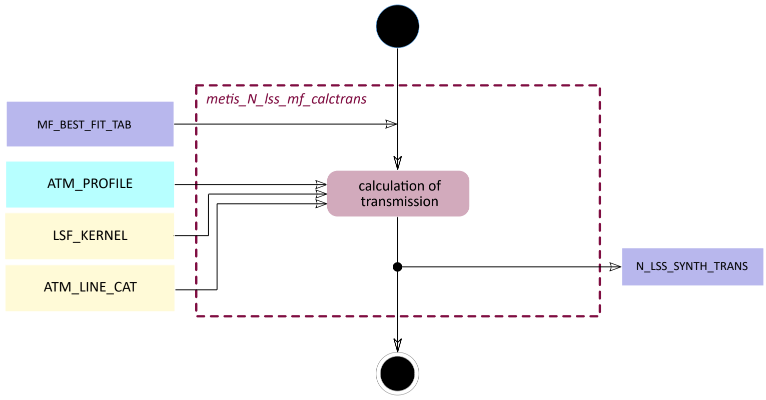


Figure 39: metis_N_lss_mf_calctrans – Recipe to calculate the synthetic transmission to be applied as telluric correction.

Name:	`metis_N_lss_mf_calctrans`
Purpose:	Calculation of the synthetic transmission
Type:	Post-calibration
Requirements:	METIS-4051, METIS-6091
Templates:	None

Input data:	`MF_BEST_FIT_TAB`
	`LSF_KERNEL`
	`ATM_PROFILE`
	`ATM_LINE_CAT`

Parameters:	`molecfit` parameters (c.f. [RD16])
Algorithm:	Calculate the entire transmission curve by means of the best-fit parameters
Output data:	`N_LSS_SYNTH_TRANS`
Expected accuracies:	n/a
QC1 parameters:	cf. [RD16]

6.5.9 metis_N_lss_mf_correct: Telluric correction

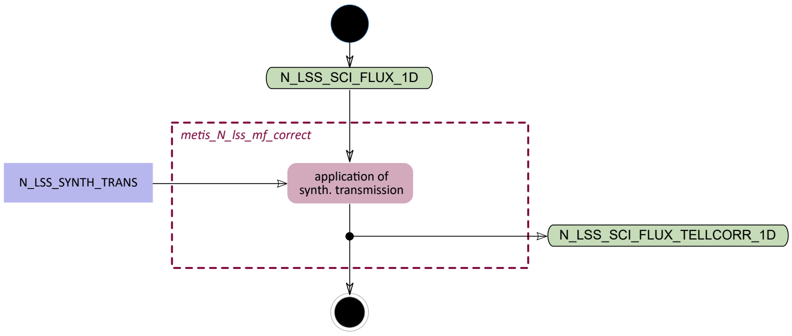


Figure 40: metis_N_lss_mf_correct – Recipe to apply the telluric correction.

Name:	metis_N_lss_mf_correct
Purpose:	Apply the synthetic transmission to the science spectra
Type:	Post-calibration
Requirements:	METIS-4051, METIS-6091
Templates:	None
Input data:	N_LSS_SCI_FLUX_1D N_LSS_SYNTH_TRANS
Parameters:	None
Algorithm:	Apply telluric correction, i.e. divide the input science spectrum by the synthetic transmission
Output data:	N_LSS_SCI_FLUX_TELLCORR_1D
Expected accuracies:	Telluric removal must be good enough to reach the required spectro-photometric accuracy (10% within an atmospheric band). Desired: 2% ([RD6])
QC1 parameters:	cf. [RD16]

6.6 LM integral-field spectroscopy (IFU) recipes

6.6.1 metis_ifu_wavecal: IFU wavelength calibration

This recipe processes daytime wavelength calibration images to derive the pixel-to-wavelength relation for the LM integral-field spectrograph.

The calibration template will use the lasers in the warm calibration unit to finely sample the desired wavelength range. The WCU has three lasers [RD6]: (1) a fixed laser at 3.39 µm, (2) the Quantum Cascade Laser (QCL), a laser tuneable from at least 4.68 µm to 4.78 µm), and (3) a fixed laser at 5.26 µm. The tuneable laser can be tuned so quickly during a long exposure with the long-slit spectrograph or the LMS such that a single exposure with multiple lines is created.

The image will consist of lines for each wavelength and slice. The solution will have to provide for each detector pixel (x, y) the slice number i, the spatial position ξ along the slice and the wavelength in the dispersion correction. As the slices and wavelength lines may be tilted with respect to the detector columns and rows, a combined solution is required

$$\xi = f_i(x, y) \tag{7}$$
$$\lambda = g_i(x, y) \tag{8}$$

The functions f_i and g_i are expected to be sufficiently accurately described by low-order polynomials.

In principle we know this relation from our optical models, but we expect small deviations ($\lesssim 1$ px) because e.g. the main dispersion grating mechanism in the LMS did not come back to exactly to the nominal position. We expect the offset from the optical model to be well represented either by a simple linear function or a low-order polynomial. The exact shape of the wavelength-to-pixel relation will be determined during AIT.

The wavelength range of the LM band is only partially covered by the lasers. The model will therefore be calibrated only on the part of the range covered by the lasers and subsequently interpolated to the whole image. This calibrated optical model is then used by the other recipes as a first guess for the wavelength solution.

The boundaries of the slice image on the detector are obtained by measuring the left and right edges of the wavelength lines. The slice number is then obtained by counting the slices according to the optical design of the spectrograph. The wavelength of each line is known from the settings of the QCL, the x coordinate is obtained by using the distortion table from metis_ifu_distortion

The recipe produces a multi-extension FITS file with an image extension mapping wavelength across each detector in the array. A table extension holds the polynomial coefficients.

Name:	metis_ifu_wavecal

Purpose:	Determine pixel-to-wavelength transformation.
Requirements:	METIS-6074, METIS-10300
Type:	Calibration
Templates:	`METIS_ifu_cal_InternalWave`

Input data:	`IFU_WAVE_RAW`
	`MASTER_DARK_IFU`
	`BADPIX_MAP_IFU`
	`IFU_DISTORTION_TABLE`

Parameters:	None
Algorithm:	Measure line locations (left and right edges, centroid by Gaussian fit). Compute deviation from optical models. Compute wavelength solution $\xi(x,y,i)$, $\lambda(x,y,i)$. Compute wavelength map.
Output data:	`IFU_WAVECAL`
Expected accuracies:	1/5th of a pixel after post-processing (cf. [RD6], METIS-6074)

QC1 parameters:	`QC IFU WAVECAL RMS`
	`QC IFU WAVECAL NLINES`
	`QC IFU WAVECAL PEAK CNTS`
	`QC IFU WAVECAL LINE WIDTH`

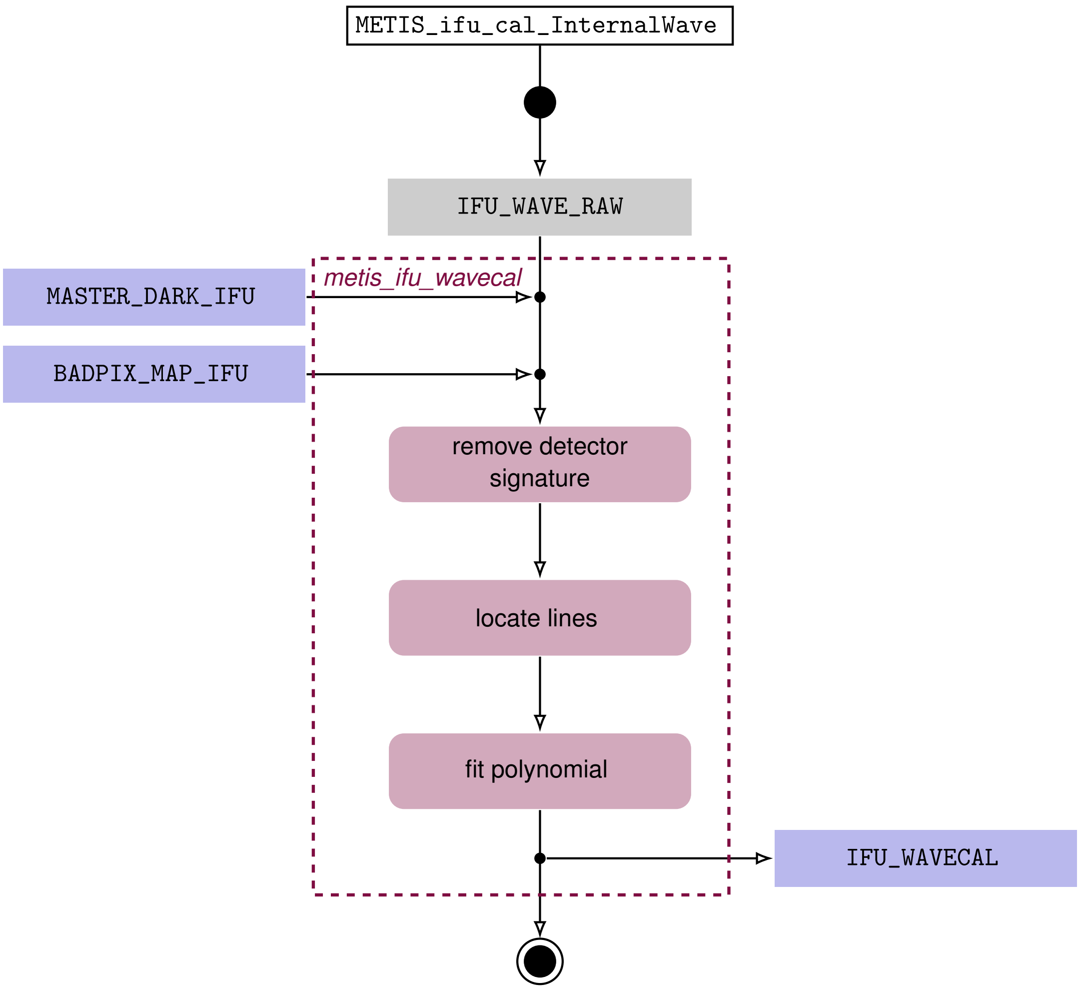


Figure 41: `metis_ifu_wavecal` – daytime wavelength calibration for the IFU.

6.6.2 metis_ifu_rsrf: IFU relative spectral response function

This recipe creates a spectroscopic master flat and determines the relative spectral response function (RSRF) for the four HAWAII2RG detectors of the LM spectrograph. The input data are obtained by illuminating the field of view with the black-body calibration lamp at two different temperatures. The RSRF is then determined by dividing the image by the known lamp continuum shape for the respective temperature. We refer to the two-dimensional image obtained by this division as MASTER_FLAT_IFU and the one-dimensional reponse function obtained by averaging at constant wavelength as RSRF. The bad pixel mask can be updated by identifying pixels that deviate strongly from their neighbours.

Name:	metis_ifu_rsrf
Purpose:	Create relative spectral response function for the IFU detector.
Requirements:	METIS-6131, METIS-6698
Type:	Calibration
Templates:	METIS_ifu_cal_rsrf
Input data:	IFU_RSRF_RAW (Raw flats taken with black-body calibration lamp.)
	MASTER_DARK_IFU
	BADPIX_MAP_IFU
	IFU_WAVECAL: image with wavelength at each pixel.
Parameters:	None
Algorithm:	Create continuum image by mapping Planck spectrum at T_{lamp} to wavelength image.
	Divide exposures by continuum image.
	Average exposures to yield master flat (2D RSRF).
	Average in spatial direction to obtain relative response function
Output data:	MASTER_FLAT_IFU
	RSRF_IFU
	BADPIX_MAP_IFU
Expected accuracies:	3% (METIS-6698)
QC1 parameters:	QC IFU RSRF NBADPIX

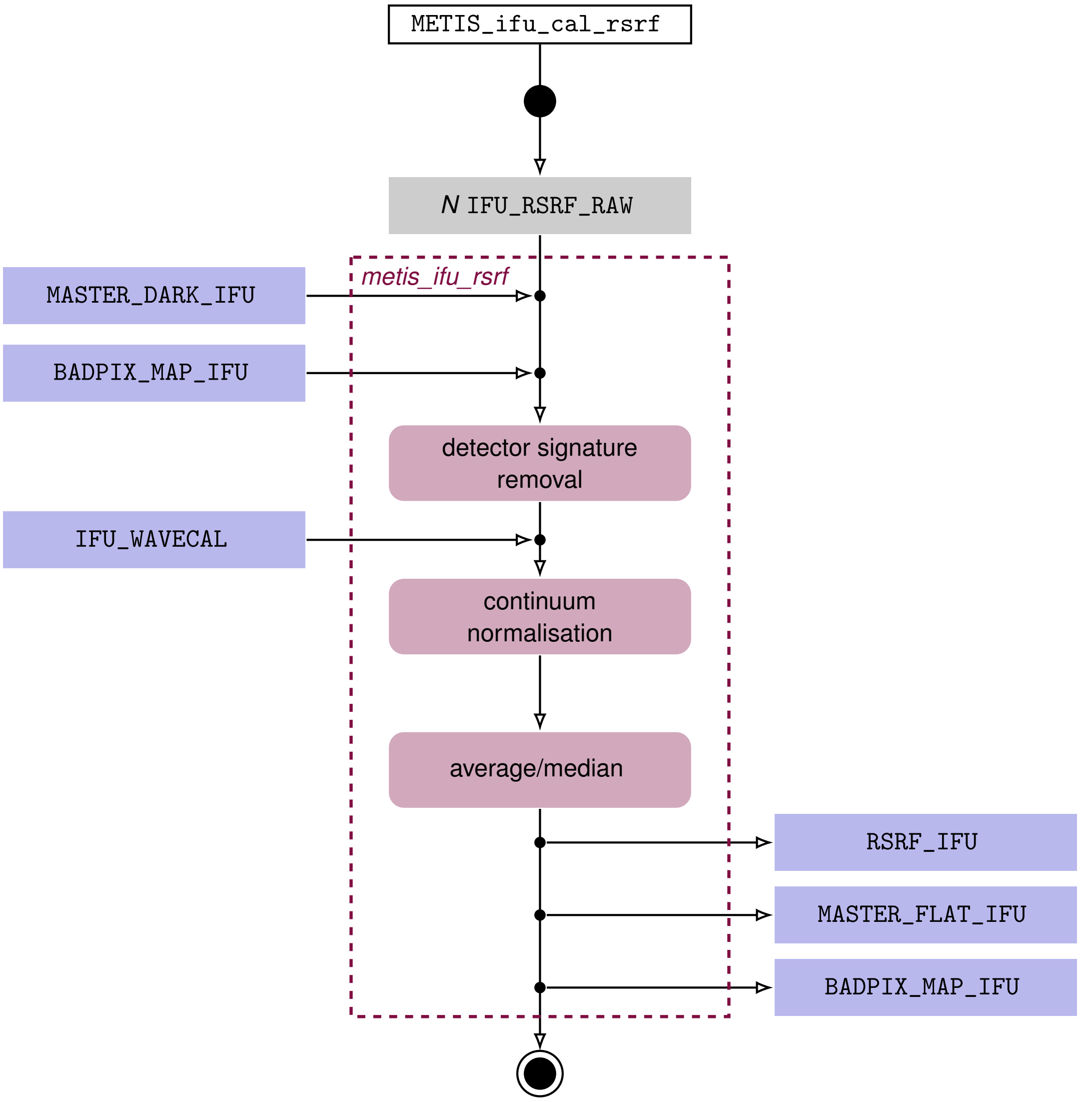


Figure 42: `metis_ifu_rsrf` – creation of IFU relative spectral response function.

6.6.3 metis_ifu_std_process: IFU flux standard reduction

This recipe reduces and analyses a series of IFU observations of a spectroscopic flux standard star. The comparison of the measured detector counts (ADU) with the tabulated spectrum of the star gives the wavelength-dependent conversion from ADU to physical units (photons per second per centimetre square per micron per arcsec square).

The level of stray light is estimated in the dark areas between the spectra and subtracted from the entire frame. The distribution of stray light across the field can only be characterised once the instrument is built. It is to be hoped that subtraction of a constant or a low-level 2D polynomial fit will be sufficient.

The sky and thermal background is estimated from blank sky observations (if obtained during the observing sequence) or by combining the (dithered) science frames.

The wavelength calibration is taken from the daylight calibration. It may be refined by measuring telluric emission and/or absorption lines (by fitting with `molecfit`).

Name:	metis_ifu_std_process
Purpose:	Determine conversion between detector counts and physical source flux.
Requirements:	METIS-6131
Type:	Calibration
Templates:	METIS_ifu_cal_standard
Input data:	IFU_STD_RAW (Raw spectra of flux standard star)
	MASTER_DARK_IFU
	RSRF_IFU (2D relative spectral response function)
	BADPIX_MAP_IFU
	IFU_WAVECAL
	IFU_DISTORTION_TABLE
Parameters:	None
Algorithm:	Subtract dark, divide by master flat
	Estimate stray light and subtract
	Estimate background and subtract
	Rectify spectra and assemble cube
	Extract 1D spectrum of star
	Compute and apply telluric correction
	Compute conversion to physical units as function of wavelength.

Output data:	IFU_STD_REDUCED_CUBE
	IFU_STD_BACKGROUND_CUBE
	IFU_STD_REDUCED_1D
	IFU_STD_TELLURIC_1D
	FLUXCAL_TAB
Expected accuracies:	$<5\%$ absolute flux calibration
QC1 parameters:	QC IFU STD STRAYLIGHT MEAN

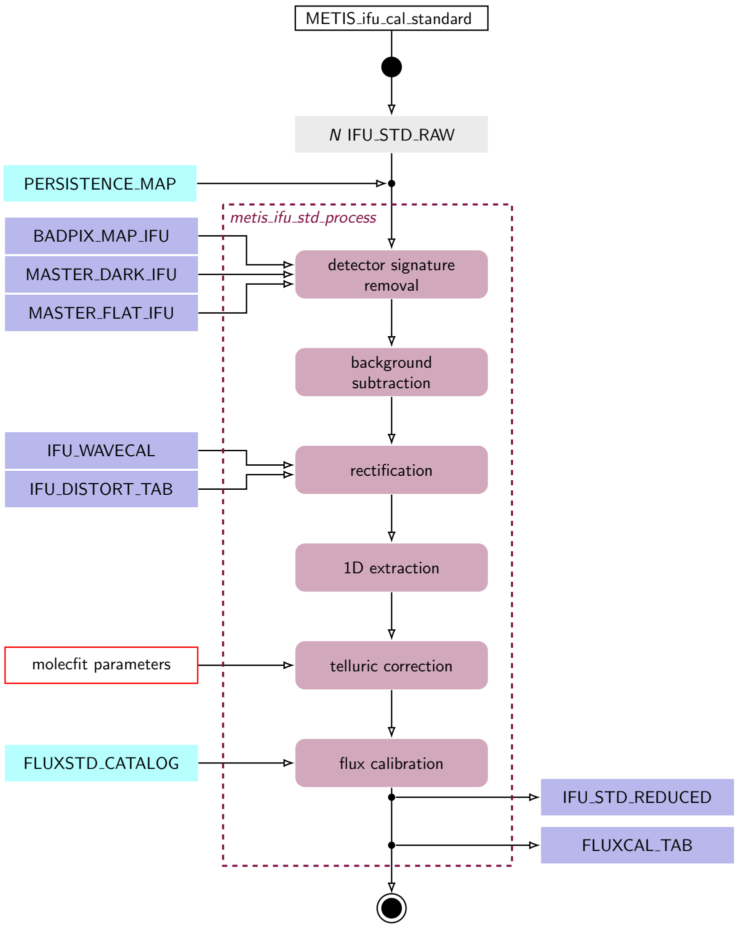


Figure 43: metis_ifu_std_process – reduction of IFU flux standard frames and flux calibration (not all data products are shown).

6.6.4 metis_ifu_sci_process: IFU science reduction

This recipe performs basic reduction of raw science exposures applying dark and RSRF correction and flux calibration (i.e. conversion of pixel values to physical units) on each exposure individually. The recipe will be able to process data from either the nominal or the extended wavelength mode. For the nominal mode, all slices belong to the same echelle order. For the extended mode, slices belonging to the same echelle order are grouped and processing is iterated over the echelle orders.

For the LM band detectors in the IFU, the pixels on the edges of the detectors will be masked with the following widths [RD25] (METIS-9141) (Fig. 44):

- 64 columns on each "outside" of the 2x2 detector array in the dispersion direction
- 0 columns on each "inside" of the 2x2 detector array in the dispersion direction
- 32 rows at the top and bottom of each of the 4 detectors.

Note: We define rows and columns in the H2RG detector as follow:

- A row is readout by 32 outputs
- A column is readout by 1 output

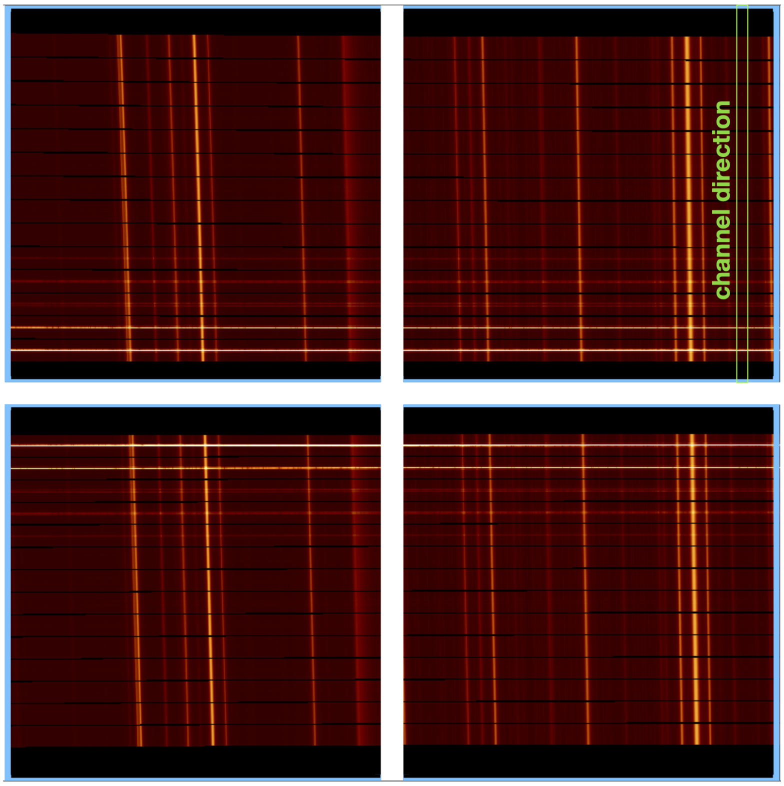


Figure 44: The IFU masking scheme. Masked regions are in light blue.

The level of stray light is estimated in the dark areas between the spectra and subtracted from the entire frame. The distribution of stray light across the field can only be characterised once the instrument is built. It is to be hoped that subtraction of a constant or a low-level 2D polynomial fit will be sufficient.

The sky and thermal background, as well as residual straylight, is estimated from blank sky observations if these are available in the sequence of input frames or by combining (dithered) science frames. The initial wavelength solution is taken from the daylight calibration. It may be checked and corrected by measuring atmospheric lines if a sufficient number is available in the limited wavelength range.

A telluric correction is determined by this recipe by automatically extracting a 1D spectrum from "object" pixels identified by a thresholding algorithm. `molecfit` is applied to this spectrum and the correction is mapped back to the reduced 2D images or 3D cubes using the wavelength images. In an interactive environment (Reflex workflow) the telluric correction may be improved by asking the user to define an extraction aperture adapted to the target structure.

The recipe produces the following (intermediate) data products:

- Reduced 2D detector images. These are accompanied by additional information describing the geometry of the slice layout, target position and wavelength calibration to the extent that the exposure can be combined with other exposures into a single rectified spectral cube. This information can be stored in the FITS header or a table extension.
- A rectified spectral cube for each exposure with a linear wavelength grid, constructed by resampling each spectral slice onto a spatial-wavelength grid common to all slices. The spatial pixels are rectangular with along-slit pixel scale given by the detector pixel scale and the across-slit pixel scale given by the slice width.
- A spectral cube obtained by combining all exposures taken within a template. This step involves the image reconstruction discussed in Sect. 8.9 of [AD1].

For the nominal mode, each output is a single-extension FITS file corresponding to one echelle order. For the extended mode, each of the echelle orders results in an extension in a multi-extension FITS file.

The recipe as described here is run in the science pipelines. For the observatory pipeline, a variant of the recipe may be implemented with reduced functionality and output. The observatory recipe may also have to include features to determine QC parameters for the LM-band images that are taken in parallel with the IFU exposures, similar to `metis_lm_img_basic_reduce`.

Name:	`metis_ifu_sci_process`
Purpose:	Reduction of individual science exposures.
Requirements:	METIS-6131, METIS-6309
Type:	Science

Templates:	METIS_ifu_obs_FixedSkyOffset METIS_ifu_obs_GenericOffset METIS_ifu_ext_obs_FixedSkyOffset METIS_ifu_ext_obs_GenericOffset METIS_ifu_vc_obs_FixedSkyOffset METIS_ifu_ext_vc_obs_FixedSkyOffset METIS_ifu_app_obs_Stare METIS_ifu_ext_app_obs_Stare METIS_ifu_cal_psf
Input data:	IFU_SCI_RAW (Dithered science exposures.) IFU_SKY_RAW (Blank sky images, if available.) MASTER_DARK_IFU RSRF_IFU (2D relative spectral response function) BADPIX_MAP_IFU IFU_WAVECAL FLUXCAL_TAB (Flux calibration table) IFU_DISTORTION_TABLE LSF_KERNEL (Line spread kernel to be used with molecfit)
Parameters:	telluric correction (yes/no)
Algorithm:	Subtract dark, divide by master flat Analyse and optionally remove masked regions and correct crosstalk and ghosts Estimate stray light and subtract Estimate background from dithered science exposures or blank-sky exposures and subtract. Apply flux calibration. Rectify spectra and assemble cube Extract 1D object spectrum Compute telluric correction and apply to reduced images and cube
Output data:	IFU_SCI_REDUCED (2D, per exposure) IFU_SCI_REDUCED_TAC (2D, per exposure) IFU_SCI_BACKGROUND (2D, per exposure) IFU_SCI_REDUCED_CUBE (3D, per exposure) IFU_SCI_REDUCED_CUBE_TAC (3D, per exposure)

	IFU_SCI_COMBINED (3D)
	IFU_SCI_COMBINED_TAC (3D)
	IFU_SCI_OBJECT_1D (1D)
	IFU_SCI_TELLURIC_1D
Expected accuracies:	for wavelength: 1/5th of a pixel after post-processing
	(cf. [RD6], METIS-6074
	for flux: 10% over an atmospheric band
	$<$ 30% absolute line flux accuracy
	$<$ 5% absolute flux calibration
	(cf. [RD6], R-MET-107, R-MET-82)
QC1 parameters:	None

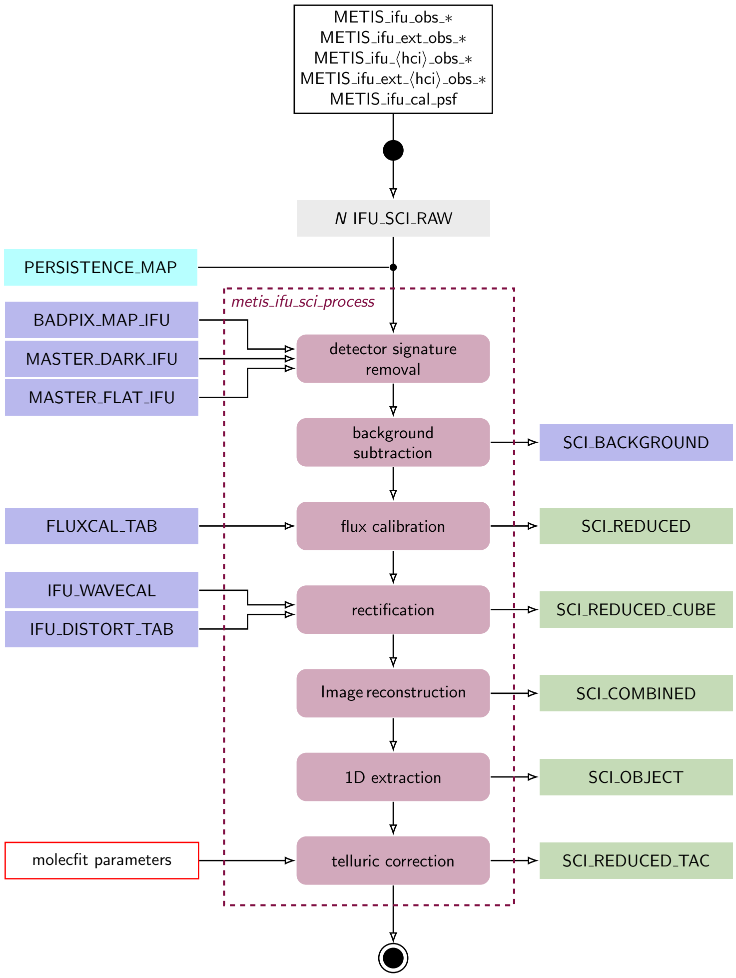


Figure 45: metis_ifu_sci_process – reduction of IFU science frames.

6.6.5 metis_ifu_tellcorr: IFU telluric absorption correction

This recipe corrects for telluric absorption in a reduced IFU data cube. The correction is done via a model atmospheric spectrum derived with molecfit.

An automatic telluric correction can be performed as part of metis_ifu_sci_process. In an interactive environment it may be better to do the telluric correction as a separate post-processing step with a user-defined aperture for the extraction of a 1D object spectrum. The spectrum is extracted from a combined cube (IFU_SCI_COMBINED) but may be applied to other products of metis_ifu_sci_process specified in the input set of frames.

Name:	metis_ifu_tellcorr
Purpose:	Remove telluric absorption features
Requirements:	METIS-6091
Type:	Calibration / post processing
Templates:	—
Input data:	IFU_SCI_COMBINED – reduced combined IFU cube
	LSF_KERNEL – Line spread kernel to be used with molecfit
	ATM_PROFILE – Atmospheric input profile to be used with molecfit
Parameters:	extraction aperture parameters
	molecfit parameters
	atmospheric profile incl. radiometer data
	line spread kernel
Algorithm:	extract 1D spectrum
	Application of molecfit
Output data:	IFU_SCI_REDUCED_TAC
Expected accuracies:	2% [RD24]
QC1 parameters:	None

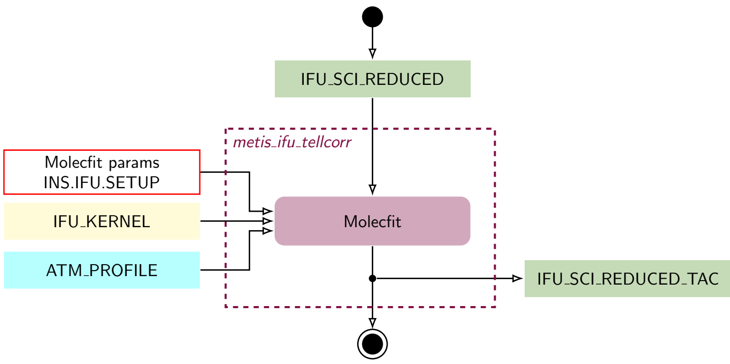


Figure 46: metis_ifu_tellcorr – telluric correction of reduced IFU science cubes.

6.6.6 metis_ifu_sci_postprocess: IFU science postprocessing

This recipe combines a number of reduced IFU exposures covering a different spatial and wavelength ranges into a single data cube. The positions and orientations of the exposures may differ as follows (cf. [AD2]):

Spatial dithering: The target is placed at different positions along and across the slice. Along-slice dithering aids in background subtraction, across-slice dithering is necessary image reconstruction given that the slice width undersamples the PSF.

Field rotation: The field is rotated by 90 degrees between exposures. The cube of a single exposure has different pixel scales along and across the slice. The goal of combining exposures at different rotation angles is to reconstruct images on a square grid with pixel scale given by the detector scale (8.2 mas). The exact procedure remains to be investigated; one of the major challenges is to find the exact centre of rotation (Sect. 8.9 of [AD1]).

Spectral dithering: Sequences of exposures are taken at various echelle angles in order to cover an increased contiguous wavelength range. In the extended mode, such a sequence may cover the wavelength gaps between echelle order coverage.

In order to allow co-addition of data from separate OBs, possibly taken months apart, the wavelengths will be corrected to the heliocentric reference system before co-addition.

The recipe is only used in the science-grade pipelines, not at the observatory.

Name:	metis_ifu_sci_postprocess
Purpose:	Coaddition and mosaicing of reduced science cubes.
Requirements:	METIS-6131
Type:	Science
Templates:	None
Input data:	Reduced science cubes (IFU_SCI_REDUCED, IFU_SCI_REDUCED_TAC)
Parameters:	None
Algorithm:	Call ifu_grid_output to find the output grid encompassing all input cubes
	Call ifu_resampling to resample input cubes to output grid
	Call ifu_coadd to stack the images
Output data:	IFU_SCI_COADD
	IFU_SCI_COADD_ERROR
QC1 parameters:	—

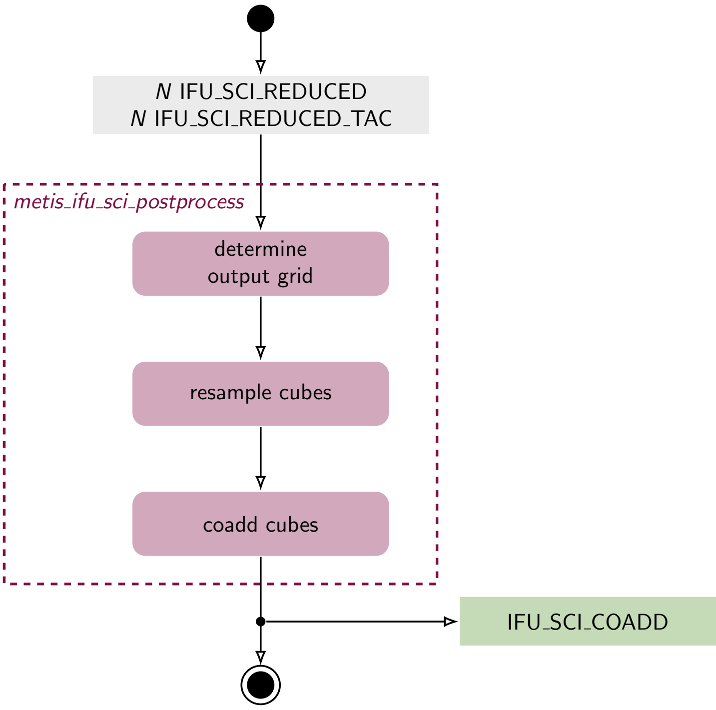


Figure 47: `metis_ifu_sci_postprocess` – post-processing (coaddition) of reduced IFU science frames.

6.6.7 metis_ifu_distortion: IFU distortion calibration

Calibration of the geometric distortion of the IFU is done by observing a pin hole mask located in a focal plane within the instrument. The distortion is described in terms of a polynomial model whose coefficients can be used to map positions in in the detector array to sky positions. Measurement of the FWHM of the spots gives an indication of the variation of spectral resolution across the field of view.

Name:	metis_ifu_distortion
Purpose:	Determine geometric distortion coefficients for the IFU.
Requirements:	METIS-6087, METIS-6073
Type:	Calibration
Templates:	METIS_ifu_cal_distortion
Input data:	IFU_DISTORTION_RAW (Images of multi-pinhole mask.)
Parameters:	None
Algorithm:	Calculate table mapping pixel position to position on sky.
Output data:	IFU_DISTORTION_TABLE
	IFU_DIST_REDUCED
Expected accuracies:	1/10th of a pixel after post-processing
	(cf. [RD6], R-MET-106, METIS-167, METIS-1371)
QC1 parameters:	QC IFU DISTORT RMS: RMS deviation between measured position and model
	QC IFU DISTORT FWHM: Measured FWHM of spots
	QC IFU DISTORT NSPOTS: Number of identified spots

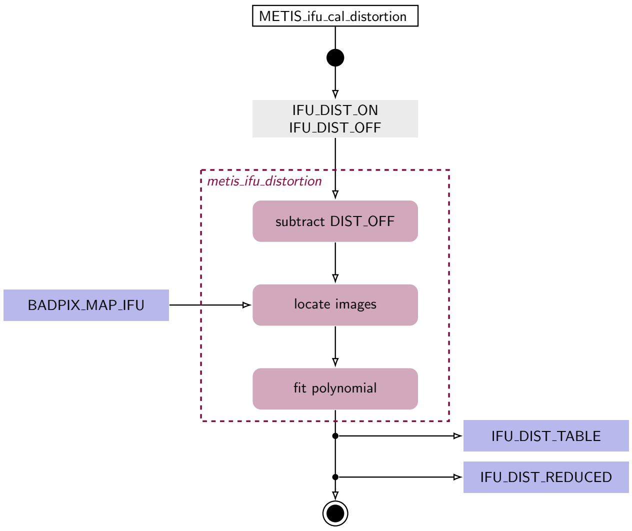


Figure 48: `metis_ifu_distortion` – IFU distortion calibration

6.7 ADI Post Processing recipes

The following recipes can be used by astronomers in an offline way perform basic ADI processing on data which have already undergone basic calibration, via the standard LM/N processing methods. As it relies on reduced data they will not be executed in a scheduled way at the telescope. For more detailed HCI reductions the observers will have to rely on their own more specialized code, but intermediate data products will be optionally provided in these recipes to facilitate their dedicated HCI reductions. Potentially these three recipes can be combined into one with a logical decision tree. To minimize interpolation artefacts any interpolation steps are to be combined as much as possible. Bad pixel maps and image stacks without background subtraction are available as output from the earlier science processing recipes.

6.7.1 metis_img_adi_cgrph: IMG_LM/N RAVC/CVC ADI Post Processing

The following recipes is applicable for ADI post processing for the LM and N band, and CVC/RAVC coronagraphs. An input set of observations consists of a time sequence of ADI images in LM or N band, which have already undergone basic calibration.

For each image, the centroid of the central source is determined, distortion corrections are performed, and the images are aligned on a subpixel scale. The median PSF is then estimated and subtracted from all images following the first step of the standard ADI technique of Marois et al (2006), which implicitly also subtracts the thermal background. Each image is then derotated using the known position angle and coadded to produce the final science image. In addition, the images prior to PSF subtraction are derotated and combined to produce a second final image.

In addition to the final images, the calibrated cube is used to calculate the raw and post-ADI contrast curves as well as the ADI throughput curve. The intrinsic radial throughput of the coronagraph is taken from static calibrations while the post-processing losses are estimated from injection and retrieval of artificial companions with a known brightness and separation.

Off-axis unsaturated PSFs which are needed for the ADI process are either collected as part of the observations, static calibrations or available from the QACITS control loop. If collected as part of the OB they are processed by the regular science recipes (with compensation of any neutral density transmission).

Name:	metis_img_adi_cgrph
Purpose:	Classical ADI post processing for CVC/RAVC coronagraphs
Requirements:	METIS-5989
Templates:	None
Type:	Science
Input data:	LM_SCI_BASIC_REDUCED or N_SCI_BKG_SUBTRACTED
	LM_DISTORTION_TABLE or N_DISTORTION_TABLE

	LM_cgrph_SCI_THROUGHPUT or N_cgrph_SCI_THROUGHPUT
	LM_OFF_AXIS_PSF_RAW or N_OFF_AXIS_PSF_RAW
Matched keywords:	Detector ID
	Filter ID
	Object ID
	coronagraphic mask
Parameters:	combination method (median, mean, sigclip, . . .)
	parameters for combination method
	resampling method
	parameters for resampling method
	start and end limit for contrast curve (in λ/D)
	frame exclusion thresholds dependent on AO parameters and centroid offset
Algorithm:	call lm_adi_cgrph_centroid or n_adi_cgrph_centroid to determine the centroids of the central PSFs
	call adi_regrid to apply distortion map and regrid images based on position of central PSFs
	call lm_adi_cgrph_psf or n_adi_cgrph_psf to determine the median PSF
	Subtract median PSF from all frames (hdrl_imagelist_sub_image)
	call adi_derotate to derotate both PSF subtracted and unsubtracted images
	coadd derotated images (hdrl_imagelist_collapse)
	call det_adi_cgrph_contrast for raw and post processed contrast curves
Output data:	LM_cgrph_SCI_CALIBRATED or N_cgrph_SCI_CALIBRATED
	LM_cgrph_SCI_CENTRED or N_cgrph_SCI_CENTRED
	LM_cgrph_CENTROID_TAB or N_cgrph_CENTROID_TAB
	LM_cgrph_SCI_SPECKLE or N_cgrph_SCI_SPECKLE
	LM_cgrph_SCI_DEROTATED_PSFSUB or N_cgrph_SCI_DEROTATED_PSFSUB
	LM_cgrph_SCI_DEROTATED or N_cgrph_SCI_DEROTATED

	LM_cgrph_SCI_CONTRAST_RADPROF or N_cgrph_SCI_CONTRAST_RADPROF
	LM_cgrph_SCI_CONTRAST_ADI or N_cgrph_SCI_CONTRAST_ADI
	LM_cgrph_SCI_THROUGHPUT or N_cgrph_SCI_THROUGHPUT
	LM_cgrph_SCI_COVERAGE or N_cgrph_SCI_COVERAGE
	LM_cgrph_SCI_SNR or N_cgrph_SCI_SNR
	LM_cgrph_PSF_MEDIAN org N_cgrph_PSF_MEDIAN
Expected accuracies:	n/a
QC1 parameters:	QC det cgrph SCI NEXPOSURES
	QC det cgrph SCI FWHM nn
	QC det cgrph SCI SNR MEAN
	QC det cgrph SCI SNR PEAK
	QC det cgrph SCI CONTRAST RAW LAMD
	QC det cgrph SCI CONTRAST ADI LAMD
hdrl functions:	hdrl_imagelist_collapse
	hdrl_imagelist_sub_image
	hdrl_catalogue_compute
	hdrl_resample_compute

6.7.2 metis_lm_adi_app: IMG_LM APP ADI Post Processing

The following recipe is applicable for ADI post processing for the LM band, in combination with the APP coronagraph. It is very similar to the recipe for RAVC/CVC coronagraphs, with the addition of steps for merging together the two half PSFs, and of applying an angular wedge mask before the derotation and stacking, and contrast curve calculations steps. An input set of observations consists of a time sequence of ADI images in LM band, which have already undergone basic calibration.

For each image, the centroid of the central source is determined for all three PSFs and distortion corrections are performed. The PSFs are aligned at a sub-pixel scale and extracted; the extracted coronagraphic PSFs are merged to produce a complete PSF and the third PSF is used to form a cube of calibrated leakage PSFs. The mean/median/sigmaclipped PSF is estimated and subtracted from each frame of the merged coronagraphic PSF. Each image is then derotated to place the off-axis source at the same on-sky angle and coadded to produce the final stacked science image. In addition, the images prior to PSF subtraction are derotated and combined to produce a second final stacked image.

In addition to the final images, the stack of derotated, PSF subtracted images are used to calculate the raw and post-ADI contrast curves as well as the ADI throughput curve and coverage map containing the effective number of included frames.

Name:	metis_lm_adi_app
Purpose:	Classical ADI post processing for APP coronagraph
Requirements:	METIS-5989
Templates:	None
Type:	Science
Input data:	LM_SCI_BASIC_REDUCED
	LM_DISTORTION_TABLE
	LM_OFF_AXIS_PSF_RAW
Matched keywords:	Detector ID
	Filter ID
	Object ID

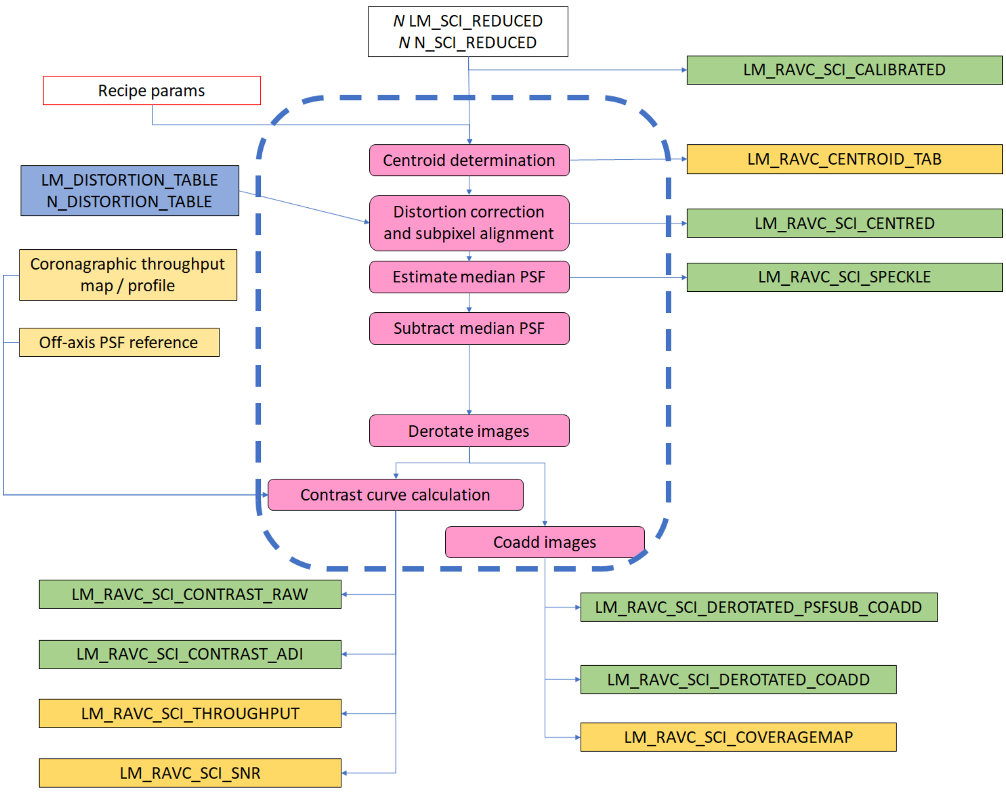


Figure 49: metis_img_adi_cgrph – DET ADI post processing for RAVC/CVC coronagraph.

	coronagraphic mask
Parameters:	combination method (median, mean, sigclip, . . .)
	parameters for combination method
	resampling method
	parameters for resampling method
	start and end limit to contrast curve (in λ/D)
	frame exclusion thresholds dependent on AO parameters and centroid offset
Algorithm:	call lm_adi_app_centroid to determine the centroids of the central PSFs
	call adi_regrid to apply distortion map and regrid images based on position of central PSFs
	call lm_merge_app_adi_psf to merge the coronagraphic PSFs
	call lm_adi_app_psf to determine the median PSF
	Subtract median PSF from all frames (hdrl_imagelist_sub_image)
	call adi_derotate to derotate both PSF subtracted and unsubtracted images
	coadd derotated images with image mask (hdrl_imagelist_collapse)
	call lm_adi_app_contrast for raw and post processed images
Output data:	LM_APP_SCI_CALIBRATED
	LM_APP_SCI_CENTRED
	LM_APP_CENTROID_TAB
	LM_APP_SCI_SPECKLE
	LM_APP_SCI_DEROTATED_PSFSUB
	LM_APP_SCI_DEROTATED
	LM_APP_SCI_CONTRAST_RADPROF
	LM_APP_SCI_CONTRAST_ADI
	LM_APP_SCI_THROUGHPUT
	LM_APP_SCI_COVERAGE
	LM_APP_SCI_SNR
	LM_APP_PSF_MEDIAN
Expected accuracies:	n/a

QC1 parameters:	QC det APP SCI NEXPOSURES
	QC det APP SCI FWHM nn
	QC det APP SCI SNR MEAN
	QC det APP SCI SNR PEAK
	QC det APP SCI CONTRAST RAW LAMD
	QC det APP SCI CONTRAST ADI LAMD
hdrl functions:	hdrl_imagelist_collapse
	hdrl_imagelist_sub_image
	hdrl_catalogue_compute
	hdrl_resample_compute

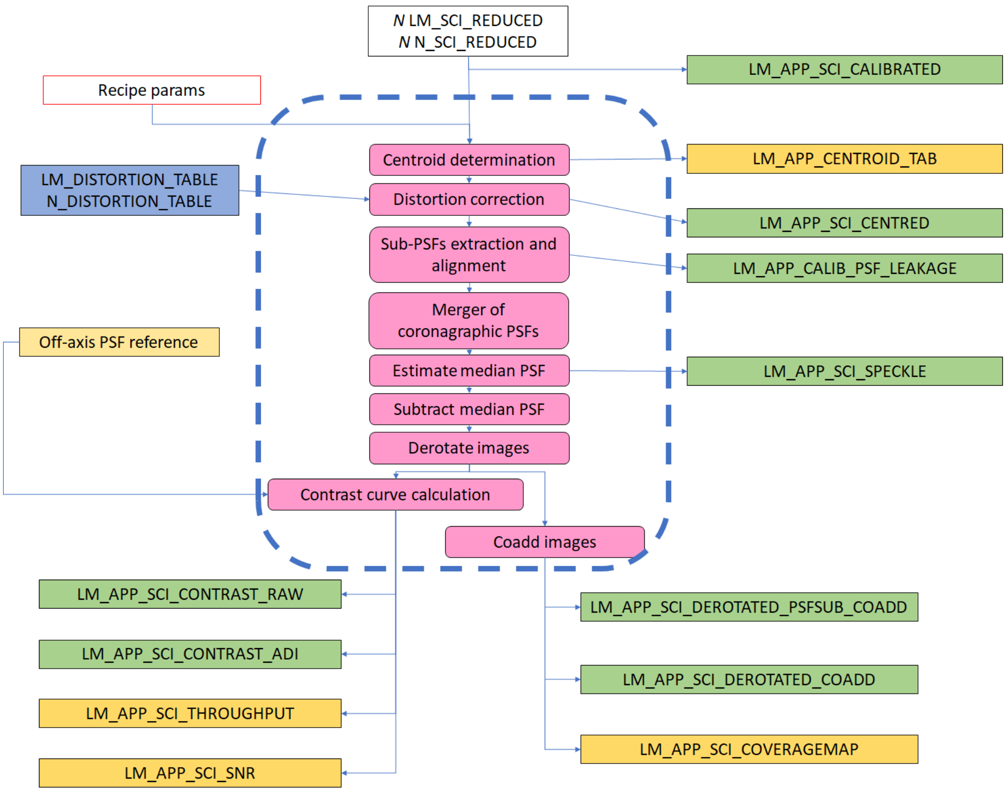


Figure 50: metis_lm_adi_app – ADI post processing for APP coronagraph.

6.7.3 metis_ifu_adi_cgrph: IFU ADI Post Processing

The following recipe is applicable for ADI post processing for the IFU data cubes and the RAVC/CVC and APP coronagraphs. As only a single target can be targeted in the limited field of view the methods overlap between coronagraphs. For the IFU observations, the input is a set of reduced 3D (spectral and spatial) data cubes on a rectified grid. Note that the reduction steps after the square pixel reconstruction are essentially identical to the non-IFU case, except for an added dimension to loop over.

For each wavelength slice in each cube the centroid is determined by a QACITS-like algorithm in the case of the focal plane coronagraphs (RAVC/CVC) or through 2D cross-correlation with a template PSF for the APP coronagraph. This centroid information is stored in a table together with timestamps, parallactic angle and bad frame flags (based on AO loop status, AO performance, atmospheric parameters and centroid offset). As the ADI step requires square pixels following previous work on combining ADI techniques with IFUs (such as SPHERE/IFS, SINFONI), the rectangular spatial grid is interpolated or nearest neighbor filled to produce a square pixel image. It is acknowledged that one spatial dimension is undersampled which may lead to reduced performance compared to a Nyquist-sampled PSF. The mean/median/sigmaclipped PSF (in time) is estimated for each wavelength and subtracted from each image in the cube. After derotation the cubes are combined in time to give a coadded cube. For the APP a wedge shape is used. The limited field of view of the IFU means that only one APP dark hole can be centered on the IFU. The derotated cubes are also used to generate post ADI contrast curves and contrast curves with input from the radial coronagraph throughput profile and off-axis PSFs. In addition coverage maps are produced.

Name:	`metis_ifu_adi_cgrph`
Purpose:	Classical ADI post processing for APP/CVC/RAVC coronagraphs with IFU
Requirements:	METIS-5989
Templates:	None
Type:	Science
Input data:	`IFU_SCI_REDUCED`
	`IFU_DISTORTION_TABLE`
	`IFU_cgrph_SCI_THROUGHPUT`
	`IFU_OFF_AXIS_PSF_RAW`
Matched keywords:	Detector ID
	Filter ID
	Object ID
Parameters:	combination method (median, mean, sigclip, ...)
	parameters for combination method
	resampling method
	parameters for resampling method
	start and end limit to contrast curve (in λ/D)

	frame exclusion thresholds dependent on AO parameters and centroid offset
Algorithm:	call det_adi_cgrph_centroid to determine the location of the central PSFs
	call ifu_adi_regrid to perform distortion correction, square pixel reconstruction and sub-pixel alignment
	call det_adi_cgrph_psf to determine the median PSF
	Subtract median PSF from all frames (hdrl_imagelist_sub_image)
	call adi_derotate to derotate both PSF subtracted and un-subtracted images
	coadd derotated images (hdrl_imagelist_collapse)
	call det_adi_cgrph_contrast for raw and post processed images
Output data:	IFU_cgrph_SCI_CALIBRATED
	IFU_cgrph_SCI_CENTRED
	IFU_cgrph_CENTROID_TAB
	IFU_cgrph_SCI_SPECKLE
	IFU_cgrph_SCI_DEROTATED_PSFSUB
	IFU_cgrph_SCI_DEROTATED
	IFU_cgrph_SCI_CONTRAST_RADPROF
	IFU_cgrph_SCI_CONTRAST_ADI
	IFU_cgrph_SCI_THROUGHPUT
	IFU_cgrph_SCI_SNR
	IFU_cgrph_SCI_COVERAGE
Expected accuracies:	n/a
QC1 parameters:	QC IFU cgrph SCI NEXPOSURES
	QC IFU cgrph SCI FWHM nn
	QC IFU cgrph SCI SNR MEAN
	QC IFU cgrph SCI SNR PEAK
	QC IFU cgrph SCI CONTRAST RAW LAMD
	QC IFU cgrph SCI CONTRAST ADI LAMD
hdrl functions:	hdrl_imagelist_collapse
	hdrl_imagelist_sub_image
	hdrl_catalogue_compute
	hdrl_resample_compute

6.8 Recipes for engineering templates

The CLC coronagraph was removed from the baseline coronagraphic modes before FDR however the coronagraph would be technically available during engineering. At this stage the DRL will not have the corresponding recipes to use the CLC. However, if the need arises during commissioning or after to make the CLC mode available, its DRL recipe can be easily adapted from the baseline RAVC/CVC coronagraph recipes as it is related in design and usage.

6.8.1 metis_pupil_imaging: Pupil imaging

This recipe refers to pupil imaging using the science detectors. Pupil imaging is needed to verify the alignment and illumination of the pupil masks (part of the HCI coronagraphs) with the telescope beam. It is not foreseen to be used by scientists in regular operation.

Name	metis_pupil_imaging
Purpose:	Apply basic reduction to pupil imaging data.

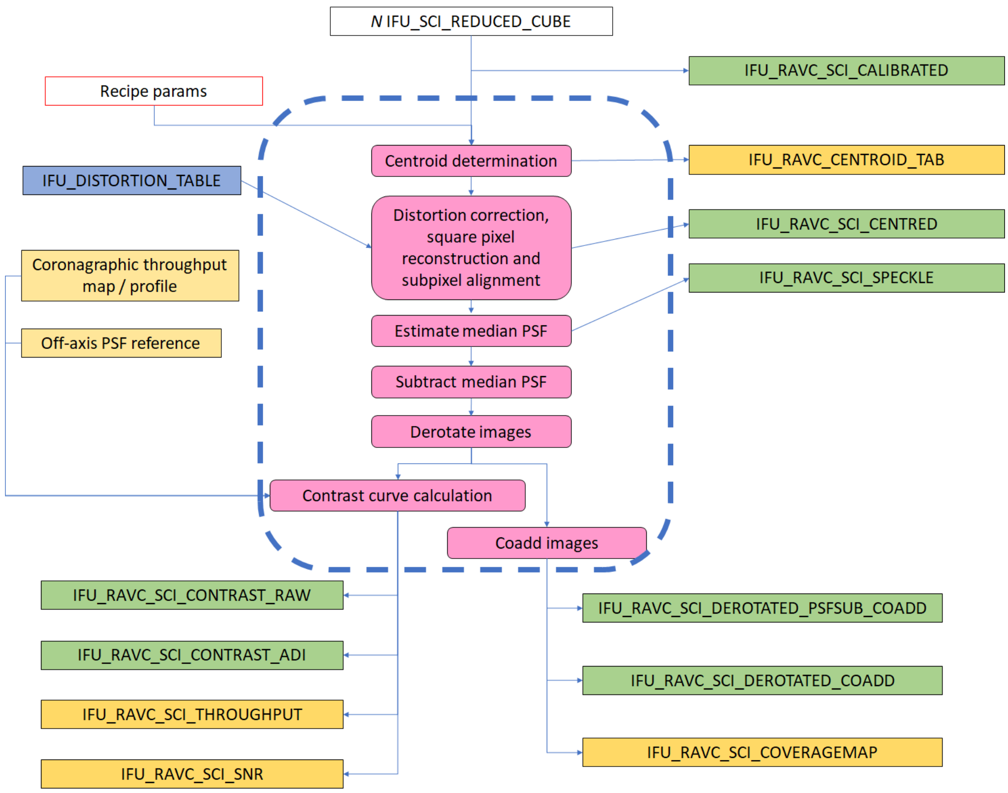


Figure 51: metis_ifu_adi_cgrph – IFU ADI post processing for RAVC/CVC coronagraph.

Requirements:	–
Type:	Maintenance
Templates:	METIS_pup_lm METIS_pup_n
Input data:	LM_PUPIL_RAW or N_PUPIL_RAW
Matched keywords:	Detector ID
Algorithm	Apply dark current and flat field corrections.
Output data:	LM_PUPIL_REDUCED or N_PUPIL_REDUCED
Expected accuracies:	n/a
QC1 parameters:	None

6.8.2 metis_img_chophome: Chopper Home Position recipe

The recipe metis_img_chophome aims to detect chopper mirror zero positions. Currently it is foreseen on daily basis to be carried out, but is for sure necessary after switching on the chopper (e.g. after instrument interventions) or induced by unforeseen events like earthquakes (cf. Section "Chopper Home Position" in [RD6]).

The procedure consists of measuring the position of a point source from the WCU, that has been centred on the WFS pyramid (in the K-band), in the IMG_LM mode. Then, taking the respective positional metrology values of the WFS-FS and the chopper, the relative coordinates between the WFS Pyramid focal plane, and the science focal planes is established.

Name:	metis_img_chophome
Purpose:	Detection of the chopper mirror home position
Type:	Calibration
Requirements:	None
Templates:	METIS_img_lm_cal_ChopperHome
Input data:	LM_CHOPPERHOME_RAW
	PERSISTENCE_MAP
	LINEARITY_2RG
	GAIN_MAP_2RG
	BADPIX_MAP_2RG
	MASTER_DARK_2RG
	MASTER_IMG_FLAT_LAMP_LM
Parameters:	None
Algorithm:	remove detector signature
	remove median background
	apply flatfield
	detect reference source from WCU via centroid peak detection
	Calculate mirror offset
Output data:	Offset of the chopper mirror to be piped either into the Instrument Control System (ICS) for correction
	or to be used in thee pipeline for astrometric correction
Expected accuracies:	0.1mas accuracy of the centroid position (cf. [RD6])
QC1 parameters:	None

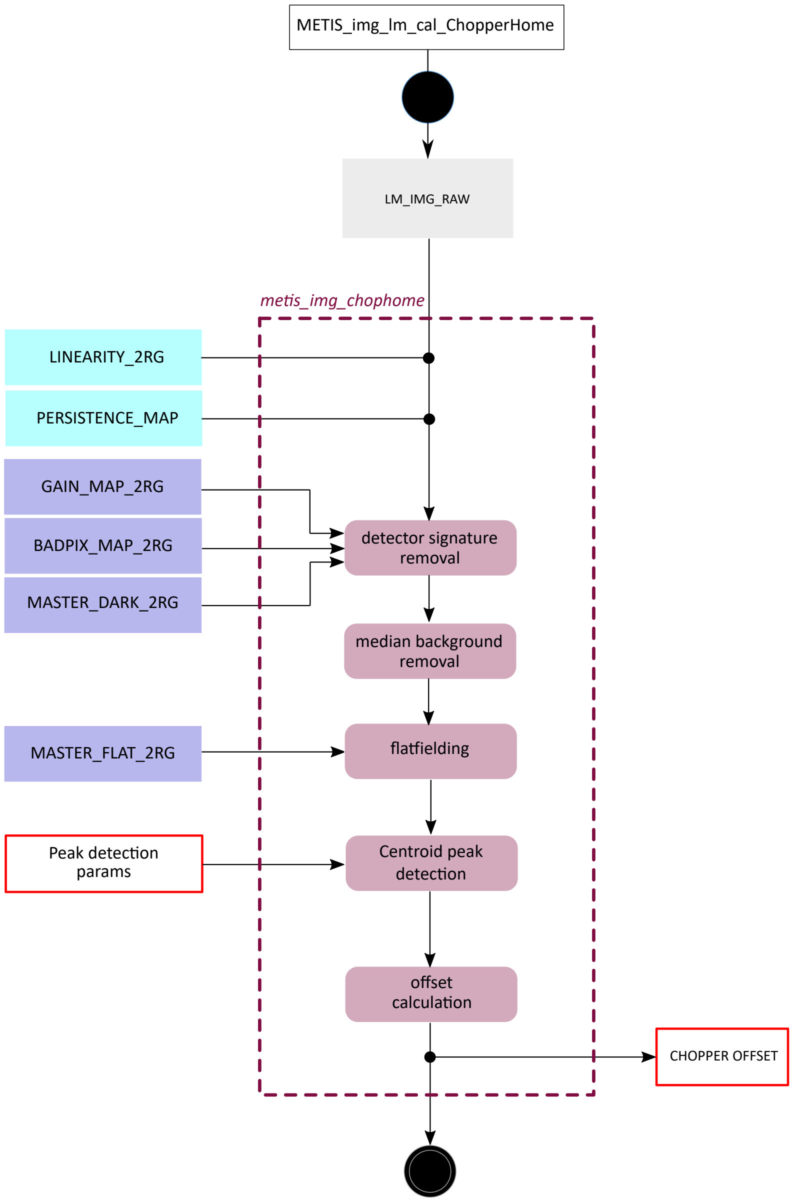


Figure 52: metis_img_chophome – Recipe workflow to detect the zero position of the chopper mirror.

6.8.3 metis_lm/n_adc_slitloss: Slit loss determination

The recipes metis_lm_adc_slitloss (Fig. 54) and metis_n_adc_slitloss (Fig. 55) aims to determine the throughput as function of the object position along the across-slit direction. It is expected that the usage of the fixed positioned ADC will introduce flux losses (cf. Section "Calibration of slit losses" in [RD6]). For the determination, the point sources (i.e. mask of the WCU) is placed on several positions (distance $\sim \frac{1}{10}\lambda/D$) across the slit (cf. Fig. 53), and measure the wavelength dependent flux changes with respect to the respective positions. Finally, a simple model is determined to be able to correct for the flux losses (see Section "Calibration of slit losses" in the Calibration Plan [RD6] for more details). This recipe is to be carried out once in a while to update the static calibration database.

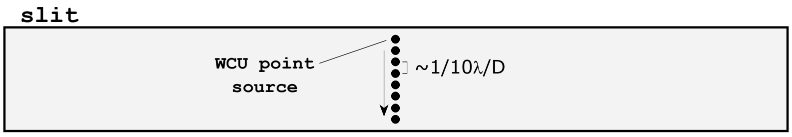


Figure 53: Algorithm for the slit-loss determination in recipe metis_lm_adc_slitloss

Name:	metis_lm_adc_slitloss
Purpose:	Determination of the ADC induced slit losses
Type:	Calibration
Requirements:	METIS-6074, METIS-2757, METIS-9099, METIS-9150
Templates:	METIS_spec_lm_cal_SlitAdc
Input data:	LM_SLITLOSSES_RAW
	LM_WCU_OFF_RAW
	PERSISTENCE_MAP
	LINEARITY_2RG
	GAIN_MAP_2RG
	BADPIX_MAP_2RG
	MASTER_DARK_2RG
	MASTER_IMG_FLAT_LAMP_LM
Parameters:	exposure time, offset positions
Algorithm:	remove detector signature
	remove dark
	apply flatfield
	detect reference source from WCU via centroid peak detection

	apply aperture photometry
	calculate (simple) slitloss model (details to be defined)
Output data:	LM_ADC_SLITLOSS (Slit loss model as function of the wavelength and object position across the slit
Expected accuracies:	3% (cf. [RD24])

Name:	metis_n_adc_slitloss
Purpose:	Determination of the ADC induced slit losses
Type:	Calibration
Requirements:	METIS-6074, METIS-2757, METIS-9099, METIS-9150
Input data:	N_SLITLOSSES_RAW
	N_WCU_OFF_RAW
	PERSISTENCE_MAP
	LINEARITY_GEO
	GAIN_MAP_GEO
	BADPIX_MAP_GEO
	MASTER_DARK_GEO
	MASTER_IMG_FLAT_LAMP_N
Parameters:	exposure time, offset positions
Algorithm:	remove detector signature
	remove dark
	apply flatfield
	detect reference source from WCU via centroid peak detection
	apply aperture photometry
	calculate (simple) slitloss model (details to be defined)
Output data:	N_ADC_SLITLOSS (Slit loss model as function of the wavelength and object position across the slit)
Expected accuracies:	3% (cf. [RD24])

6.8.4 Fringing correction

It is unclear for the time being how much of a problem will be with the METIS detectors, and what the best strategy will be to tackle it. Therefore, the method to use will be chosen based on AIT results (METIS-9151, for rationale and basic method description see Ch. 3.12 in the Calibration Plan [RD6]).

Whether a stand-alone recipe will be required, or if the fringe-map will become part of another recipe, is part of that uncertainty. If needed, the design of said recipe will be minimal work and is thus omitted in this document.

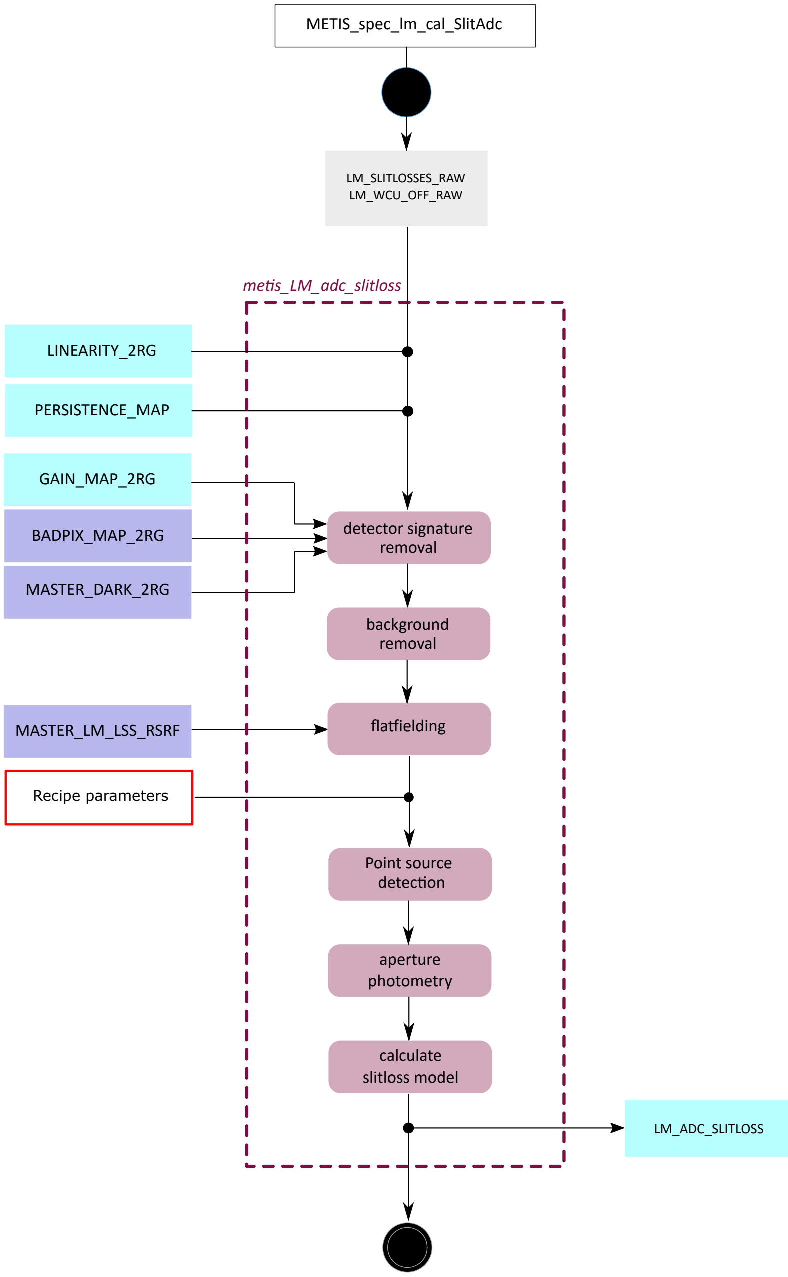


Figure 54: metis_lm_adc_slitloss – Recipe workflow to determine the ADC induced slit losses.

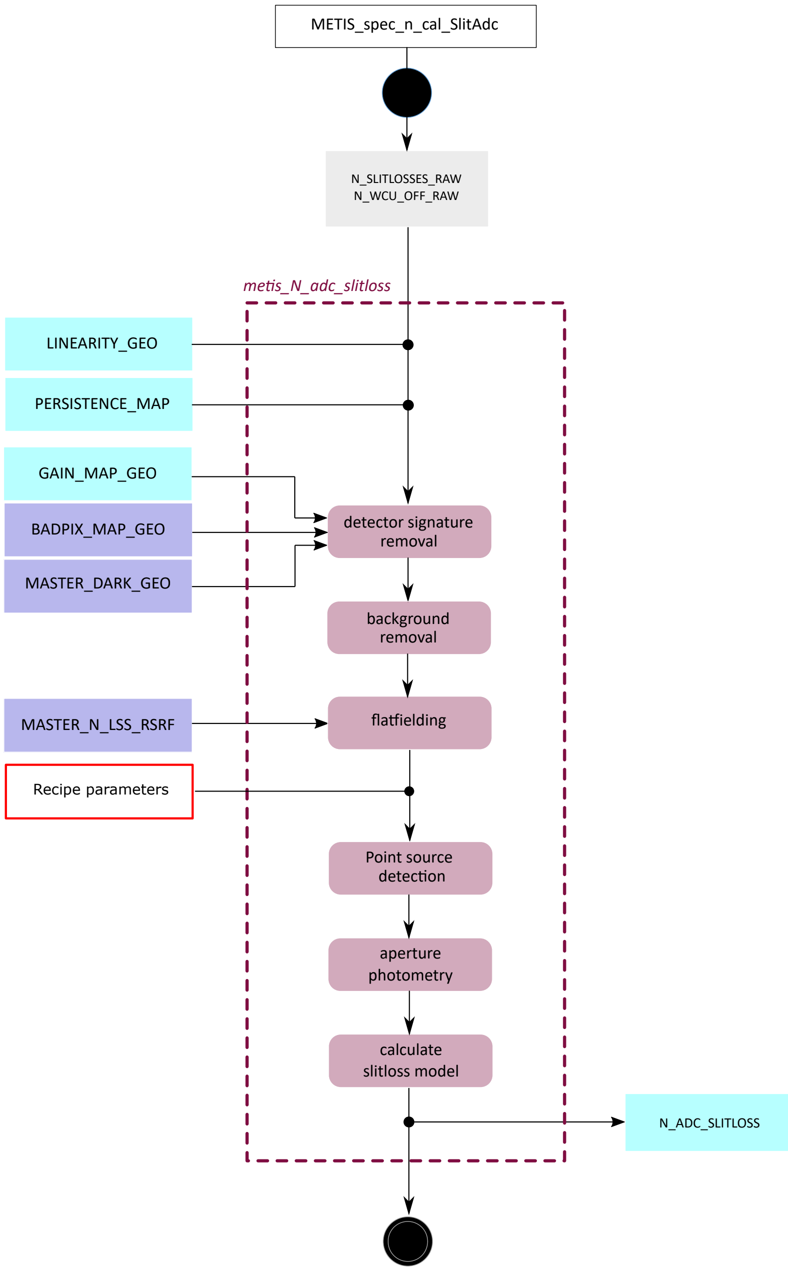


Figure 55: metis_n_adc_slitloss – Recipe workflow to determine the ADC induced slit losses.

7 DRL Functions

All functions, plugins, macros and data types will be documented using *Doxygen* which is the standard documentation tool for CPL, HDRL and ESO pipelines. The reference manual for the pipeline system is created automatically from the Doxygen strings. This fulfills METIS-9355.

7.1 Detector Functions

7.1.1 Determine Dark Frames

Name:	`metis_determine_dark`
Purpose:	Determine the dark current of the detectors and create dark images
Used in recipes:	`metis_det_dark`, `metis_det_lingain`
Input:	$n\times$ `const hdrl_image * input`
Other inputs:	combination method (`median`, `mean`, `sigclip`,...)
	parameters for combination method
QC outputs:	QC DARK MEAN
	QC DARK MEDIAN
	QC DARK RMS
Outputs:	Dark frame
	`cpl_error_code`
General description:	Determination of dark frames for subtraction of dark current
Mathematical description:	Median or mean of input images, with sigma clipping
Quality assessment:	Through QC parameters
Error conditions:	See [RD1].
Unit tests:	See [RD1].

7.1.2 Flag Deviant Pixels in Dark Frame

Name:	`metis_update_dark_mask`
Purpose:	Flag deviant (hot, cold, bad) pixels in the master dark and update the image mask
Used in recipes:	`metis_det_dark`

Input:	`const hdrl_image * input`
Other inputs:	Threshold(s) for deviant pixel detection
QC outputs:	QC DARK NHOTPIX QC DARK NCOLDPIX QC DARK NBADPIX
Outputs:	Updated dark frame mask `cpl_error_code`
General description:	Flag deviant (hot/cold/bad) pixels in master dark
Mathematical description:	flag pixels outside the provided thresholds
Quality assessment:	Through QC parameters
Error conditions:	See [RD1].
Unit tests:	See [RD1].

7.1.3 Non-linearity Correction

Name:	`img_nonlinear_correction`
Purpose:	Correction for detector non-linearity
Used in recipes:	`metis_lm_img_basic_reduce`
Input:	$n\times$ `const hdrl_image * input`
Outputs:	Non-linearity corrected images [px] `cpl_error_code`
General description:	Correction of detector non-linearity
Mathematical description:	See Section 6.1.1
Quality assessment:	Through QC parameters
Error conditions:	See [RD1].
Unit tests:	See [RD1].

7.1.4 Crosstalk correction

Name:	img_crosstalk_correction
Purpose:	Correction for detector crosstalk
Used in recipes:	metis_lm_img_basic_reduce
Input:	$n\times$ const hdrl_image * input
Outputs:	Crosstalk corrected images [px] cpl_error_code
General description:	Correction of detector crosstalk
Mathematical description:	See Section 6.2.2
Quality assessment:	Through QC parameters
Error conditions:	See [RD1].
Unit tests:	See [RD1].

7.1.5 Apply Persistence Correction

Name:	metis_apply_persistence_correction
Purpose:	Apply the persistence correction to raw images
Used in recipes:	metis_lm_img_flat
Input:	$n\times$ const hdrl_image * input
Other inputs: PERSISTENCE_MAP	
QC outputs: QC PERSIST COUNT	
Outputs:	Corrected raw images cpl_error_code
General description:	Persistence correction of raw images
Mathematical description:	see Section 10.1
Quality assessment:	Through QC parameters
Error conditions:	See [RD1].
Unit tests:	See [RD1].

7.2 IFU observing mode

7.2.1 IFU wavelength calibration

Name:	ifu_wavecal
Purpose:	Find the pixel-to-wavelength conversion for IFU exposures
Used in recipes:	metis_ifu_sci_process
Input:	const hdrl_image * input
Outputs:	IFU_WAVECAL [px]
	cpl_error_code
General description:	
Mathematical description:	See section 6.6.1
Quality assessment:	Through QC parameters
Error conditions:	See [RD1].
Unit tests:	See [RD1].

7.2.2 IFU output grid determination

Name:	ifu_grid_output
Purpose:	Obtain maximal useful resolution from a set of dithered exposures
Used in recipes:	metis_ifu_sci_postprocess
Input:	6$\times$ const hdrl_image * input
Other inputs:	precise position and orientation of individual exposures
Outputs:	IFU_SCI_COMBINED [px]
	cpl_error_code
General description:	Dither and co-add the individual exposures
Mathematical description:	See section 6.6.6
Quality assessment:	Through QC parameters
Error conditions:	See [RD1].
Unit tests:	See [RD1].

7.2.3 IFU multi-exposure resampling

Name:	ifu_resampling
Purpose:	Obtain maximal useful resolution from a set of dithered exposures
Used in recipes:	metis_ifu_sci_postprocess
Input:	$6\times$ const hdrl_image * input
Other inputs:	precise position and orientation of individual exposures
Outputs:	IFU_SCI_COMBINED [px] cpl_error_code
General description:	Resample the IFU exposures with rectangular pixels onto a square grid
Mathematical description:	See section 6.6.6
Quality assessment:	Through QC parameters
Error conditions:	See [RD1].
Unit tests:	See [RD1].

7.2.4 IFU multi-exposure co-add

Name:	ifu_coadd
Purpose:	Obtain maximal useful resolution from a set of dithered exposures
Used in recipes:	metis_ifu_sci_postprocess
Input:	$6\times$ const hdrl_image * input
Outputs:	IFU_SCI_COADD [px] IFU_SCI_COADD_ERROR [px] cpl_error_code
General description:	Co-add the properly aligned exposures
Mathematical description:	See section 6.6.6
Quality assessment:	Through QC parameters
Error conditions:	See [RD1].
Unit tests:	See [RD1].

7.3 IMG observing mode

7.3.1 Detrending

Name:	img_detrend
Purpose:	Remove detector signals
Used in recipes:	metis_lm_img_basic_reduce
Input:	const hdrl_image * input const ls_master_dark_image * input const ls_master_flat_image * input
Outputs:	Detrended images [px] cpl_error_code
General description:	De-trending the raw image
Mathematical description:	See Section 6.2.2
Quality assessment:	Through QC parameters
Error conditions:	See [RD1].
Unit tests:	See [RD1].

7.3.2 Building sky background

Name:	img_skybackground_build
Purpose:	Building thermal background signals
Used in recipes:	metis_lm_img_background
Input:	const hdrl_image * input const ls_skybackground_image
Outputs:	Building sky background from images [px] cpl_error_code
General description:	Removing sky backround from images
Mathematical description:	See Section 6.2.3
Quality assessment:	Through QC parameters
Error conditions:	See [RD1].
Unit tests:	See [RD1].

7.3.3 Remove sky background

Name:	img_skybackground_removal
Purpose:	Remove sky background signals
Used in recipes:	metis_lm_img_background
Input:	const hdrl_image * input
	const ls_skybackground_image
Outputs:	Removing sky background from images [px]
	cpl_error_code
General description:	Removing sky backround from images
Mathematical description:	See Section 6.2.3
Quality assessment:	Through QC parameters
Error conditions:	See [RD1].
Unit tests:	See [RD1].

7.3.4 Create Master LM Flat

Name:	metis_lm_img_flat
Purpose:	Create master flat field for the LM-band imaging detector
Used in recipes:	metis_lm_img_flat
Input:	$n\times$ const hdrl_image * input
Other inputs:	combination method (median, mean, sigclip,...)
	parameters for combination method
	BADPIX_MAP_2RG
QC outputs:	QC LM MASTERFLAT RMS
Outputs:	Master Flat
	cpl_error_code
General description:	Determination of master flat for flat fielding
Mathematical description:	Combine images with the same DIT, fit slope of pixels against illumination level
Quality assessment:	Through QC parameters
Error conditions:	See [RD1].
Unit tests:	See [RD1].

7.3.5 Create N Master Flat

Name:	metis_n_img_flat
Purpose:	Create master flat field for the N-band imaging detector
Used in recipes:	metis_n_img_flat
Input:	$n\times$ const hdrl_image * input
Other inputs:	combination method (median, mean, sigclip,...)
	parameters for combination method
	BADPIX_MAP_GEO
QC outputs:	QC N MASTERFLAT RMS
Outputs:	Master Flat
	cpl_error_code
General description:	Determination of master flat for flat fielding
Mathematical description:	Combine images with the same DIT, fit slope of pixels against illumination level
Quality assessment:	Through QC parameters

Error conditions:	See [RD1].
Unit tests:	See [RD1].

7.3.6 Flag Deviant Pixels in LM Flat Field

Name:	metis_update_lm_flat_mask
Purpose:	Flag deviant pixels in the LM master flat and update the image mask
Used in recipes:	metis_lm_img_flat
Input:	flat const hdrl_image * input BADPIX_MAP_2RG Threshold(s) for deviant pixel detection
QC outputs:	QC LM FLAT NBADPIX QC LM FLAT MEAN ## QC LM FLAT RMS ##
Outputs:	Updated flat field mask cpl_error_code
General description:	Flag deviant pixels in master flat
Mathematical description:	flag pixels outside the provided threshold(s)
Quality assessment:	Through QC parameters
Error conditions:	See [RD1].
Unit tests:	See [RD1].

7.3.7 Flag Deviant Pixels in N Flat Field

Name:	metis_update_n_flat_mask
Purpose:	Flag deviant pixels in the N master flat and update the image mask
Used in recipes:	metis_n_img_flat
Input:	flat const hdrl_image * input BADPIX_MAP_GEO Threshold(s) for deviant pixel detection

QC outputs:	QC N FLAT NBADPIX QC N FLAT MEAN ## QC N FLAT RMS ##
Outputs:	Updated flat field mask `cpl_error_code`
General description:	Flag deviant pixels in master flat
Mathematical description:	flag pixels outside the provided threshold(s)
Quality assessment:	Through QC parameters
Error conditions:	See [RD1].
Unit tests:	See [RD1].

7.3.8 metis_derive_gain

Name:	`metis_derive_gain`
Purpose:	Determine the gain.
Used in recipes:	`metis_det_lingain`
Input:	$n\times$ `const double * means`
Outputs:	gain [e/adu] `cpl_error_code`
General description:	Determine the gain as the slope of variance against mean of detlin images.
Mathematical description:	See Section 5.4.1
Quality assessment:	Through QC parameters
Error conditions:	None.

7.3.9 metis_derive_nonlinearity

Name:	`metis_derive_nonlinearity`
Purpose:	Determine the non-linearity coefficients.
Used in recipes:	`metis_det_lingain`

Input:	$n\times$ hdrl_image * image Dark corrected non-linearity raws.
Outputs:	LINEARITY_det cpl_error_code
General description:	Determine the non-linearity coefficients.
Mathematical description:	low-order polynomial fit of the individual pixel values as function of the illumination intensity
Quality assessment:	Through QC parameters
Error conditions:	None.

7.3.10 Measure LM Band Flux of Standard Star

Name:	lm_calculate_std_flux
Purpose:	Calculate LM band flux and position of standard star in detector units
Used in recipes:	metis_lm_img_std_process
Input:	$n\times$ const hdrl_image * input
QC outputs:	QC LM IMG STD BACKGD RMS QC LM STD PEAK CNTS QC LM STD APERTURE CNTS QC LM STD STREHL QC LM STD AIRMASS
Outputs:	position and flux of stars in detector units (hdrl_catalogue_result structure) cpl_error_code
General description:	Photometry of standard star
Mathematical description:	See Section 6.2.4
Quality assessment:	Through QC parameters
Error conditions:	See [RD1].
Unit tests:	See [RD1].

7.3.11 Measure N band Flux of Standard Star

Name:	n_calculate_std_flux
Purpose:	Calculate N band flux and position of standard star in detector units
Used in recipes:	metis_n_img_std_process
Input:	const hdrl_image * input
QC outputs:	QC N IMG STD BACKGD RMS
	QC N STD PEAK CNTS
	QC N STD APERTURE CNTS
	QC N STD STREHL
	QC N STD AIRMASS
Outputs:	position and flux of stars in detector units (hdrl_catalogue_result structure)
	cpl_error_code
General description:	Photometry of standard star
Mathematical description:	See Section 6.3.3
Quality assessment:	Through QC parameters
Error conditions:	See [RD1].
Unit tests:	See [RD1].

7.3.12 Calculate Flux Calibration

Name:	calculate_std_fluxcal
Purpose:	Calculate the conversion between instrumental and physical flux units
Used in recipes:	metis_lm_img_std_process
Input:	Flux of standard star in instrumental units
Other inputs:	photometric standard catalogue
Outputs:	FLUXCAL_TAB
	cpl_error_code
General description:	Calculate flux conversion to physical units

Mathematical description:	See Section 6.2.4
Quality assessment:	Through QC parameters
Error conditions:	See [RD1].
Unit tests:	See [RD1].

7.3.13 Calculate Detection Limits

Name:	`calculate_detection_limits`
Purpose:	Calculate Detection Limits
Used in recipes:	`metis_lm_img_std_process`
Input:	`const hdrl_image * input`
Other inputs:	`FLUXCAL_TAB`
QC outputs:	QC det LM SENSITIVITY QC det LM AREA SENSITIVITY
Outputs:	detection limits for standard star `cpl_error_code`
General description:	Calculate detection limits of standard star
Mathematical description:	See Section 6.2.4
Quality assessment:	Through QC parameters
Error conditions:	See [RD1].
Unit tests:	See [RD1].

7.3.14 Detect peak centroid location

Name:	`detect_centroid_peak`
Purpose:	Detect the location of a source peak by a centroid

Used in recipes:	`metis_img_chophome`
	`metis_lm_adc_slitloss`
	`metis_n_adc_slitloss`

Input:	$n\times$ `const hdrl_image * input`
Outputs:	Location of detected peak [px]

	`cpl_error_code`
General description:	Detection of a source by centroid fit
Mathematical description:	standard method
Quality assessment:	Through QC parameters
Error conditions:	See [RD1].
Unit tests:	See [RD1].

7.3.15 Convert LM Image to Physical Flux

Name:	`lm_scale_image_flux`
Purpose:	Calculate the conversion between instrumental and physical flux units
Used in recipes:	`metis_lm_img_calibrate`
Input:	`LM_SCI_BKG_SUBTRACTED`
`FLUXCAL_TAB`	
Other inputs:	None
QC outputs:	None
Outputs:	`cpl_error_code`
General description:	Convert instrumental flux to ph/s
Mathematical description:	See Section 6.2.5
Quality assessment:	Through QC parameters
Error conditions:	See [RD1].
Unit tests:	See [RD1].

7.3.16 Add LM Calibration Information to Header

Name:	`lm_update_header_distortion`
Purpose:	Update the FITS header with calibration data (WCS, distortion, units)
Used in recipes:	`metis_lm_img_calibrate`
Input:	`LM_SCI_BKG_SUBTRACTED`

	LM_DISTORTION_TABLE
QC outputs:	None
Output FITS files:	LM_SCI_CALIBRATED
Outputs:	cpl_error_code
General description:	Add disortion, WCS and BUNIT information to FITS header
Mathematical description:	See Section 6.2.5
Quality assessment:	None
Error conditions:	See [RD1].
Unit tests:	See [RD1].

7.3.17 Convert N Image to Physical Flux

Name:	n_scale_image_flux
Purpose:	Calculate the conversion between instrumental and physical flux units
Used in recipes:	metis_n_img_calibrate
Input:	N_SCI_BKG_SUBTRACTED
FLUXCAL_TAB	
Other inputs:	None
QC outputs:	None
Outputs:	cpl_error_code
General description:	Convert instrumental flux to ph/s
Mathematical description:	See Section 6.3.4
Quality assessment:	Through QC parameters
Error conditions:	See [RD1].
Unit tests:	See [RD1].

7.3.18 Add N Calibration Information to Header

Name:	n_update_header_distortion
Purpose:	Update the FITS header with calibration data (WCS, distortion, units)
Used in recipes:	metis_n_img_calibrate
Input:	N_SCI_BKG_SUBTRACTED N_DISTORTION_TABLE
QC outputs:	None
Output FITS files:	N_SCI_CALIBRATED
Outputs:	cpl_error_code
General description:	Add disortion and BUNIT information to FITS header
Mathematical description:	See Section 6.3.4
Quality assessment:	None
Error conditions:	See [RD1].
Unit tests:	See [RD1].

7.3.19 Fit Distortion Parameters

Name:	fit_distortion
Purpose:	Fit optical distortion coefficients based on pinhole mask image
Used in recipes:	metis_lm_img_distortion metis_n_img_distortion
Function Parameters:	parameters for fitting routine
Input:	Catalogue of detected sources PINHOLE_TABLE
QC outputs:	QC det DISTORT RMS QC det DISTORT NSOURCE
Output FITS files:	det_DIST_REDUCED det_DISTORTION_MAP
Outputs:	det_DISTORTION_TABLE cpl_error_code

General description:	Fit optical distortion coefficients based on pinhole mask image
Mathematical description:	See Section 6.2.7
Quality assessment:	None
Error conditions:	See [RD1].
Unit tests:	See [RD1].

7.3.20 Cutout Region Around Beam

Name:	`cutout_region`
Purpose:	Cutout a region around a beam in N band image
Used in recipes:	`metis_n_img_restore`
Function Parameters:	Size of cutout region
Input:	`N_SCI_CALIBRATED`
QC outputs: None	
General description:	Cutout a region around the positive and negative beams in an N-band image
Mathematical description:	See Section 6.3.5
Quality assessment:	None
Error conditions:	See [RD1].
Unit tests:	See [RD1].

7.4 LSS observing mode

7.4.1 Order background correction

Name:	`correct_order_bg`
Purpose:	Removal of order background contamination (e.g. stray light)

Used in recipes:	metis_LM_lss_rsrf metis_N_lss_rsrf metis_LM_lss_wave metis_LM_lss_std metis_N_lss_std metis_LM_lss_sci metis_N_lss_sci
Input:	$n\times$ const hdrl_image * input
Other outputs:	cpl_error_code
General description:	Removal of stray light by a 2D-polynomial fits of the order background
Mathematical description:	see Section 5.3.1
Quality assessment:	Through QC parameters
Error conditions:	See [RD1].
Unit tests:	See [RD1].

7.4.2 Subtract WCU OFF frame from frame

Name:	subtract_wcu_off_illum
Purpose:	Subtract a WCU-OFF frame
Used in recipes:	metis_LM_lss_rsrf metis_N_lss_rsrf metis_lm_adc_slitloss metis_n_adc_slitloss
Input:	const hdrl_image * input
Other inputs:	None
Other outputs:	cpl_error_code
General description:	Subtracts a WCU-OFF frame from an WCU image
Mathematical description:	see [RD19] and [RD20]
Quality assessment:	Through QC parameters
Error conditions:	See [RD1].
Unit tests:	See [RD1].

7.4.3 Calculate blackbody spectrum

Name:	calc_bb
Purpose:	Calculate blackbody spectrum
Used in recipes:	metis_LM_lss_rsrf metis_N_lss_rsrf
Input:	temperature parameter
Other inputs:	None
Other outputs:	cpl_error_code const hdrl_spectrum1D * output
General description:	Calculates a blackbody spectrum for the RSRF normalisation
Mathematical description:	usual Planck formula
Quality assessment:	Through QC parameters
Error conditions:	See [RD1].
Unit tests:	See [RD1].

7.4.4 Normalise RSRF

Name:	norm_flat
Purpose:	Creates normalised flats from LM_LSS_RSRF_RAW / N_LSS_RSRF_RAW
Used in recipes:	metis_LM_lss_rsrf metis_N_lss_rsrf
Input:	const hdrl_image * input
Other outputs:	cpl_error_code
General description:	Creates normalised RSRF
Mathematical description:	see [RD19] and [RD20]
Quality assessment:	Through QC parameters
Error conditions:	See [RD1].
Unit tests:	See [RD1].

7.4.5 Normalise spectrum

Name:	norm_spec
Purpose:	Creates unity-normalised version from an input STD spectra
Used in recipes:	metis_LM_lss_std metis_N_lss_std
Input:	const hdrl_image * input
Other outputs:	cpl_error_code
General description:	Creates normalised version of a STD input spectrum by fitting the continuum and subsequent division of the fit
Mathematical description:	Polynomial fit on regions known to contain continuum only; these regions will be defined in Table REF_STD_CAT
Quality assessment:	Through QC parameters
Error conditions:	See [RD1].
Unit tests:	See [RD1].

7.4.6 Apply RSRF

Name:	apply_rsrf
Purpose:	applies MASTER_LM_LSS_RSRF to LM-frames applies MASTER_N_LSS_RSRF to N-frames
Used in recipes:	metis_LM_lss_trace metis_N_lss_trace metis_LM_lss_wave metis_LM_lss_std metis_N_lss_std metis_LM_lss_sci metis_N_lss_sci metis_lm_adc_slitloss metis_n_adc_slitloss
Inputs:	const hdrl_image * input
Other outputs:	cpl_error_code
General description:	Normal flatfield process for correcting pixel-to-pixel sensitivities

Mathematical description:	Division by MASTER_LM_LSS_RSRF or MASTER_N_LSS_RSRF, respectively
Quality assessment:	Through QC parameters
Error conditions:	See [RD1].
Unit tests:	See [RD1].

7.4.7 Determine response

Name:	determine_response
Purpose:	Determination of the spectral response function
Used in recipes:	metis_LM_lss_std metis_N_lss_std
Input:	const hdrl_spectrum1D * input
Other inputs:	const hdrl_spectrum1D * input
Other outputs:	cpl_error_code
General description:	Determination of the instrumental response function to be used for the absolute flux calibration
Mathematical description:	see HDRL manual
Quality assessment:	Through QC parameters
Error conditions:	See [RD1].
Unit tests:	See [RD1].

7.4.8 Remove sky background

Name:	remove_sky_background
Purpose:	Remove sky background from spectra
Used in recipes:	metis_LM_lss_std metis_LM_lss_sci metis_N_lss_std metis_N_lss_sci
Input:	const hdrl_image * input
Other inputs:	None

Other outputs:	`cpl_error_code`
General description:	Removes the sky emission background (nodding/chop-nodding technique)
Mathematical description:	see [AD2], Section 1.4
Quality assessment:	Through QC parameters
Error conditions:	See [RD1].
Unit tests:	See [RD1].

7.4.9 Slit curvature detection

Name:	`slit_curvature`
Purpose:	Determines the slit curvature along the orders

Used in recipes:	`metis_LM_lss_wave`
	`metis_LM_lss_std`
	`metis_LM_lss_sci`
	`metis_N_lss_std`
	`metis_N_lss_sci`

Input:	`const hdrl_image * input`
Other inputs:	None
Other outputs:	`cpl_error_code`
General description:	Determines the tilt and shear of the orders using the sky emission lines
Mathematical description:	see [RD19] and [RD20]
Quality assessment:	Through QC parameters
Error conditions:	See [RD1].
Unit tests:	See [RD1].

7.4.10 Order trace detection

Name:	detect_order_trace
Purpose:	Determines the order traces on the detectors
Used in recipes:	metis_LM_lss_wave metis_LM_lss_std metis_LM_lss_sci metis_N_lss_std metis_N_lss_sci
Input:	const hdrl_image * input
Other inputs:	None
Other outputs:	cpl_error_code
General description:	Determines the order locations on the detectors
Mathematical description:	see [RD19] and [RD20]
Quality assessment:	Through QC parameters
Error conditions:	See [RD1].
Unit tests:	See [RD1].

7.4.11 Object extraction

Name:	extract_object
Purpose:	Extract object spectrum from 2D-spectrum
Used in recipes:	metis_LM_lss_std metis_N_lss_std metis_LM_lss_sci metis_N_lss_sci
Input:	const hdrl_image * input const hdrl_image * background hdrl_image * output
Other outputs:	cpl_error_code
General description:	Routine to extract a 1D spectrum of the target from the 2D spectrum
Mathematical description:	See optimal extraction algorithm [RD19] and [RD20]

Quality assessment:	Through QC parameters
Error conditions:	See [RD1].
Unit tests:	See [RD1].

7.4.12 Apply wavelength calibration

Name:	`apply_wavecal`
Purpose:	applies `LM_LSS_WAVE_GUESS`
Used in recipes:	`metis_LM_lss_std` `metis_LM_lss_sci`
Inputs:	`const hdrl_spectrum1D * input`
Other outputs:	`cpl_error_code`
General description:	Applies the first guess wavelength calibration to LM LSS data
Quality assessment:	Through QC parameters
Error conditions:	See [RD1].
Unit tests:	See [RD1].

7.4.13 Apply flux calibration

Name:	`apply_fluxcal`
Purpose:	applies `MASTER_LM_RESPONSE` or `MASTER_N_RESPONSE` to science frames
Used in recipes:	`metis_LM_lss_sci` `metis_N_lss_sci`
Inputs:	`const hdrl_spectrum1D * input`
Other outputs:	`cpl_error_code`
General description:	Applies the absolute flux calibration to science frames
Quality assessment:	Through QC parameters
Error conditions:	See [RD1].
Unit tests:	See [RD1].

7.4.14 Apply telluric correction

Name:	apply_tellcorr
Purpose:	applies LM_SYNTH_TRANS and N_SYNTH_TRANS to corresponding standard star spectrum (LM_LSS_STD_1D and N_LSS_STD_1D)
Used in recipes:	metis_LM_lss_sci metis_N_lss_sci
Inputs:	const hdrl_spectrum1D * input
Other outputs:	cpl_error_code
General description:	Applies a simple transmission to STD spectra better determine the response curve
Quality assessment:	Through QC parameters
Error conditions:	See [RD1].
Unit tests:	See [RD1].

7.5 ADI observing mode

7.5.1 Detect centroid in LM images

Name:	lm_adi_cgrph_centroid
Purpose:	Detect the centroid in a sequence of LM band CVC/RAVC coronographic images
Used in recipes:	metis_img_adi_cgrph
Input:	$n\times$ const hdrl_image * input
QC outputs:	QC LM cgrph FWHM nn
Outputs:	lm_cgrph_CENTROID_TAB cpl_error_code
General description:	Centroiding of source in LM band coronagraphic images
Mathematical description:	see Section 5.2
Quality assessment:	Through QC parameters
Error conditions:	See [RD1].
Unit tests:	See [RD1].

7.5.2 Detect centroid in N images

Name:	n_adi_cgrph_centroid
Purpose:	Detect the centroids in a sequence of N band CVC/RAVC coronographic images
Used in recipes:	metis_img_adi_cgrph
Input:	$n\times$ const hdrl_image * input
QC outputs:	QC N cgrph FWHM nn
Outputs:	n_cgrph_CENTROID_TAB cpl_error_code
General description:	Centroiding of source in N band coronagraphic images
Mathematical description:	see Section 5.2
Quality assessment:	Through QC parameters
Error conditions:	See [RD1].
Unit tests:	See [RD1].

7.5.3 Detect centroid in APP LM images

Name:	lm_adi_app_centroid
Purpose:	Determine the centroid in a sequence of LM band APP coronographic images
Used in recipes:	metis_lm_adi_app
Input:	$n\times$ const hdrl_image * input
QC outputs:	QC LM APP FWHM nn
Outputs:	lm_app_CENTROID_TAB cpl_error_code
General description:	Determine source location in LM band APP coronagraphic images, through the WFS-FS position and by centroiding
Mathematical description:	see Section 5.2
Quality assessment:	Through QC parameters
Error conditions:	See [RD1].
Unit tests:	See [RD1].

7.5.4 Calculate Median PSF for ADI LM band

Name:	lm_adi_cgrph_psf
Purpose:	Calculate median PSF for sequence of ADI images
Used in recipes:	metis_img_adi_cgrph
Function Parameters:	combination method (median, mean, sigma clipped...) parameters for combination method
Input:	$n\times$ const hdrl_image * input lm_cgrph_CENTROID_TAB
QC outputs:	QC det cgrph SCI FWHM nn
Outputs:	lm_cgrph_PSF_MEDIAN
Outputs:	hdrl_image * psf_median cpl_error_code
General description:	Calculation of median PSF for sequence of ADI images
Mathematical description:	see Section 5.2
Quality assessment:	Through QC parameters
Error conditions:	See [RD1].
Unit tests:	See [RD1].

7.5.5 Calculate median PSF for ADI N band

Name:	n_adi_cgrph_psf
Purpose:	Calculate median PSF for sequence of ADI images
Used in recipes:	metis_img_adi_cgrph
Function Parameters:	combination method (median, mean, sigma clipped...) parameters for combination method
Input:	$n\times$ const hdrl_image * input N_cgrph_CENTROID_TAB
QC outputs:	QC det cgrph SCI FWHM nn
Outputs:	N_cgrph_PSF_MEDIAN
Outputs:	hdrl_image * psf_median cpl_error_code

General description:	Calculation of median PSF for sequence of ADI images
Mathematical description:	see Section 5.2
Quality assessment:	Through QC parameters
Error conditions:	See [RD1].
Unit tests:	See [RD1].

7.5.6 Calculate median PSF for APP LM band

Name:	`lm_adi_app_psf`
Purpose:	Calculate median PSF for sequence of ADI images
Used in recipes:	`metis_lm_adi_app`
Function Parameters:	combination method (median, mean, sigma clipped...)
	parameters for combination method
Input:	$n\times$ `const hdrl_image * input`
	`LM_app_CENTROID_TAB`
QC outputs:	`QC det APP SCI FWHM nn`
Outputs:	`LM_APP_PSF_MEDIAN`
Outputs:	`hdrl_image * psf_median`
	`cpl_error_code`
General description:	Calculation of median PSF for sequence of ADI images
Mathematical description:	see Section 5.2
Quality assessment:	Through QC parameters
Error conditions:	See [RD1].
Unit tests:	See [RD1].

7.5.7 Merge PSFs for LM band APP image

Name:	`lm_merge_app_psf`
Purpose:	Merge the components of the PSF for an LM band APP coronagraph image
Used in recipes:	`metis_lm_adi_app`

Function Parameters:	combination method (median, mean, sigma clipped...) parameters for combination method
Input:	$n\times$ const hdrl_image * input
QC outputs:	None
Outputs:	cpl_error_code
General description:	Merge the components of the PSF for an LM band APP coronagraph image
Mathematical description:	see Section 5.2
Quality assessment:	Through QC parameters
Error conditions:	See [RD1].
Unit tests:	See [RD1].

7.5.8 Apply distortion correction

Name:	adi_regrid
Purpose:	Apply distortion correction and regrid to align images
Used in recipes:	metis_img_adi_cgrph
Function Parameters:	Resampling method parameters for resampling method
Input:	$n\times$ const hdrl_image * input det_cgrph_CENTROID_TAB det_DISTORTION_TABLE
QC outputs:	None
Output FITS files:	det_cgrph_SCI_CENTRED
Outputs:	cpl_error_code
General description:	Apply the distortion correction and align images on a sub-pixel scale
Mathematical description:	see Section 5.2
Quality assessment:	Through QC parameters
Error conditions:	See [RD1].
Unit tests:	See [RD1].

7.5.9 Regrid IFU image

Name:	ifu_adi_regrid
Purpose:	Apply distortion correction, perform square pixel reconstruction, and regrid to align images
Used in recipes:	metis_img_adi_cgrph
Function Parameters:	Resampling method
	parameters for resampling method
Input:	$n\times$ const hdrl_image * input
	det_cgrph_CENTROID_TAB
	det_DISTORTION_TABLE]]
QC outputs:	None
Output FITS files:	det_cgrph_SCI_CENTRED
Outputs:	cpl_error_code
General description:	Apply the distortion correction, perform square pixel reconstruction, and align images on a subpixel scale
Mathematical description:	see Section 5.2
Quality assessment:	Through QC parameters
Error conditions:	See [RD1].
Unit tests:	See [RD1].

7.5.10 Derotate ADI images

Name:	adi_derotate
Purpose:	Derotate a sequence of coronagraphic images
Used in recipes:	metis_img_adi_cgrph
Function Parameters: method for resampling	
Input:	$n\times$ const hdrl_image * input
QC outputs:	QC det cgrph SCI SNR MEAN
	QC det cgrph SCI SNR PEAK
Output FITS files:	det_cgrph_SCI_DEROTATED_PSFSUB

	det_cgrph_SCI_DEROTATED
Outputs:	det_cgrph_PSF_MEDIAN
General description:	derotate a sequence of ADI images
Mathematical description:	see Section 5.2
Quality assessment:	Through QC parameters
Error conditions:	See [RD1].
Unit tests:	See [RD1].

7.5.11 Calculate contrast curve for LM band

Name:	lm_adi_cgrph_contrast
Purpose:	Calculate contrast curves for a sequence of LM band coronagraphic images, for the RAVC/CVC coronagraph
Used in recipes:	metis_img_adi_cgrph
Function Parameters: None	
Input:	$n\times$ const hdrl_image * input
Other inputs:	Off-axis PSF reference
QC outputs:	QC LM cgrph SCI CONTRAST RAW LAMD QC LM cgrph SCI CONTRAST ADI LAMD
Output FITS files:	LM_cgrph_SCI_CONTRAST_RADPROF LM_cgrph_SCI_CONTRAST_ADI LM_cgrph_SCI_THROUGHPUT
Outputs:	cpl_error_code
General description:	Calculate contrast curves for a sequence of LM band coronagraphic images, for the RAVC/CVC coronagraph
Mathematical description:	see Section 5.2
Quality assessment:	Through QC parameters
Error conditions:	See [RD1].
Unit tests:	See [RD1].

7.5.12 Calculate contrast curve for N band

Name:	n_adi_cgrph_contrast
Purpose:	Calculate contrast curves for a sequence of N band coronagraphic images, for the RAVC/CVC coronagraph
Used in recipes:	metis_img_adi_cgrph
Function Parameters: None	
Input:	$n\times$ const hdrl_image * input
Other inputs:	Off-axis PSF reference
QC outputs:	QC N cgrph SCI CONTRAST RAW LAMD QC N cgrph SCI CONTRAST ADI LAMD
Output FITS files:	N_cgrph_SCI_CONTRAST_RADPROF N_cgrph_SCI_CONTRAST_ADI N_cgrph_SCI_THROUGHPUT
Outputs:	cpl_error_code
General description:	Calculate contrast curves for a sequence of N band coronagraphic images, for the RAVC/CVC coronagraph
Mathematical description:	see Section 5.2
Quality assessment:	Through QC parameters
Error conditions:	See [RD1].
Unit tests:	See [RD1].

7.5.13 Calculate contrast curve for APP LM band

Name:	lm_adi_app_contrast
Purpose:	Calculate contrast curves for a sequence of LM band coronagraphic images, for the APP coronagraph
Used in recipes:	metis_lm_adi_app
Function Parameters: None	
Input:	$n\times$ const hdrl_image * input
Other inputs:	Off-axis PSF reference

QC outputs:	QC det APP SCI CONTRAST RAW LAMD QC det APP SCI CONTRAST ADI LAMD
Output FITS files:	LM_APP_SCI_CONTRAST_RADPROF LM_APP_SCI_CONTRAST_ADI LM_APP_SCI_THROUGHPUT
Outputs:	cpl_error_code
General description:	Calculate contrast curves for a sequence of LM band coronagraphic images, for the APP coronagraph
Mathematical description:	see Section 5.2
Quality assessment:	Through QC parameters
Error conditions:	See [RD1].
Unit tests:	See [RD1].

8 DRL Data Items and Structures

This Section describes the C Data Items and Data Structures that represent inside the C code the FITS input and output files of the recipes. METIS follows the approach by MATISSE [RD27], as suggested by the Dataflow for ESO Observatories Deliverables Standard [AD5]. The conversion between data structures and Flexible Image Transport System (FITS) files and vice versa will be implemented using the abstractions provided by CPL and HDRL.

Clarification of the terms used (see also [RD18]):

- `cpl_propertylist`: Key-value pairs like FITS headers.
- `cpl_image`: Representation of an image using two arrays of pixels: data, and bad pixels.
- `cpl_imagelist`: List of `cpl_images`.
- `cpl_table`: Tabular data like a catalog.
- `hdrl_image`: Higher level image, with three pixel arrays per image: data, uncertainty, and data quality. The `hdrl_image` will be used as primary structures to contain image data, because the three pixel arrays map very well to the imaging file formats.
- `hdrl_imagelist`: List of `hdrl_images`.
- `*`: Pointer to a single instance of a type.
- `**`: Pointer to a list of instances of a type (actually, a pointer to a list of pointers each pointing to a single instance).

E.g.

- `cpl_propertylist * keywords: Primary keywords:` a pointer to the `cpl_propertylist` that holds the FITS headers of the primary extension,
- `cpl_propertylist ** extkeywords: Extension keywords`: a pointer to a list of pointers to `cpl_propertylist` instances that hold the FITS headers for each extension,
- `hdrl_image * image: Image`: a pointer to a `hdrl_image` instance holding the one image (for the central detector, or spanning all detectors) of this structure,
- `hdrl_imagelist * images: Images`: a pointer to a `hdrl_imagelist` instance holding all the images (one for each detector) of this structure.

There are Data Reduction Library (DRL) functions for creating, deleting, saving and loading data for each DRL data structure when applicable (Sections 7.2, 7.3, and 7.4).

8.1 Static and external calibration database data items

Static calibrations are data which are updated very rarely only and stay static the most of the time or arise from external sources. The first data are created by specific calibration recipes invoked only once in a while (e.g. the detector linearity and gain determination section 6.1.1). External data either created individually for each frame by ESO as in case of the PERSISTENCE_MAP, or taken from external databases (e.g. HITRAN in case of the ATM_LINE_CAT).

8.1.1 General calibration database item structures

This section describes items of the static calibration database, which are used in all/more than one, the Imaging Mode (IMG) and the LSS pipelines. This concerns mainly the detector calibration files.

8.1.1.1 GAIN_MAP_det

FITS file structure:

Name:	GAIN_MAP_det
Description:	Gain map
PRO.CATG:	GAIN_MAP_det
OCA keywords:	PRO.CATG
DO.CATG:	GAIN_MAP_det
Created by recipe:	metis_det_lingain
Input for:	metis_LM_lss_rsrf metis_LM_lss_trace metis_LM_lss_wave metis_LM_lss_std metis_LM_lss_sci metis_N_lss_rsrf metis_N_lss_trace metis_N_lss_std metis_N_lss_sci metis_img_chophome metis_lm_adc_slitloss metis_n_adc_slitloss
Processing FITS Keywords:	provided at Preliminary Acceptance Europe (PAE)
Purpose:	Correcting for differences in gain.

Corresponding CPL structure:

1. cpl_propertylist * keywords: Primary keywords (PRO.CATG, PRO.TECH, DET.ID)
2. hdrl_image ** image: Images image
3. cpl_propertylist * plistarray[]: Extension keywords

8.1.1.2 BADPIX_MAP_det

FITS file structure:

Name:	BADPIX_MAP_det
Description:	Bad pixel map. Also contains detector masks.
PRO.CATG:	BADPIX_MAP_det
OCA keywords:	PRO.CATG
DO.CATG:	BADPIX_MAP_det
Created by recipe:	metis_det_lingain metis_ifu_rsrf metis_det_dark metis_lm_img_flat metis_n_img_flat
Input for:	metis_ifu_wavecal metis_ifu_rsrf metis_ifu_std_process metis_ifu_sci_process metis_lm_img_flat metis_lm_img_sci_postprocess metis_lm_img_distortion metis_n_img_flat metis_n_img_chopnod metis_n_img_distortion metis_LM_lss_rsrf metis_LM_lss_trace metis_LM_lss_wave

		metis_LM_lss_std metis_LM_lss_sci metis_N_lss_rsrf metis_N_lss_trace metis_N_lss_std metis_N_lss_sci metis_img_chophome metis_lm_adc_slitloss metis_n_adc_slitloss
Processing Keywords:	FITS	provided at PAE

Corresponding CPL structure:

1. cpl_propertylist * keywords: Primary keywords (PRO.CATG
2. cpl_image ** image: one image per detector with only the data quality layer in use
3. cpl_propertylist * plistarray[]: Extension keywords

8.1.1.3 BADPIX_MAP_2RG See BADPIX_MAP_det.

8.1.1.4 BADPIX_MAP_GEO See BADPIX_MAP_det.

8.1.1.5 BADPIX_MAP_IFU See BADPIX_MAP_det.

8.1.1.6 LINEARITY_det

FITS file structure:

Name:	LINEARITY_det
Description:	Coefficients for the pixel non-linearity correction
PRO.CATG:	LINEARITY_det
OCA keywords:	PRO.CATG
DO.CATG:	LINEARITY_det

Created by recipe:	metis_det_lingain
Input for:	metis_det_dark metis_LM_lss_rsrf metis_LM_lss_trace metis_LM_lss_wave metis_LM_lss_std metis_LM_lss_sci metis_N_lss_rsrf metis_N_lss_trace metis_N_lss_std metis_N_lss_sci metis_img_chophome metis_lm_adc_slitloss metis_n_adc_slitloss
Processing FITS Keywords:	provided at PAE

Corresponding CPL structure:

1. cpl_propertylist * keywords: Primary keywords (PRO.CATG
2. hdrl_image ** image: list of images with coefficients for the non-linearity correction
3. cpl_propertylist ** plistarray[]: Extension keywords

8.1.1.7 MASTER_DARK_det

Depending on context, a MASTER_DARK_det can refer to either a

1. MASTER_DARK_GEO
2. MASTER_DARK_2RG
3. MASTER_DARK_IFU

8.1.1.8 MASTER_DARK_2RG

FITS file structure:

Name:	MASTER_DARK_2RG

Description:	Master dark frame for LM detector data
PRO.CATG:	MASTER_DARK_2RG
OCA keywords:	PRO.CATG
DO.CATG:	MASTER_DARK_2RG
Created by:	metis_det_dark
Input for:	metis_lm_img_flat metis_lm_img_basic_reduce metis_LM_lss_rsrf metis_LM_lss_trace metis_LM_lss_wave metis_LM_lss_std metis_LM_lss_sci metis_img_chophome metis_lm_adc_slitloss metis_lm_img_basic_reduce
Processing FITS Keywords:	provided at PAE

Corresponding CPL structure:

1. cpl_propertylist * keywords: Primary keywords (DPR.CATG, DPR.TECH, DPR.TYPE, INS.OPTI3.NAME, INS.OPTI9.NAME, INS.OPTI10.NAME)
2. hdrl_image * image: Single image
3. cpl_propertylist * plistarray[]: Extension keywords

8.1.1.9 MASTER_DARK_GEO

FITS file structure:

Name:	MASTER_DARK_GEO
Description:	Master dark frame for N detector data

PRO.CATG:	MASTER_DARK_GEO
OCA keywords:	PRO.CATG
DO.CATG:	MASTER_DARK_GEO
Created by:	metis_det_dark
Input for:	metis_n_img_flat metis_N_lss_rsrf metis_N_lss_trace metis_N_lss_std metis_N_lss_sci metis_n_adc_slitloss
Processing FITS Keywords:	provided at PAE

Corresponding CPL structure:

1. cpl_propertylist * keywords: Primary keywords (DPR.CATG, DPR.TECH, DPR.TYPE, INS.OPTI3.NAME, INS.OPTI9.NAME, INS.OPTI10.NAME)
2. hdrl_image * image: Single image
3. cpl_propertylist * plistarray[]: Extension keywords

8.1.2 IFU calibration database item structures

8.1.2.1 RSRF_IFU

FITS file structure:

Name:	RSRF_IFU
Description:	2D relative spectral response function
PRO.CATG:	RSRF_IFU
OCA keywords:	PRO.CATG
DO.CATG:	RSRF_IFU
Created by:	metis_ifu_rsrf

Input for:	metis_ifu_std_process metis_ifu_sci_process
Processing FITS Keywords:	provided at PAE

Corresponding CPL structure:

1. cpl_propertylist * keywords: Primary keywords (PRO.CATG)
2. hdrl_image ** image: Four images with spectral response of each pixel
3. cpl_propertylist ** plistarray[]: Extension keywords

8.1.3 IMG calibration database item structures

8.1.3.1 det_DISTORTION_TABLE Depending on context, a det_DISTORTION_TABLE can refer to either a

1. N_DISTORTION_TABLE
2. LM_DISTORTION_TABLE
3. IFU_DISTORTION_TABLE

8.1.3.2 LM_DISTORTION_TABLE

FITS TABLE file structure:

Name:	LM_DISTORTION_TABLE
Description:	Table of distortion information
PRO.CATG:	LM_DISTORTION_TABLE
OCA keywords:	PRO.CATG
DO.CATG:	LM_DISTORTION_TABLE
Created by:	metis_lm_img_distortion
Input for:	metis_lm_img_calibrate metis_img_adi_cgrph

		metis_lm_adi_app
Processing Keywords:	FITS	provided at PAE

8.1.3.3 LM_DISTORTION_TABLE

Corresponding CPL structure:

1. cpl_propertylist * keywords: Primary keywords (DPR.CATG, DPR.TECH, DPR.TYPE, INS.OPTI3.NAME, INS.OPTI9.NAME, INS.OPTI10.NAME)
2. cpl_table * table
3. cpl_propertylist * plistarray[]: Extension keywords

8.1.3.4 N_DISTORTION_TABLE

FITS TABLE file structure:

Name:		N_DISTORTION_TABLE
Description:		Table of distortion information
PRO.CATG:		N_DISTORTION_TABLE
OCA keywords:		PRO.CATG
DO.CATG:		N_DISTORTION_TABLE
Created by:		metis_n_img_distortion
Input for:		metis_n_img_calibrate
		metis_img_adi_cgrph
Processing Keywords:	FITS	provided at PAE

8.1.3.5 N_DISTORTION_TABLE

Corresponding CPL structure:

1. cpl_propertylist * keywords: Primary keywords (DPR.CATG, DPR.TECH, DPR.TYPE, INS.OPTI3.NAME, INS.OPTI9.NAME, INS.OPTI10.NAME)
2. cpl_table * table: Tables
3. cpl_propertylist * plistarray[]: Extension keywords

8.1.3.6 det_DISTORTION_MAP

Depending on context, a det_DISTORTION_MAP can refer to either a

1. N_DISTORTION_MAP
2. LM_DISTORTION_MAP

8.1.3.7 LM_DISTORTION_MAP

FITS IMAGE file structure:

Name:	LM_DISTORTION_MAP
Description:	Map of pixel scale across the detector
PRO.CATG:	LM_DISTORTION_MAP
OCA keywords:	PRO.CATG
DO.CATG:	LM_DISTORTION_MAP
Created by:	metis_lm_img_distortion
Processing FITS Keywords:	provided at PAE

8.1.3.8 LM_DISTORTION_MAP

Corresponding CPL structure:

1. cpl_propertylist * keywords: Primary keywords (DPR.CATG, DPR.TECH, DPR.TYPE, INS.OPTI3.NAME, INS.OPTI9.NAME, INS.OPTI10.NAME)
2. cpl_image * map
3. cpl_propertylist * plistarray[]: Extension keywords

8.1.3.9 N_DISTORTION_MAP

FITS IMAGE file structure:

Name:	N_DISTORTION_MAP
Description:	Map of pixel scale across the detector
PRO.CATG:	N_DISTORTION_MAP
OCA keywords:	PRO.CATG
DO.CATG:	N_DISTORTION_MAP
Created by:	metis_n_img_distortion
Processing FITS Keywords:	provided at PAE

8.1.3.10 N_DISTORTION_MAP

Corresponding CPL structure:

1. cpl_propertylist * keywords: Primary keywords (DPR.CATG, DPR.TECH, DPR.TYPE, INS.OPTI3.NAME, INS.OPTI9.NAME, INS.OPTI10.NAME)
2. cpl_image * map
3. cpl_propertylist * plistarray[]: Extension keywords

8.1.3.11 FLUXSTD_CATALOG

FITS file structure:

Name:	FLUXSTD_CATALOG
Description:	Catalog of standard stars
PRO.CATG:	FLUXSTD_CATALOG
OCA keywords:	None
DO.CATG:	FLUXSTD_CATALOG
Input for:	metis_lm_img_std_process metis_n_img_std_process

8.1.3.12 PINHOLE_TABLE

FITS file structure:

Name:	PINHOLE_TABLE
Description:	Table of pinhole locations.
PRO.CATG:	PINHOLE_TABLE
OCA keywords:	PRO.CATG
DO.CATG:	PINHOLE_TABLE
Used in recipes:	metis_lm_img_distortion metis_n_img_distortion
Processing FITS Keywords:	provided at PAE

Corresponding CPL structure:

1. cpl_propertylist * keywords: Primary keywords (PRO.CATG)
2. hdrl_table * image: table with pinhole locations
3. cpl_propertylist * plistarray[]: Extension keywords

8.1.3.13 FLUXCAL_TAB

FITS file structure:

Name:	FLUXCAL_TAB
Description:	Conversion between instrumental and physical flux units.
PRO.CATG:	FLUXCAL_TAB
OCA keywords:	PRO.CATG
DO.CATG:	FLUXCAL_TAB
Input for:	metis_ifu_sci_process metis_lm_img_calibrate metis_n_img_calibrate
Produced by recipe:	metis_lm_img_std_process metis_n_img_std_process metis_ifu_std_process
Processing FITS Keywords:	provided at PAE

Corresponding CPL structure:

1. cpl_propertylist * keywords: Primary keywords (PRO.CATG)
2. hdrl_table * table: table
3. cpl_propertylist * plistarray[]: Extension keywords

8.1.4 LSS calibration database item structures

External calibration data

8.1.4.1 PERSISTENCE_MAP

FITS file structure:

Name:	PERSISTENCE_MAP
Description:	Persistence map
PRO.CATG:	PERSISTENCE_MAP

OCA keywords:	PRO.CATG
DO.CATG:	PERSISTENCE_MAP
Source:	created by ESO with recipe metis_det_persistence
Input for:	metis_det_dark metis_LM_lss_rsrf metis_LM_lss_trace metis_LM_lss_wave metis_LM_lss_std metis_LM_lss_sci metis_N_lss_rsrf metis_N_lss_trace metis_N_lss_std metis_N_lss_sci metis_img_chophome metis_lm_adc_slitloss metis_n_adc_slitloss
Processing FITS Keywords:	provided at PAE
Purpose:	removal of persistence patterns

Corresponding CPL structure:

1. cpl_propertylist * keywords: Primary keywords (PRO.CATG, PRO.TECH, DET.ID)
2. hdrl_image * image: Single image
3. cpl_propertylist * plistarray[]: Extension keywords

8.1.4.2 ATM_LINE_CAT

FITS file structure:

Name:	ATM_LINE_CAT
Description:	Line list of atmospheric emission and absorption lines

PRO.CATG:	ATM_LINE_CAT
OCA keywords:	PRO.CATG
DO.CATG:	ATM_LINE_CAT
Source:	HITRAN database (https://hitran.org/)
Input for:	metis_LM_lss_std metis_LM_lss_sci metis_LM_lss_mf_model metis_LM_lss_mf_calctrans metis_N_lss_std metis_N_lss_sci metis_N_lss_mf_model metis_N_lss_mf_calctrans
Processing FITS Keywords:	provided at PAE
Purpose:	wavelength calibration sky emission removal telluric correction

Corresponding CPL structure:

1. cpl_propertylist * keywords: Primary keywords (PRO.CATG)
2. cpl_table * table: Tables
3. cpl_propertylist * plistarray[]: Extension keywords

8.1.4.3 AO_PSF_MODEL

FITS file structure:

Name:	AO_PSF_MODEL
Description:	Model of the AO induced PSF
PRO.CATG:	AO_PSF_MODEL
OCA keywords:	PRO.CATG

DO.CATG:	AO_PSF_MODEL
Source:	PSF modelling
Input for:	metis_LM_lss_std metis_N_lss_std
Processing FITS Keywords:	provided at PAE
Purpose:	flux calibration

Corresponding CPL structure:

1. cpl_propertylist * keywords: Primary keywords (PRO.CATG)
2. hdrl_imagelist * image: Three image layers (data, error, mask)
3. cpl_propertylist * plistarray[]: Extension keywords

8.1.4.4 ATM_PROFILE

FITS file structure:

Name:	ATM_PROFILE
Description:	atmospheric profile containing height information on temperature, pressure and molecular abundances
PRO.CATG:	ATM_PROFILE
OCA keywords:	PRO.CATG
DO.CATG:	ATM_PROFILE
Source:	Taken from https://eodg.atm.ox.ac.uk/RFM/atm/
Input for:	metis_ifu_tellcorr metis_LM_lss_mf_model metis_LM_lss_mf_calctrans metis_N_lss_mf_model metis_N_lss_mf_calctrans
Comment:	Currently the equ.atm is standard. Refinement with data from L-HATPRO radiometer desired.

Processing FITS Keywords:	provided at PAE
Purpose:	telluric correction

Corresponding CPL structure:

1. cpl_propertylist * keywords: Primary keywords (PRO.CATG)
2. cpl_table * table: Tables
3. cpl_propertylist * plistarray[]: Extension keywords

Static calibration data

8.1.4.5 LASER_TAB

FITS file structure:

Name:	LASER_TAB
Description:	Line list of the WCU laser sources
PRO.CATG:	LASER_TAB
OCA keywords:	PRO.CATG
DO.CATG:	LASER_TAB
Source:	Lab measurements during AIT phase
Input for:	metis_LM_lss_wave
Processing FITS Keywords:	provided at PAE
Purpose:	wavelength calibration

Corresponding CPL structure:

1. cpl_propertylist * keywords: Primary keywords (PRO.CATG)
2. cpl_table * table: Tables
3. cpl_propertylist * plistarray[]: Extension keywords

8.1.4.6 REF_STD_CAT

FITS file structure:

Name:	REF_STD_CAT
Description:	Catalogue of flux standard stars (reference spectra)
PRO.CATG:	REF_STD_CAT
OCA keywords:	PRO.CATG
DO.CATG:	REF_STD_CAT
Source:	most probably same as CRyogenic high-resolution InfraRed Echelle Spectrograph (CRIRES) and VLT Imager and Spectrometer for mid Infrared (VISIR); see also [RD6]
Input for:	metis_LM_lss_std metis_N_lss_std
Processing FITS Keywords:	provided at PAE
Purpose:	flux calibration

Corresponding CPL structure:

1. cpl_propertylist * keywords: Primary keywords (PRO.CATG)
2. cpl_table * table: Tables
3. cpl_propertylist * plistarray[]: Extension keywords

8.1.4.7 LM_ADC_SLITLOSS

FITS file structure:

Name:	LM_ADC_SLITLOSS
Description:	Table of the LM-band slitlosses as function of the object position across the slit
PRO.CATG:	LM_ADC_SLITLOSS
OCA keywords:	PRO.CATG
DO.CATG:	LM_ADC_SLITLOSS

Source:	recipe metis_lm_adc_slitloss (see Section 6.8.3 and [RD6])
Input for:	metis_LM_lss_std metis_LM_lss_sci
Processing FITS Keywords:	provided at PAE
Purpose:	flux calibration

Corresponding CPL structure:

1. cpl_propertylist * keywords: Primary keywords (PRO.CATG)
2. cpl_table * table: Tables
3. cpl_propertylist * plistarray[]: Extension keywords

8.1.4.8 N_ADC_SLITLOSS

FITS file structure:

Name:	N_ADC_SLITLOSS
Description:	Table of the N-band slitlosses as function of the object position across the slit
PRO.CATG:	N_ADC_SLITLOSS
OCA keywords:	PRO.CATG
DO.CATG:	N_ADC_SLITLOSS
Source:	recipe metis_n_adc_slitloss (see Section 6.8.3 and [RD6])
Input for:	metis_N_lss_std metis_N_lss_sci
Processing FITS Keywords:	provided at PAE
Purpose:	flux calibration

Corresponding CPL structure:

1. `cpl_propertylist * keywords:` Primary keywords (PRO.CATG)
2. `cpl_table * table:` Tables
3. `cpl_propertylist * plistarray[]:` Extension keywords

8.1.4.9 LSF_KERNEL

FITS file structure:

Name:	LSF_KERNEL
Description:	Wavelength dependent model of the LSF
PRO.CATG:	LSF_KERNEL
OCA keywords:	PRO.CATG
DO.CATG:	LSF_KERNEL
Source:	Determined during AIT phase and commissioning
Input for:	metis_ifu_sci_process metis_ifu_tellcorr metis_LM_lss_mf_model metis_LM_lss_mf_calctrans metis_N_lss_mf_model metis_N_lss_mf_calctrans
Processing FITS Keywords:	provided at PAE
Purpose:	telluric correction

Corresponding CPL structure:

1. `cpl_propertylist * keywords:` Primary keywords (PRO.CATG)
2. `cpl_table * table:` Tables
3. `cpl_propertylist * plistarray[]:` Extension keywords

8.1.4.10 N_LSS_DIST_SOL

FITS file structure:

Name:	N_LSS_DIST_SOL
Description:	N-band geometrical distortion solution
PRO.CATG:	N_LSS_DIST_SOL
OCA keywords:	PRO.CATG
DO.CATG:	N_LSS_DIST_SOL
Source:	Determined during AIT phase with N-band laser sources
Input for:	metis_N_lss_std metis_N_lss_sci
Processing FITS Keywords:	provided at PAE
Purpose:	wavelength calibration / rectification

Corresponding CPL structure:

1. cpl_propertylist * keywords: Primary keywords (PRO.CATG)
2. cpl_table * table: Tables
3. cpl_propertylist * plistarray[]: Extension keywords

8.1.4.11 N_LSS_WAVE_GUESS

FITS file structure:

Name:	N_LSS_WAVE_GUESS
Description:	First guess of the N-band wavelength solution
PRO.CATG:	N_LSS_WAVE_GUESS
OCA keywords:	PRO.CATG
DO.CATG:	N_LSS_WAVE_GUESS
Source:	During AIT phase N-band laser sources will be available to create the first guess of the wavelength solution
Input for:	metis_N_lss_std

	metis_N_lss_sci
Processing Keywords:	FITS provided at PAE
Purpose:	wavelength calibration

Corresponding CPL structure:

1. cpl_propertylist * keywords: Primary keywords (PRO.CATG)
2. cpl_table * table: Tables
3. cpl_propertylist * plistarray[]: Extension keywords

8.1.4.12 LM_SYNTH_TRANS

FITS file structure:

Name:	LM_SYNTH_TRANS
Description:	Synthetic transmission curve to be used for telluric correction of flux standard stars
PRO.CATG:	LM_SYNTH_TRANS
OCA keywords:	PRO.CATG
DO.CATG:	LM_SYNTH_TRANS
Source:	Calculated by molecfit with averaged parameters
Input for:	metis_LM_lss_std
Processing Keywords:	FITS provided at PAE
Purpose:	telluric correction of flux standard stars

Corresponding CPL structure:

1. cpl_propertylist * keywords: Primary keywords (PRO.CATG)
2. hdrl_spectrum1D * spectrum: Spectrum
3. cpl_propertylist * plistarray[]: Extension keywords

8.1.4.13 N_SYNTH_TRANS

FITS file structure:

Name:	N_SYNTH_TRANS
Description:	Synthetic transmission curve to be used for telluric correction of flux standard stars
PRO.CATG:	N_SYNTH_TRANS
OCA keywords:	PRO.CATG
DO.CATG:	N_SYNTH_TRANS
Source:	Calculated by molecfit with averaged parameters
Input for:	metis_N_lss_std
Processing FITS Keywords:	provided at PAE
Purpose:	telluric correction of flux standard stars

Corresponding CPL structure:

1. cpl_propertylist * keywords: Primary keywords (PRO.CATG)
2. hdrl_spectrum1D * spectrum: Spectrum
3. cpl_propertylist * plistarray[]: Extension keywords

8.2 IFU mode data items

8.2.1 Raw data item structures

8.2.1.1 IFU_WAVE_RAW

FITS file structure:

Name:	IFU_WAVE_RAW
Description:	Raw exposure of the WCU laser sources through the IFU to achieve the first guess of the wavelength calibration.
DPR.CATG:	CALIB
DPR.TECH:	IFU

DPR.TYPE:	WAVE
OCA keywords:	DPR.CATG, DPR.TECH, DPR.TYPE, INS.OPTI3.NAME, INS.OPTI9.NAME, INS.OPTI10.NAME
DO.CATG:	IFU_WAVE_RAW
Template:	METIS_ifu_cal_InternalWave
Input for:	metis_ifu_wavecal
Processing FITS Keywords:	provided at PAE

Corresponding CPL structure:

1. cpl_propertylist * keywords: Primary keywords (DPR.CATG, DPR.TECH, DPR.TYPE, INS.OPTI3.NAME, INS.OPTI9.NAME, INS.OPTI10.NAME)
2. hdrl_image ** image: Four images
3. cpl_propertylist * plistarray[]: Extension keywords

8.2.1.2 IFU_RSRF_RAW

FITS file structure:

Name:	IFU_RSRF_RAW
Description:	Raw flats taken with black-body calibration lamp.
DPR.CATG:	CALIB
DPR.TECH:	IFU
DPR.TYPE:	RSRF
OCA keywords:	DPR.CATG, DPR.TECH, DPR.TYPE, INS.OPTI3.NAME, INS.OPTI9.NAME, INS.OPTI10.NAME
DO.CATG:	IFU_RSRF_RAW
Template:	METIS_ifu_cal_rsrf
Input for recipe:	metis_ifu_rsrf

Processing FITS Keywords:	provided at PAE

Corresponding CPL structure:

1. cpl_propertylist * keywords: Primary keywords (DPR.CATG, DPR.TECH, DPR.TYPE, INS.OPTI3.NAME, INS.OPTI9.NAME, INS.OPTI10.NAME)
2. hdrl_image ** image: Four images
3. cpl_propertylist * plistarray[]: Extension keywords

8.2.1.3 IFU_DISTORTION_RAW

FITS file structure:

Name:	IFU_DISTORTION_RAW
Description:	Images of multi-pinhole mask.
DPR.CATG:	CALIB
DPR.TECH:	IFU
DPR.TYPE:	DISTORTION
OCA keywords:	DPR.CATG, DPR.TECH, DPR.TYPE, INS.OPTI3.NAME, INS.OPTI9.NAME, INS.OPTI10.NAME
DO.CATG:	IFU_DISTORTION_RAW
Template:	METIS_ifu_cal_distortion
Input for recipe:	metis_ifu_distortion
Processing FITS Keywords:	provided at PAE

Corresponding CPL structure:

1. cpl_propertylist * keywords: Primary keywords (DPR.CATG, DPR.TECH, DPR.TYPE, INS.OPTI3.NAME, INS.OPTI9.NAME, INS.OPTI10.NAME)
2. hdrl_image ** image: Four images
3. cpl_propertylist * plistarray[]: Extension keywords

8.2.1.4 IFU_STD_RAW

FITS file structure:

Name:	IFU_STD_RAW
Description:	Raw spectra of flux standard star.
DPR.CATG:	CALIB
DPR.TECH:	IFU
DPR.TYPE:	STD
OCA keywords:	DPR.CATG, DPR.TECH, DPR.TYPE, INS.OPTI3.NAME, INS.OPTI9.NAME, INS.OPTI10.NAME
DO.CATG:	IFU_STD_RAW
Template:	METIS_ifu_cal_standard
Input for recipe:	metis_ifu_std_process
Processing FITS Keywords:	provided at PAE

Corresponding CPL structure:

1. cpl_propertylist * keywords: Primary keywords (DPR.CATG, DPR.TECH, DPR.TYPE, INS.OPTI3.NAME, INS.OPTI9.NAME, INS.OPTI10.NAME)
2. hdrl_image ** image: Four images for each nod/offset position
3. cpl_propertylist * plistarray[]: Extension keywords

8.2.1.5 IFU_SCI_RAW

FITS file structure:

Name:	IFU_SCI_RAW
Description:	IFU raw exposure of a science object.
DPR.CATG:	SCIENCE
DPR.TECH:	IFU
DPR.TYPE:	OBJECT
OCA keywords:	DPR.CATG, DPR.TECH, DPR.TYPE, INS.OPTI3.NAME, INS.OPTI9.NAME, INS.OPTI10.NAME, INS.OPTI11.NAME
DO.CATG:	IFU_SCI_RAW
Templates:	METIS_ifu_obs_FixedSkyOffset METIS_ifu_obs_GenericOffset METIS_ifu_ext_obs_FixedSkyOffset METIS_ifu_ext_obs_GenericOffset METIS_ifu_vc_obs_FixedSkyOffset METIS_ifu_ext_vc_obs_FixedSkyOffset METIS_ifu_app_obs_Stare METIS_ifu_ext_app_obs_Stare METIS_ifu_cal_psf
Input for recipe:	metis_ifu_sci_process
Processing FITS Keywords:	provided at PAE

Corresponding CPL structure:

1. cpl_propertylist * keywords: Primary keywords (DPR.CATG, DPR.TECH, DPR.TYPE, INS.OPTI3.NAME, INS.OPTI9.NAME, INS.OPTI10.NAME, INS.OPTI11.NAME)
2. hdrl_image ** image: Four images for each nodding/offset position
3. cpl_propertylist * plistarray[]: Extension keywords

8.2.1.6 IFU_SKY_RAW

FITS file structure:

Name:	IFU_SKY_RAW
Description:	Blank sky exposure, optional.
DPR.CATG:	CALIB
DPR.TECH:	IFU
DPR.TYPE:	SKY
OCA keywords:	DPR.CATG, DPR.TECH, DPR.TYPE, INS.OPTI3.NAME, INS.OPTI9.NAME, INS.OPTI10.NAME, INS.OPTI11.NAME
DO.CATG:	IFU_SKY_RAW
Templates:	METIS_ifu_obs_FixedSkyOffset METIS_ifu_obs_GenericOffset METIS_ifu_ext_obs_FixedSkyOffset METIS_ifu_ext_obs_GenericOffset METIS_ifu_vc_obs_FixedSkyOffset METIS_ifu_ext_vc_obs_FixedSkyOffset METIS_ifu_app_obs_Stare METIS_ifu_ext_app_obs_Stare METIS_ifu_cal_psf
Input for recipe:	metis_ifu_sci_process
Processing FITS Keywords:	provided at PAE

Corresponding CPL structure:

1. cpl_propertylist * keywords: Primary keywords (DPR.CATG, DPR.TECH, DPR.TYPE, INS.OPTI3.NAME, INS.OPTI9.NAME, INS.OPTI10.NAME, INS.OPTI11.NAME)
2. hdrl_image ** image: Four images for each nodding/offset position
3. cpl_propertylist * plistarray[]: Extension keywords

8.2.2 Master calibration / intermediate data item structures

8.2.2.1 MASTER_DARK_IFU

FITS file structure:

Name:	MASTER_DARK_IFU
Description:	Master dark frame for IFU detector data
PRO.CATG:	MASTER_DARK_IFU
OCA keywords:	PRO.CATG
DO.CATG:	MASTER_DARK_IFU
Created by:	metis_det_dark
Input for recipes:	metis_ifu_rsrf metis_ifu_wavecal metis_ifu_std_process metis_ifu_sci_process
Processing FITS Keywords:	provided at PAE

Corresponding CPL structure:

1. cpl_propertylist * keywords: Primary keywords (DPR.CATG, DPR.TECH, DPR.TYPE, INS.OPTI3.NAME, INS.OPTI9.NAME, INS.OPTI10.NAME)
2. hdrl_image * image: Single image
3. cpl_propertylist * plistarray[]: Extension keywords

8.2.2.2 MASTER_FLAT_IFU

FITS file structure:

Name:	MASTER_FLAT_IFU
Description:	Master flat frame for IFU image data

DO.CATG:	MASTER_FLAT_IFU
PRO.CATG:	MASTER_FLAT_IFU
OCA keywords:	PRO.CATG
Created by:	metis_ifu_rsrf
Input for recipes:	None
Processing FITS Keywords:	provided at PAE

Corresponding CPL structure:

1. cpl_propertylist * keywords: Primary keywords (PRO.CATG)
2. hdrl_image * image: Four images
3. cpl_propertylist * plistarray[]: Extension keywords

8.2.2.3 IFU_WAVECAL

FITS file structure:

Name:	IFU_WAVECAL
Description:	Image with wavelength at each pixel.
PRO.CATG:	IFU_WAVECAL
OCA keywords:	PRO.CATG
DO.CATG:	IFU_WAVECAL
Created by:	metis_ifu_wavecal
Input for:	metis_ifu_rsrf metis_ifu_std_process metis_ifu_sci_process
Processing FITS Keywords:	provided at PAE

Corresponding CPL structure:

1. cpl_propertylist * keywords: Primary keywords (PRO.CATG)
2. hdrl_image ** image: Four images with wavelength of each pixel
3. cpl_propertylist ** plistarray[]: Extension keywords

8.2.2.4 IFU_STD_BACKGROUND_CUBE

FITS file structure:

Name:	IFU_STD_BACKGROUND_CUBE
Description:	A rectified spectral cube of the background with a linear wavelength grid.
PRO.CATG:	IFU_STD_BACKGROUND_CUBE
OCA keywords:	PRO.CATG
DO.CATG:	IFU_STD_BACKGROUND_CUBE
Created by:	metis_ifu_std_process
Processing FITS Keywords:	provided at PAE

Corresponding CPL structure:

1. cpl_propertylist * keywords: Primary keywords (PRO.CATG)
2. hdrl_imagelist * image: Spectral cube
3. cpl_propertylist * plistarray[]: Extension keywords

8.2.2.5 IFU_STD_REDUCED_CUBE

FITS file structure:

Name:	IFU_STD_REDUCED_CUBE
Description:	Reduced 2D detector image of spectroscopic flux standard star.

PRO.CATG:	IFU_STD_REDUCED_CUBE
OCA keywords:	PRO.CATG
DO.CATG:	IFU_STD_REDUCED_CUBE
Created by:	metis_ifu_std_process
Processing FITS Keywords:	provided at PAE

Corresponding CPL structure:

1. cpl_propertylist * keywords: Primary keywords (PRO.CATG)
2. hdrl_image ** image: Four images
3. cpl_propertylist ** plistarray[]: Extension keywords

8.2.2.6 IFU_STD_TELLURIC_1D

FITS file structure:

Name:	IFU_STD_TELLURIC_1D
Description:	Spectrum of telluric standard star.
PRO.CATG:	IFU_STD_TELLURIC_1D
OCA keywords:	PRO.CATG
DO.CATG:	IFU_STD_TELLURIC_1D
Created by:	metis_ifu_std_process
Processing FITS Keywords:	provided at PAE

Corresponding CPL structure:

1. cpl_propertylist * keywords: Primary keywords (PRO.CATG)
2. cpl_table * image: table
3. cpl_propertylist * plistarray[]: Extension keywords

8.2.2.7 IFU_STD_REDUCED_1D

FITS file structure:

Name:	IFU_STD_REDUCED_1D
Description:	Spectrum of a reduced telluric standard star.
PRO.CATG:	IFU_STD_REDUCED_1D
OCA keywords:	PRO.CATG
DO.CATG:	IFU_STD_REDUCED_1D
Created by:	metis_ifu_std_process
Processing FITS Keywords:	provided at PAE

Corresponding CPL structure:

1. cpl_propertylist * keywords: Primary keywords (PRO.CATG)
2. cpl_table * image: table
3. cpl_propertylist * plistarray[]: Extension keywords

8.2.3 Final data item structures

8.2.3.1 IFU_SCI_REDUCED

FITS file structure:

Name:	IFU_SCI_REDUCED
Description:	Reduced 2D detector image of science object.
PRO.CATG:	IFU_SCI_REDUCED
OCA keywords:	PRO.CATG
DO.CATG:	IFU_SCI_REDUCED
Created by:	metis_ifu_sci_process
Input for:	metis_ifu_adi_cgrph
Processing FITS Keywords:	provided at PAE

Corresponding CPL structure:

1. cpl_propertylist * keywords: Primary keywords (PRO.CATG)
2. hdrl_image ** image: Four images
3. cpl_propertylist ** plistarray[]: Extension keywords

8.2.3.2 IFU_SCI_BACKGROUND

FITS file structure:

Name:	IFU_SCI_BACKGROUND
Description:	Reduced 2D detector image of background.
PRO.CATG:	IFU_SCI_BACKGROUND
OCA keywords:	PRO.CATG
DO.CATG:	IFU_SCI_BACKGROUND
Created by:	metis_ifu_sci_process
Processing FITS Keywords:	provided at PAE

Corresponding CPL structure:

1. cpl_propertylist * keywords: Primary keywords (PRO.CATG)
2. hdrl_image ** image: Four images
3. cpl_propertylist ** plistarray[]: Extension keywords

8.2.3.3 IFU_SCI_REDUCED_TAC

FITS file structure:

Name:	IFU_SCI_REDUCED_TAC
Description:	Reduced and telluric absorption corrected 2D detector image of science object.
PRO.CATG:	IFU_SCI_REDUCED_TAC

OCA keywords: PRO.CATG
DO.CATG: IFU_SCI_REDUCED_TAC

Created by: metis_ifu_sci_process
metis_ifu_tellcorr
Input for: metis_ifu_sci_postprocess
Processing FITS Keywords: provided at PAE

Corresponding CPL structure:

1. cpl_propertylist * keywords: Primary keywords (PRO.CATG)
2. hdrl_image ** image: Four images
3. cpl_propertylist ** plistarray[]: Extension keywords

8.2.3.4 IFU_SCI_REDUCED_CUBE

FITS file structure:

Name: IFU_SCI_REDUCED_CUBE

Description: A rectified spectral cube with a linear wavelength grid.

PRO.CATG: IFU_SCI_REDUCED_CUBE
OCA keywords: PRO.CATG
DO.CATG: IFU_SCI_REDUCED_CUBE

Created by: metis_ifu_sci_process
Processing FITS Keywords: provided at PAE

Corresponding CPL structure:

1. cpl_propertylist * keywords: Primary keywords (PRO.CATG)
2. hdrl_imagelist * image: Spectral cube
3. cpl_propertylist * plistarray[]: Extension keywords

8.2.3.5 IFU_SCI_REDUCED_CUBE_TAC

FITS file structure:

Name:	IFU_SCI_REDUCED_CUBE_TAC
Description:	A telluric absorption corrected rectified spectral cube with a linear wavelength grid.
PRO.CATG:	IFU_SCI_REDUCED_CUBE_TAC
OCA keywords:	PRO.CATG
DO.CATG:	IFU_SCI_REDUCED_CUBE_TAC
Created by:	metis_ifu_sci_process
Processing FITS Keywords:	provided at PAE

Corresponding CPL structure:

1. cpl_propertylist * keywords: Primary keywords (PRO.CATG)
2. hdrl_imagelist * image: Spectral cube
3. cpl_propertylist * plistarray[]: Extension keywords

8.2.3.6 IFU_SCI_COMBINED

FITS file structure:

Name:	IFU_SCI_COMBINED
Description:	Spectral cube of science object.
PRO.CATG:	IFU_SCI_COMBINED
OCA keywords:	PRO.CATG
DO.CATG:	IFU_SCI_COMBINED
Created by:	metis_ifu_sci_process
Input for:	metis_ifu_tellcorr
Processing FITS Keywords:	provided at PAE

Corresponding CPL structure:

1. cpl_propertylist * keywords: Primary keywords (PRO.CATG)
2. hdrl_imagelist * image: Spectral cube
3. cpl_propertylist * plistarray[]: Extension keywords

8.2.3.7 IFU_SCI_COMBINED_TAC

FITS file structure:

Name:	IFU_SCI_COMBINED_TAC
Description:	Telluric absorption corrected spectral cube of science object.
PRO.CATG:	IFU_SCI_COMBINED_TAC
OCA keywords:	PRO.CATG
DO.CATG:	IFU_SCI_COMBINED_TAC
Created by:	metis_ifu_sci_process
Processing FITS Keywords:	provided at PAE

Corresponding CPL structure:

1. cpl_propertylist * keywords: Primary keywords (PRO.CATG)
2. hdrl_imagelist * image: Spectral cube
3. cpl_propertylist * plistarray[]: Extension keywords

8.2.3.8 IFU_SCI_OBJECT_1D

FITS file structure:

Name:	IFU_SCI_OBJECT_1D
Description:	Spectrum of science object.
PRO.CATG:	IFU_SCI_OBJECT_1D

OCA keywords:	PRO.CATG
DO.CATG:	IFU_SCI_OBJECT_1D
Created by:	metis_ifu_sci_process
Processing FITS Keywords:	provided at PAE

Corresponding CPL structure:

1. cpl_propertylist * keywords: Primary keywords (PRO.CATG)
2. cpl_table * image: table
3. cpl_propertylist * plistarray[]: Extension keywords

8.2.3.9 IFU_SCI_TELLURIC_1D

FITS file structure:

Name:	IFU_SCI_TELLURIC_1D
Description:	Telluric absorption corrected spectrum of science object.
PRO.CATG:	IFU_SCI_TELLURIC_1D
OCA keywords:	PRO.CATG
DO.CATG:	IFU_SCI_TELLURIC_1D
Created by:	metis_ifu_sci_process
Processing FITS Keywords:	provided at PAE

Corresponding CPL structure:

1. cpl_propertylist * keywords: Primary keywords (PRO.CATG)
2. cpl_table * image: table
3. cpl_propertylist * plistarray[]: Extension keywords

8.2.3.10 IFU_SCI_COADD

FITS file structure:

Name:	IFU_SCI_COADD
Description:	Spectral cube of science object, a coadd of a number of reduced IFU exposures covering a different spatial and wavelength ranges.
PRO.CATG:	IFU_SCI_COADD
OCA keywords:	PRO.CATG
DO.CATG:	IFU_SCI_COADD
Created by:	metis_ifu_sci_postprocess
Processing FITS Keywords:	provided at PAE

Corresponding CPL structure:

1. cpl_propertylist * keywords: Primary keywords (PRO.CATG)
2. hdrl_imagelist * image: Spectral cube
3. cpl_propertylist * plistarray[]: Extension keywords

8.2.3.11 IFU_SCI_COADD_ERROR

FITS file structure:

Name:	IFU_SCI_COADD_ERROR
Description:	The standard error of an IFU_SCI_COADD.
PRO.CATG:	IFU_SCI_COADD_ERROR
OCA keywords:	PRO.CATG
DO.CATG:	IFU_SCI_COADD_ERROR
Created by:	metis_ifu_sci_postprocess
Processing FITS Keywords:	provided at PAE

Corresponding CPL structure:

1. cpl_propertylist * keywords: Primary keywords (PRO.CATG)
2. hdrl_imagelist * image: Spectral cube
3. cpl_propertylist * plistarray[]: Extension keywords

8.2.3.12 IFU_DIST_REDUCED

FITS TABLE file structure:

Name:	IFU_DIST_REDUCED
Description:	Table of polynomial coefficients for distortion correction
PRO.CATG:	IFU_DIST_REDUCED
OCA keywords:	PRO.CATG
DO.CATG:	IFU_DIST_REDUCED
Created by:	metis_ifu_distortion
Processing FITS Keywords:	provided at PAE

8.2.3.13 IFU_DIST_REDUCED

Corresponding CPL structure:

1. cpl_propertylist * keywords: Primary keywords (PRO.CATG)
2. cpl_table * table: Distortion table
3. cpl_propertylist * plistarray[]: Extension keywords

8.3 IMG mode data items

8.3.1 Raw data item structures

8.3.1.1 LM_IMAGE_SCI_RAW

FITS file structure:

Name:	LM_IMAGE_SCI_RAW
Description:	Raw exposure of the LM image mode.
DPR.CATG:	SCIENCE
DPR.TECH:	IMAGE,LM
DPR.TYPE:	OBJECT
OCA keywords:	DPR.CATG, DPR.TECH, DPR.TYPE, INS.OPTI3.NAME, INS.OPTI9.NAME, INS.OPTI10.NAME
DO.CATG:	LM_IMAGE_SCI_RAW
Template:	METIS_img_lm_cal_standard METIS_img_lm_obs_AutoJitter METIS_img_lm_obs_GenericOffset METIS_img_lmn_obs_AutoChopNod METIS_img_lmn_obs_GenericChopNod METIS_ifu_obs_GenericOffset METIS_ifu_ext_obs_GenericOffset METIS_ifu_app_obs_Stare METIS_ifu_ext_app_obs_Stare METIS_img_lm_cal_psf METIS_ifu_cal_psf METIS_ifu_vc_obs_FixedSkyOffset METIS_ifu_ext_vc_obs_FixedSkyOffset METIS_img_lm_obs_FixedSkyOffset METIS_img_lm_app_obs_FixedOffset METIS_img_lm_vc_obs_FixedSkyOffset METIS_ifu_obs_FixedSkyOffset METIS_ifu_ext_obs_FixedSkyOffset
Input for:	metis_lm_img_basic_reduce
Processing FITS Keywords:	provided at PAE

Corresponding CPL structure:

1. cpl_propertylist * keywords: Primary keywords (DPR.CATG, DPR.TECH, DPR.TYPE, INS.OPTI3.NAME, INS.OPTI9.NAME, INS.OPTI10.NAME)
2. hdrl_image * image: Single image
3. cpl_propertylist * plistarray[]: Extension keywords

8.3.1.2 N_IMAGE_SCI_RAW

FITS file structure:

Name:	N_IMAGE_SCI_RAW
Description:	Raw exposure of the N image mode.
DPR.CATG:	SCIENCE
DPR.TECH:	IMAGE,N
DPR.TYPE:	OBJECT
OCA keywords:	DPR.CATG, DPR.TECH, DPR.TYPE, INS.OPTI3.NAME, INS.OPTI9.NAME, INS.OPTI10.NAME
DO.CATG:	N_IMAGE_SCI_RAW
Template:	METIS_img_n_cal_standard METIS_img_n_obs_AutoChopNod METIS_img_n_obs_GenericChopNod METIS_img_n_cvc_obs_AutoChop METIS_img_n_cal_psf METIS_img_lmn_obs_AutoChopNod METIS_img_lmn_obs_GenericChopNod
Input for recipe:	metis_n_img_chopnod
Processing FITS Keywords:	provided at PAE

Corresponding CPL structure:

1. cpl_propertylist * keywords: Primary keywords (DPR.CATG, DPR.TECH, DPR.TYPE, INS.OPTI3.NAME, INS.OPTI9.NAME, INS.OPTI10.NAME)
2. hdrl_image * image: Single image
3. cpl_propertylist * plistarray[]: Extension keywords

8.3.1.3 LM_CHOPPERHOME_RAW

FITS file structure:

Name:	LM_CHOPPERHOME_RAW
Description:	Raw exposure of the LM image mode.
DPR.CATG:	CALIB
DPR.TECH:	IMAGE,LM
DPR.TYPE:	CHOPHOME
OCA keywords:	DPR.CATG, DPR.TECH, DPR.TYPE, INS.OPTI3.NAME, INS.OPTI9.NAME, INS.OPTI10.NAME
DO.CATG:	LM_CHOPPERHOME_RAW
Template:	METIS_img_lm_cal_ChopperHome
Input for:	metis_img_chophome
Processing FITS Keywords:	provided at PAE

Corresponding CPL structure:

1. cpl_propertylist * keywords: Primary keywords (DPR.CATG, DPR.TECH, DPR.TYPE, INS.OPTI3.NAME, INS.OPTI9.NAME, INS.OPTI10.NAME)
2. hdrl_image * image: Single image
3. cpl_propertylist * plistarray[]: Extension keywords

8.3.1.4 DETLIN_det_RAW

An DETLIN_det_RAW can be one of

- DETLIN_2RG_RAW
- DETLIN_GEO_RAW
- DETLIN_IFU_RAW

8.3.1.5 DETLIN_2RG_RAW

FITS file structure:

Name:	DETLIN_2RG_RAW
Description:	Raw data for non-linearity determination for LM observations.
DPR.CATG:	CALIB
DPR.TECH:	IMAGE,LM
DPR.TYPE:	DETLIN
OCA keywords:	DPR.CATG, DPR.TECH, DPR.TYPE
DO.CATG:	DETLIN_2RG_RAW
Templates:	METIS_img_lm_cal_DetLin
Input for recipe:	metis_det_lingain
Processing FITS Keywords:	provided at PAE

Corresponding CPL structure:

1. cpl_propertylist * keywords: Primary keywords (DPR.CATG, DPR.TECH, DPR.TYPE, INS.OPTI3.NAME, INS.OPTI9.NAME, INS.OPTI10.NAME)
2. hdrl_image * image: Single image
3. cpl_propertylist * plistarray[]: Extension keywords

8.3.1.6 DETLIN_GEO_RAW

FITS file structure:

Name:	DETLIN_GEO_RAW

Description:	Raw data for non-linearity determination.
DPR.CATG:	CALIB
DPR.TECH:	IMAGE,N
DPR.TYPE:	DETLIN
OCA keywords:	DPR.CATG, DPR.TECH, DPR.TYPE
DO.CATG:	DETLIN_GEO_RAW
Templates:	METIS_img_n_cal_DetLin
Input for recipe:	metis_det_lingain
Processing FITS Keywords:	provided at PAE

Corresponding CPL structure:

1. cpl_propertylist * keywords: Primary keywords (DPR.CATG, DPR.TECH, DPR.TYPE, INS.OPTI3.NAME, INS.OPTI9.NAME, INS.OPTI10.NAME)
2. hdrl_image * image: Single image
3. cpl_propertylist * plistarray[]: Extension keywords

8.3.1.7 DETLIN_IFU_RAW

FITS file structure:

Name:	DETLIN_IFU_RAW
Description:	Raw data for non-linearity determination.
DPR.CATG:	CALIB
DPR.TECH:	IFU
DPR.TYPE:	DETLIN
OCA keywords:	DPR.CATG, DPR.TECH, DPR.TYPE
DO.CATG:	DETLIN_IFU_RAW
Templates:	METIS_ifu_cal_DetLin
Input for recipe:	metis_det_lingain

Processing Keywords:	FITS	provided at PAE

Corresponding CPL structure:

1. cpl_propertylist * keywords: Primary keywords (DPR.CATG, DPR.TECH, DPR.TYPE, INS.OPTI3.NAME, INS.OPTI9.NAME, INS.OPTI10.NAME)
2. hdrl_image * image: Single image
3. cpl_propertylist * plistarray[]: Extension keywords

8.3.1.8 DARK_det_RAW

An DARK_det_RAW can be one of

- DARK_2RG_RAW
- DARK_GEO_RAW
- DARK_IFU_RAW

8.3.1.9 DARK_2RG_RAW

FITS file structure:

Name:		DARK_2RG_RAW
Description:		Raw data for creating a master dark.
DPR.CATG:		CALIB
DPR.TECH:		IMAGE,LM
DPR.TYPE:		DARK
OCA keywords:		DPR.CATG, DPR.TECH, DPR.TYPE, DET.ID, DET.DIT
DO.CATG:		DARK_2RG_RAW
Templates:		METIS_gen_cal_dark METIS_gen_cal_InsDark
Input for recipe:		metis_det_dark
Processing Keywords:	FITS	provided at PAE

Corresponding CPL structure:

1. cpl_propertylist * keywords: Primary keywords (DPR.CATG, DPR.TECH, DPR.TYPE)
2. hdrl_image * image: Single image
3. cpl_propertylist * plistarray[]: Extension keywords

8.3.1.10 DARK_GEO_RAW

FITS file structure:

Name:	DARK_GEO_RAW
Description:	Raw data for creating a master dark.
DPR.CATG:	CALIB
DPR.TECH:	IMAGE,N
DPR.TYPE:	DARK
OCA keywords:	DPR.CATG, DPR.TECH, DPR.TYPE, DET.ID, DET.DIT
DO.CATG:	DARK_GEO_RAW
Templates:	METIS_gen_cal_dark METIS_gen_cal_InsDark
Input for recipe:	metis_det_dark
Processing FITS Keywords:	provided at PAE

Corresponding CPL structure:

1. cpl_propertylist * keywords: Primary keywords (DPR.CATG, DPR.TECH, DPR.TYPE)
2. hdrl_image * image: Single image
3. cpl_propertylist * plistarray[]: Extension keywords

8.3.1.11 DARK_IFU_RAW

FITS file structure:

Name:	DARK_IFU_RAW
Description:	Raw data for creating a master dark.
DPR.CATG:	CALIB
DPR.TECH:	IFU
DPR.TYPE:	DARK
OCA keywords:	DPR.CATG, DPR.TECH, DPR.TYPE, DET.ID, DET.DIT
DO.CATG:	DARK_IFU_RAW
Templates:	METIS_gen_cal_dark METIS_gen_cal_InsDark
Input for recipe:	metis_det_dark
Processing FITS Keywords:	provided at PAE

Corresponding CPL structure:

1. cpl_propertylist * keywords: Primary keywords (DPR.CATG, DPR.TECH, DPR.TYPE)
2. hdrl_image * image: Single image
3. cpl_propertylist * plistarray[]: Extension keywords

8.3.1.12 det_WCU_OFF_RAW An det_WCU_OFF_RAW can be one of

- LM_WCU_OFF_RAW
- N_WCU_OFF_RAW
- IFU_WCU_OFF_RAW

8.3.1.13 LM_WCU_OFF_RAW

FITS file structure:

Name:	LM_WCU_OFF_RAW

Description:	Raw data for dark subtraction in other recipes.
DPR.CATG:	CALIB
DPR.TECH:	IMAGE,LM
DPR.TYPE:	DARK,WCUOFF
OCA keywords:	DPR.CATG, DPR.TECH, DPR.TYPE
DO.CATG:	LM_WCU_OFF_RAW
Templates:	METIS_img_lm_cal_DetLin METIS_spec_lm_cal_SlitAdc
Input for:	metis_det_lingain metis_lm_img_distortion metis_lm_adc_slitloss
Processing FITS Keywords:	provided at PAE

Corresponding CPL structure:

1. cpl_propertylist * keywords: Primary keywords (DPR.CATG, DPR.TECH, DPR.TYPE, INS.OPTI3.NAME, INS.OPTI12.NAME, INS.OPTI13.NAME)
2. hdrl_image * image: image
3. cpl_propertylist * plistarray[]: Extension keywords

8.3.1.14 N_WCU_OFF_RAW

FITS file structure:

Name:	N_WCU_OFF_RAW
Description:	Raw data for dark subtraction in other recipes.
DPR.CATG:	CALIB
DPR.TECH:	IMAGE,N
DPR.TYPE:	DARK,WCUOFF
OCA keywords:	DPR.CATG, DPR.TECH, DPR.TYPE

DO.CATG:	N_WCU_OFF_RAW
Templates:	METIS_img_n_cal_DetLin METIS_img_n_cal_distortion METIS_spec_n_cal_slit
Input for:	metis_det_lingain metis_n_img_distortion metis_n_adc_slitloss
Processing FITS Keywords:	provided at PAE

Corresponding CPL structure:

1. cpl_propertylist * keywords: Primary keywords (DPR.CATG, DPR.TECH, DPR.TYPE, INS.OPTI3.NAME, INS.OPTI12.NAME, INS.OPTI13.NAME)
2. hdrl_image * image: image
3. cpl_propertylist * plistarray[]: Extension keywords

8.3.1.15 IFU_WCU_OFF_RAW

FITS file structure:

Name:	IFU_WCU_OFF_RAW
Description:	Raw data for dark subtraction in other recipes.
DPR.CATG:	CALIB
DPR.TECH:	IFU
DPR.TYPE:	DARK,WCUOFF
OCA keywords:	DPR.CATG, DPR.TECH, DPR.TYPE
DO.CATG:	IFU_WCU_OFF_RAW
Templates:	METIS_ifu_cal_DetLin
Input for:	metis_det_lingain
Processing FITS Keywords:	provided at PAE

Corresponding CPL structure:

1. cpl_propertylist * keywords: Primary keywords (DPR.CATG, DPR.TECH, DPR.TYPE, INS.OPTI3.NAME, INS.OPTI12.NAME, INS.OPTI13.NAME)
2. hdrl_image * image: image
3. cpl_propertylist * plistarray[]: Extension keywords

8.3.1.16 LM_FLAT_LAMP_RAW

FITS file structure:

Name:	LM_FLAT_LAMP_RAW
Description:	Flat field image taken with lamp or sky.
DPR.CATG:	CALIB
DPR.TECH:	IMAGE,LM
DPR.TYPE:	FLAT,LAMP
OCA keywords:	DPR.CATG, DPR.TECH, DPR.TYPE, INS.OPTI3.NAME, INS.OPTI12.NAME, INS.OPTI13.NAME
DO.CATG:	LM_FLAT_LAMP_RAW
Template:	METIS_img_lm_cal_InternalFlat
Input for recipe:	metis_lm_img_flat
Processing FITS Keywords:	provided at PAE

Corresponding CPL structure:

1. cpl_propertylist * keywords: Primary keywords (DPR.CATG, DPR.TECH, DPR.TYPE, INS.OPTI3.NAME, INS.OPTI12.NAME, INS.OPTI13.NAME)
2. hdrl_image ** image: Four images
3. cpl_propertylist * plistarray[]: Extension keywords

8.3.1.17 LM_FLAT_TWILIGHT_RAW

FITS file structure:

Name:	LM_FLAT_TWILIGHT_RAW
Description:	Flat field image taken with lamp or sky.
DPR.CATG:	CALIB
DPR.TECH:	IMAGE,LM
DPR.TYPE:	FLAT,TWILIGHT
OCA keywords:	DPR.CATG, DPR.TECH, DPR.TYPE, INS.OPTI3.NAME, INS.OPTI12.NAME, INS.OPTI13.NAME
DO.CATG:	LM_FLAT_TWILIGHT_RAW
Template:	METIS_img_lm_cal_TwilightFlat
Input for recipe:	metis_lm_img_flat
Processing FITS Keywords:	provided at PAE

Corresponding CPL structure:

1. cpl_propertylist * keywords: Primary keywords (DPR.CATG, DPR.TECH, DPR.TYPE, INS.OPTI3.NAME, INS.OPTI12.NAME, INS.OPTI13.NAME)
2. hdrl_image ** image: Four images
3. cpl_propertylist * plistarray[]: Extension keywords

8.3.1.18 N_FLAT_LAMP_RAW

FITS file structure:

Name:	N_FLAT_LAMP_RAW
Description:	Flat field image taken with lamp.
DPR.CATG:	CALIB
DPR.TECH:	IMAGE,N

DPR.TYPE:	FLAT,LAMP
OCA keywords:	DPR.CATG, DPR.TECH, DPR.TYPE, INS.OPTI3.NAME, INS.OPTI12.NAME, INS.OPTI13.NAME
DO.CATG:	N_FLAT_LAMP_RAW
Template:	METIS_img_n_cal_InternalFlat
Input for recipe:	metis_n_img_flat
Processing FITS Keywords:	provided at PAE

Corresponding CPL structure:

1. cpl_propertylist * keywords: Primary keywords (DPR.CATG, DPR.TECH, DPR.TYPE, INS.OPTI3.NAME, INS.OPTI12.NAME, INS.OPTI13.NAME)
2. hdrl_image * image: Singe image
3. cpl_propertylist * plistarray[]: Extension keywords

8.3.1.19 N_FLAT_TWILIGHT_RAW

FITS file structure:

Name:	N_FLAT_TWILIGHT_RAW
Description:	Flat field image taken with sky.
DPR.CATG:	CALIB
DPR.TECH:	IMAGE,N
DPR.TYPE:	FLAT,TWILIGHT
OCA keywords:	DPR.CATG, DPR.TECH, DPR.TYPE, INS.OPTI3.NAME, INS.OPTI12.NAME, INS.OPTI13.NAME
DO.CATG:	N_FLAT_TWILIGHT_RAW
Template:	METIS_img_n_cal_TwilightFlat
Input for recipe:	metis_n_img_flat

Processing Keywords:	FITS	provided at PAE

Corresponding CPL structure:

1. cpl_propertylist * keywords: Primary keywords (DPR.CATG, DPR.TECH, DPR.TYPE, INS.OPTI3.NAME, INS.OPTI12.NAME, INS.OPTI13.NAME)
2. hdrl_image * image: Singe image
3. cpl_propertylist * plistarray[]: Extension keywords

8.3.1.20 LM_DISTORTION_RAW

FITS file structure:

Name:	LM_DISTORTION_RAW
Description:	Images of grid mask in WCU-FP2 or CFO-FP2.
DPR.CATG:	CALIB
DPR.TECH:	IMAGE,LM
DPR.TYPE:	DISTORTION
OCA keywords:	DPR.CATG, DPR.TECH, DPR.TYPE, INS.OPTI3.NAME, INS.OPTI9.NAME, INS.OPTI10.NAME
DO.CATG:	LM_DISTORTION_RAW
Template:	METIS_img_lm_cal_distortion
Input for recipe:	metis_lm_img_distortion
Processing FITS Keywords:	provided at PAE

Corresponding CPL structure:

1. cpl_propertylist * keywords: Primary keywords (DPR.CATG, DPR.TECH, DPR.TYPE, INS.OPTI3.NAME, INS.OPTI9.NAME, INS.OPTI10.NAME)
2. hdrl_image * image: Single image
3. cpl_propertylist * plistarray[]: Extension keywords

8.3.1.21 N_DISTORTION_RAW

FITS file structure:

Name:	N_DISTORTION_RAW
Description:	Images of grid mask in WCU-FP2 or CFO-FP2.
DPR.CATG:	CALIB
DPR.TECH:	IMAGE,N
DPR.TYPE:	DISTORTION
OCA keywords:	DPR.CATG, DPR.TECH, DPR.TYPE, INS.OPTI3.NAME, INS.OPTI9.NAME, INS.OPTI10.NAME
DO.CATG:	N_DISTORTION_RAW
Template:	METIS_img_n_cal_distortion
Input for recipe:	metis_n_img_distortion
Processing FITS Keywords:	provided at PAE

Corresponding CPL structure:

1. cpl_propertylist * keywords: Primary keywords (DPR.CATG, DPR.TECH, DPR.TYPE, INS.OPTI3.NAME, INS.OPTI9.NAME, INS.OPTI10.NAME)
2. hdrl_image * image: Single image
3. cpl_propertylist * plistarray[]: Extension keywords

8.3.1.22 LM_PUPIL_RAW

FITS file structure:

Name:	LM_PUPIL_RAW
Description:	Raw exposure of the pupil in LM image mode.
DPR.CATG:	TECHNICAL
DPR.TECH:	PUP,M
DPR.TYPE:	PUPIL
OCA keywords:	DPR.CATG, DPR.TECH, DPR.TYPE, INS.OPTI3.NAME, INS.OPTI9.NAME, INS.OPTI10.NAME
DO.CATG:	LM_PUPIL_RAW
Template:	METIS_pup_lm
Input for recipe:	metis_pupil_imaging
Processing FITS Keywords:	provided at PAE

Corresponding CPL structure:

1. cpl_propertylist * keywords: Primary keywords (DPR.CATG, DPR.TECH, DPR.TYPE, INS.OPTI3.NAME, INS.OPTI9.NAME, INS.OPTI10.NAME)
2. hdrl_image * image: Single image
3. cpl_propertylist * plistarray[]: Extension keywords

8.3.1.23 N_PUPIL_RAW

FITS file structure:

Name:	N_PUPIL_RAW
Description:	Raw exposure of the the pupil in N image mode.
DPR.CATG:	TECHNICAL
DPR.TECH:	PUP,N

DPR.TYPE:	PUPIL
OCA keywords:	DPR.CATG, DPR.TECH, DPR.TYPE, INS.OPTI3.NAME, INS.OPTI9.NAME, INS.OPTI10.NAME
DO.CATG:	N_PUPIL_RAW
Template:	METIS_pup_n
Input for recipe:	metis_pupil_imaging
Processing FITS Keywords:	provided at PAE

Corresponding CPL structure:

1. cpl_propertylist * keywords: Primary keywords (DPR.CATG, DPR.TECH, DPR.TYPE, INS.OPTI3.NAME, INS.OPTI9.NAME, INS.OPTI10.NAME)
2. hdrl_image * image: Single image
3. cpl_propertylist * plistarray[]: Extension keywords

8.3.2 Master calibration / intermediate data item structures

8.3.2.1 MASTER_IMG_FLAT_LAMP_LM

FITS file structure:

Name:	MASTER_IMG_FLAT_LAMP_LM
Description:	Master flat frame for LM image data
PRO.CATG:	MASTER_IMG_FLAT_LAMP_LM
OCA keywords:	PRO.CATG
DO.CATG:	MASTER_IMG_FLAT_LAMP_LM
Created by:	metis_lm_img_flat
Input for:	metis_lm_img_basic_reduce metis_img_chophome metis_lm_adc_slitloss

Processing Keywords:	FITS	provided at PAE

Corresponding CPL structure:

1. cpl_propertylist * keywords: Primary keywords (DPR.CATG, DPR.TECH, DPR.TYPE, INS.OPTI3.NAME, INS.OPTI9.NAME, INS.OPTI10.NAME)
2. hdrl_image * image: Single image
3. cpl_propertylist * plistarray[]: Extension keywords

8.3.2.2 MASTER_IMG_FLAT_TWILIGHT_LM

FITS file structure:

Name:	MASTER_IMG_FLAT_TWILIGHT_LM
Description:	Master flat frame for LM image data
PRO.CATG:	MASTER_IMG_FLAT_TWILIGHT_LM
OCA keywords:	PRO.CATG
DO.CATG:	MASTER_IMG_FLAT_TWILIGHT_LM
Created by:	metis_lm_img_flat
Input for:	metis_lm_img_basic_reduce
Processing Keywords: FITS	provided at PAE

Corresponding CPL structure:

1. cpl_propertylist * keywords: Primary keywords (DPR.CATG, DPR.TECH, DPR.TYPE, INS.OPTI3.NAME, INS.OPTI9.NAME, INS.OPTI10.NAME)
2. hdrl_image * image: Single image
3. cpl_propertylist * plistarray[]: Extension keywords

8.3.2.3 MASTER_IMG_FLAT_LAMP_N

FITS file structure:

Name:	MASTER_IMG_FLAT_LAMP_N
Description:	Master flat frame for N image data
PRO.CATG:	MASTER_IMG_FLAT_LAMP_N
OCA keywords:	PRO.CATG
DO.CATG:	MASTER_IMG_FLAT_LAMP_N
Created by:	metis_n_img_flat
Input for:	metis_n_img_chopnod metis_n_adc_slitloss
Processing FITS Keywords:	provided at PAE

Corresponding CPL structure:

1. cpl_propertylist * keywords: Primary keywords (DPR.CATG, DPR.TECH, DPR.TYPE, INS.OPTI3.NAME, INS.OPTI9.NAME, INS.OPTI10.NAME)
2. hdrl_image * image: Single image
3. cpl_propertylist * plistarray[]: Extension keywords

8.3.2.4 MASTER_IMG_FLAT_TWILIGHT_N

FITS file structure:

Name:	MASTER_IMG_FLAT_TWILIGHT_N
Description:	Master flat frame for N image data
PRO.CATG:	MASTER_IMG_FLAT_TWILIGHT_N
OCA keywords:	PRO.CATG
DO.CATG:	MASTER_IMG_FLAT_TWILIGHT_N

Created by:		metis_n_img_flat
Input for:		metis_n_img_chopnod
Processing Keywords:	FITS	provided at PAE

Corresponding CPL structure:

1. cpl_propertylist * keywords: Primary keywords (DPR.CATG, DPR.TECH, DPR.TYPE, INS.OPTI3.NAME, INS.OPTI9.NAME, INS.OPTI10.NAME)
2. hdrl_image * image: Single image
3. cpl_propertylist * plistarray[]: Extension keywords

8.3.2.5 LM_STD_BASIC_REDUCED

FITS file structure:

Name:		LM_STD_BASIC_REDUCED
Description:		Standard detrended exposure of the LM image mode.
PRO.CATG:		LM_STD_BASIC_REDUCED
OCA keywords:		PRO.CATG, INS.OPTI3.NAME, INS.OPTI9.NAME, INS.OPTI10.NAME
DO.CATG:		LM_STD_BASIC_REDUCED
Produced by recipe:		metis_lm_img_basic_reduce
Input for recipe:		metis_lm_img_background
Processing Keywords:	FITS	provided at PAE

Corresponding CPL structure:

1. cpl_propertylist * keywords: Primary keywords (DPR.CATG, DPR.TECH, DPR.TYPE, INS.OPTI3.NAME, INS.OPTI9.NAME, INS.OPTI10.NAME)
2. hdrl_image * image: Single image
3. cpl_propertylist * plistarray[]: Extension keywords

8.3.2.6 LM_SCI_BKG

FITS file structure:

Name:	LM_SCI_BKG
Description:	Thermal background of science LM exposures.
PRO.CATG:	LM_SCI_BKG
OCA keywords:	PRO.CATG, INS.OPTI3.NAME, INS.OPTI9.NAME, INS.OPTI10.NAME
DO.CATG:	LM_SCI_BKG
Produced by recipe:	metis_lm_img_background
Input for recipe:	None
Processing FITS Keywords:	provided at PAE

Corresponding CPL structure:

1. cpl_propertylist * keywords: Primary keywords (DPR.CATG, DPR.TECH, DPR.TYPE, INS.OPTI3.NAME, INS.OPTI9.NAME, INS.OPTI10.NAME)
2. hdrl_image * image: Single image
3. cpl_propertylist * plistarray[]: Extension keywords

8.3.2.7 LM_STD_BKG

FITS file structure:

Name:	LM_STD_BKG
Description:	Thermal background of standard LM exposures.
PRO.CATG:	LM_STD_BKG
OCA keywords:	PRO.CATG, INS.OPTI3.NAME, INS.OPTI9.NAME, INS.OPTI10.NAME
DO.CATG:	LM_STD_BKG
Created by:	metis_lm_img_background
Processing FITS Keywords:	provided at PAE

Corresponding CPL structure:

1. cpl_propertylist * keywords: Primary keywords (DPR.CATG, DPR.TECH, DPR.TYPE, INS.OPTI3.NAME, INS.OPTI9.NAME, INS.OPTI10.NAME)
2. hdrl_image * image: Single image
3. cpl_propertylist * plistarray[]: Extension keywords

8.3.2.8 LM_SCI_BKG_SUBTRACTED

FITS file structure:

Name:	LM_SCI_BKG_SUBTRACTED
Description:	Thermal background subtracted images of science LM exposures.
PRO.CATG:	LM_SCI_BKG_SUBTRACTED
OCA keywords:	PRO.CATG, INS.OPTI3.NAME, INS.OPTI9.NAME, INS.OPTI10.NAME
DO.CATG:	LM_SCI_BKG_SUBTRACTED
Created by:	metis_lm_img_background

Input for:	metis_lm_img_calibrate
Processing FITS Keywords:	provided at PAE

Corresponding CPL structure:

1. cpl_propertylist * keywords: Primary keywords (PRO.CATG, INS.OPTI3.NAME, INS.OPTI9.NAME, INS.OPTI10.NAME)
2. hdrl_image * image: Single image
3. cpl_propertylist * plistarray[]: Extension keywords

8.3.2.9 LM_STD_BKG_SUBTRACTED

FITS file structure:

Name:	LM_STD_BKG_SUBTRACTED
Description:	Thermal background subtracted images of standard LM exposures.
PRO.CATG:	LM_STD_BKG_SUBTRACTED
OCA keywords:	PRO.CATG, INS.OPTI3.NAME, INS.OPTI9.NAME, INS.OPTI10.NAME
DO.CATG:	LM_STD_BKG_SUBTRACTED
Produced by recipe:	metis_lm_img_background
Input for:	metis_lm_img_std_process
Processing FITS Keywords:	provided at PAE

Corresponding CPL structure:

1. cpl_propertylist * keywords: Primary keywords (PRO.CATG, INS.OPTI3.NAME, INS.OPTI9.NAME, INS.OPTI10.NAME)
2. hdrl_image * image: Single image
3. cpl_propertylist * plistarray[]: Extension keywords

8.3.2.10 N_STD_BKG_SUBTRACTED

FITS file structure:

Name:	N_STD_BKG_SUBTRACTED
Description:	Thermal background subtracted images of standard N exposures.
PRO.CATG:	N_STD_BKG_SUBTRACTED
OCA keywords:	PRO.CATG, INS.OPTI3.NAME, INS.OPTI9.NAME, INS.OPTI10.NAME
DO.CATG:	N_STD_BKG_SUBTRACTED
Produced by recipe:	metis_n_img_chopnod
Input for recipe:	metis_n_img_std_process
Processing FITS Keywords:	provided at PAE

Corresponding CPL structure:

1. cpl_propertylist * keywords: Primary keywords (PRO.CATG, INS.OPTI3.NAME, INS.OPTI9.NAME, INS.OPTI10.NAME)
2. hdrl_image * image: Single image
3. cpl_propertylist * plistarray[]: Extension keywords

8.3.2.11 LM_STD_OBJECT_CAT

FITS TABLE file structure:

Name:	LM_STD_OBJECT_CAT
Description:	Catalog of masked objects in standard LM exposures.
PRO.CATG:	LM_STD_OBJECT_CAT
OCA keywords:	PRO.CATG
DO.CATG:	LM_STD_OBJECT_CAT

Created by:	metis_lm_img_background
Processing FITS Keywords:	provided at PAE

Corresponding CPL structure:

1. cpl_propertylist * keywords: Primary keywords (DPR.CATG, DPR.TECH, DPR.TYPE, INS.OPTI3.NAME, INS.OPTI9.NAME, INS.OPTI10.NAME)
2. hdrl_image * image: Single image
3. cpl_propertylist * plistarray[]: Extension keywords

8.3.3 Final data item structures

8.3.3.1 LM_SCI_BASIC_REDUCED

FITS file structure:

Name:	LM_SCI_BASIC_REDUCED
Description:	Science grade detrended exposure of the LM image mode.
PRO.CATG:	LM_SCI_BASIC_REDUCED
OCA keywords:	PRO.CATG, INS.OPTI3.NAME, INS.OPTI9.NAME, INS.OPTI10.NAME
DO.CATG:	LM_SCI_BASIC_REDUCED
Input for:	metis_lm_img_background metis_img_adi_cgrph metis_lm_adi_app
Produced by recipe:	metis_lm_img_basic_reduce
Processing FITS Keywords:	provided at PAE

Corresponding CPL structure:

1. cpl_propertylist * keywords: Primary keywords (DPR.CATG, DPR.TECH, DPR.TYPE, INS.OPTI3.NAME, INS.OPTI9.NAME, INS.OPTI10.NAME)
2. hdrl_image * image: Single image
3. cpl_propertylist * plistarray[]: Extension keywords

8.3.3.2 N_SCI_BKG_SUBTRACTED

FITS file structure:

Name:	N_SCI_BKG_SUBTRACTED
Description:	Thermal background subtracted images of science N exposures.
PRO.CATG:	N_SCI_BKG_SUBTRACTED
OCA keywords:	PRO.CATG, INS.OPTI3.NAME, INS.OPTI9.NAME, INS.OPTI10.NAME
DO.CATG:	N_SCI_BKG_SUBTRACTED
Produced by recipe:	metis_n_img_chopnod
Input for:	metis_n_img_calibrate metis_img_adi_cgrph
Processing FITS Keywords:	provided at PAE

Corresponding CPL structure:

1. cpl_propertylist * keywords: Primary keywords (PRO.CATG, INS.OPTI3.NAME, INS.OPTI9.NAME, INS.OPTI10.NAME)
2. hdrl_image * image: Single image
3. cpl_propertylist * plistarray[]: Extension keywords

8.3.3.3 LM_SCI_OBJECT_CAT

FITS TABLE file structure:

Name:	LM_SCI_OBJECT_CAT
Description:	Catalog of masked objects in science LM exposures.
PRO.CATG:	LM_SCI_OBJECT_CAT
OCA keywords:	PRO.CATG
DO.CATG:	LM_SCI_OBJECT_CAT
Created by:	metis_lm_img_background
Processing FITS Keywords:	provided at PAE

Corresponding CPL structure:

1. cpl_propertylist * keywords: Primary keywords (DPR.CATG, DPR.TECH, DPR.TYPE, INS.OPTI3.NAME, INS.OPTI9.NAME, INS.OPTI10.NAME)
2. hdrl_image * image: Single image
3. cpl_propertylist * plistarray[]: Extension keywords

8.3.3.4 LM_SCI_CALIBRATED

FITS file structure:

Name:	LM_SCI_CALIBRATED
Description:	LM band image with flux calibration, WC coordinate system and distorion information
PRO.CATG:	LM_SCI_CALIBRATED
OCA keywords:	PRO.CATG
DO.CATG:	LM_SCI_CALIBRATED
Created by:	metis_lm_img_calibrate
Input for:	metis_lm_img_sci_postprocess

Processing Keywords:	FITS	provided at PAE

8.3.3.5 LM_SCI_CALIBRATED

Corresponding CPL structure:

1. cpl_propertylist * keywords: Primary keywords (DPR.CATG, DPR.TECH, DPR.TYPE, INS.OPTI3.NAME, INS.OPTI9.NAME, INS.OPTI10.NAME)
2. hdrl_image * image: Single image
3. cpl_propertylist * plistarray[]: Extension keywords

8.3.3.6 N_SCI_CALIBRATED

FITS file structure:

Name:		N_SCI_CALIBRATED
Description:		N band image with flux calibration and distorion information
PRO.CATG:		N_SCI_CALIBRATED
OCA keywords:		PRO.CATG
DO.CATG:		N_SCI_CALIBRATED
Created by:		metis_n_img_calibrate
Input for:		metis_n_img_restore
Processing Keywords:	FITS	provided at PAE

8.3.3.7 N_SCI_CALIBRATED

Corresponding CPL structure:

1. cpl_propertylist * keywords: Primary keywords (DPR.CATG, DPR.TECH, DPR.TYPE, INS.OPTI3.NAME, INS.OPTI9.NAME, INS.OPTI10.NAME)
2. hdrl_image * image: Single image
3. cpl_propertylist * plistarray[]: Extension keywords

8.3.3.8 LM_SCI_COADD

FITS file structure:

Name:	LM_SCI_COADD
Description:	Coadded, mosaiced LM image.
PRO.CATG:	LM_SCI_COADD
OCA keywords:	PRO.CATG
DO.CATG:	LM_SCI_COADD
Input for recipe:	None
Produced by recipe:	metis_lm_img_sci_postprocess
Processing FITS Keywords:	provided at PAE

Corresponding CPL structure:

1. cpl_propertylist * keywords: Primary keywords (PRO.CATG)
2. hdrl_image * image: Single image
3. cpl_propertylist * plistarray[]: Extension keywords

8.3.3.9 N_SCI_RESTORED

FITS file structure:

Name:	N_SCI_RESTORED
Description:	N band image with a single positive beam restored from chop-nod image
PRO.CATG:	N_SCI_RESTORED
OCA keywords:	PRO.CATG
DO.CATG:	N_SCI_RESTORED
Created by:	metis_n_img_restore
Processing FITS Keywords:	provided at PAE

8.3.3.10 N_SCI_RESTORED

Corresponding CPL structure:

1. cpl_propertylist * keywords: Primary keywords (DPR.CATG, DPR.TECH, DPR.TYPE, INS.OPTI3.NAME, INS.OPTI9.NAME, INS.OPTI10.NAME)
2. hdrl_image * image: Single image
3. cpl_propertylist * plistarray[]: Extension keywords

8.3.3.11 det_DIST_REDUCED Depending on context, a det_DIST_REDUCED can refer to either a

1. N_DIST_REDUCED
2. LM_DIST_REDUCED

8.3.3.12 LM_DIST_REDUCED

FITS TABLE file structure:

Name:	LM_DIST_REDUCED
Description:	Table of polynomial coefficients for distortion correction
PRO.CATG:	LM_DIST_REDUCED

OCA keywords: PRO.CATG
DO.CATG: LM_DIST_REDUCED

Created by: metis_lm_img_distortion
Processing FITS Keywords: provided at PAE

8.3.3.13 LM_DIST_REDUCED

Corresponding CPL structure:

1. cpl_propertylist * keywords: Primary keywords (DPR.CATG, DPR.TECH, DPR.TYPE, INS.OPTI3.NAME, INS.OPTI9.NAME, INS.OPTI10.NAME)
2. cpl_table * table
3. cpl_propertylist * plistarray[]: Extension keywords

8.3.3.14 N_DIST_REDUCED

FITS TABLE file structure:

Name: N_DIST_REDUCED

Description: Table of polynomial coefficients for distortion correction

PRO.CATG: N_DIST_REDUCED

OCA keywords: PRO.CATG
DO.CATG: N_DIST_REDUCED

Created by: metis_n_img_distortion
Processing FITS Keywords: provided at PAE

8.3.3.15 N_DIST_REDUCED

Corresponding CPL structure:

1. cpl_propertylist * keywords: Primary keywords (DPR.CATG, DPR.TECH, DPR.TYPE, INS.OPTI3.NAME, INS.OPTI9.NAME, INS.OPTI10.NAME)
2. cpl_table * table
3. cpl_propertylist * plistarray[]: Extension keywords

8.3.3.16 LM_PUPIL_REDUCED

FITS file structure:

Name:	LM_PUPIL_REDUCED
Description:	Reduced pupil image in LM mode.
PRO.CATG:	LM_PUPIL_REDUCED
OCA keywords:	PRO.CATG
DO.CATG:	LM_PUPIL_REDUCED
Input for recipe:	None
Produced by recipe:	metis_pupil_imaging
Processing FITS Keywords:	provided at PAE

Corresponding CPL structure:

1. cpl_propertylist * keywords: Primary keywords (PRO.CATG)
2. hdrl_image * image: Single image
3. cpl_propertylist * plistarray[]: Extension keywords

8.3.3.17 N_PUPIL_REDUCED

FITS file structure:

Name:	N_PUPIL_REDUCED
Description:	Reduced pupil image in N mode.
PRO.CATG:	N_PUPIL_REDUCED
OCA keywords:	PRO.CATG, INS.OPTI3.NAME, INS.OPTI9.NAME, INS.OPTI10.NAME
DO.CATG:	N_PUPIL_REDUCED
Input for recipe:	None
Produced by recipe:	metis_pupil_imaging
Processing FITS Keywords:	provided at PAE

Corresponding CPL structure:

1. cpl_propertylist * keywords: Primary keywords (DPR.CATG, DPR.TECH, DPR.TYPE, INS.OPTI3.NAME, INS.OPTI9.NAME, INS.OPTI10.NAME)
2. hdrl_image * image: Single image
3. cpl_propertylist * plistarray[]: Extension keywords

8.3.3.18 LM_STD_COMBINED

FITS file structure:

Name:	LM_STD_COMBINED
Description:	Stacked LM band exposures.
PRO.CATG:	LM_STD_COMBINED
OCA keywords:	PRO.CATG
DO.CATG:	LM_STD_COMBINED
Input for recipe:	None
Produced by recipe:	metis_lm_img_std_process

Processing Keywords:	FITS	provided at PAE

Corresponding CPL structure:

1. cpl_propertylist * keywords: Primary keywords (PRO.CATG)
2. hdrl_image * image: Single image
3. cpl_propertylist * plistarray[]: Extension keywords

8.4 LSS mode data items

8.4.1 Raw data item structures

8.4.1.1 LM_SLITLOSSES_RAW

FITS file structure:

Name:	LM_SLITLOSSES_RAW
Description:	Raw exposure for determining the ADC slitlosses.
DPR.CATG:	CALIB
DPR.TECH:	LSS,LM
DPR.TYPE:	SLITLOSS
OCA keywords:	DPR.CATG, DPR.TECH, DPR.TYPE
DO.CATG:	LM_SLITLOSSES_RAW
Template:	METIS_spec_lm_cal_SlitAdc
Input for recipes:	metis_lm_adc_slitloss
Processing FITS Keywords:	provided at PAE

Corresponding CPL structure:

1. cpl_propertylist * keywords: Primary keywords (DPR.CATG, DPR.TECH, DPR.TYPE, INS.OPTI3.NAME, INS.OPTI9.NAME, INS.OPTI10.NAME)
2. hdrl_image * image: Single image
3. cpl_propertylist * plistarray[]: Extension keywords

8.4.1.2 N_SLITLOSSES_RAW

FITS file structure:

Name:	N_SLITLOSSES_RAW
Description:	Raw exposure for determining the ADC slitlosses.

DPR.CATG:	CALIB
DPR.TECH:	LSS,N
DPR.TYPE:	SLITLOSS
OCA keywords:	DPR.CATG, DPR.TECH, DPR.TYPE
DO.CATG:	N_SLITLOSSES_RAW
Template:	METIS_spec_n_cal_slit
Input for recipes:	metis_n_adc_slitloss
Processing FITS Keywords:	provided at PAE

Corresponding CPL structure:

1. cpl_propertylist * keywords: Primary keywords (DPR.CATG, DPR.TECH, DPR.TYPE, INS.OPTI3.NAME, INS.OPTI9.NAME, INS.OPTI10.NAME)
2. hdrl_image * image: Single image
3. cpl_propertylist * plistarray[]: Extension keywords

8.4.1.3 LM_LSS_RSRF_RAW

FITS file structure:

Name:	LM_LSS_RSRF_RAW
Description:	Raw exposure of the WCU flatfield lamp through the LSS to achieve the RSRF.
DPR.CATG:	CALIB
DPR.TECH:	LSS,LM
DPR.TYPE:	FLAT,LAMP
OCA keywords:	DPR.CATG, DPR.TECH, DPR.TYPE, INS.OPTI3.NAME, INS.OPTI9.NAME, INS.OPTI10.NAME
DO.CATG:	LM_LSS_RSRF_RAW
Template:	METIS_spec_lm_cal_rsrf
Input for recipe:	metis_lm_lss_rsrf

Processing FITS Keywords:	provided at PAE

Corresponding CPL structure:

1. cpl_propertylist * keywords: Primary keywords (DPR.CATG, DPR.TECH, DPR.TYPE, INS.OPTI3.NAME, INS.OPTI9.NAME, INS.OPTI10.NAME)
2. hdrl_image * image: Single image
3. cpl_propertylist * plistarray[]: Extension keywords

8.4.1.4 LM_LSS_RSRF_PINH_RAW

FITS file structure:

Name:	LM_LSS_RSRF_PINH_RAW
Description:	Raw exposure of the WCU flatfield lamp through the LSS to achieve the order detection / distortion model.
DPR.CATG:	CALIB
DPR.TECH:	LSS,LM
DPR.TYPE:	FLAT,LAMP,PINH
OCA keywords:	DPR.CATG, DPR.TECH, DPR.TYPE, INS.OPTI3.NAME, INS.OPTI9.NAME, INS.OPTI10.NAME, INS.OPTI20.NAME
DO.CATG:	LM_LSS_RSRF_PINH_RAW
Template:	METIS_spec_lm_cal_rsrfpinh
Input for recipe:	metis_lm_lss_trace
Processing FITS Keywords:	provided at PAE

Corresponding CPL structure:

1. cpl_propertylist * keywords: Primary keywords (DPR.CATG, DPR.TECH, DPR.TYPE, INS.OPTI3.NAME, INS.OPTI9.NAME, INS.OPTI10.NAME, INS.OPTI20.NAME)
2. hdrl_image * image: Single image
3. cpl_propertylist * plistarray[]: Extension keywords

8.4.1.5 LM_LSS_WAVE_RAW

FITS file structure:

Name:	LM_LSS_WAVE_RAW
Description:	Raw exposure of the WCU laser sources through the LSS to achieve the first guess of the wavelength calibration.
DPR.CATG:	CALIB
DPR.TECH:	LSS,LM
DPR.TYPE:	WAVE
OCA keywords:	DPR.CATG, DPR.TECH, DPR.TYPE, INS.OPTI3.NAME, INS.OPTI9.NAME, INS.OPTI10.NAME
DO.CATG:	LM_LSS_WAVE_RAW
Template:	METIS_spec_lm_cal_InternalWave
Input for recipe:	metis_lm_lss_wave
Processing FITS Keywords:	provided at PAE

Corresponding CPL structure:

1. cpl_propertylist * keywords: Primary keywords (DPR.CATG, DPR.TECH, DPR.TYPE, INS.OPTI3.NAME, INS.OPTI9.NAME, INS.OPTI10.NAME)
2. hdrl_image * image: Single image
3. cpl_propertylist * plistarray[]: Extension keywords

8.4.1.6 LM_LSS_STD_RAW

FITS file structure:

Name:	LM_LSS_STD_RAW
Description:	LM-band long-slit spectroscopy raw exposure of a flux standard star.
DPR.CATG:	CALIB
DPR.TECH:	LSS,LM
DPR.TYPE:	STD
OCA keywords:	DPR.CATG, DPR.TECH, DPR.TYPE, INS.OPTI3.NAME, INS.OPTI9.NAME, INS.OPTI10.NAME
DO.CATG:	LM_LSS_STD_RAW
Template:	METIS_spec_lm_cal_Standard METIS_spec_lmn_obs_AutoChopNodOnSlit
Input for recipe:	metis_lm_lss_std
Processing FITS Keywords:	provided at PAE

Corresponding CPL structure:

1. cpl_propertylist * keywords: Primary keywords (DPR.CATG, DPR.TECH, DPR.TYPE, INS.OPTI3.NAME, INS.OPTI9.NAME, INS.OPTI10.NAME)
2. hdrl_image * image: Single image for each nod/offset position
3. cpl_propertylist * plistarray[]: Extension keywords

8.4.1.7 LM_LSS_SCI_RAW

FITS file structure:

Name:	LM_LSS_SCI_RAW
Description:	LM-band long-slit spectroscopy raw exposure of a science object.

DPR.CATG:	SCIENCE
DPR.TECH:	LSS,LM
DPR.TYPE:	OBJECT
OCA keywords:	DPR.CATG, DPR.TECH, DPR.TYPE, INS.OPTI3.NAME, INS.OPTI9.NAME, INS.OPTI10.NAME, INS.OPTI11.NAME
DO.CATG:	LM_LSS_SCI_RAW
Templates:	METIS_spec_lm_obs_AutoNodOnSlit METIS_spec_lmn_obs_AutoChopNodOnSlit METIS_spec_lm_obs_GenericOffset
Input for recipe:	metis_lm_lss_sci
Processing FITS Keywords:	provided at PAE

Corresponding CPL structure:

1. cpl_propertylist * keywords: Primary keywords (DPR.CATG, DPR.TECH, DPR.TYPE, INS.OPTI3.NAME, INS.OPTI9.NAME, INS.OPTI10.NAME, INS.OPTI11.NAME)
2. hdrl_image * image: Single image for each nodding/offset position
3. cpl_propertylist * plistarray[]: Extension keywords

8.4.1.8 N_LSS_RSRF_RAW

FITS file structure:

Name:	N_LSS_RSRF_RAW
Description:	Raw exposure of the WCU flatfield lamp through the LSS to achieve the RSRF.
DPR.CATG:	CALIB
DPR.TECH:	LSS,N
DPR.TYPE:	FLAT,LAMP

OCA keywords:	DPR.CATG, DPR.TECH, DPR.TYPE, INS.OPTI3.NAME, INS.OPTI12.NAME, INS.OPTI13.NAME
DO.CATG:	N_LSS_RSRF_RAW
Template:	METIS_spec_n_cal_rsrf
Input for recipe:	metis_n_lss_rsrf
Processing FITS Keywords:	provided at PAE

Corresponding CPL structure:

1. cpl_propertylist * keywords: Primary keywords (DPR.CATG, DPR.TECH, DPR.TYPE, INS.OPTI3.NAME, INS.OPTI12.NAME, INS.OPTI13.NAME)
2. hdrl_image * image: Single image
3. cpl_propertylist * plistarray[]: Extension keywords

8.4.1.9 N_LSS_WAVE_RAW

FITS file structure:

Name:	N_LSS_WAVE_RAW
Description:	Raw exposure of the WCU laser sources through the LSS to achieve the first guess of the wavelength calibration (AIT phase only).
DPR.CATG:	CALIB
DPR.TECH:	LSS,N
DPR.TYPE:	WAVE
OCA keywords:	DPR.CATG, DPR.TECH, DPR.TYPE, INS.OPTI3.NAME, INS.OPTI12.NAME, INS.OPTI13.NAME
DO.CATG:	N_LSS_WAVE_RAW
Template:	METIS_spec_n_cal_InternalWave
Input for recipe:	metis_lm_lss_wave
Processing FITS Keywords:	provided at PAE

Corresponding CPL structure:

1. cpl_propertylist * keywords: Primary keywords (DPR.CATG, DPR.TECH, DPR.TYPE, INS.OPTI3.NAME, INS.OPTI12.NAME, INS.OPTI13.NAME)
2. hdrl_image * image: Single image
3. cpl_propertylist * plistarray[]: Extension keywords

8.4.1.10 N_LSS_RSRF_PINH_RAW

FITS file structure:

Name:	N_LSS_RSRF_PINH_RAW
Description:	Raw exposure of the WCU flatfield lamp through the LSS to achieve the order detection / distortion model.
DPR.CATG:	CALIB
DPR.TECH:	LSS,N
DPR.TYPE:	FLAT,LAMP,PINH
OCA keywords:	DPR.CATG, DPR.TECH, DPR.TYPE, INS.OPTI3.NAME, INS.OPTI9.NAME, INS.OPTI10.NAME, INS.OPTI20.NAME
DO.CATG:	N_LSS_RSRF_PINH_RAW
Template:	METIS_spec_n_cal_rsrfpinh
Input for recipe:	metis_n_lss_trace
Processing FITS Keywords:	provided at PAE

Corresponding CPL structure:

1. cpl_propertylist * keywords: Primary keywords (DPR.CATG, DPR.TECH, DPR.TYPE, INS.OPTI3.NAME, INS.OPTI9.NAME, INS.OPTI10.NAME, INS.OPTI20.NAME)
2. hdrl_image * image: Single image
3. cpl_propertylist * plistarray[]: Extension keywords

8.4.1.11 N_LSS_STD_RAW

FITS file structure:

Name:	N_LSS_STD_RAW
Description:	N-band long-slit spectroscopy raw exposure of a flux standard star.
DPR.CATG:	CALIB
DPR.TECH:	LSS,N
DPR.TYPE:	STD
OCA keywords:	DPR.CATG, DPR.TECH, DPR.TYPE, INS.OPTI3.NAME, INS.OPTI11.NAME, INS.OPTI12.NAME, INS.OPTI13.NAME
DO.CATG:	N_LSS_STD_RAW
Template:	METIS_spec_n_cal_Standard METIS_spec_lmn_obs_AutoChopNodOnSlit
Input for recipe:	metis_n_lss_std
Processing FITS Keywords:	provided at PAE

Corresponding CPL structure:

1. cpl_propertylist * keywords: Primary keywords (DPR.CATG, DPR.TECH, DPR.TYPE, INS.OPTI3.NAME, INS.OPTI11.NAME, INS.OPTI12.NAME, INS.OPTI13.NAME)
2. hdrl_image * image: Single image for each chop/nod position
3. cpl_propertylist * plistarray[]: Extension keywords

8.4.1.12 N_LSS_SCI_RAW

FITS file structure:

Name:	N_LSS_SCI_RAW
Description:	N-band long-slit spectroscopy raw exposure of a science object.
DPR.CATG:	SCIENCE

DPR.TECH:	LSS,N
DPR.TYPE:	OBJECT
OCA keywords:	DPR.CATG, DPR.TECH, DPR.TYPE, INS.OPTI11.NAME, INS.OPTI12.NAME, INS.OPTI13.NAME, INS.OPTI14.NAME
DO.CATG:	N_LSS_SCI_RAW
Templates:	METIS_spec_n_obs_AutoChopNodOnSlit METIS_spec_lmn_obs_AutoChopNodOnSlit
Input for recipe:	metis_n_lss_sci
Processing FITS Keywords:	provided at PAE

Corresponding CPL structure:

1. cpl_propertylist * keywords: Primary keywords (DPR.CATG, DPR.TECH, DPR.TYPE, INS.OPTI11.NAME, INS.OPTI12.NAME, INS.OPTI13.NAME , INS.OPTI14.NAME)
2. hdrl_image * image: Single image for each chop/nod position
3. cpl_propertylist * plistarray[]: Extension keywords

8.4.2 Master calibration / intermediate data item structures

8.4.2.1 MASTER_LM_LSS_RSRF

FITS file structure:

Name:	MASTER_LM_LSS_RSRF
Description:	LM-band LSS Master RSRF.
PRO.CATG:	MASTER_LM_LSS_RSRF
OCA keywords:	PRO.CATG, INS.OPTI9.NAME, INS.OPTI10.NAME, INS.OPTI11.NAME
DO.CATG:	MASTER_LM_LSS_RSRF
Created by:	metis_lm_lss_rsrf
Input for recipes:	metis_lm_lss_trace metis_lm_lss_wave metis_lm_lss_std metis_lm_lss_sci
Processing FITS Keywords:	provided at PAE

Corresponding CPL structure:

1. cpl_propertylist * keywords: Primary keywords (PRO.CATG, INS.OPTI9.NAME, INS.OPTI10.NAME, INS.OPTI11.NAME)
2. hdrl_imagelist * image: Three image layers (data, error, mask)
3. cpl_propertylist * plistarray[]: Extension keywords

8.4.2.2 MEDIAN_LM_LSS_RSRF_IMG

FITS file structure:

Name:	MEDIAN_LM_LSS_RSRF_IMG
Description:	LM-band LSS Median RSRF.

PRO.CATG:	MEDIAN_LM_LSS_RSRF_IMG
OCA keywords:	PRO.CATG, INS.OPTI9.NAME, INS.OPTI10.NAME, INS.OPTI11.NAME
DO.CATG:	n/a
Created by:	metis_lm_lss_rsrf
Processing FITS Keywords:	provided at PAE
Comment:	intermediate data product used for QC only

Corresponding CPL structure:

1. cpl_propertylist * keywords: Primary keywords (PRO.CATG, INS.OPTI9.NAME, INS.OPTI10.NAME, INS.OPTI11.NAME)
2. hdrl_imagelist * image: Three image layers (data, error, mask)
3. cpl_propertylist * plistarray[]: Extension keywords

8.4.2.3 MEAN_LM_LSS_RSRF_IMG

FITS file structure:

Name:	MEAN_LM_LSS_RSRF_IMG
Description:	LM-band LSS Mean RSRF.
PRO.CATG:	MEAN_LM_LSS_RSRF_IMG
OCA keywords:	PRO.CATG, INS.OPTI9.NAME, INS.OPTI10.NAME, INS.OPTI11.NAME
DO.CATG:	n/a
Created by:	metis_lm_lss_rsrf
Processing FITS Keywords:	provided at PAE
Comment:	intermediate data product used for QC only

Corresponding CPL structure:

1. cpl_propertylist * keywords: Primary keywords (PRO.CATG, INS.OPTI9.NAME, INS.OPTI10.NAME, INS.OPTI11.NAME)
2. hdrl_imagelist * image: Three image layers (data, error, mask)
3. cpl_propertylist * plistarray[]: Extension keywords

8.4.2.4 MASTER_N_LSS_RSRF

FITS file structure:

Name:	MASTER_N_LSS_RSRF
Description:	LM-band LSS Master RSRF.
PRO.CATG:	MASTER_N_LSS_RSRF
OCA keywords:	PRO.CATG, INS.OPTI12.NAME, INS.OPTI13.NAME, INS.OPTI14.NAME
DO.CATG:	MASTER_N_LSS_RSRF
Created by:	metis_n_lss_rsrf
Input for recipes:	metis_n_lss_trace metis_n_lss_std metis_n_lss_sci
Processing FITS Keywords:	provided at PAE

Corresponding CPL structure:

1. cpl_propertylist * keywords: Primary keywords (PRO.CATG, INS.OPTI12.NAME, INS.OPTI13.NAME, INS.OPTI14.NAME)
2. hdrl_imagelist * image: Three image layers (data, error, mask)
3. cpl_propertylist * plistarray[]: Extension keywords

8.4.2.5 MEDIAN_N_LSS_RSRF_IMG

FITS file structure:

Name:	MEDIAN_N_LSS_RSRF_IMG
Description:	LM-band LSS Median RSRF.
PRO.CATG:	MEDIAN_N_LSS_RSRF_IMG
OCA keywords:	PRO.CATG, INS.OPTI12.NAME, INS.OPTI13.NAME, INS.OPTI14.NAME
DO.CATG:	n/a
Created by:	metis_n_lss_rsrf
Processing FITS Keywords:	provided at PAE
Comment:	intermediate data product used for QC only

Corresponding CPL structure:

1. cpl_propertylist * keywords: Primary keywords (PRO.CATG, INS.OPTI12.NAME, INS.OPTI13.NAME, INS.OPTI14.NAME)
2. hdrl_imagelist * image: Three image layers (data, error, mask)
3. cpl_propertylist * plistarray[]: Extension keywords

8.4.2.6 MEAN_N_LSS_RSRF_IMG

FITS file structure:

Name:	MEAN_N_LSS_RSRF_IMG
Description:	LM-band LSS Mean RSRF.
PRO.CATG:	MEAN_N_LSS_RSRF_IMG
OCA keywords:	PRO.CATG, INS.OPTI12.NAME, INS.OPTI13.NAME, INS.OPTI14.NAME
DO.CATG:	n/a
Created by:	metis_n_lss_rsrf

Processing Keywords:	FITS	provided at PAE
Comment:		intermediate data product used for QC only

Corresponding CPL structure:

1. cpl_propertylist * keywords: Primary keywords (PRO.CATG, INS.OPTI12.NAME, INS.OPTI13.NAME, INS.OPTI14.NAME)
2. hdrl_imagelist * image: Three image layers (data, error, mask)
3. cpl_propertylist * plistarray[]: Extension keywords

8.4.2.7 LM_LSS_TRACE

FITS file structure:

Name:	LM_LSS_TRACE
Description:	Polynomial fit of the LM order edges (i.e. order location on chip)
PRO.CATG:	LM_LSS_TRACE
OCA keywords:	PRO.CATG
DO.CATG:	LM_LSS_TRACE
Created by:	metis_lm_lss_trace
Input for:	metis_LM_lss_wave
Processing FITS Keywords:	provided at PAE
Purpose:	wavelength calibration / rectification

Corresponding CPL structure:

1. cpl_propertylist * keywords: Primary keywords (PRO.CATG)
2. cpl_table * table: Tables
3. cpl_propertylist * plistarray[]: Extension keywords

8.4.2.8 N_LSS_TRACE

FITS file structure:

Name:	N_LSS_TRACE
Description:	Polynomial fit of the N order edges (i.e. order location on chip)
PRO.CATG:	N_LSS_TRACE
OCA keywords:	PRO.CATG
DO.CATG:	N_LSS_TRACE
Created by:	metis_n_lss_trace
Input for:	metis_N_lss_std metis_N_lss_sci
Processing FITS Keywords:	provided at PAE

Corresponding CPL structure:

1. cpl_propertylist * keywords: Primary keywords (PRO.CATG)
2. cpl_table * table: Tables
3. cpl_propertylist * plistarray[]: Extension keywords

8.4.2.9 LM_LSS_CURVE

FITS file structure:

Name:	LM_LSS_CURVE
Description:	Slit curvature table
PRO.CATG:	LM_LSS_CURVE
OCA keywords:	PRO.CATG
DO.CATG:	LM_LSS_CURVE
Created by:	metis_lm_lss_wave
Processing FITS Keywords:	provided at PAE

Corresponding CPL structure:

1. cpl_propertylist * keywords: Primary keywords (PRO.CATG)
2. cpl_table * table: Tables
3. cpl_propertylist * plistarray[]: Extension keywords

8.4.2.10 LM_LSS_DIST_SOL

FITS file structure:

Name:	LM_LSS_DIST_SOL
Description:	LM-band geometrical distortion solution
PRO.CATG:	LM_LSS_DIST_SOL
OCA keywords:	PRO.CATG
DO.CATG:	LM_LSS_DIST_SOL
Created by:	metis_lm_lss_wave
Input for:	metis_LM_lss_std metis_LM_lss_sci
Processing FITS Keywords:	provided at PAE

Corresponding CPL structure:

1. cpl_propertylist * keywords: Primary keywords (PRO.CATG)
2. cpl_table * table: Tables
3. cpl_propertylist * plistarray[]: Extension keywords

8.4.2.11 LM_LSS_WAVE_GUESS

FITS file structure:

Name:	LM_LSS_WAVE_GUESS

Description:	First guess of the N-band wavelength solution
PRO.CATG:	LM_LSS_WAVE_GUESS
OCA keywords:	PRO.CATG
DO.CATG:	LM_LSS_WAVE_GUESS
Created by:	metis_lm_lss_wave
Input for:	metis_LM_lss_std metis_LM_lss_sci
Processing FITS Keywords:	provided at PAE

Corresponding CPL structure:

1. cpl_propertylist * keywords: Primary keywords (PRO.CATG)
2. cpl_table * table: Tables
3. cpl_propertylist * plistarray[]: Extension keywords

8.4.2.12 LM_LSS_STD_OBJ_MAP

FITS file structure:

Name:	LM_LSS_STD_OBJ_MAP
Description:	Image with detected object pixels of the flux standard star.
PRO.CATG:	LM_LSS_STD_OBJ_MAP
OCA keywords:	PRO.CATG, INS.OPTI9.NAME, INS.OPTI10.NAME, INS.OPTI11.NAME
DO.CATG:	n/a
Created by:	metis_lm_lss_std
Processing FITS Keywords:	provided at PAE
Comment:	intermediate data product used for QC and as mask

Corresponding CPL structure:

1. cpl_propertylist * keywords: Primary keywords (PRO.CATG, INS.OPTI9.NAME, INS.OPTI10.NAME, INS.OPTI11.NAME)
2. hdrl_image * image: Single image
3. cpl_propertylist * plistarray[]: Extension keywords

8.4.2.13 LM_LSS_STD_SKY_MAP

FITS file structure:

Name:	LM_LSS_STD_SKY_MAP
Description:	Image with detected sky pixels of the flux standard star observation.
PRO.CATG:	LM_LSS_STD_SKY_MAP
OCA keywords:	PRO.CATG, INS.OPTI9.NAME, INS.OPTI10.NAME, INS.OPTI11.NAME
DO.CATG:	n/a
Created by:	metis_lm_lss_std
Processing FITS Keywords:	provided at PAE
Comment:	intermediate data product used for QC and as mask

Corresponding CPL structure:

1. cpl_propertylist * keywords: Primary keywords (PRO.CATG, INS.OPTI9.NAME, INS.OPTI10.NAME, INS.OPTI11.NAME)
2. hdrl_image * image: Single image
3. cpl_propertylist * plistarray[]: Extension keywords

8.4.2.14 LM_LSS_STD_1D

FITS file structure:

Name:	LM_LSS_STD_1D
Description:	Extracted 1d flux standard star spectrum.
PRO.CATG:	LM_LSS_STD_1D
OCA keywords:	PRO.CATG, INS.OPTI9.NAME, INS.OPTI10.NAME, INS.OPTI11.NAME
DO.CATG:	LM_LSS_STD_1D
Created by:	metis_lm_lss_std
Processing FITS Keywords:	provided at PAE
Comment:	intermediate data product also used for QC

Corresponding CPL structure:

1. cpl_propertylist * keywords: Primary keywords (PRO.CATG, INS.OPTI9.NAME, INS.OPTI10.NAME, INS.OPTI11.NAME)
2. hdrl_spectrum1D * spectrum: Spectrum
3. cpl_propertylist * plistarray[]: Extension keywords

8.4.2.15 N_LSS_STD_OBJ_MAP

FITS file structure:

Name:	N_LSS_STD_OBJ_MAP
Description:	Image with detected object pixels of the flux standard star..
PRO.CATG:	N_LSS_STD_OBJ_MAP
OCA keywords:	PRO.CATG, INS.OPTI12.NAME, INS.OPTI13.NAME, INS.OPTI14.NAME
DO.CATG:	n/a
Created by:	metis_n_lss_std
Processing FITS Keywords:	provided at PAE
Comment:	intermediate data product used for QC and as mask

Corresponding CPL structure:

1. cpl_propertylist * keywords: Primary keywords (PRO.CATG, INS.OPTI12.NAME, INS.OPTI13.NAME, INS.OPTI14.NAME)
2. hdrl_image * image: Single image
3. cpl_propertylist * plistarray[]: Extension keywords

8.4.2.16 N_LSS_STD_SKY_MAP

FITS file structure:

Name:	N_LSS_STD_SKY_MAP
Description:	Image with detected plain sky pixels of the flux standard star observation.
PRO.CATG:	N_LSS_STD_SKY_MAP
OCA keywords:	PRO.CATG, INS.OPTI12.NAME, INS.OPTI13.NAME, INS.OPTI14.NAME
DO.CATG:	n/a
Created by:	metis_n_lss_std
Processing FITS Keywords:	provided at PAE
Comment:	intermediate data product used for QC and as mask

Corresponding CPL structure:

1. cpl_propertylist * keywords: Primary keywords (PRO.CATG, INS.OPTI12.NAME, INS.OPTI13.NAME, INS.OPTI14.NAME)
2. hdrl_image * image: Single image
3. cpl_propertylist * plistarray[]: Extension keywords

8.4.2.17 N_LSS_STD_1D

FITS file structure:

Name:	N_LSS_STD_1D
Description:	Extracted 1d science spectrum.
PRO.CATG:	N_LSS_STD_1D
OCA keywords:	PRO.CATG, INS.OPTI12.NAME, INS.OPTI13.NAME, INS.OPTI14.NAME
DO.CATG:	N_LSS_STD_1D
Created by:	metis_n_lss_std
Processing FITS Keywords:	provided at PAE
Comment:	intermediate data product also used for QC

Corresponding CPL structure:

1. cpl_propertylist * keywords: Primary keywords (PRO.CATG, INS.OPTI12.NAME, INS.OPTI13.NAME, INS.OPTI14.NAME)
2. hdrl_spectrum1D * spectrum: Spectrum
3. cpl_propertylist * plistarray[]: Extension keywords

8.4.2.18 LM_LSS_SCI_OBJ_MAP

FITS file structure:

Name:	LM_LSS_SCI_OBJ_MAP
Description:	Image with detected object pixels of the science observation.
PRO.CATG:	LM_LSS_SCI_OBJ_MAP
OCA keywords:	PRO.CATG, INS.OPTI9.NAME, INS.OPTI10.NAME, INS.OPTI11.NAME
DO.CATG:	n/a
Created by:	metis_lm_lss_sci
Processing FITS Keywords:	provided at PAE
Comment:	intermediate data product used for QC and as mask

Corresponding CPL structure:

1. cpl_propertylist * keywords: Primary keywords (PRO.CATG, INS.OPTI9.NAME, INS.OPTI10.NAME, INS.OPTI11.NAME)
2. hdrl_image * image: Single image
3. cpl_propertylist * plistarray[]: Extension keywords

8.4.2.19 LM_LSS_SCI_SKY_MAP

FITS file structure:

Name:	LM_LSS_SCI_SKY_MAP
Description:	Image with detected plain sky pixels of the science observation.
PRO.CATG:	LM_LSS_SCI_SKY_MAP
OCA keywords:	PRO.CATG, INS.OPTI9.NAME, INS.OPTI10.NAME, INS.OPTI11.NAME
DO.CATG:	n/a
Created by:	metis_lm_lss_sci
Processing FITS Keywords:	provided at PAE
Comment:	intermediate data product used for QC and as mask

Corresponding CPL structure:

1. cpl_propertylist * keywords: Primary keywords (PRO.CATG, INS.OPTI9.NAME, INS.OPTI10.NAME, INS.OPTI11.NAME)
2. hdrl_image * image: Single image
3. cpl_propertylist * plistarray[]: Extension keywords

8.4.2.20 LM_LSS_SCI_2D

FITS file structure:

Name:	LM_LSS_SCI_2D
Description:	rectified 2d LM-band spectrum of the science object.
PRO.CATG:	LM_LSS_SCI_2D
OCA keywords:	PRO.CATG, INS.OPTI9.NAME, INS.OPTI10.NAME, INS.OPTI11.NAME
DO.CATG:	LM_LSS_SCI_2D
Created by:	metis_lm_lss_sci
Processing FITS Keywords:	provided at PAE
Comment:	intermediate data product also used for QC

Corresponding CPL structure:

1. cpl_propertylist * keywords: Primary keywords (PRO.CATG, INS.OPTI9.NAME, INS.OPTI10.NAME, INS.OPTI11.NAME)
2. hdrl_imagelist * images: Images
3. cpl_propertylist * plistarray[]: Extension keywords

8.4.2.21 LM_LSS_SCI_1D

FITS file structure:

Name:	LM_LSS_SCI_1D
Description:	Extracted 1d science spectrum.
PRO.CATG:	LM_LSS_SCI_1D
OCA keywords:	PRO.CATG, INS.OPTI9.NAME, INS.OPTI10.NAME, INS.OPTI11.NAME
DO.CATG:	LM_LSS_SCI_1D
Created by:	metis_lm_lss_sci
Processing FITS Keywords:	provided at PAE
Comment:	intermediate data product used for QC

Corresponding CPL structure:

1. cpl_propertylist * keywords: Primary keywords (PRO.CATG, INS.OPTI9.NAME, INS.OPTI10.NAME, INS.OPTI11.NAME)
2. hdrl_spectrum1D * spectrum: Spectrum
3. cpl_propertylist * plistarray[]: Extension keywords

8.4.2.22 N_LSS_SCI_OBJ_MAP

FITS file structure:

Name:	N_LSS_SCI_OBJ_MAP
Description:	Image with detected object pixels of the science frame.
PRO.CATG:	N_LSS_SCI_OBJ_MAP
OCA keywords:	PRO.CATG, INS.OPTI12.NAME, INS.OPTI13.NAME, INS.OPTI14.NAME
DO.CATG:	n/a
Created by:	metis_n_lss_sci
Processing FITS Keywords:	provided at PAE
Comment:	intermediate data product used for QC and as mask

Corresponding CPL structure:

1. cpl_propertylist * keywords: Primary keywords (PRO.CATG, INS.OPTI12.NAME, INS.OPTI13.NAME, INS.OPTI14.NAME)
2. hdrl_image * image: Single image
3. cpl_propertylist * plistarray[]: Extension keywords

8.4.2.23 N_LSS_SCI_SKY_MAP

FITS file structure:

Name:	N_LSS_SCI_SKY_MAP
Description:	Image with detected plain sky pixels of the science frame.
PRO.CATG:	N_LSS_SCI_SKY_MAP
OCA keywords:	PRO.CATG, INS.OPTI12.NAME, INS.OPTI13.NAME, INS.OPTI14.NAME
DO.CATG:	n/a
Created by:	metis_n_lss_sci
Processing FITS Keywords:	provided at PAE
Comment:	intermediate data product used for QC and as mask

Corresponding CPL structure:

1. cpl_propertylist * keywords: Primary keywords (PRO.CATG, INS.OPTI12.NAME, INS.OPTI13.NAME, INS.OPTI14.NAME)
2. hdrl_image * image: Single image
3. cpl_propertylist * plistarray[]: Extension keywords

8.4.2.24 N_LSS_SCI_2D

FITS file structure:

Name:	N_LSS_SCI_2D
Description:	rectified 2d N-band spectrum of the science object.
PRO.CATG:	N_LSS_SCI_2D
OCA keywords:	PRO.CATG, INS.OPTI12.NAME, INS.OPTI13.NAME, INS.OPTI14.NAME
DO.CATG:	N_LSS_SCI_2D
Created by:	metis_n_lss_sci
Processing FITS Keywords:	provided at PAE
Comment:	intermediate data product also used for QC

Corresponding CPL structure:

1. cpl_propertylist * keywords: Primary keywords (PRO.CATG, INS.OPTI12.NAME, INS.OPTI13.NAME, INS.OPTI14.NAME)
2. hdrl_imagelist * images: Images
3. cpl_propertylist * plistarray[]: Extension keywords

8.4.2.25 N_LSS_SCI_1D

FITS file structure:

Name:	N_LSS_SCI_1D
Description:	Extracted 1d science spectrum.
PRO.CATG:	N_LSS_SCI_1D
OCA keywords:	PRO.CATG, INS.OPTI12.NAME, INS.OPTI13.NAME, INS.OPTI14.NAME
DO.CATG:	N_LSS_SCI_1D
Created by:	metis_n_lss_sci
Processing FITS Keywords:	provided at PAE
Comment:	intermediate data product used for QC

Corresponding CPL structure:

1. cpl_propertylist * keywords: Primary keywords (PRO.CATG, INS.OPTI12.NAME, INS.OPTI13.NAME, INS.OPTI14.NAME)
2. hdrl_spectrum1D * spectrum: Spectrum
3. cpl_propertylist * plistarray[]: Extension keywords

8.4.2.26 STD_TRANSMISSION

Name:	STD_TRANSMISSION

Description:	Transmission curve derived by means of the STD star
PRO.CATG:	STD_TRANSMISSION
OCA keywords:	PRO.CATG, INS.MODE, INS.SPEC.SETUP
DO.CATG:	STD_TRANSMISSION
Produced by recipe:	metis_LM_lss_std metis_N_lss_std
Input for recipe(s):	metis_LM_LSS_sci
QC Parameters:	none
Processing FITS Keywords:	provided at PAE

Corresponding CPL structure:

Data structure:

1. cpl_propertylist * keywords: Primary keywords ()
2. hdrl_imagelist * images: Images
3. cpl_propertylist ** extkeywords: Extension keywords

8.4.2.27 MASTER_LM_RESPONSE

Name:	MASTER_LM_RESPONSE
Description:	Master LM-band response function for absolute flux calibration
PRO.CATG:	MASTER_LM_RESPONSE
OCA keywords:	PRO.CATG, INS.MODE, INS.SPEC.SETUP
DO.CATG:	MASTER_LM_RESPONSE
Produced by recipe:	metis_LM_lss_std
Input for recipe(s):	metis_LM_LSS_sci
QC Parameters:	none

Processing FITS Keywords:	provided at PAE

Corresponding CPL structure:

Data structure:
1. `cpl_propertylist * keywords: Primary keywords ()`
2. `hdrl_imagelist * images: Images`
3. `cpl_propertylist ** extkeywords: Extension keywords`

8.4.2.28 MASTER_N_RESPONSE

Name:	MASTER_N_RESPONSE
Description:	Master N-band response function for absolute flux calibration
PRO.CATG:	MASTER_N_RESPONSE
OCA keywords:	PRO.CATG, INS.MODE, INS.SPEC.SETUP
DO.CATG:	MASTER_N_RESPONSE
Produced by recipe:	metis_N_lss_std
Input for recipe(s):	metis_N_LSS_sci
QC Parameters:	none
Processing FITS Keywords:	provided at PAE

Corresponding CPL structure:

Data structure:
1. `cpl_propertylist * keywords: Primary keywords ()`
2. `hdrl_imagelist * images: Images`
3. `cpl_propertylist ** extkeywords: Extension keywords`

8.4.2.29 MF_BEST_FIT_TAB

FITS file structure:

Name:	MF_BEST_FIT_TAB
Description:	Table of best-fit molecfit values
PRO.CATG:	MF_BEST_FIT_TAB
OCA keywords:	PRO.CATG
DO.CATG:	MF_BEST_FIT_TAB
Created by:	metis_LM_lss_mf_model metis_N_lss_mf_model
Input for:	metis_LM_lss_mf_calctrans metis_N_lss_mf_calctrans
Processing FITS Keywords:	provided at PAE
Purpose:	wavelength calibration / rectification

Corresponding CPL structure:

1. cpl_propertylist * keywords: Primary keywords (PRO.CATG)
2. cpl_table * table: Tables
3. cpl_propertylist * plistarray[]: Extension keywords

8.4.2.30 LM_LSS_SYNTH_TRANS

FITS file structure:

Name:	LM_LSS_SYNTH_TRANS
Description:	Synthetic transmission curve to be used for telluric correction of flux standard stars
PRO.CATG:	LM_LSS_SYNTH_TRANS
OCA keywords:	PRO.CATG
DO.CATG:	LM_LSS_SYNTH_TRANS
Created by:	metis_LM_lss_mf_calctrans

Input for:	metis_LM_lss_mf_correct
Processing FITS Keywords:	provided at PAE

Corresponding CPL structure:

1. cpl_propertylist * keywords: Primary keywords (PRO.CATG)
2. hdrl_spectrum1D * spectrum: Spectrum
3. cpl_propertylist * plistarray[]: Extension keywords

8.4.2.31 N_LSS_SYNTH_TRANS

FITS file structure:

Name:	N_LSS_SYNTH_TRANS
Description:	Synthetic transmission curve to be used for telluric correction of flux standard stars
PRO.CATG:	N_LSS_SYNTH_TRANS
OCA keywords:	PRO.CATG
DO.CATG:	N_LSS_SYNTH_TRANS
Created by:	metis_N_lss_mf_calctrans
Input for:	metis_N_lss_mf_correct
Processing FITS Keywords:	provided at PAE

Corresponding CPL structure:

1. cpl_propertylist * keywords: Primary keywords (PRO.CATG)
2. hdrl_spectrum1D * spectrum: Spectrum
3. cpl_propertylist * plistarray[]: Extension keywords

8.4.3 Final data item structures

The pipeline aims for final data products following the data format described in the SDP-document ([AD4]). We therefore give here only those final files, which are intended to be supplementary final data products.

8.4.3.1 LM_LSS_SCI_FLUX_2D

FITS file structure:

Name:	LM_LSS_SCI_FLUX_2D
Description:	rectified flux-calibrated 2d LM-band spectrum of the science object.
PRO.CATG:	LM_LSS_SCI_FLUX_2D
OCA keywords:	PRO.CATG, INS.OPTI9.NAME, INS.OPTI10.NAME, INS.OPTI11.NAME
DO.CATG:	LM_LSS_SCI_FLUX_2D
Created by:	metis_lm_lss_sci
Processing FITS Keywords:	provided at PAE
Comment:	intermediate data product also used for QC

Corresponding CPL structure:

1. cpl_propertylist * keywords: Primary keywords (PRO.CATG, INS.OPTI9.NAME, INS.OPTI10.NAME, INS.OPTI11.NAME)
2. hdrl_imagelist * images: Images
3. cpl_propertylist * plistarray[]: Extension keywords

8.4.3.2 N_LSS_SCI_FLUX_2D

FITS file structure:

Name:	N_LSS_SCI_FLUX_2D
Description:	rectified flux-calibrated 2d N-band spectrum of the science object.

PRO.CATG:	N_LSS_SCI_FLUX_2D
OCA keywords:	PRO.CATG, INS.OPTI12.NAME, INS.OPTI13.NAME, INS.OPTI14.NAME
DO.CATG:	N_LSS_SCI_FLUX_2D
Created by:	metis_n_lss_sci
Processing FITS Keywords:	provided at PAE
Comment:	intermediate data product also used for QC

Corresponding CPL structure:

1. cpl_propertylist * keywords: Primary keywords (PRO.CATG, INS.OPTI12.NAME, INS.OPTI13.NAME, INS.OPTI14.NAME)
2. hdrl_imagelist * images: Images
3. cpl_propertylist * plistarray[]: Extension keywords

8.4.3.3 LM_LSS_SCI_FLUX_1D

FITS file structure:

Name:	LM_LSS_SCI_FLUX_1D
Description:	Extracted, flux-calibrated 1d science spectrum.
PRO.CATG:	LM_LSS_SCI_FLUX_1D
OCA keywords:	PRO.CATG, INS.OPTI9.NAME, INS.OPTI10.NAME, INS.OPTI11.NAME
DO.CATG:	LM_LSS_SCI_FLUX_1D
Created by:	metis_lm_lss_sci
Input for:	metis_LM_lss_mf_model metis_LM_lss_mf_correct
Processing FITS Keywords:	provided at PAE
Comment:	intermediate data product used for QC

Corresponding CPL structure:

1. cpl_propertylist * keywords: Primary keywords (PRO.CATG, INS.OPTI9.NAME, INS.OPTI10.NAME, INS.OPTI11.NAME)
2. hdrl_spectrum1D * spectrum: Spectrum
3. cpl_propertylist * plistarray[]: Extension keywords

8.4.3.4 N_LSS_SCI_FLUX_1D

FITS file structure:

Name:	N_LSS_SCI_FLUX_1D
Description:	Extracted, flux-calibrated 1d science spectrum.
PRO.CATG:	N_LSS_SCI_FLUX_1D
OCA keywords:	PRO.CATG, INS.OPTI12.NAME, INS.OPTI13.NAME, INS.OPTI14.NAME
DO.CATG:	N_LSS_SCI_FLUX_1D
Created by:	metis_n_lss_sci
Input for:	metis_N_lss_mf_model metis_N_lss_mf_correct
Processing FITS Keywords:	provided at PAE
Comment:	intermediate data product used for QC

Corresponding CPL structure:

1. cpl_propertylist * keywords: Primary keywords (PRO.CATG, INS.OPTI12.NAME, INS.OPTI13.NAME, INS.OPTI14.NAME)
2. hdrl_spectrum1D * spectrum: Spectrum
3. cpl_propertylist * plistarray[]: Extension keywords

8.4.3.5 LM_LSS_STD_WAVE

FITS file structure:

Name:	LM_LSS_STD_WAVE
Description:	Wavelength solution based on STD star
PRO.CATG:	LM_LSS_STD_WAVE
OCA keywords:	PRO.CATG
DO.CATG:	LM_LSS_STD_WAVE
Created by:	metis_lm_lss_std
Processing FITS Keywords:	provided at PAE

Corresponding CPL structure:

1. cpl_propertylist * keywords: Primary keywords (PRO.CATG)
2. cpl_table * table: Tables
3. cpl_propertylist * plistarray[]: Extension keywords

8.4.3.6 LM_LSS_SCI_FLUX_TELLCORR_1D

FITS file structure:

Name:	LM_LSS_SCI_FLUX_TELLCORR_1D
Description:	Extracted, flux-calibrated 1d science spectrum.
PRO.CATG:	LM_LSS_SCI_FLUX_TELLCORR_1D
OCA keywords:	PRO.CATG, INS.OPTI9.NAME, INS.OPTI10.NAME, INS.OPTI11.NAME
DO.CATG:	LM_LSS_SCI_FLUX_TELLCORR_1D
Created by:	metis_LM_lss_mf_correct
Processing FITS Keywords:	provided at PAE
Comment:	intermediate data product used for QC

Corresponding CPL structure:

1. cpl_propertylist * keywords: Primary keywords (PRO.CATG, INS.OPTI9.NAME, INS.OPTI10.NAME, INS.OPTI11.NAME)
2. hdrl_spectrum1D * spectrum: Spectrum
3. cpl_propertylist * plistarray[]: Extension keywords

8.4.3.7 N_LSS_SCI_FLUX_TELLCORR_1D

FITS file structure:

Name:	N_LSS_SCI_FLUX_TELLCORR_1D
Description:	Extracted, flux-calibrated, telluric corrected 1d science spectrum.
PRO.CATG:	N_LSS_SCI_FLUX_TELLCORR_1D
OCA keywords:	PRO.CATG, INS.OPTI12.NAME, INS.OPTI13.NAME, INS.OPTI14.NAME
DO.CATG:	N_LSS_SCI_FLUX_TELLCORR_1D
Created by:	metis_N_lss_mf_correct
Processing FITS Keywords:	provided at PAE
Comment:	intermediate data product used for QC

Corresponding CPL structure:

1. cpl_propertylist * keywords: Primary keywords (PRO.CATG, INS.OPTI12.NAME, INS.OPTI13.NAME, INS.OPTI14.NAME)
2. hdrl_spectrum1D * spectrum: Spectrum
3. cpl_propertylist * plistarray[]: Extension keywords

8.5 ADI data items

8.5.1 Raw data item structures

8.5.1.1 LM_OFF_AXIS_PSF_RAW

FITS image structure:

Name:	LM_OFF_AXIS_PSF_RAW
Description:	Raw off axis PSF image
DPR.CATG:	CALIB
DPR.TECH:	IMAGE,LM
DPR.TYPE:	PSF,OFFAXIS
OCA keywords:	DPR.CATG, DPR.TECH, DPR.TYPE
DO.CATG:	LM_OFF_AXIS_PSF_RAW
Templates:	METIS_img_lm_vc_obs_FixedSkyOffset
Input for:	metis_img_adi_cgrph metis_lm_adi_app
Processing FITS Keywords:	provided at PAE

Corresponding CPL structure:

1. cpl_propertylist * keywords: Primary keywords (DPR.CATG, DPR.TECH, DPR.TYPE, INS.OPTI3.NAME, INS.OPTI9.NAME, INS.OPTI10.NAME)
2. hdrl_image * image: Single Image
3. cpl_propertylist * plistarray[]: Extension keywords

8.5.1.2 N_OFF_AXIS_PSF_RAW

FITS image structure:

Name:	N_OFF_AXIS_PSF_RAW

Description:	Raw off axis PSF image
DPR.CATG:	CALIB
DPR.TECH:	IMAGE,N
DPR.TYPE:	PSF,OFFAXIS
OCA keywords:	DPR.CATG, DPR.TECH, DPR.TYPE
DO.CATG:	N_OFF_AXIS_PSF_RAW
Templates:	METIS_img_n_cvc_obs_AutoChop
Input for recipe:	metis_img_adi_cgrph
Processing FITS Keywords:	provided at PAE

Corresponding CPL structure:

1. cpl_propertylist * keywords: Primary keywords (DPR.CATG, DPR.TECH, DPR.TYPE, INS.OPTI3.NAME, INS.OPTI9.NAME, INS.OPTI10.NAME)
2. hdrl_image * image: Single Image
3. cpl_propertylist * plistarray[]: Extension keywords

8.5.1.3 IFU_OFF_AXIS_PSF_RAW

FITS image structure:

Name:	IFU_OFF_AXIS_PSF_RAW
Description:	Raw off axis PSF image
DPR.CATG:	CALIB
DPR.TECH:	IFU
DPR.TYPE:	PSF,OFFAXIS
OCA keywords:	DPR.CATG, DPR.TECH, DPR.TYPE
DO.CATG:	IFU_OFF_AXIS_PSF_RAW
Templates:	METIS_ifu_vc_obs_FixedSkyOffset

	METIS_ifu_ext_vc_obs_FixedSkyOffset
Input for recipe:	metis_ifu_adi_cgrph
Processing FITS Keywords:	provided at PAE

Corresponding CPL structure:

1. cpl_propertylist * keywords: Primary keywords (DPR.CATG, DPR.TECH, DPR.TYPE, INS.OPTI3.NAME, INS.OPTI9.NAME, INS.OPTI10.NAME)
2. hdrl_image ** image: Four Images
3. cpl_propertylist * plistarray[]: Extension keywords

8.5.2 Master calibration / intermediate data item structures

8.5.2.1 LM_cgrph_SCI_THROUGHPUT

FITS image structure:

Name:	LM_cgrph_SCI_THROUGHPUT
Description:	ADI throughput curve
PRO.CATG:	LM_cgrph_SCI_THROUGHPUT
OCA keywords:	PRO.CATG
DO.CATG:	LM_cgrph_SCI_THROUGHPUT
Created by recipe:	metis_img_adi_cgrph
Input for:	metis_img_adi_cgrph
Processing FITS Keywords:	provided at PAE

Corresponding CPL structure:
1. cpl_propertylist * keywords: Primary keywords (PRO.CATG
2. hdrl_image * image: Single Image
3. cpl_propertylist * plistarray[]: Extension keywords

8.5.2.2 N_cgrph_SCI_THROUGHPUT

FITS image structure:

Name:	N_cgrph_SCI_THROUGHPUT
Description:	ADI throughput curve
PRO.CATG:	N_cgrph_SCI_THROUGHPUT
OCA keywords:	PRO.CATG
DO.CATG:	N_cgrph_SCI_THROUGHPUT
Created by recipe:	metis_img_adi_cgrph
Input for:	metis_img_adi_cgrph
Processing FITS Keywords:	provided at PAE

Corresponding CPL structure:
1. cpl_propertylist * keywords: Primary keywords (PRO.CATG
2. hdrl_image * image: Single Image
3. cpl_propertylist * plistarray[]: Extension keywords

8.5.2.3 IFU_cgrph_SCI_THROUGHPUT

FITS image structure:

Name:	IFU_cgrph_SCI_THROUGHPUT

Description:	ADI throughput curve
PRO.CATG:	IFU_cgrph_SCI_THROUGHPUT
OCA keywords:	PRO.CATG
DO.CATG:	IFU_cgrph_SCI_THROUGHPUT
Created by:	metis_ifu_adi_cgrph
Input for:	metis_ifu_adi_cgrph
Processing FITS Keywords:	provided at PAE

Corresponding CPL structure:

1. cpl_propertylist * keywords: Primary keywords (DPR.CATG, DPR.TECH, DPR.TYPE, INS.OPTI3.NAME, INS.OPTI9.NAME, INS.OPTI10.NAME)
2. hdrl_image * image: IFU Datacube
3. cpl_propertylist * plistarray[]: Extension keywords

8.5.2.4 IFU_DISTORTION_TABLE

FITS structure:

Name:	IFU_DISTORTION_TABLE
Description:	Table of distortion coefficients for an IFU data set
PRO.CATG:	IFU_DISTORTION_TABLE
OCA keywords:	PRO.CATG
DO.CATG:	IFU_DISTORTION_TABLE
Created by:	metis_ifu_distortion
Input for:	metis_ifu_wavecal metis_ifu_std_process metis_ifu_sci_process metis_ifu_adi_cgrph

Processing Keywords:	FITS provided at PAE

Corresponding CPL structure:

1. cpl_propertylist * keywords: Primary keywords (DPR.CATG, DPR.TECH, DPR.TYPE, INS.OPTI3.NAME, INS.OPTI9.NAME, INS.OPTI10.NAME)
2. cpl_table * table: table of distortion coefficients
3. cpl_propertylist * plistarray[]: Extension keywords

8.5.3 Final data item structures

8.5.3.1 LM_APP_SCI_CALIBRATED

FITS image structure:

Name:	LM_APP_SCI_CALIBRATED
Description:	Coronagraphic image after distortion correction
PRO.CATG:	LM_APP_SCI_CALIBRATED
OCA keywords:	PRO.CATG
DO.CATG:	LM_APP_SCI_CALIBRATED
Created by:	metis_lm_adi_app
Processing Keywords:	FITS provided at PAE

Corresponding CPL structure:

1. cpl_propertylist * keywords: Primary keywords (DPR.CATG, DPR.TECH, DPR.TYPE, INS.OPTI3.NAME, INS.OPTI9.NAME, INS.OPTI10.NAME)
2. hdrl_image * image: Single Image
3. cpl_propertylist * plistarray[]: Extension keywords

8.5.3.2 LM_APP_SCI_CENTRED

FITS image structure:

Name:	LM_APP_SCI_CENTRED
Description:	Coronagraphic image after centering on the PSF and subpixel realignment
PRO.CATG:	LM_APP_SCI_CENTRED
OCA keywords:	PRO.CATG
DO.CATG:	LM_APP_SCI_CENTRED
Created by:	metis_lm_adi_app
Processing FITS Keywords:	provided at PAE

Corresponding CPL structure:

1. cpl_propertylist * keywords: Primary keywords (DPR.CATG, DPR.TECH, DPR.TYPE, INS.OPTI3.NAME, INS.OPTI9.NAME, INS.OPTI10.NAME)
2. hdrl_image * image: Image Cube
3. cpl_propertylist * plistarray[]: Extension keywords

8.5.3.3 LM_APP_SCI_SPECKLE

FITS image structure:

Name:	LM_APP_SCI_SPECKLE
Description:	PSFZZZSpeckle image from coronagraphic data
PRO.CATG:	LM_APP_SCI_SPECKLE
OCA keywords:	PRO.CATG
DO.CATG:	LM_APP_SCI_SPECKLE
Created by:	metis_lm_adi_app

Processing Keywords:	FITS	provided at PAE

Corresponding CPL structure:

1. cpl_propertylist * keywords: Primary keywords (DPR.CATG, DPR.TECH, DPR.TYPE, INS.OPTI3.NAME, INS.OPTI9.NAME, INS.OPTI10.NAME)
2. hdrl_image * image: Single Image
3. cpl_propertylist * plistarray[]: Extension keywords

8.5.3.4 LM_APP_SCI_DEROTATED_PSFSUB

FITS image structure:

Name:		LM_APP_SCI_DEROTATED_PSFSUB
Description:		Coronagraphic image after PSF subtraction, derotation and coaddition
PRO.CATG:		LM_APP_SCI_DEROTATED_PSFSUB
OCA keywords:		PRO.CATG
DO.CATG:		LM_APP_SCI_DEROTATED_PSFSUB
Created by:		metis_lm_adi_app
Processing Keywords:	FITS	provided at PAE

Corresponding CPL structure:

1. cpl_propertylist * keywords: Primary keywords (DPR.CATG, DPR.TECH, DPR.TYPE, INS.OPTI3.NAME, INS.OPTI9.NAME, INS.OPTI10.NAME)
2. hdrl_image * image: Image Cube
3. cpl_propertylist * plistarray[]: Extension keywords

8.5.3.5 LM_APP_SCI_DEROTATED

FITS image structure:

Name:	LM_APP_SCI_DEROTATED
Description:	Coronagraphic image after derotation and coaddition
PRO.CATG:	LM_APP_SCI_DEROTATED
OCA keywords:	PRO.CATG
DO.CATG:	LM_APP_SCI_DEROTATED
Created by:	metis_lm_adi_app
Processing FITS Keywords:	provided at PAE

Corresponding CPL structure:

1. cpl_propertylist * keywords: Primary keywords (DPR.CATG, DPR.TECH, DPR.TYPE, INS.OPTI3.NAME, INS.OPTI9.NAME, INS.OPTI10.NAME)
2. hdrl_image * image: Single Image
3. cpl_propertylist * plistarray[]: Extension keywords

8.5.3.6 LM_APP_SCI_COVERAGE

FITS image structure:

Name:	LM_APP_SCI_COVERAGE
Description:	Map of effective number of frames contributing to the final coronographic image
PRO.CATG:	LM_APP_SCI_COVERAGE
OCA keywords:	PRO.CATG
DO.CATG:	LM_APP_SCI_COVERAGE
Created by:	metis_lm_adi_app

Processing FITS Keywords:	provided at PAE

Corresponding CPL structure:

1. cpl_propertylist * keywords: Primary keywords (DPR.CATG, DPR.TECH, DPR.TYPE, INS.OPTI3.NAME, INS.OPTI9.NAME, INS.OPTI10.NAME)
2. hdrl_image * image: Single Image
3. cpl_propertylist * plistarray[]: Extension keywords

8.5.3.7 LM_APP_SCI_SNR

FITS image structure:

Name:	LM_APP_SCI_SNR
Description:	ADI SNR Map
PRO.CATG:	LM_APP_SCI_SNR
OCA keywords:	PRO.CATG
DO.CATG:	LM_APP_SCI_SNR
Created by:	metis_lm_adi_app
Processing FITS Keywords:	provided at PAE

Corresponding CPL structure:

1. cpl_propertylist * keywords: Primary keywords (DPR.CATG, DPR.TECH, DPR.TYPE, INS.OPTI3.NAME, INS.OPTI9.NAME, INS.OPTI10.NAME)
2. hdrl_image * image: Single Image
3. cpl_propertylist * plistarray[]: Extension keywords

8.5.3.8 LM_APP_SCI_CONTRAST_RADPROF

FITS image structure:

Name:	LM_APP_SCI_CONTRAST_RADPROF
Description:	Raw contrast curve for ADI observations; a radial light intensity profile normalized to the brightness of the star if it were not obscured by the coronagraph.
PRO.CATG:	LM_APP_SCI_CONTRAST_RADPROF
OCA keywords:	PRO.CATG
DO.CATG:	LM_APP_SCI_CONTRAST_RADPROF
Created by:	metis_lm_adi_app
Processing FITS Keywords:	provided at PAE

Corresponding CPL structure:

1. cpl_propertylist * keywords: Primary keywords (DPR.CATG, DPR.TECH, DPR.TYPE, INS.OPTI3.NAME, INS.OPTI9.NAME, INS.OPTI10.NAME)
2. hdrl_image * image: 1D Image
3. cpl_propertylist * plistarray[]: Extension keywords

8.5.3.9 LM_APP_SCI_CONTRAST_ADI

FITS image structure:

Name:	LM_APP_SCI_CONTRAST_ADI
Description:	Post-ADI contrast curve for ADI observations
PRO.CATG:	LM_APP_SCI_CONTRAST_ADI
OCA keywords:	PRO.CATG
DO.CATG:	LM_APP_SCI_CONTRAST_ADI
Created by:	metis_lm_adi_app

Processing Keywords:	FITS	provided at PAE

Corresponding CPL structure:

1. cpl_propertylist * keywords: Primary keywords (DPR.CATG, DPR.TECH, DPR.TYPE, INS.OPTI3.NAME, INS.OPTI9.NAME, INS.OPTI10.NAME)
2. hdrl_image * image: 1D Image
3. cpl_propertylist * plistarray[]: Extension keywords

8.5.3.10 LM_APP_SCI_THROUGHPUT

FITS image structure:

Name:	LM_APP_SCI_THROUGHPUT
Description:	ADI throughput curve
PRO.CATG:	LM_APP_SCI_THROUGHPUT
OCA keywords:	PRO.CATG
DO.CATG:	LM_APP_SCI_THROUGHPUT
Created by:	metis_lm_adi_app
Input for:	None
Processing Keywords: FITS	provided at PAE

Corresponding CPL structure:

1. cpl_propertylist * keywords: Primary keywords (DPR.CATG, DPR.TECH, DPR.TYPE, INS.OPTI3.NAME, INS.OPTI9.NAME, INS.OPTI10.NAME)
2. hdrl_image * image: Single Image
3. cpl_propertylist * plistarray[]: Extension keywords

8.5.3.11 LM_APP_CENTROID_TAB

FITS structure:

Name:	LM_APP_CENTROID_TAB
Description:	Table of source centroid positions for a sequence of ADI images
PRO.CATG:	LM_APP_CENTROID_TAB
OCA keywords:	PRO.CATG
DO.CATG:	LM_APP_CENTROID_TAB
Created by:	metis_lm_adi_app
Processing FITS Keywords:	provided at PAE

Corresponding CPL structure:

1. cpl_propertylist * keywords: Primary keywords (DPR.CATG, DPR.TECH, DPR.TYPE, INS.OPTI3.NAME, INS.OPTI9.NAME, INS.OPTI10.NAME)
2. cpl_table * table: table of centroid positions
3. cpl_propertylist * plistarray[]: Extension keywords

8.5.3.12 det_cgrph_SCI_CALIBRATED

FITS image structure:

Name:	det_cgrph_SCI_CALIBRATED
Description:	Coronagraphic image after distortion correction
PRO.CATG:	det_cgrph_SCI_CALIBRATED
OCA keywords:	PRO.CATG
DO.CATG:	det_cgrph_SCI_CALIBRATED
Created by:	metis_img_adi_cgrph

Processing Keywords:	FITS	provided at PAE

Corresponding CPL structure:

1. cpl_propertylist * keywords: Primary keywords (DPR.CATG, DPR.TECH, DPR.TYPE, INS.OPTI3.NAME, INS.OPTI9.NAME, INS.OPTI10.NAME)
2. hdrl_image * image: Single Image
3. cpl_propertylist * plistarray[]: Extension keywords

8.5.3.13 det_cgrph_SCI_CENTRED

FITS image structure:

Name:		det_cgrph_SCI_CENTRED
Description:		Coronagraphic image after centering on the PSF and subpixel realignment
PRO.CATG:		det_cgrph_SCI_CENTRED
OCA keywords:		PRO.CATG
DO.CATG:		det_cgrph_SCI_CENTRED
Created by:		metis_img_adi_cgrph
Processing Keywords:	FITS	provided at PAE

Corresponding CPL structure:

1. cpl_propertylist * keywords: Primary keywords (DPR.CATG, DPR.TECH, DPR.TYPE, INS.OPTI3.NAME, INS.OPTI9.NAME, INS.OPTI10.NAME)
2. hdrl_image * image: Image Cube
3. cpl_propertylist * plistarray[]: Extension keywords

8.5.3.14 det_cgrph_SCI_SPECKLE

FITS image structure:

Name:	det_cgrph_SCI_SPECKLE
Description:	PSFZZZSpeckle image from coronagraphic data
PRO.CATG:	det_cgrph_SCI_SPECKLE
OCA keywords:	PRO.CATG
DO.CATG:	det_cgrph_SCI_SPECKLE
Created by:	metis_img_adi_cgrph
Processing FITS Keywords:	provided at PAE

Corresponding CPL structure:

1. cpl_propertylist * keywords: Primary keywords (DPR.CATG, DPR.TECH, DPR.TYPE, INS.OPTI3.NAME, INS.OPTI9.NAME, INS.OPTI10.NAME)
2. hdrl_image * image: Single Image
3. cpl_propertylist * plistarray[]: Extension keywords

8.5.3.15 det_cgrph_SCI_DEROTATED_PSFSUB

FITS image structure:

Name:	det_cgrph_SCI_DEROTATED_PSFSUB
Description:	Coronagraphic image after PSF subtraction, derotation and coaddition
PRO.CATG:	det_cgrph_SCI_DEROTATED_PSFSUB
OCA keywords:	PRO.CATG
DO.CATG:	det_cgrph_SCI_DEROTATED_PSFSUB
Created by:	metis_img_adi_cgrph

Processing Keywords:	FITS	provided at PAE

Corresponding CPL structure:

1. cpl_propertylist * keywords: Primary keywords (DPR.CATG, DPR.TECH, DPR.TYPE, INS.OPTI3.NAME, INS.OPTI9.NAME, INS.OPTI10.NAME)
2. hdrl_image * image: Image Cube
3. cpl_propertylist * plistarray[]: Extension keywords

8.5.3.16 det_cgrph_SCI_DEROTATED

FITS image structure:

Name:	det_cgrph_SCI_DEROTATED
Description:	Coronagraphic image after derotation and coaddition
PRO.CATG:	det_cgrph_SCI_DEROTATED
OCA keywords:	PRO.CATG
DO.CATG:	det_cgrph_SCI_DEROTATED
Created by:	metis_img_adi_cgrph
Processing FITS Keywords:	provided at PAE

Corresponding CPL structure:

1. cpl_propertylist * keywords: Primary keywords (DPR.CATG, DPR.TECH, DPR.TYPE, INS.OPTI3.NAME, INS.OPTI9.NAME, INS.OPTI10.NAME)
2. hdrl_image * image: Single Image
3. cpl_propertylist * plistarray[]: Extension keywords

8.5.3.17 det_cgrph_SCI_COVERAGE

FITS image structure:

Name:	det_cgrph_SCI_COVERAGE
Description:	Map of effective number of frames contributing to the final coronographic image
PRO.CATG:	det_cgrph_SCI_COVERAGE
OCA keywords:	PRO.CATG
DO.CATG:	det_cgrph_SCI_COVERAGE
Created by:	metis_img_adi_cgrph
Processing FITS Keywords:	provided at PAE

Corresponding CPL structure:

1. cpl_propertylist * keywords: Primary keywords (DPR.CATG, DPR.TECH, DPR.TYPE, INS.OPTI3.NAME, INS.OPTI9.NAME, INS.OPTI10.NAME)
2. hdrl_image * image: Single Image
3. cpl_propertylist * plistarray[]: Extension keywords

8.5.3.18 det_cgrph_SCI_SNR

FITS image structure:

Name:	det_cgrph_SCI_SNR
Description:	ADI SNR Map
PRO.CATG:	det_cgrph_SCI_SNR
OCA keywords:	PRO.CATG
DO.CATG:	det_cgrph_SCI_SNR
Created by:	metis_img_adi_cgrph

Processing Keywords:	FITS	provided at PAE

Corresponding CPL structure:

1. cpl_propertylist * keywords: Primary keywords (DPR.CATG, DPR.TECH, DPR.TYPE, INS.OPTI3.NAME, INS.OPTI9.NAME, INS.OPTI10.NAME)
2. hdrl_image * image: Single Image
3. cpl_propertylist * plistarray[]: Extension keywords

8.5.3.19 det_cgrph_SCI_CONTRAST_RADPROF

FITS image structure:

Name:	det_cgrph_SCI_CONTRAST_RADPROF
Description:	Raw contrast curve for ADI observations; a radial light intensity profile normalized to the brightness of the star if it were not obscured by the coronagraph.
PRO.CATG:	det_cgrph_SCI_CONTRAST_RADPROF
OCA keywords:	PRO.CATG
DO.CATG:	det_cgrph_SCI_CONTRAST_RADPROF
Created by:	metis_img_adi_cgrph
Processing Keywords: FITS	provided at PAE

Corresponding CPL structure:

1. cpl_propertylist * keywords: Primary keywords (DPR.CATG, DPR.TECH, DPR.TYPE, INS.OPTI3.NAME, INS.OPTI9.NAME, INS.OPTI10.NAME)
2. hdrl_image * image: 1D Image
3. cpl_propertylist * plistarray[]: Extension keywords

8.5.3.20 det_cgrph_SCI_CONTRAST_ADI

FITS image structure:

Name:	det_cgrph_SCI_CONTRAST_ADI
Description:	Post-ADI contrast curve for ADI observations
PRO.CATG:	det_cgrph_SCI_CONTRAST_ADI
OCA keywords:	PRO.CATG
DO.CATG:	det_cgrph_SCI_CONTRAST_ADI
Created by:	metis_img_adi_cgrph
Processing FITS Keywords:	provided at PAE

Corresponding CPL structure:

1. cpl_propertylist * keywords: Primary keywords (DPR.CATG, DPR.TECH, DPR.TYPE, INS.OPTI3.NAME, INS.OPTI9.NAME, INS.OPTI10.NAME)
2. hdrl_image * image: 1D Image
3. cpl_propertylist * plistarray[]: Extension keywords

8.5.3.21 det_cgrph_CENTROID_TAB

FITS structure:

Name:	det_cgrph_CENTROID_TAB
Description:	Table of source centroid positions for a sequence of ADI images
PRO.CATG:	det_cgrph_CENTROID_TAB
OCA keywords:	PRO.CATG
DO.CATG:	det_cgrph_CENTROID_TAB
Created by:	metis_img_adi_cgrph

Processing Keywords:	FITS	provided at PAE

Corresponding CPL structure:

1. cpl_propertylist * keywords: Primary keywords (DPR.CATG, DPR.TECH, DPR.TYPE, INS.OPTI3.NAME, INS.OPTI9.NAME, INS.OPTI10.NAME)
2. cpl_table * table: table of centroid positions
3. cpl_propertylist * plistarray[]: Extension keywords

8.5.3.22 IFU_cgrph_SCI_CALIBRATED

FITS image structure:

Name:	IFU_cgrph_SCI_CALIBRATED
Description:	Coronagraphic image after distortion correction
PRO.CATG:	IFU_cgrph_SCI_CALIBRATED
OCA keywords:	PRO.CATG
DO.CATG:	IFU_cgrph_SCI_CALIBRATED
Created by:	metis_ifu_adi_cgrph
Processing Keywords: FITS	provided at PAE

Corresponding CPL structure:

1. cpl_propertylist * keywords: Primary keywords (DPR.CATG, DPR.TECH, DPR.TYPE, INS.OPTI3.NAME, INS.OPTI9.NAME, INS.OPTI10.NAME)
2. hdrl_image * image: IFU Datacube
3. cpl_propertylist * plistarray[]: Extension keywords

8.5.3.23 IFU_cgrph_SCI_CENTRED

FITS image structure:

Name:	IFU_cgrph_SCI_CENTRED
Description:	Coronagraphic image after centering on the PSF and subpixel realignment
PRO.CATG:	IFU_cgrph_SCI_CENTRED
OCA keywords:	PRO.CATG
DO.CATG:	IFU_cgrph_SCI_CENTRED
Created by:	metis_ifu_adi_cgrph
Processing FITS Keywords:	provided at PAE

Corresponding CPL structure:

1. cpl_propertylist * keywords: Primary keywords (DPR.CATG, DPR.TECH, DPR.TYPE, INS.OPTI3.NAME, INS.OPTI9.NAME, INS.OPTI10.NAME)
2. hdrl_image * image: IFU Datacube
3. cpl_propertylist * plistarray[]: Extension keywords

8.5.3.24 IFU_cgrph_SCI_SPECKLE

FITS image structure:

Name:	IFU_cgrph_SCI_SPECKLE
Description:	PSFZZZSpeckle image from coronagraphic data
PRO.CATG:	IFU_cgrph_SCI_SPECKLE
OCA keywords:	PRO.CATG
DO.CATG:	IFU_cgrph_SCI_SPECKLE
Created by:	metis_ifu_adi_cgrph

Processing FITS Keywords:	provided at PAE

Corresponding CPL structure:

1. cpl_propertylist * keywords: Primary keywords (DPR.CATG, DPR.TECH, DPR.TYPE, INS.OPTI3.NAME, INS.OPTI9.NAME, INS.OPTI10.NAME)
2. hdrl_image * image: IFU Datacube
3. cpl_propertylist * plistarray[]: Extension keywords

8.5.3.25 IFU_cgrph_SCI_DEROTATED_PSFSUB

FITS image structure:

Name:	IFU_cgrph_SCI_DEROTATED_PSFSUB
Description:	Coronagraphic image after PSF subtraction, derotation and coaddition
PRO.CATG:	IFU_cgrph_SCI_DEROTATED_PSFSUB
OCA keywords:	PRO.CATG
DO.CATG:	IFU_cgrph_SCI_DEROTATED_PSFSUB
Created by:	metis_ifu_adi_cgrph
Processing FITS Keywords:	provided at PAE

Corresponding CPL structure:

1. cpl_propertylist * keywords: Primary keywords (DPR.CATG, DPR.TECH, DPR.TYPE, INS.OPTI3.NAME, INS.OPTI9.NAME, INS.OPTI10.NAME)
2. hdrl_image * image: 4D IFU Cube
3. cpl_propertylist * plistarray[]: Extension keywords

8.5.3.26 IFU_cgrph_SCI_DEROTATED

FITS image structure:

Name:	IFU_cgrph_SCI_DEROTATED
Description:	Coronagraphic image after derotation and coaddition
PRO.CATG:	IFU_cgrph_SCI_DEROTATED
OCA keywords:	PRO.CATG
DO.CATG:	IFU_cgrph_SCI_DEROTATED
Created by:	metis_ifu_adi_cgrph
Processing FITS Keywords:	provided at PAE

Corresponding CPL structure:

1. cpl_propertylist * keywords: Primary keywords (DPR.CATG, DPR.TECH, DPR.TYPE, INS.OPTI3.NAME, INS.OPTI9.NAME, INS.OPTI10.NAME)
2. hdrl_image * image: IFU Datacube
3. cpl_propertylist * plistarray[]: Extension keywords

8.5.3.27 IFU_cgrph_SCI_COVERAGE

FITS image structure:

Name:	IFU_cgrph_SCI_COVERAGE
Description:	Map of effective number of frames contributing to the final coronographic image
PRO.CATG:	IFU_cgrph_SCI_COVERAGE
OCA keywords:	PRO.CATG
DO.CATG:	IFU_cgrph_SCI_COVERAGE
Created by:	metis_ifu_adi_cgrph

Processing Keywords:	FITS	provided at PAE

Corresponding CPL structure:

1. cpl_propertylist * keywords: Primary keywords (DPR.CATG, DPR.TECH, DPR.TYPE, INS.OPTI3.NAME, INS.OPTI9.NAME, INS.OPTI10.NAME)
2. hdrl_image * image: IFU Datacube
3. cpl_propertylist * plistarray[]: Extension keywords

8.5.3.28 IFU_cgrph_SCI_SNR

FITS image structure:

Name:	IFU_cgrph_SCI_SNR
Description:	ADI SNR Map
PRO.CATG:	IFU_cgrph_SCI_SNR
OCA keywords:	PRO.CATG
DO.CATG:	IFU_cgrph_SCI_SNR
Created by:	metis_ifu_adi_cgrph
Processing FITS Keywords:	provided at PAE

Corresponding CPL structure:

1. cpl_propertylist * keywords: Primary keywords (DPR.CATG, DPR.TECH, DPR.TYPE, INS.OPTI3.NAME, INS.OPTI9.NAME, INS.OPTI10.NAME)
2. hdrl_image * image: IFU Datacube
3. cpl_propertylist * plistarray[]: Extension keywords

8.5.3.29 IFU_cgrph_SCI_CONTRAST_RADPROF

FITS image structure:

Name: IFU_cgrph_SCI_CONTRAST_RADPROF

Description: Raw contrast curve for ADI observations; a radial light intensity profile normalized to the brightness of the star if it were not obscured by the coronagraph.

PRO.CATG: IFU_cgrph_SCI_CONTRAST_RADPROF

OCA keywords: PRO.CATG

DO.CATG: IFU_cgrph_SCI_CONTRAST_RADPROF

Created by: metis_ifu_adi_cgrph

Processing FITS Keywords: provided at PAE

Corresponding CPL structure:

1. cpl_propertylist * keywords: Primary keywords (DPR.CATG, DPR.TECH, DPR.TYPE, INS.OPTI3.NAME, INS.OPTI9.NAME, INS.OPTI10.NAME)
2. hdrl_image * image: 2D Image
3. cpl_propertylist * plistarray[]: Extension keywords

8.5.3.30 IFU_cgrph_SCI_CONTRAST_ADI

FITS image structure:

Name: IFU_cgrph_SCI_CONTRAST_ADI

Description: Post-ADI contrast curve for ADI observations

PRO.CATG: IFU_cgrph_SCI_CONTRAST_ADI

OCA keywords: PRO.CATG

DO.CATG: IFU_cgrph_SCI_CONTRAST_ADI

Created by: metis_ifu_adi_cgrph

Processing Keywords:	FITS	provided at PAE

Corresponding CPL structure:

1. cpl_propertylist * keywords: Primary keywords (DPR.CATG, DPR.TECH, DPR.TYPE, INS.OPTI3.NAME, INS.OPTI9.NAME, INS.OPTI10.NAME)
2. hdrl_image * image: 2D Image
3. cpl_propertylist * plistarray[]: Extension keywords

8.5.3.31 IFU_cgrph_CENTROID_TAB

FITS structure:

Name:	IFU_cgrph_CENTROID_TAB
Description:	Table of central source centroids for an IFU cube
PRO.CATG:	IFU_cgrph_CENTROID_TAB
OCA keywords:	PRO.CATG
DO.CATG:	IFU_cgrph_CENTROID_TAB
Created by:	metis_ifu_adi_cgrph
Processing Keywords:	FITS provided at PAE

Corresponding CPL structure:

1. cpl_propertylist * keywords: Primary keywords (DPR.CATG, DPR.TECH, DPR.TYPE, INS.OPTI3.NAME, INS.OPTI9.NAME, INS.OPTI10.NAME)
2. cpl_table * table: table of centroid positions
3. cpl_propertylist * plistarray[]: Extension keywords

8.5.3.32 det_cgrph_PSF_MEDIAN

FITS image structure:

Name:	det_cgrph_PSF_MEDIAN
Description:	Median PSF
PRO.CATG:	det_cgrph_PSF_MEDIAN
OCA keywords:	PRO.CATG
DO.CATG:	det_cgrph_PSF_MEDIAN
Created by recipe:	metis_img_adi_cgrph
Input for recipe:	None
Processing FITS Keywords:	provided at PAE

Corresponding CPL structure:

1. cpl_propertylist * keywords: Primary keywords (PRO.CATG
2. hdrl_image * image: Single Image
3. cpl_propertylist * plistarray[]: Extension keywords

8.5.3.33 LM_APP_PSF_MEDIAN

FITS image structure:

Name:	LM_APP_PSF_MEDIAN
Description:	Median PSF
PRO.CATG:	LM_APP_PSF_MEDIAN
OCA keywords:	PRO.CATG
DO.CATG:	LM_APP_PSF_MEDIAN
Created by recipe:	metis_lm_adi_app
Input for recipe:	None

Processing Keywords:	FITS	provided at PAE

Corresponding CPL structure:

1. `cpl_propertylist * keywords:` Primary keywords (PRO.CATG
2. `hdrl_image * image:` Single Image
3. `cpl_propertylist * plistarray[]:` Extension keywords

9 HDRL ALGORITHMS

The METIS Data Reduction Software (DRS) will make good use of HDRL functions and data structures, not the least by relying on its built-in error-propagation. The recipe descriptions (Ch. 6) list the functions that will be used, so this information is not repeated here.

9.1 HDRL for IMG

We do not foresee a need for new HDRL algorithms for imaging parts of the DRS.

9.2 HDRL for LSS

We are currently intending the usage of the following HDRL algorithms for spectroscopy whenever applicable:

- `hdrl_spectrum1D_resample`: Resampling of 1D spectra
- `hdrl_efficiency_compute`: For monitoring the system's health and performance we intend to use this built-in function to compute the efficiency of the LSS spectroscopic mode.
- `hdrl_response_compute()`: This function provides a 1D response as function of the wavelength.
- `hdrl_utils_airmass()`: To compute the airmass

In the meanwhile there are well developed algorithms available for spectroscopy-specific tasks, which are already in use in ESO pipelines and which can be generalized to be used in the HDRL. This especially applies to algorithms developed by Piskunov and collaborators ([RD20], [RD19]). We therefore recommend including their following algorithms into the HDRL:

- flatfield normalisation
- curvature determination
- slit decomposition
- wavelength calibration
- continuum normalisation

As some of these algorithms are already implemented in the CRIRES+ pipeline and are therefore already based on CPL an inclusion into HDRL should be possible.

9.3 HDRL for IFU

Similar to the LSS above, the reduction of the IFU will rely on the algorithms from the CRIRES pipeline, as shown for the distortion correction algorithm in Ch. 10.5.2 where this pipeline directly gets applied to METIS simulations.

The METIS DRS will benefit from the availability of these routines in ESO-CPL form in any case, either by adapting and maintaining its own version of the functionality, or preferably by using their integration into the HDRL.

10 CRITICAL ALGORITHMS

This section summarizes the status of the critical algorithms that were identified in the Data Reduction Library Specifications document [AD1] at PDR. Note that ‘critical’ in this context stands for ‘needs prototyping’, and ‘non-critical’ below does not mean ‘unimportant’, just that there is a reason for not needing a prototype.

1. Persistence correction (10.1)
    - *Reason at PDR*: Persistence is a major issue in modern IR detectors, and the determination of this pattern relies on observations previously done, which might arise from completely other observing runs and are therefore proprietary.
    - *Status at FDR*: The persistence correction algorithm will be developed by ESO, making the part in the Data Reduction Library non-critical.
    - *Prototype delivery*: None
2. Detector Masks (10.2)
    - *Reason at PDR*: Reason unknown.
    - *Status at FDR*: Standard procedures apply, therefore not critical.
    - *Prototype delivery*: None.
3. Bad pixel determination (10.3)
    - *Reason at PDR*: Reason unknown.
    - *Status at FDR*: Standard procedures apply, therefore not critical.
    - *Prototype delivery*: None.
4. Background subtraction (10.4)
    - *Reason at PDR*: A proper background correction is essential to ensure accurate photometric and spectroscopic analysis of the observed sources because observations in the mid-infrared are affected by the high sky and telescope background.
    - *Status at FDR*: Standard subtraction techniques (dithering, chopping and nodding) will be used, which do not require prototyping. More complex algorithms that would have required prototypes, e.g. involving principal component analysis, have been ruled out since PDR.
    - *Prototype delivery*: None

5a. LSS Wavelength calibration and distortion correction (10.5.1)
- *Reason at PDR*: A new algorithm is necessary for wavelength calibration and distortion correction for LSS.

- *Status at FDR*: We will use the algorithms from PyReduce.
- *Prototype delivery*: An adaptation of the PyReduce package.

5b. IFU Wavelength calibration and distortion correction (10.5.2)

- *Reason at PDR*: A new algorithm is necessary for wavelength calibration and distortion correction for IFU.
- *Status at FDR*: Use the same algorithms as for LSS (PyReduce), but via their incarnation in the CRIRES pipeline.
- *Prototype delivery*: A JuPyter-notebook with instructions to call the CRIRES pipeline and example input/output files.

6. Telluric correction (10.6)

- *Reason at PDR*: Telluric correction, i.e. the removal of absorption features arising in the Earth's atmosphere, is a critical issue as the imprint of molecular species present in our air may vary on different timescales down to minutes due to changes in their composition and their amount.
- *Status at FDR*: We either use molecfit or a telluric standard star. Both ways are well proven, and therefore we will not deliver a prototype.
- *Prototype delivery*: None.

7. Error propagation (10.7)

- *Reason at PDR*: Error propagation is important.
- *Status at FDR*: The HDRL provides standardized mechanisms for error propagation; prototyping is therefore not necessary.
- *Prototype delivery*: None.

8. N-band image restoration (10.8)

- *Reason at PDR*: There is no standard algorithm for extended sources.
- *Status at FDR*: The science drivers (AGN and circumstellar disks) are compact enough to treat as point-like, using the VISIR algorithm for compact sources. Extended diffuse objects will be observed with large chop-offset for background subtraction and thus no specific algorithm is necessary.
- *Prototype delivery*: None.

9. IFU image and cube reconstruction (10.9)

- *Reason at PDR*: Due to the width of the slices in the LM integral-field spectrograph of 20.7 mas, the PSF is undersampled in the across-slice direction, and there is no known cube reconstruction algorithm.

- *Status at FDR*: A prototype algorithm is implemented in Python.
- *Prototype delivery*: Python package.

10. IFU data rate (10.10)
    - *Reason at PDR*: For very bright sources, short exposures result in high data rates which may present a problem for the observatory pipeline which has to deal with the data in real time.
    - *Status at FDR*: The data rate is under control and does not require prototyping.
    - *Prototype delivery*: None.

The following additional critical algorithms were identified in the period between PDR and FDR:

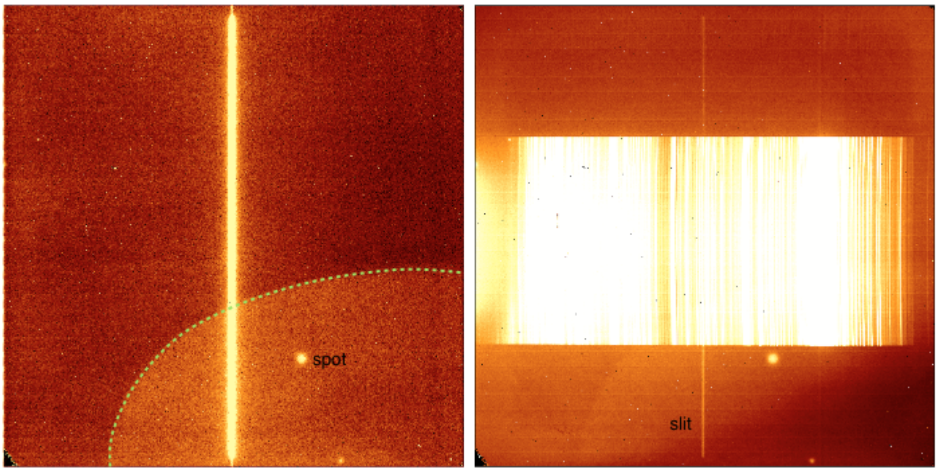
11. ADI algorithm (10.11)
    - *Reason at FDR*: Considering many of the science cases for METIS are focusing on direct imaging / high contrast imaging we deem it critical that we demonstrate that METIS-like data can be ADI-reduced without major issues.
    - *Status at FDR*: ADI algorithms for all HCI observing modes are known from literature, however considering many METIS science cases fall under HCI we demonstrate prototype ADI algorithms for the focal-plane and pupil-plane coronagraphs as well ADI+SDI for the partially undersampled IFU with METIS-like simulated data.
    - *Prototype delivery*: Python package.

10.1 Persistence correction

Persistence is a major issue in modern IR detectors, in particular in the Hawaii2RG devices (HgCdTe based, see Fig. 56 [taken from LBT website[21]]). This detector type also shows significant differences between the individual chips. Fortunately, this pattern can be corrected via simple subtraction as a very first step. The GeoSnap detector is expected to not suffer from persistence (see [0]).

However, since the determination of this pattern relies on observations previously done, this approach requires access to these data, which might arise from completely other observing runs and are therefore proprietary. Therefore, the avoidance of persistence, i.e. a sophisticated planning / persistence management should be one of the major goals for the planning of the observations and the operational concept. In case a persistence correction is required, a subtraction of a persistence map (`PERSISTENCE_MAP`) is foreseen in any individual recipe. This map is created by the recipe `metis_det_persistence` (cf. Section 6.1.3) , which is carried out by ESO and relies on the algorithm provided by ESO.

[21] https://sites.google.com/a/lbto.org/luci/instrument-characteristics/detector#TOC-Persistence



Persistence from unsaturated sky in the acquisition imaging (larger area below green dashed line and the spot)

Persistence from the through-slit image during acquisition is visible for several spectroscopic integrations

Figure 56: Example for the persistence effect (Courtesy of LBT website[21])

10.2 Detector Masks

In MATISSE the engineers created specific masks covering 32 pixels at the edge of the Aquarius detector, which was prone to crosstalk. Crosstalk probably arises from the shared series buses in the detector readout electronics (see Figure on page 8 in [RD25]). For the METIS detectors similar masks as in MATISSE are forseen in order to correct for crosstalk (cf. Polarion METIS-3093). In [RD25], the correction is described as follows:

> Cross-talk correction is done in two steps using the masked pixels in the vertical direction, which are equivalent to two masked outputs.
>
> - Step 1 : The [w]hole line is corrected by an offset.
> - Step 2 : Each pixel is corrected using the corresponding masked pixel in terms of raw number in the two vertical masked outputs.

Fig. 57 taken from [RD25], the minutes of a detector meeting between the METIS and MATISSE consortia held in May 2017 in Bonn.

MATISSE has dealt with the detector masks adequately and the same procedures will be used for METIS; a prototype is therefore not made.

10.3 Bad pixel determination

Bad pixels are an issue in any detector and have to be are monitored and stored. This is usually done with the help of DARK and FLATFIELD frames. Cold/hot pixels can be identified by using DARKS since they have pixel values which are far from an expected values (e.g. median value).

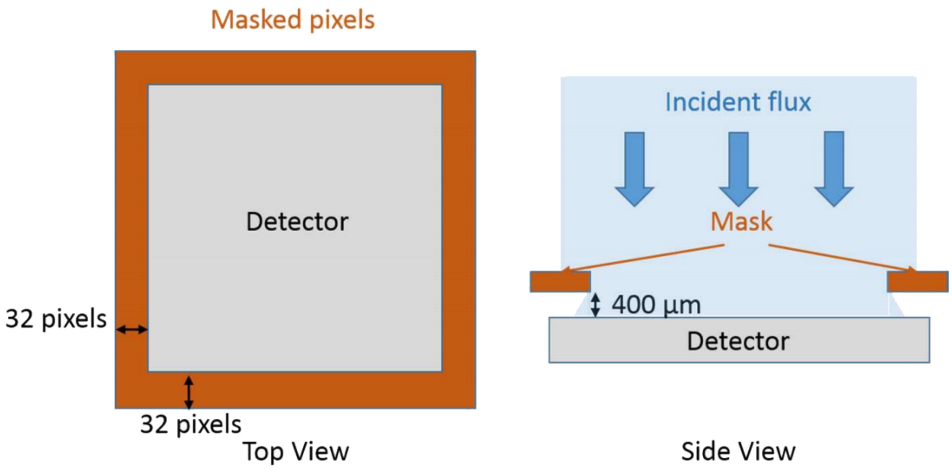


Figure 57: Aquarius detector masks as realised in MATISSE ([RD25], courtesy of S. Mouzali).

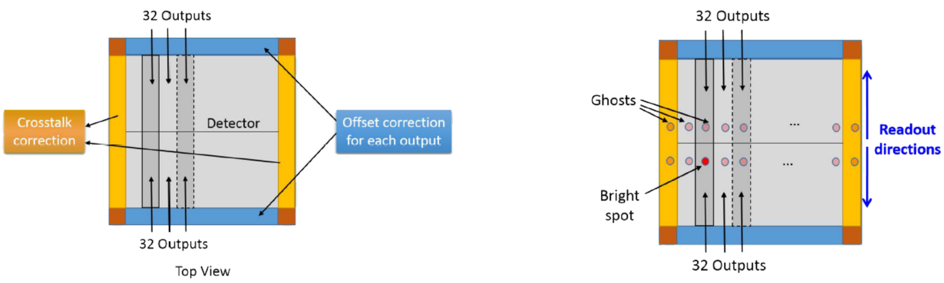


Figure 58: Correction for the crosstalk ([RD25], courtesy of S. Mouzali).

Non-linear pixels can be detected with illumination flats, that is, the detector is illuminated uniformly by a flatfield source. Using several exposure times / flux levels, non-linearities in pixels can be found by fitting polynomials to each individual pixel.

We intend to introduce a bad pixel classification similar to the convention introduced in the X-Shooter Pipeline Manual (cf. Section 11.3 in [RD28]), adapted to our needs.

10.4 Background subtraction

Observations in the mid-infrared are affected by the high sky background, the telescope background, and detector variations and non-linearities. A proper background correction is thus essential to ensure accurate photometric and spectroscopic analysis of the observed sources. As METIS will face an unprecedented level of complexity in the background subtraction due to

1. the high background dominated by the large number of warm mirrors,
2. the internal chopping, and
3. the complexities of nodding with an AO-corrected instrument,

a dedicated research project has been started to better understand the origin of chop-residuals and to evaluate chop-only background removal strategies.

Nevertheless, standard subtraction techniques (dithering, chopping and nodding) will be used, which not require prototyping. More complex algorithms that would have required prototyping, e.g. involving principal component analysis, have been ruled out since PDR.

10.4.1 LM bands

Small ($< 1000''$) and slow (1 min timescale) dithered offsets of the field with respect to the LM IMG or IFU detector are expected to be performed by the METIS-internal chopper mirror. The pipeline will determine the sky background from the dithered images and produce background maps without the sources and background-subtracted versions of the maps with the sources. For In-field-dithering, this is done by determining a flux scaling factor for each "dither" position, aligning the exposures (by either using a 2d cross-correlation routine on bright sources or by using the offset values applied to the chopper), scaling the frames to a common median and removing objects by rejecting the highest and lowest pixels. The remaining pixels are then averaged, or medianed, to produce the sky frame which is then scaled to match the median of the object frame before being subtracted. The sky subtraction is further improved by following the previous steps to produce the combined image to locate all the sources. Then the background frames are combined again while excluding the sources positions. The best approach to determine the flux scaling factor of each dither exposure is yet to be determined (e.g. by median scaling or by a 2D/PCA approach based on [RD29]). The pipeline would also support sky subtraction using separate sky images for out-of-field dithering modes, i.e. when the observed field is crowded or full of extended emission.

10.4.2 N bands

To ensure proper background sampling at the longer wavelengths, small ($< 1000''$) and fast ($\approx$ 10Hz) chopping offsets of the field with respect to the N IMG detector are expected to be performed by the METIS-internal chopper mirror. The chopping residuals from the previous step will be corrected by nodding the telescope to a different position and repeating the same chopping procedure. A 3-point parallel nodding sequence is followed, which should give a higher SNR than the 2 point pattern used in e.g. VISIR (cf. [AD2]). The

The pipeline will determine the sky background from the chopped and nodded images and produce background maps without the sources and background-subtracted versions of the maps with the sources. For each nodding cycle the subsequent chop-cycle frames are subtracted from each other (mean of on-source frames minus mean of off-source frames) resulting in a single chop-difference frame, i.e. nod half-cycle frame. Then for subsequent nodding cycles the nod half-cycle frames are subtracted from each other resulting in a nod-difference frame. The mean of all nod-difference frames is the final background-subtracted image. Additionally, the optimal extraction (PSF-weighting) will be used to subtract the positive/negative source images from the final background-subtract image (2/3/4 depending on the relative chopping/nodding directions) to produce a single stacked image of the sources of interest.

There might be extensive spatial modulation (dithering) within a nod half cycle. That is, the 3-point chop pattern is repeated a few times, then the slightly move the central position is moved slightly after which the 3-point chop pattern is repeated. This is done several times in a nod-half cycle, and then repeated in the same pattern in the other nod position after the nod is performed. This is to mitigate the (many) bad/hot pixels in the GeoSnap array, therefore chop-cycle frames will be subtracted such that the bad pixels can be worked around.

10.5 Wavelength calibration and distortion correction

The wavelength calibration and distortion correction critical algorithm is split in a LSS part (Section 10.5.1) and an IFU part (Section 10.5.2).

10.5.1 LSS Wavelength calibration and distortion correction

The MIR range is dominated by thermal and line emission in the Earth's atmosphere. These emission lines can be used to determine both the curvature/tilt-distortion of the LSS spectrograph and subsequently the wavelength calibration. We adapt the PyReduce package [RD20] employing state-of-the-art functions for optimal extraction of echelle spectra. The package works successfully on several ESO instruments and has been adopted for the CRIRES+ pipeline. In the following sections we assess its functionality on simulated METIS spectroscopic data.

10.5.1.1 Implementing METIS in PyReduce PyReduce [RD20] is an open source Python implementation[22] (with some C components) of the IDL-based REDUCE pipeline [RD19]. The package supports data reduction of several echelle spectrographs, e.g. CRIRES+, HARPS, and can be optimized to work on any instrument, also on a long slit spectrograph as in the case of METIS. In order to adapt PyReduce to work on simulated METIS LSS data, we created a custom instrument class and defined all the needed parameters to run PyReduce within a single script (Method 1[23]). This provided a quick way to finding the needed settings to run the package successfully on METIS data before a complete implementation is done following Method 2. The full implementation requires several configuration files:

- Custom instrument class (`metis.py`) serving several functions such as loading a json file (`load_info`) with FITS header information, finding and sorting files (`sort_files`) for the different reduction steps, modifying fits header information (`add_header_info`), finding the wavelength calibration guess file (`get_wavecal_filename`) etc.
- Header keyword map (`metis.json`).
- PyReduce runtime configuration file (`settings_metis.json`).
- Wavelength calibration initial guess file (e.g. `metis_lss_m_2D.npz`) containing a numpy recarray called `cs_lines` which includes information on the detector positions of the

[22] https://github.com/AWehrhahn/PyReduce
[23] https://pyreduce-astro.readthedocs.io/en/latest/instruments.html

wavelength calibration lines. More details in Sect. 10.5.1.6.

- PyReduce runtime script (`metis_example.py`), in which the user defines where the data are located, which METIS LSS mode to use (*L*, *M*, or *N*-band), PyReduce steps to run, and where they could change any parameter pertaining to PyReduce steps before inserting them into the file `settings_metis.json`.

Placing the above files in their respective PyReduce folders enables PyReduce to run METIS ScopeSim simulated files as any other instrument. PyReduce performs many functions when reducing spectroscopic data including basic data reduction like bias determination, flatfielding, continuum fitting. Here we investigate mainly the steps relevant to the mentioned critical algorithms: `"curvature", and "wavecal"`.

10.5.1.2 Simulated input 'raw' data To demonstrate the feasibility of adopting PyReduce algorithms to METIS purposes we use data simulated with ScopeSim for all three LSS modes (*L*, *M*, or *N*-band) for the 8000 mas × 19 mas slit (see Fig. 59). Then header keywords of the simulated data were added/modified to enable PyReduce to sort the individual files according to `metis.json`. Here we list the files - listed here for the case of *L*-band but similarly for the *M* and *N*-bands - that are used to operate PyReduce, which can be downloaded from[24]:

- `lss_l_thermal.fits`: spectroscopic flat field (Fig. 60)
- `lss_l_pinholes.fits`: pinhole frame with the flat field (Fig. 61)
- `lss_l_sky.fits`: sky emission line spectrum covering the full slit (Fig. 62)

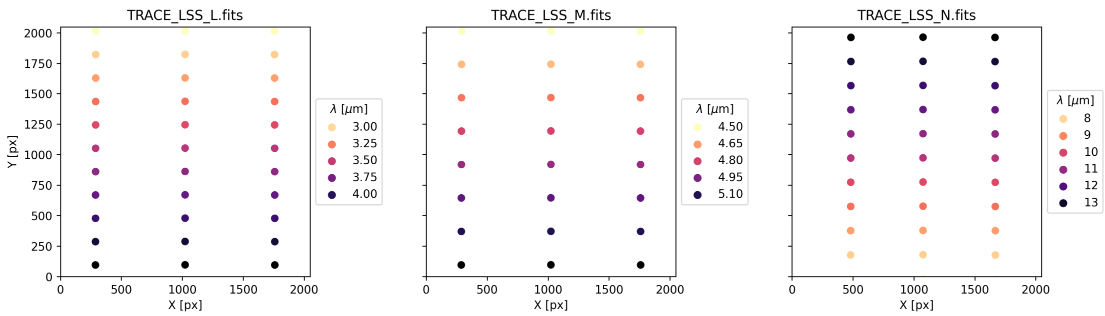


Figure 59: Spectral layout of the METIS LSS mode of all three supported bands: The spectral layout is shown here for all three LSS bands as taken from the corresponding trace files - after transforming from mm to px coordinates- from the METIS IRDB for a slit length of 8 arcsec.

10.5.1.3 Installing and running PyReduce For the purpose of this report, we set up a git repository of a version of PyReduce adapted to work on simulated METIS data. This package can be downloaded from `https://github.com/nadsabha/PyReduce_ELT` or installed via Python 3 pip command:

[24] `https://www.dropbox.com/sh/h1dz80vsw4lwoel/AAAqJD_FGDGC-t12wgnPXVR8a?dl=0`

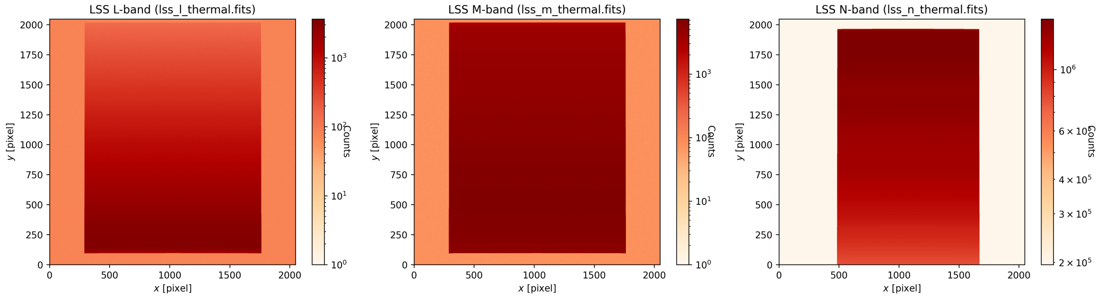


Figure 60: Long-slit spectroscopic flat field frames for LSS *L*-, *M*-, and *N*-bands.

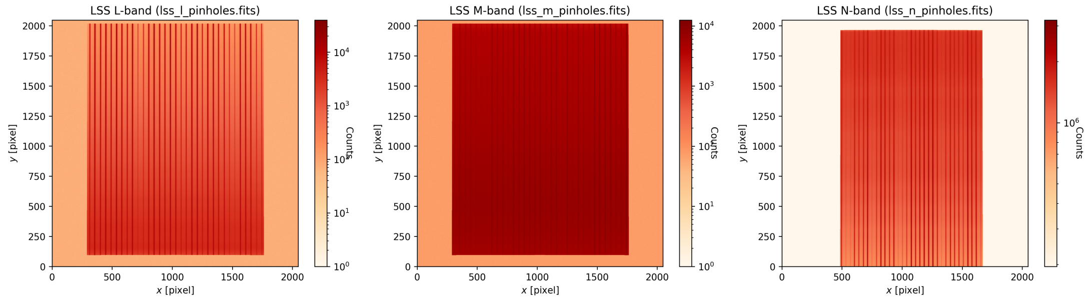


Figure 61: Pinholes with the flat field frames for LSS *L*-, *M*-, and *N*-bands.

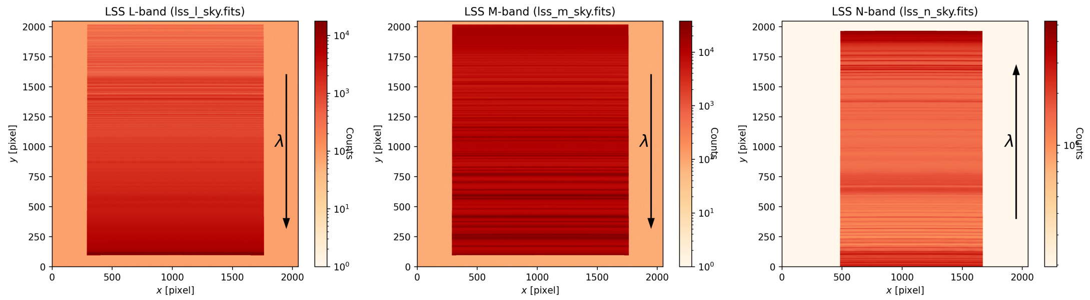


Figure 62: Sky emission line spectrum frames for LSS *L*-, *M*-, and *N*-bands.

`pip install git+https://github.com/nadsabha/PyReduce_ELT`
The package includes a README file with instructions pertaining to running PyReduce on ELT data and links to the needed input data (`README.md`).

10.5.1.4 Order detection The details of how PyReduce handles the detection of the spectroscopic orders is described in Sect. 5.3.2 and [RD19, RD20]. PyReduce rotates the images by 90 degrees counter clockwise to align the wavelength dispersion direction along the x-axis and performs the order detection on the pinhole frame with the flat field lamp. Clusters of neighboring pixels belonging to an order trace are identified and merged together according to predefined criteria. In the case of METIS, a total of thirty three polynomials (one per each pin-

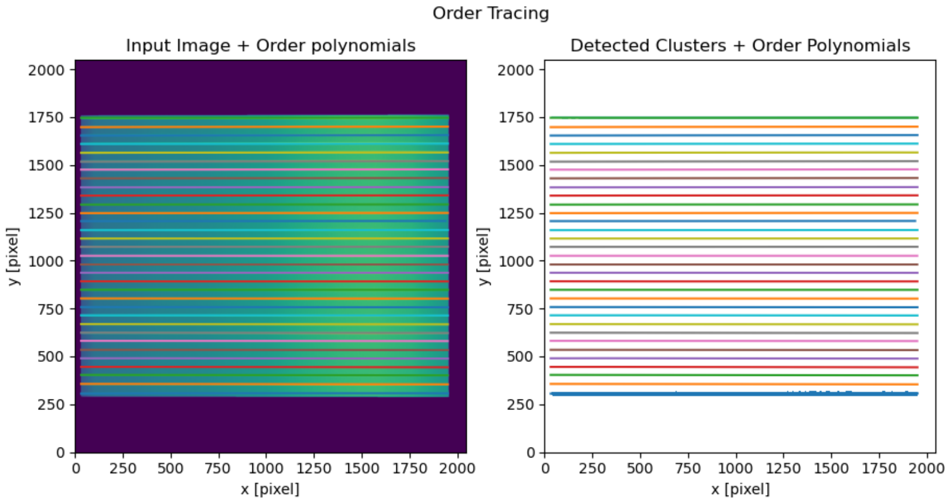


Figure 63: PyReduce output: Slit traces. Left panel: The fitted order polynomials overlaid on the image of the spectroscopic flat field with the pinholes. Right: The fitted order polynomials overlaid on the detected clusters for the order traces. For METIS data, only the central polynomial fit, corresponding to the center or mid-line of the trace, is returned and used in the subsequent steps. Shown here for the case of LSS *M*-band.

hole) are fitted as order traces for each slit trace on the detector. These correspond to the pinhole positions of the flat field frame, see Fig. 63. To correctly extract the slit trace, the main routine `reduce.py` is modified to return only the polynomial fit of the central pinhole as the slit trace on the detector, i.e. fit number 17 (or 16 as per Python convention counted from bottom to up). This allowed a correct extraction of the traces in preparation for the curvature determination step. The order trace fits are stored in the PyReduce output file `metis_lss_m.ord_default.npz` under `orders` and `column_range` recarrays.

10.5.1.5 Slit curvature PyReduce determines the slit curvature by identifying wavelength calibration spectral lines in the extracted order trace and fits the tilt and shear of each order along the image (1st order curvature and 2nd order curvature, respectively). More details on how the package handles slit curvature is discussed in Sect. 5.3.2 and [RD20].

Figures 64 & 65 shows the spectral lines used for the curvature determination overlaid by the fitted tilt and shear marked in red lines. The x-axis corresponds to the y-axis on the original fits images (Fig 62), while the y-axis of Fig. 64 refers to the order trace number on the detector as PyReduce extracted it. Order 0 is the slit trace of the long slit. The order curvature polynomial fits are stored in the PyReduce output file `metis_lss_m.shear.npz` under `tilt` and `shear` recarrays.

10.5.1.6 Wavelength calibration The algorithm for the wavelength calibration strategy is described in Sect. 5.3.3 and in [RD19, RD20]. Here we describe and assess the performance of PyReduce.

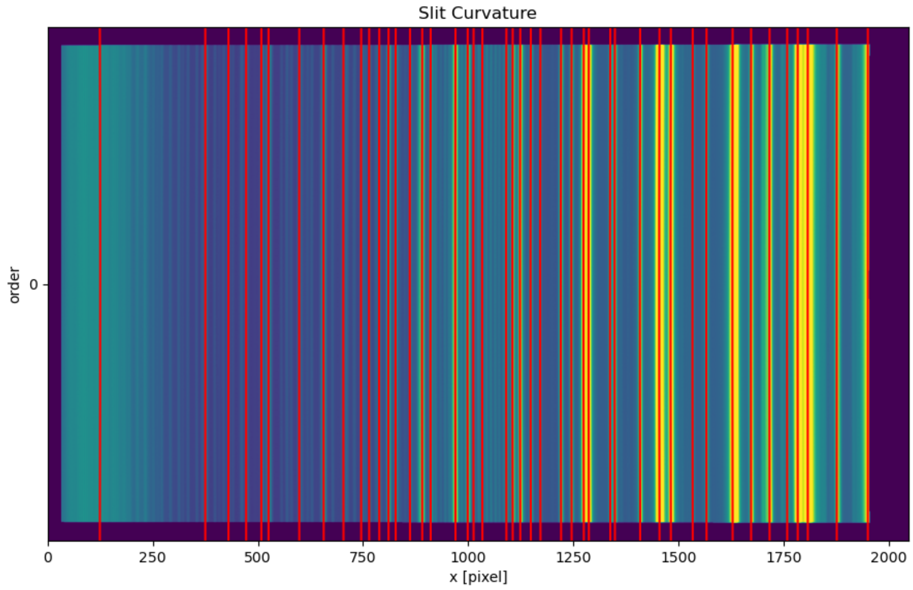


Figure 64: PyReduce output: Slit curvature determination. The spectral lines used for the curvature determination are overlaid by the extracted tilt and shear fits marked in red lines. Shown here for the case of LSS *M*-band.

After the order tracing, extraction and curvature (tilt and shear) determination, PyReduce can proceed with extracting a wavelength calibration spectrum for each order (here only one since we have an LSS mode) from the wavelength calibration frame (`lss_m_sky.fits`, Fig. 66). The order spectrum is then compared to the wavelength calibration guess file `metis_lss_m_2D.npz` of the LSS *M*-band. The `npz` file includes a numpy recarray called `cs_lines` which lists mainly the wavelengths of the calibration reference lines, the x-pixel positions for start, center, and the end of each of the line traces on the detector, and the corresponding order as per PyReduce detection convention (here is zero in the case of METIS LSS). The list of reference lines and their positions on the detector was obtained by cross-matching their wavelengths with the optical design spectral layout of METIS LSS for each band as obtained from the METIS IRDB[25] and implemented in ScopeSim (e.g. `TRACE_LSS_M.fits`, see also Figure 59). PyReduce then performs a cross-correlation to determine any offset between the reference (green lines) and the observation (red lines) as shown in PyReduce intermediate output file in Fig. 67.

Wavelength calibration residuals are then calculated for matching lines and a wavelength solution is found. The wavelength solution for METIS LSS is found by fitting a 2D polynomial, with degrees of 4 and 4 in the dispersion and the spatial direction, respectively. Figure 68 bottom panel shows the 2D wavelength solution of the extracted slit trace where it can be seen that the wavelength range and increment of the trace match the spectral lay-

[25] Instrument Reference Database, https://github.com/AstarVienna/irdb/tree/dev_master/METIS

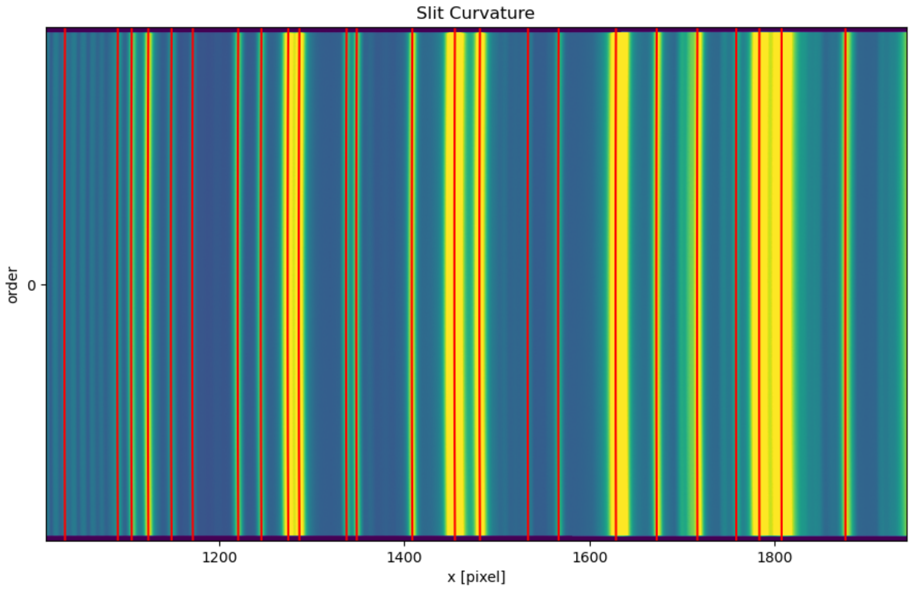


Figure 65: PyReduce output: Zoomed in version of Fig. 64.

out on detector one as seen in Fig. 59. The wavelength calibration spectrum is shown in the top panel of Fig. 68. The wavelength calibration spectrum is stored in the PyReduce output file `metis_lss_m.thar_master.fits` and the corresponding wavelength solution in `metis_lss_m.thar.npz` recarrays `wave` and `coef`, while a modified list of the wavelength calibration lines is returned in `linelist` indicating which line was used in the fitting procedure.

Wavelength calibration accuracy To assess the accuracy of the wavelength solution, the extracted wavelength calibration spectrum is compared to the input sky spectrum `SKYCALC_LSS_override.fits` from METIS IRDB (see Figure 69). The sky spectrum is based on SkyCalc, which is in turn based on HITRAN[26]. Figures 70 & 71 middle panel show the spectrum extracted by PyReduce. The vertical dashed lines indicate the reference wavelength of each detected calibration sky line. The bottom panel shows the residuals between the reference wavelength and fitted wavelength (line center) of each detected calibration line divided by its $FWHM$. As can be seen, the calculated residuals are within $\pm 0.1 \times FWHM$ for most lines.

10.5.1.7 Summary We showed that the PyReduce package (currently part of CRIRES+ pipeline) can be adapted to work on simulated METIS LSS data in all bands by creating the needed PyReduce files and tweaking the parameters used for each of the reduction steps (see linked package). All three steps of order detection, curvature determination, and wavelength

[26] www.hitran.org

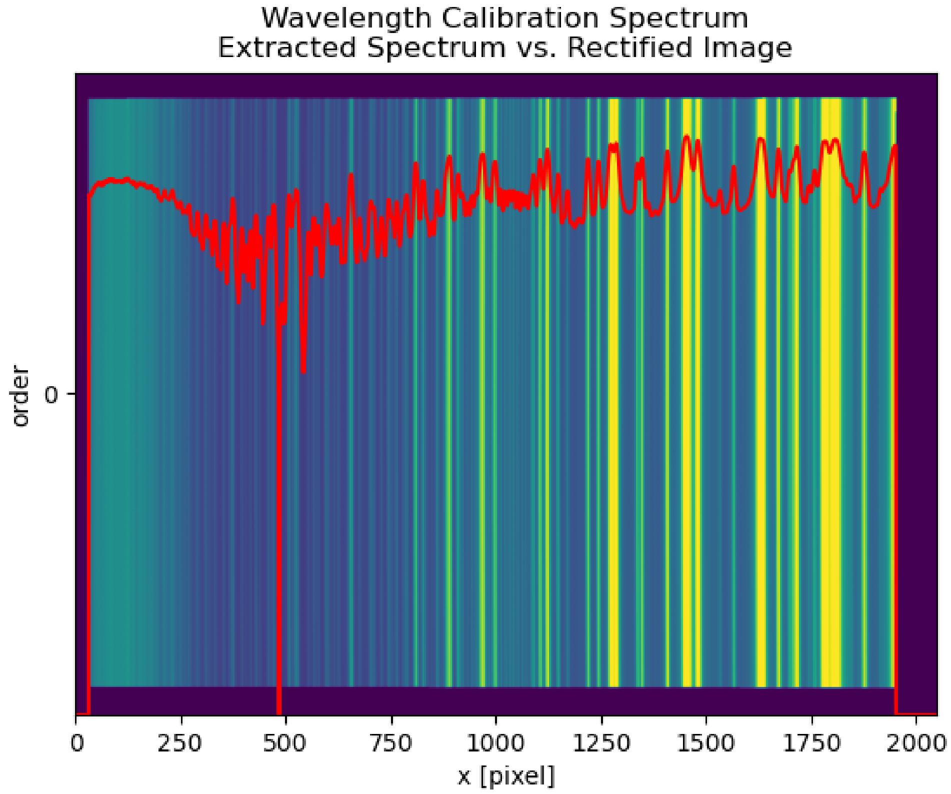


Figure 66: PyReduce output: Wavelength calibration extracted spectrum. Shown here for the case of LSS *M*-band.

calibration are successfully implemented. Further tweaking of certain parameters may be needed to improve the individual steps.

10.5.2 IFU distortion correction

The following is a summary of the steps that were taken to apply the CRIRES+ data reduction to simulation the METIS LMS IFU.

- ScopeSim runs
- Insert data into CRIRES frames
- Order tracing
- Tilt determination
- Extracting 1D spectra
- Assigning Wavelength and spatial scale to pixels in 2D spectra

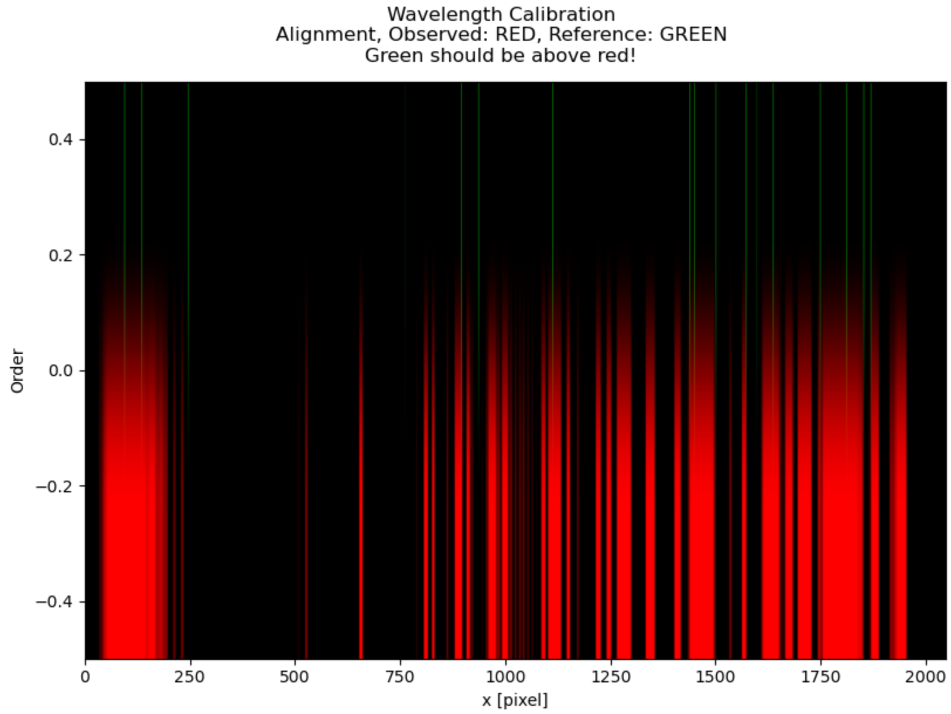


Figure 67: PyReduce output: Lines used for the wavelength calibration. The reference lines (green) and the observed lines (red) are aligned to each other for each order, where the green reference lines are shown to the top of the red observed line. Shown here for the case of LSS *M*-band.

10.5.2.1 ScopeSim As of April 2022, when these simulations were carried out, the release-version of the simulator did not support the IFU mode of METIS. Therefore a development version of the LMS-branch was istalled, after instructions from the team. The mode was set such that the The scipt that creates the frame with the sky spectrum is called `lms_sky.py` and does very little besides calling the simulator with default arguments, and instructing it to set the central wavelength of the spectrograph to arbitrary 3.55 micron. In addition, it retrieves the wavelength scale from one of the slices, in order to later ingest it into the CRIRES-pipeline.

10.5.2.2 CRIRES DRS The upgraded CRIRES is a cross-dispersed echelle slit-spectrograph for the near-infrared bands YJHKLM. It uses three of the same HAWAII2RG detectors that METIS will use four of. The fact that CRIRES images several spectral orders while METIS does slices of spatial regions, is no hindrance to applying the same methods for finding the location and shape of each order/slice in the detector grid, and to determine the orientation of the “slit”.

The CRIRES DRS is a standard ESO-pipeline that was developped from scratch for the upgraded instrument and is in operation since late 2021. It can be installed from the usual sources for ESO pipelines on their website, no particular version is needed for this exercise since the basic

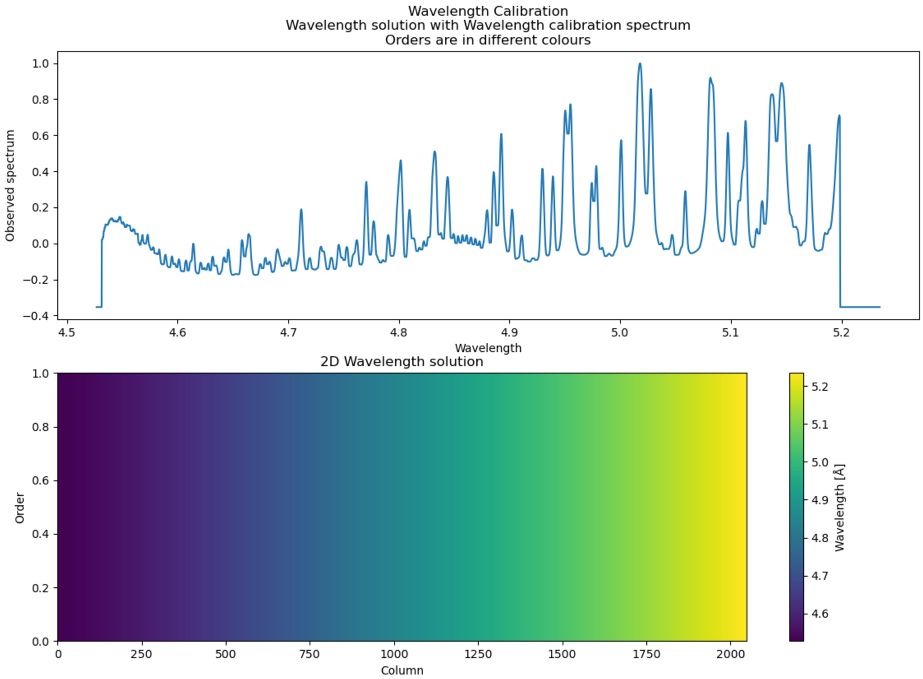


Figure 68: PyReduce output: Top: Wavelength calibration spectrum for LSS *M*-band. Bottom: 2D wavelength solution of PyReduce order 0 (LSS slit trace). The x-axis (Column) refers to the y pixel of the detector image in Fig. 59.

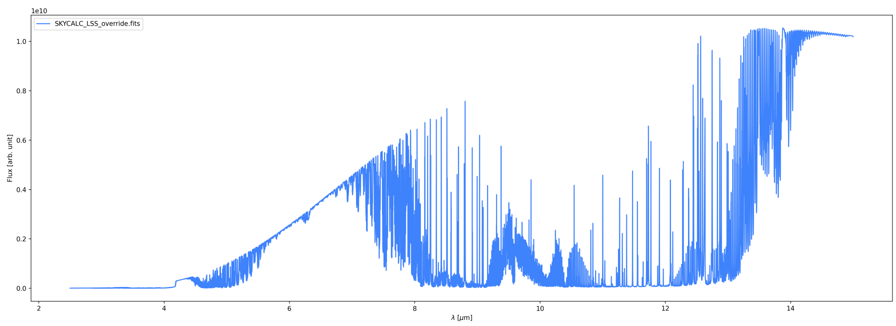


Figure 69: Input sky spectrum over the wavelength range covered by METIS LSS modes: The sky spectrum is taken from METIS IRDB file `SKYCALC_LSS_override.fits`.

algorithms have not changed.

ScopeSim produces frames for all four of the LMS detectors. Simply ignoring the fourth, the pixel values were copied into a raw frame CRIRES, thus preserving its headers and replacing

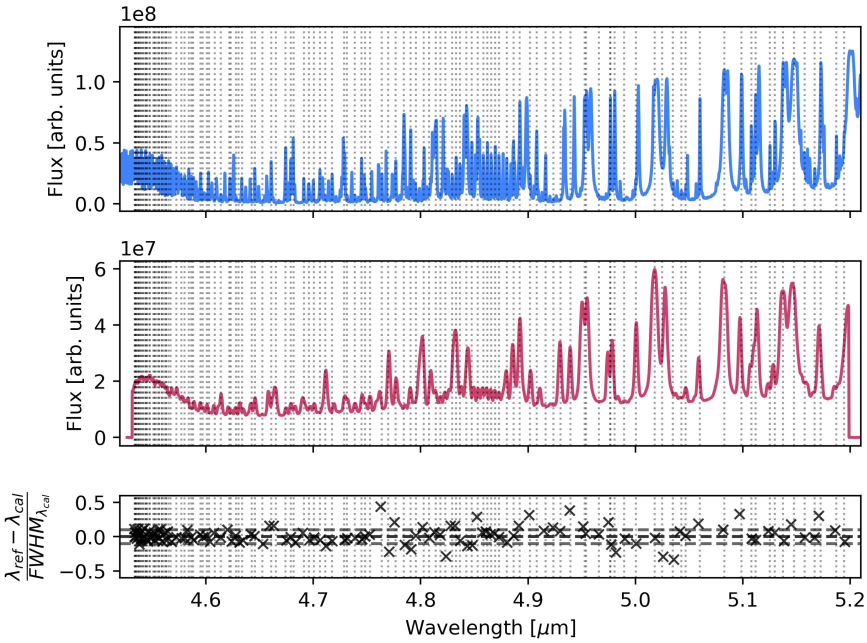


Figure 70: Residuals of the wavelength calibration for LSS M-band. The top panel displays the input sky spectrum. The extracted wavelength calibration spectrum is shown in the middle panel. The bottom panel shows the residuals of the wavelength calibration divided by the $FWHM$ of each respective line. The vertical dotted lines are the reference wavelengths of the input sky emission lines.

the data.

10.5.2.3 Order tracing By "trace" we mean the polynomial in detector coordinates (x,y) that describes the mid-line of the spectral order. This is done by smoothing and thresholding the sky frame (which has enough continuum) in order to distinguish in-order from inter-order pixels. Continuous clusters of in-order pixels are then fitted with a second-degree polynomial. The command executed was

```
# esorex cr2res_util_trace trace_sky.sof
```

where `trace_sky.sof` contains only one line, pretending the sky frame is a FLAT (which is what is usually used for tracing)

```
CIRES_sky.fits FLAT
```

The output file is `CIRES_sky_tw.fits` which is a table that now has the traces for each slice. In addition to the mid-line, it also has the polynomials for the upper and lower edges of each slice.

10.5.2.4 Slit tilt Next up is measuring the orientation of the "slit" in each slice, i.e. the tilt of spectral lines w.r.t. the detector columns. Using the trace from the previous step, each slice gets rectified by shifting columns by integer values according to the trace.

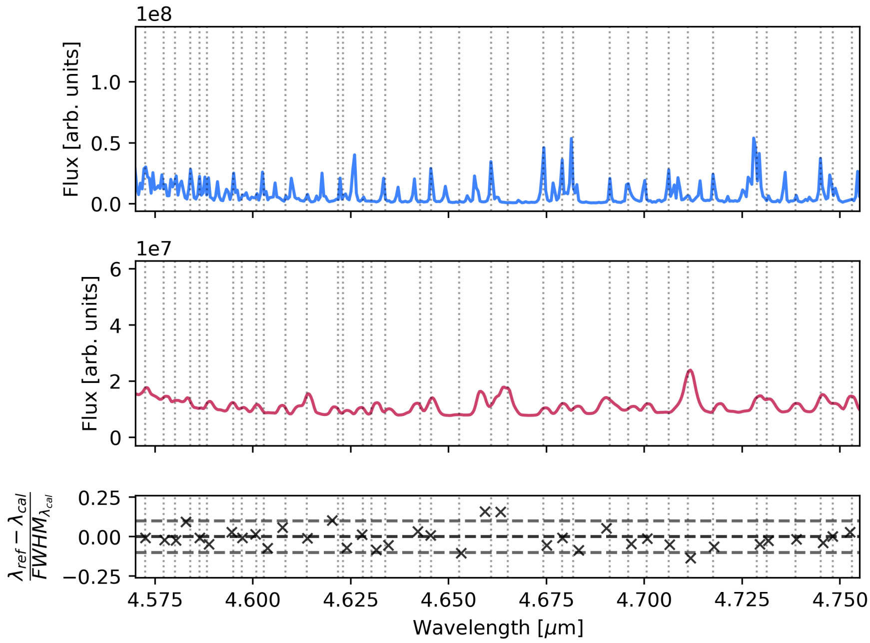
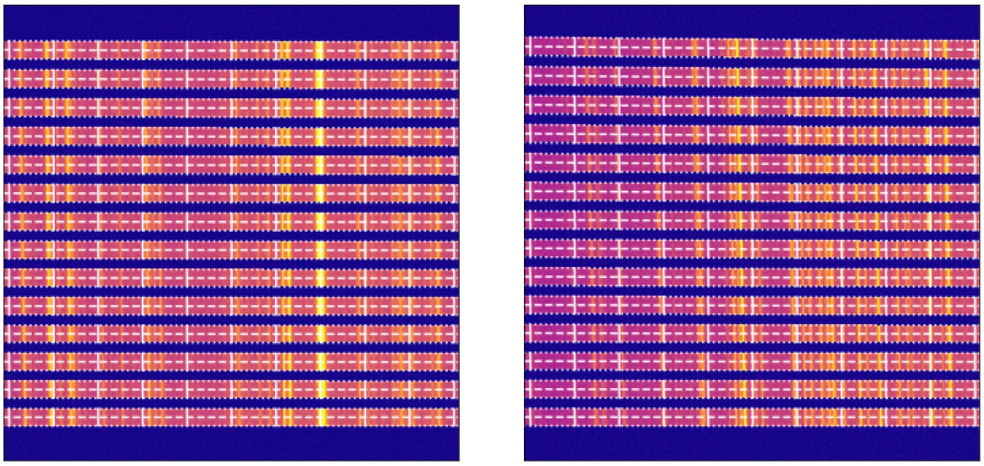


Figure 71: Zoomed in version of Fig. 70.

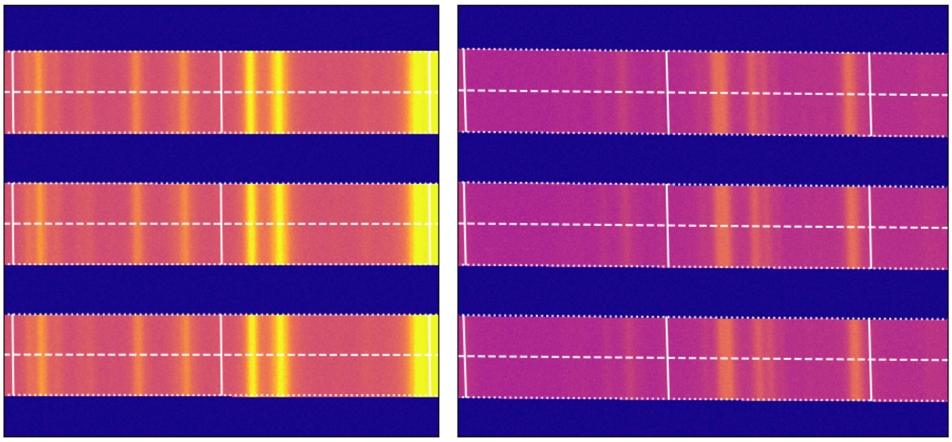
Then a peak-finder is run on each row to find spectral lines, which are then fitted with Gaussians to determine their line centers. Comparing how the line-centers change with detector rows, allows us to fit the slit tilt as a polynomyal P(y). In order to reject outliers and ensure a smooth change in the tilt, the *coefficients* of the tilt polynomials are then each fit as P(x).

These coefficients are saved in an updated FITS-table, called `CIRES_sky_tw_tw.fits`. Using the included script that evaluates the polynomials and plots them on top of the sky frame, we can have a look at the result.

[25]:
```
%run show_trace_curv.py CIRES_sky_tw_tw.fits CIRES_sky.fits
# (This plots only the top row of two detectors)
```



[26]:
```
# Zooming in allows to perceive the tilt in the regularly plotted␣
↪vertical lines that align with the data.
from IPython.display import Image, display
display(Image(filename='lms_sky_tracetilt_zoom.png'))
```



[27]:
```
tilts = fo('CIRES_sky_tw_tw.fits')[1].data['SlitPolyB']
tilts
```

[27]:
```
array([[-1.45030918e-02,  4.97644175e-06, -8.81093015e-10],
       [-1.71465266e-02,  1.19526702e-05, -4.11230539e-09],
```

```
       [-1.60470680e-02,  9.62834066e-06, -2.46179182e-09],
       [-1.56843290e-02,  1.04739179e-05, -3.39557250e-09],
       [-9.89049691e-03, -7.80064422e-07,  1.55907143e-09],
       [-1.37041189e-02,  7.36109573e-06, -1.76092183e-09],
       [-1.21335419e-02,  3.73431498e-06,  3.62338925e-10],
       [-9.88651568e-03,  1.90595104e-06,  9.70922842e-10],
       [-1.25626738e-02,  9.42000943e-06, -3.06478176e-09],
       [-1.23701034e-02,  4.81279417e-06,  6.75878571e-10],
       [-1.30267035e-02,  9.46268944e-06, -2.61068479e-09],
       [-9.47728454e-03,  3.20871517e-06,  1.27630431e-09],
       [-1.29999200e-02,  1.02179873e-05, -1.89150864e-09],
       [-1.04358752e-02,  2.52729614e-06,  1.30881039e-09]])
```

When we evaluate one of the polynomials at the detector edges and center, we find that the slit angle varies between 0.5 and 0.9 degrees.

```
[28]: dx=np.polyval(tilts[3][::-1],[1,1024,2048]) # reverse order of coeffs␣
      ↪in python
      dx
```

```
[28]: array([-0.01567386, -0.00851955, -0.00847581])
```

```
[29]: np.degrees(np.arctan(dx)) # Tilt angles
```

```
[29]: array([-0.89797241, -0.48812261, -0.48561642])
```

```
[30]: dx*80 # pixel difference between top and bottom of a slice, ~80pix high
```

```
[30]: array([-1.25390868, -0.68156423, -0.67806467])
```

10.5.2.5 Extracting into 1D spectra Before we use the “TW”-table from above to extract 1D-spectra, we need to fix the wavelength scale that is also part of the table (TW stands for TraceWave-table in CRIRES-lingo), because otherwise the spectra would have a totally wrong wavelengh scale. For simplicity, the numbering of the METIS slices was not matched with the CRIRES numbering of orders, instead we set the wavelength of one slice (saved into `lam_1.npy` by the script above) for all spectra of the same detector.

```
[31]: tw=fo('CIRES_sky_tw_tw.fits')
      for detec in [1,2]:
          lam=np.load('lam_%d.npy'%detec)
          x=np.arange(len(lam))+1
          p=np.polyfit(x,lam,2)[::-1]
          print(p)
          for row in tw['CHIP%d.INT1'%detec].data:
```

```
        row['Wavelength']=p
tw.writeto(tw.filename(),overwrite=True)
```

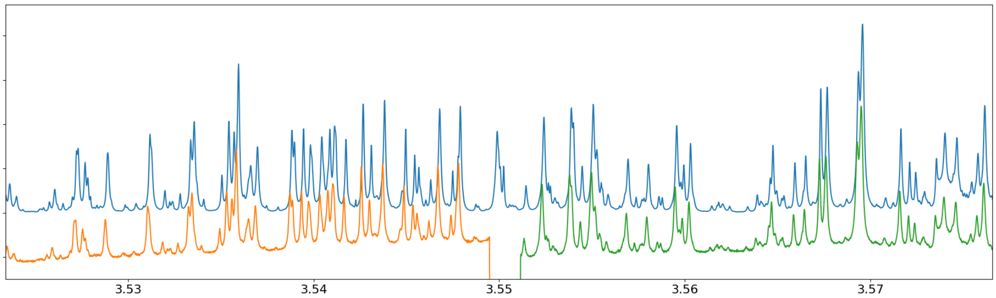
```
[ 3.55110788e+00  1.28761289e-05 -5.17343629e-11]
[ 3.52304458e+00  1.29677244e-05 -2.01943107e-11]
```

The following command runs the optimal extraction which collapses the full height of each slice into a 1D-spectrum, taking the trace and slit tilt into account and iterating to minimize the residual error. (We arbitrarily select "order #3"; again this is CRIRES-numbering and has no meaning for the purpose of this exercise.)

```
# esorex cr2res_util_extract --detector=1 --order=3 --trace=1 extract_sky.sof
```

Now we can plot the spectrum from SkyCalc, that was used by ScopeSim, against the our extracted spectrum. For size considerations, the input sky spectrum is not included in this package and we display the pre-made figure here.

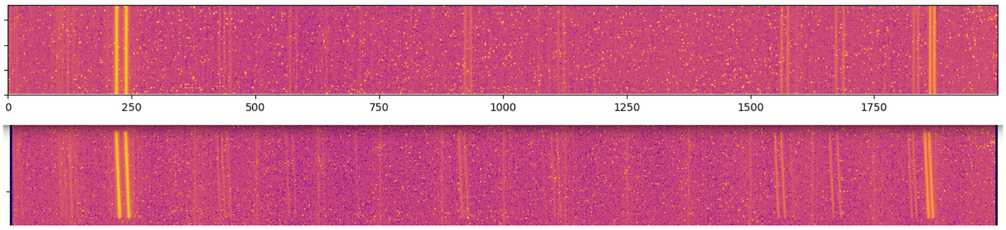
```
[32]: display(Image(filename='lms_skyrecover.png'))
```



In blue the input spectrum, in orange and green the spectra from the two detectors that cover the slice. Vertical offset and scaling are arbitrary. The slight offset in wavelength is due to the mismatch in slice number between the assigned wavelength and the one that got extracted. This nicely illustrates the task of the wavelength calibration, namely to determine this shift by cross-correlation, but this in not part of the current exercise.

10.5.2.6 2D spectra Collapsing slices (or parts of one) into 1D spectra is certainly useful, not the least for calibrations. But METIS is all about spatial resolution, of course, so this whole exercise would be incomplete without assigning to each pixel a wavelength and a speatial coordinate along the slice. Luckily, this is quite straight-forward from the information in the TW-table. The polynomials for the slice edges and mid-line, together with the known on-sky length of the slice, define the position of each pixel on the sky. To arrive at the correct wavelenth, one evaluates the slit-tilt polynomial at the current pixel's distance from the mid-line, to get the displacement in dispersion direction. Then this delta-x gets converted to delta-lambda using the wavelength solution.

[33]:
```
# plot missing, due to technical difficulties, this is a stand-in from␣
↪CRIRES-data.
display(Image(filename='crires_2d_rect.png'))
```



Any non-linear spatial distortion along the slice, as measured from the full field-of-view of the LM-Imager, or by illuminating the IFU slices with the grid of the pin-hole mask in the WCU, can be added to the spatial scale as a last step.

10.6 Telluric correction

Telluric correction, i.e. the removal of absorption features arising in the Earth's atmosphere, is a critical issue as the imprint of molecular species present in our air may vary on different timescales down to minutes, as the composition of the atmosphere may change over time. In particular the MIR range is affected (see App B).

There are two well established ways to correct for these absorptions:

- *Classical approach*: A telluric standard star (TSS) spectrum is taken ideally directly before/after the science observations at the same airmass. This TSS-spectrum is processed in the same way as the science spectrum (except the absolute flux calibration) and finally its continuum is normalised to unity. In addition, a model of this specific TSS spectrum is used to remove intrinsic spectral features. The remaining normalised spectrum (ideally) only contains the fingerprint of the Earth's atmospheric absorptions and can be used for the telluric correction. In case the model spectrum also contains absolute flux values, this star could also be appropriate for the absolute flux calibration.
- *Modelling approach*: In the last years a new method has evolved which is based on radiative transfer modelling of the Earth's atmosphere ([RD14, RD15, RD16][27]). A model of the Earth's atmosphere (probably refined with on-site measurements, e.g. with a radiometer measuring the PWV profile along the line-of-sight) in combination with a radiative transfer model and a molecular line list containing lines of various species is used to determine the transmission of the Earth's atmosphere at the time of observations by fitting specific molecular absorption features in the science spectra. The best-fit transmission function is finally used for the telluric correction.

[27] https://www.eso.org/sci/software/pipelines/skytools/molecfit

These two methods can also be combined in the way that the modelling approach is applied to a TSS spectrum, and the resulting transmission function is then applied to the science spectrum. This combination is specifically useful if the science target continuum is too weak to use the absorptions for a fit.
For the METIS pipelines we intend to incorporate both ways (including their combination). A detailed description is given in Section 5.1. As both methods are well established, we deem a dedicated prototyping not necessary.

10.7 Error propagation

All data products from the pipeline will be accompanied by an estimate of the uncertainty in the derived values in the data products, in compliance with METIS-6681.

Error estimates are necessary for the scientific exploitation of the data. They make it possible to assign significances to detections and to estimate errors on photometric and other measurements in the course of the scientific analysis of the images. The uncertainties include noise contributions from photon noise associated with the photon counting process over the integration time of an exposure, dark current noise, detector read-out noise, digitization noise, and possibly other sources.

The basic reduction procedures, such as dark subtraction and flat-field correction, add the noise from calibration images to the noise of the science exposures. These noise contributions need to be tracked through the reduction process by applying standard error propagation algorithms.

For this purpose, the DRS will make extensive use of HDRL data structures. These include built-in error propagation, for example HDRL-images have separate layers for pixel values, their error and a mask. These are used automatically when performing operations on images, such that the result has the propagated error attached. In cases where this is not sufficient, errors will be calculated manually.

Photon noise is the major noise component of mid-infrared data. The number of electrons, N_e libreated in a detector pixel over the exposure time follows a Poisson distribution with variance $\sigma^2 = \langle N_e \rangle$, where $\langle N_e \rangle$ is the expected number of electrons.

Pixel values F in a raw image are given in ADU and are related to the number of electrons via the gain factor g (in e^-/ADU):

$$F = gN_e. \tag{9}$$

The expected noise in the image is thus

$$\sigma_F = g\sqrt{\langle N_e \rangle} = \sqrt{g\langle F \rangle}. \tag{10}$$

It is a mistake to estimate the expected count rate $\langle F \rangle$ by the actual count rate F for each pixel. For a flux constant in space and time this method would give a different estimate σ_F for each pixel in the same exposure, and also for the same pixel in different exposures. This in turn leads to the undesirable result that the weighted mean of several exposures $i = 1, \ldots, N$ is biased low as pixel values (drawn from a Poisson distribution) lower than the expectation are systematically given larger weight than high pixel values:

$$\overline{F} = \frac{\sum_{i=1}^{N} F_i/\sigma_i^2}{\sum_{i=1}^{N} 1/\sigma_i^2} = \frac{N}{\sum_{i=1}^{N} 1/F_i} < \langle F \rangle \tag{11}$$

Photon noise from thermal or sky background is therefore estimated from a constant or low-order polynomial fit of the background estimate in order to suppress random pixel fluctuations.

Pixel-wise modulation is introduced by the master flat field as this quantifies the response of pixels to a constant background flux.

10.8 N-band image restoration

Images in the N band are taken in a sequence of chopped and nodded exposures. The combination of these exposures results in an image with one or more positive and negative images ("beams") of the target source, depending on the pattern of chops and nods. Image restoration refers to an algorithm to process the chop-nod difference image into an image where the various beams are combined into a single beam, providing an increased signal-to-noise ratio.

The VISIR pipeline employs a shift-and-add algorithm with proper inversion of the negative beams that works well for compact sources. More elaborate algorithms have been described that are also claimed to work for extended sources.

However, extended sources have been excluded from the scope of the pipeline. No prototype is therefore provided.

10.9 IFU image and cube reconstruction

Due to the width of the slices in the LM integral-field spectrograph of 20.7 mas, the PSF is undersampled in the across-slice direction. In order to fully sample the PSF, the following observing sequence is envisaged:

- Take three exposures, each offset perpendicular to the slice by a third of the slice width.
- Rotate the field by 90 degrees (with the derotator).
- Take three more exposures with the same across-slice dither pattern.

The pattern is visualised in Fig. 72. In principle, this pattern yields a sampling of the field at a third of the slice width (i.e. 7 mas) in both spatial directions, which would be sufficient for a full sampling of the PSF. How to implement this reconstruction and to what extent the information can be recovered from real data needs to be investigated.

For the purposes of this prototype, we start from *rectified* data, i. e. a data cube with two spatial axes x and y and a wavelength axis λ, which is orthogonal to the spatial slices. The data are linearly sampled on all three axes. The field of view is shown in Fig. 73.

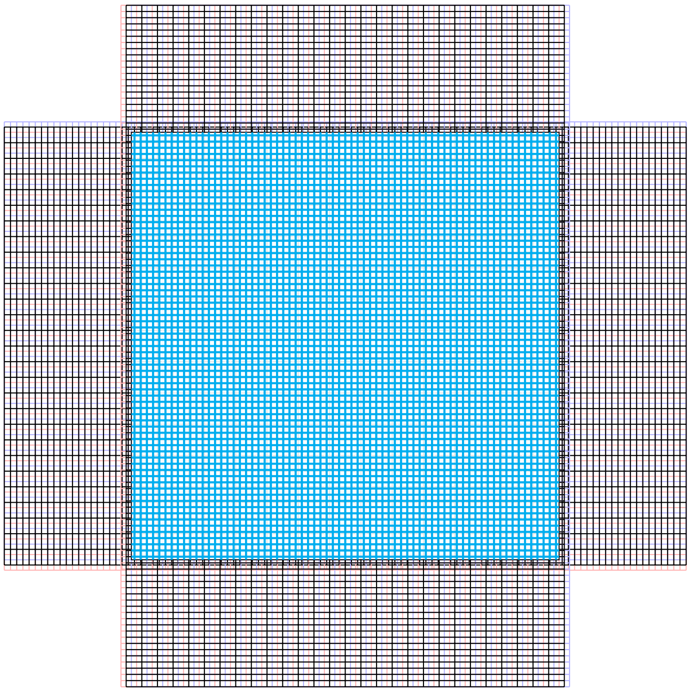


Figure 73: The figure shows a basic IFU data set consisting of six exposures. First three are taken with the slices aligned in the x-direction; the light red and blue grids are offset wrt the black one by ± 6.9 mas in the y-direction. The rectangular pixels (8.2 mas and 20.7 mas in the x- and y-directions, or along- and across slices, respectively) can be seen in the black grid. After rotation by 90 degrees the slices are aligned in the y-direction and offsets are applied in the x-direction. The overlaid cyan grid shows the area covered by all six exposures. This area is to be reconstructed on square pixels of 8.2 mas as shown.

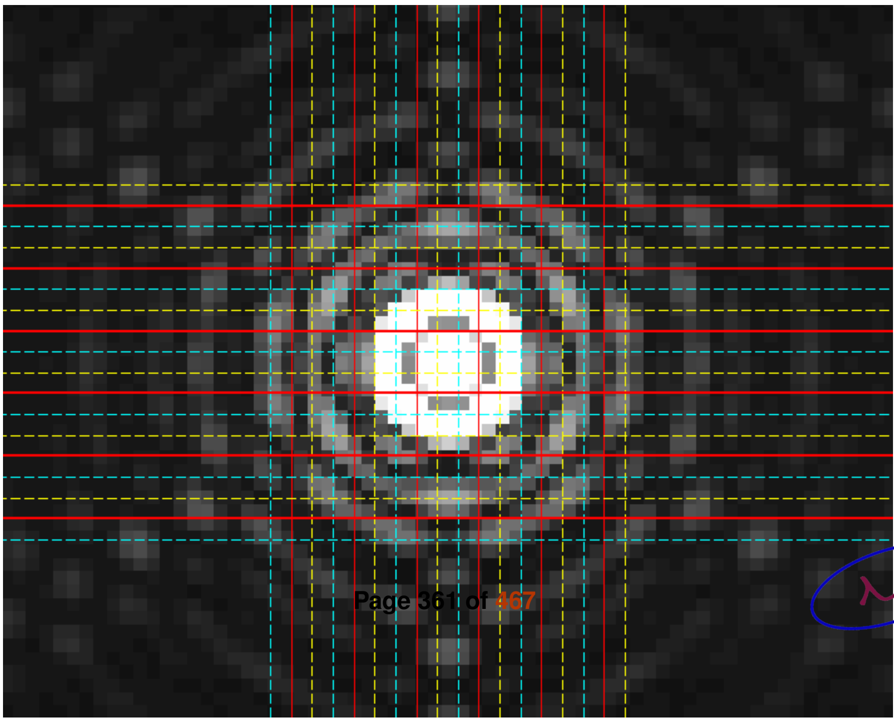


Figure 72: IFU observation pattern overlaid on a METIS SCAO PSF (by Marcus Feldt, MPIA). Red horizontal lines mark the IFU slices of a first exposure. The following exposures are spatially offset by a third of the slice width up and down, indicated by the green and cyan dashed lines. The field is then rotated by 90 degrees and three more exposures are taken with the slices marked by the vertical red and dashed green and cyan lines. The result is a regular sampling on a grid of width $1/3$ the slice width, i.e. 7 mas.

The algorithm described here is inspired by the spectro-perfectionism of Bolton & Schlegel (2010, [0]).

We start with a forward model

$$\vec{d} = \mathbf{A}\vec{m} + \vec{e}, \tag{12}$$

where $\vec{d}$ and $\vec{m}$ are the data images and the model image, respectively, both written as one-dimensional arrays (the six data images are collated into one array $\vec{d}$).[28] The vector $\vec{e}$ is the irreducible noise vector. The data $\vec{d}$ are sampled on rectangular pixels $8.2 \times 20.7\,\mathrm{mas}^2$, while the model $\vec{m}$ is constructed to be sampled on square pixels $8.2 \times 8.2\,\mathrm{mas}^2$ and aligned with the short side of the data pixels. The model matrix $\mathbf{A}$ describes how the model flux is distributed onto the data grid.

A matrix element $\mathbf{A}_{ij}$ thus gives the geometric fraction of model pixel j that overlaps with the data pixel i. Fig. 74 shows the situation for pixels that overlap completely in the x-direction. In the code, we allow for partial overlap in the x-direction as well, so that the matrix element is

$$\mathbf{A}_{ij} = f(\delta x_{ij}; D_{dx}, D_{mx}) f(\delta y_{ij}; D_{dy}, D_{my}), \tag{13}$$

where δx_{ij} and δy_{ij} are differences in horizontal and vertical positions of the data and model pixels and D_{dx}, D_{dy}, D_{mx} and D_{my} are the width and height of the pixels in the data and model grids, respectively.

The function f is given by

$$f(\delta; D_d, D_m) = \begin{cases} 1, & \text{if} \quad |\delta| \leq \frac{D_d - D_m}{2} \\ \frac{D_d + D_m}{2D_m} - \frac{1}{D_m}|\delta|, & \text{if} \quad \frac{D_d - D_m}{2} < |\delta| < \frac{D_d + D_m}{2} \\ 0, & \text{if} \quad |\delta \geq \frac{D_d + D_m}{2} \end{cases} \tag{14}$$

[28] The mapping from two-dimensional to one-dimensional arrays is in principle arbitrary and can be chosen such that the model matrix $\mathbf{A}$ has a convenient form. For the time being, the code uses the numpy method `flatten()`, which returns the array as it is stored in computer memory.

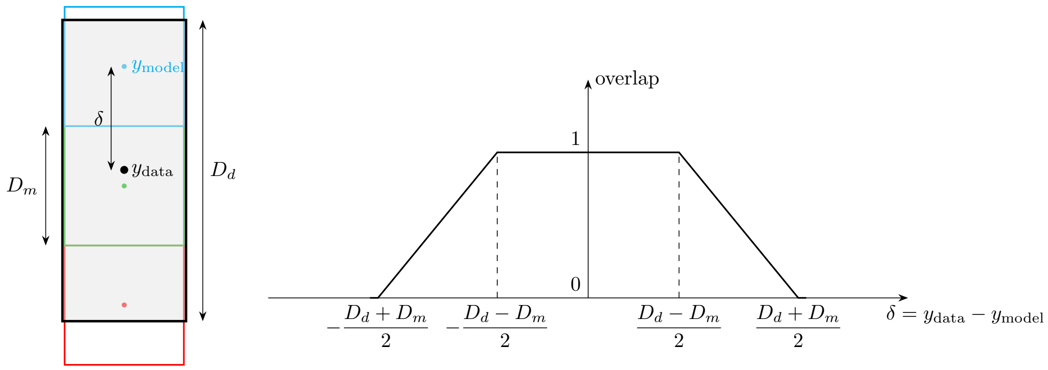


Figure 74: The left panel shows a data pixel of size $D_m \times D_d$, overlapping with three model pixels of size $D_m \times D_m$. The pixels are aligned in the x-direction, so the overlap (which gives the matrix element of the model matrix $\mathbf{A}$) depends only on the distance $\delta = y_{\text{data}} - y_{\text{model}}$ of the pixel centres through a stepwise linear function as shown on the right and given in Eq. (14).

In the case if there is significant field rotation during the observation and the data and model pixel grids are not aligned, a more complex algorithm for determination of overlap must be used:

1. For each pair of data and model pixels, the distance between their centres is computed. If it is larger than $\frac{1}{2}\sqrt{\left(D_{dx} + D_{mx}\right)^2 + \left(D_{dy} + D_{my}\right)^2}$, there is certainly no overlap and the computation may proceed with the next pair.
2. Otherwise, the overlap is computed as follows: Since both pixels are rectangles, the overlap is guaranteed to be a convex polygon with at most eight distinct vertices, including degenerate cases with zero area: no overlap, a single point or a line segment.
3. For each pair of rectangular pixels there are a total of 24 candidate vertices:
   - Each vertex of a data pixel is also a vertex of the overlap polygon, if and only if it lies within the model pixel (4 candidate vertices).
   - Each vertex of a model pixel is also a vertex of the overlap polygon, if and only if it lies within the data pixel (4 candidate vertices).
   - Each intersection of an edge of a data pixel with an edge of a model pixel is necessarily a vertex of the overlap polygon ($4 \times 4 = 16$ candidate vertices).
4. The coordinates of the barycentre of the vertices are found as the arithmetic mean of their x and y coordinates.
5. The vertices are ordered by their azimuth from the barycentre, in order to ensure that the resulting shape is a simple polygon.
6. The area of the polygon S is found as the sum of area of all triangles formed by the

barycentre and all consecutive pairs of vertices using the shoelace formula or its equivalent, namely

$$2S = \sum_{i=0}^{n-1} x_i \left(y_{i-1} - y_{i+1}\right), \tag{15}$$

where all indices are mod n, the number of vertices in the polygon.

Due to the presence of noise $\vec{e}$ in Eq. (12), a solution through direct inversion of the model matrix $\mathbf{A}$ is not possible. A solution can, however, be obtained through χ^2 minimisation:

$$\chi^2 = (\vec{d} - \mathbf{A}\vec{m})^{\mathrm{T}}\mathbf{C}^{-1}(\vec{d} - \mathbf{A}\vec{m}) \stackrel{!}{=} \min \tag{16}$$

Here, $\mathbf{C}$ is the covariance matrix, which describes the noise properties of the data. The minimisation problem is solved analytically by

$$\vec{m} = (\mathbf{A}^{\mathrm{T}}\mathbf{C}^{-1}\mathbf{A})^{-1}\mathbf{A}^{\mathrm{T}}\mathbf{C}^{-1}\vec{d} \equiv \mathbf{S}\vec{d} \tag{17}$$

In the case of the METIS IFU the data vector $\vec{d}$ has $6 \times 100 \times 28 = 16800$ components. The model has $68 \times 68 = 4624$ components (the blue grid in Fig. 73), so the matrix $\mathbf{A}$ has 16800×4624 components. The 4628×16800 solution matrix S depends on the data through the covariance matrix $\mathbf{C}$. Since the reconstruction operates on rectified IFU cubes, i.e. data that have been resampled from the raw data, the pixel noises are correlated and $\mathbf{C}$ is non-diagonal. As an approximation, the pixel noises could be treated as uncorrelated, in which case $\mathbf{C}$ would be diagonal. If $\mathbf{C}$ were further approximated by the unit matrix (giving an unweighted least-squares reconstruction), $\mathbf{S}$ would be independent of the data and could be reused and even be provided as a static calibration in the METIS pipeline.

10.10 Data rates

Observing with the shortest possible exposure times, for bright targets, results in high data rates (cf. Table 4, values taken from [RD30]). This is a potential problem for the observatory pipeline which has to deal with the data in semi-real time, meaning that no backlog of pending data reductions should accumulate.

However, the maximum estimated data rate for a single mode has decreased by a factor of four between PDR and FDR because the rate by which the IFU detectors can be read out has been decreased. This helps ameliorate the issue. The fastest frame rate will be 1 Hz. Sources that would need faster frame rates will be observed with a coronagraph and/or a ND filter.

In addition, the observatory pipeline does not have to perform a full data reduction as described in Sect. 6.6.4, but foremost compute a number of quality control parameters to assess the quality of the data and a "quick-look" at the data for the observers. In the course of the development of the observatory recipes, the details on how individual parts of the pipeline perform will become clear and there will be enough freedom in the choice of parameters to, if necessary, reduce the performance of the recipe if a high data stream is to be expected. Another option might be to compute QC parameters only on a subset of incoming frames.

This is in compliance with METIS-6075.

Table 4: Data rates

Observing mode	Max. rate [MiB s^{-1}]	Max. volume [TiB]	Night fraction [per 10h night]	Exp. volume [TiB]
Imager				
IMG_LM (burst mode)	200	5.49	0.10	0.55
IMG_N (burst mode)	182	4.99	0.10	0.50
IMG_N (half-cycle average)	32	0.88	0.00	0.00
IMG_LMN (parallel mode)	382	10.49	0.10	1.05
Spectroscopy				
SPEC_LM	200	5.49	0.05	0.27
SPEC_N	182	4.99	0.05	0.25
SPEC_LMN (parallel mode)	382	10.49	0.06	0.63
IFU + IMG_LM parallel (IFU)	64	1.76	0.54	1.25
IFU + IMG_LM parallel (IMG)	200	5.49	0.54	2.67

10.11 ADI algorithm

Considering many of the science cases for METIS are focusing on direct imaging / high contrast imaging we deem it critical that we demonstrate that METIS-like data can be ADI-reduced without major issues. ADI reduction with focal plane and pupil plane coronagraphs is therefore demonstrated. It is recognized that the required techniques are already known from earlier publications of data collected with high contrast imagers and AO-fed IFUs. This study allows the PIP team to become more familiar with them and to present prototype algorithms in a centralized location.

10.11.1 Generation of representative set of IMG_LM data: planetary system

Using a combination of the HEEPS code [RD31] and the ScopeSim code with the METIS package we have performed simulations of a star and a point source companion in order to test critical algorithms for high contrast imaging on simulated data of METIS. Using the HEEPS code we simulate a sequence of up to 12000 PSFs of an unresolved star behind the RAVC coronagraph and of an unresolved companion sufficiently far away from the coronagraph to be considered off-axis, with each PSF corresponding with an integration time of 300 milliseconds for a total of 3600 seconds of observing time. Each PSF is generated with a (SCAO-only) wavefront sampled every 300 ms (comparable to the coherence time t0 at L-band), thereby effectively time sampling the atmospheric wavefront aberrations. Both PSFs are scaled to the magnitude of the parent star ($L = 3.5$). For this demonstration we use a time sequence of 12000 PSFs but will apply some windowing and temporal binning to increase execution speed on a laptop. The two PSFs are combined together with an offset of 100 mas, an additional delta magnitude ($\Delta L = 7.7$) for the companion and field rotation over 1 hour (corresponding with 30 degrees change in position angle). The system could be described at Beta Pic b orbiting at 100 mas around its host star. A second source is added at opposite position angle to see the symmetry of the reduction (of use for the APP coronagraph which only has one dark hole). This combined source is fed into ScopeSim as a fits file with the WCS information conveying the spatial extent. The coronagraphic transmissions are transferred to ScopeSim as well during this process. In the ScopeSim step the instrumental noise and background expected from both METIS and ELT is injected and the source flux reduced according to system transmission. After these processing steps we are left with a large 3D cube of a star (x, y, time) with two planets undergoing field rotation which we use for the ADI processing step using the VIP_HCI package. For this example, the output images have been truncated to 201x201 pixels and the images have been binned to 30 seconds exposure time ($N_{\mathrm{bin}} = 100$) to further reduce execution time. Figures 75 and 76 show the instantaneous on-axis (with AO residuals and detector noise) and off-axis PSFs (noiseless).

10.11.2 Demonstration of ADI algorithm on simulated IMG_LM data

The most basic PSF subtraction of VIP_HCI is the standard ADI algorithm from Marois et al 2006, where the median of the cube is first subtracted and in a second step optimally-scaled time-localized medians are subtracted in annular rings. An instantaneous frame with the median subtracted is shown in Fig. 77 representing this phase. Afterwards each image in the cube is derotated with the known position angle. Subsequently the derotated and PSF subtracted images are averaged to give a final stacked version (see Fig. 78). When the second annular optimized subtraction step is skipped this procedure is equal to the one described in the PIP Spec. For the IFU, this ADI procedure can similarly be followed for each wavelength in the reduced cubes. In VIP_HCI it is possible to do a two-step (first ADI then SDI) or single-step reduction, in which rescaled images from other wavelength slices are used to provide additional PSF reference material.

Additionally, the contrast curves can be extracted (see Fig. 79; raw contrast over time-averaged cube, 5 sigma contrast after ADI processing). Please note that the plotted contrast is dependent on the assumptions made for this demonstration (SCAO-only effects, no additional jitter / pupil drifts / no residual atmospheric dispersion, 120 binned frames with each 100 frames of 0.3s integration time, 30 degrees image rotation). Injection and retrieval of point sources of known intensity is performed to calculate the efficiency or throughput of the ADI post-processing technique . Closer to the star the same amount of position angle movement will be seen as an increasingly smaller physical movement. Therefore, self-subtraction of a point source signal will be more pronounced and increased losses are seen close to the star. Figure 80 shows the post-processing only component of the ADI reduction losses. The radial coronagraphic throughput losses due to partial suppression of off-axis sources will be provided separately (and is not included in these sensitivity plots for this example).

Following the SNR definitions of Mawet et al 2014 the noise is calculated in annular rings and corrected for the relatively low number of effective samples. A 5-sigma sensitivity curve is produced by injection and retrieval of sources. In addition, a post-ADI SNR map is generated (see Fig. 81). Note that the two injection planets are so bright that an unmasked SNR map gives an underestimated SNR as their presence strongly alters the local noise estimate. Nonetheless

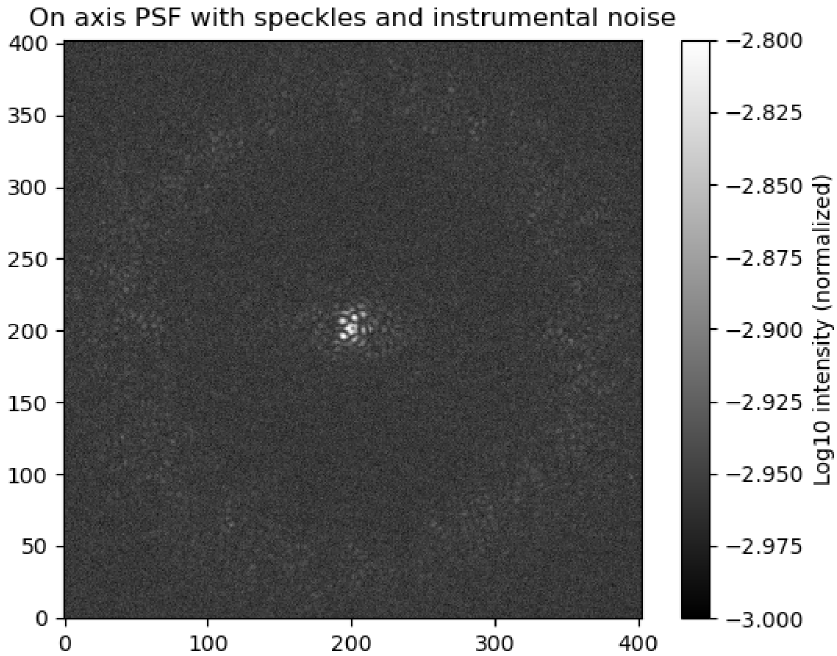


Figure 75: On-axis coronagraphic PSF with instrumental noise injected and with corrected atmospheric turbulence. The circular control region from the AO system is clearly visible.

they are both recognized as significant detections.

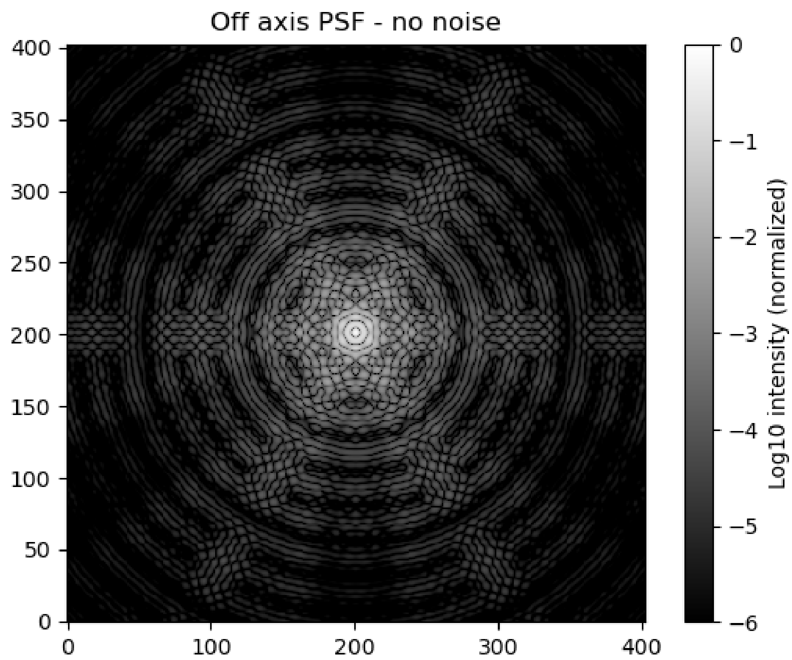


Figure 76: Off-axis PSF without instrumental noise.

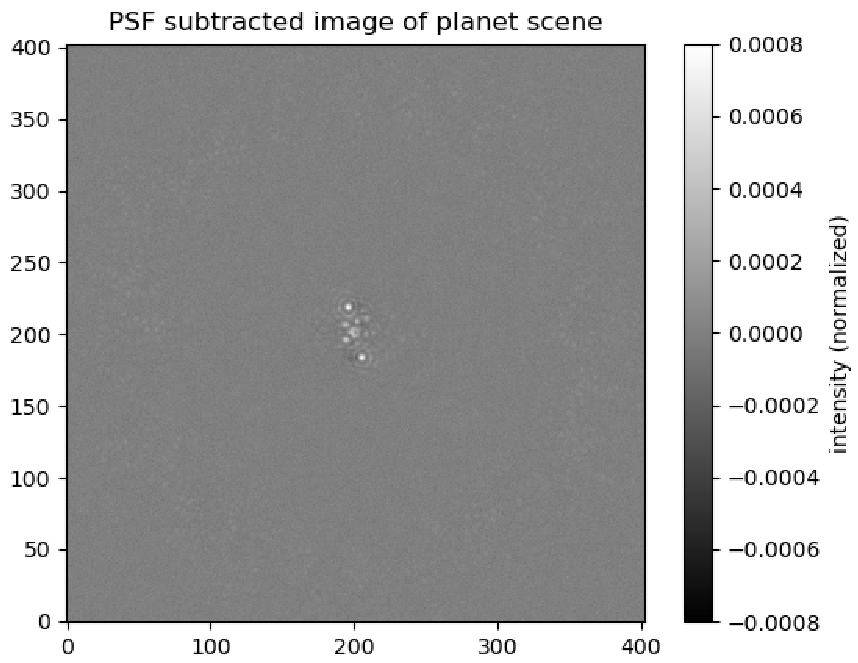


Figure 77: Single frame of image stack with mean PSF subtracted.

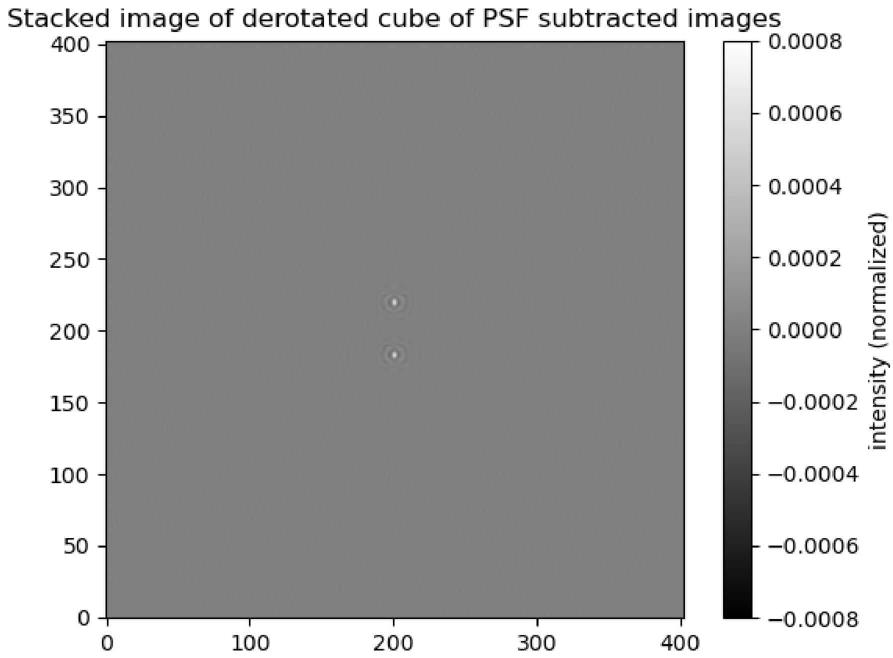


Figure 78: Derotated stack of ADI reduced images.

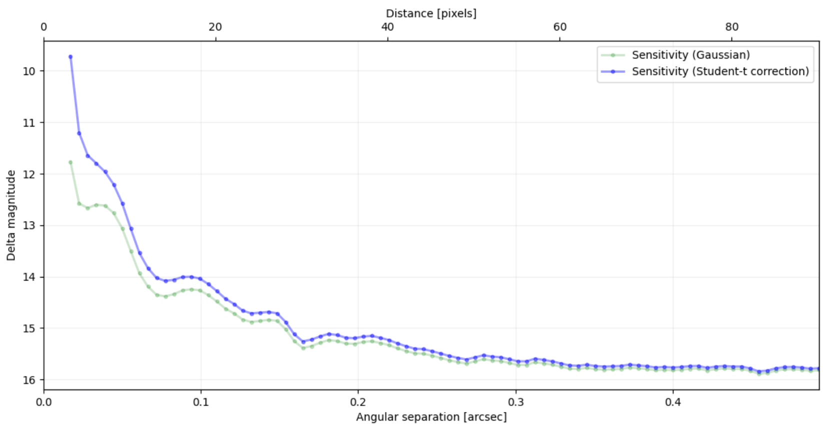


Figure 79: Achievable contrast for the $L = 3.5$ target in 1 hour integration time as a function of angular separation. Note, this contrast is dependent on the assumption made here in this simplified study and may not be representative of a more realistic scenario.

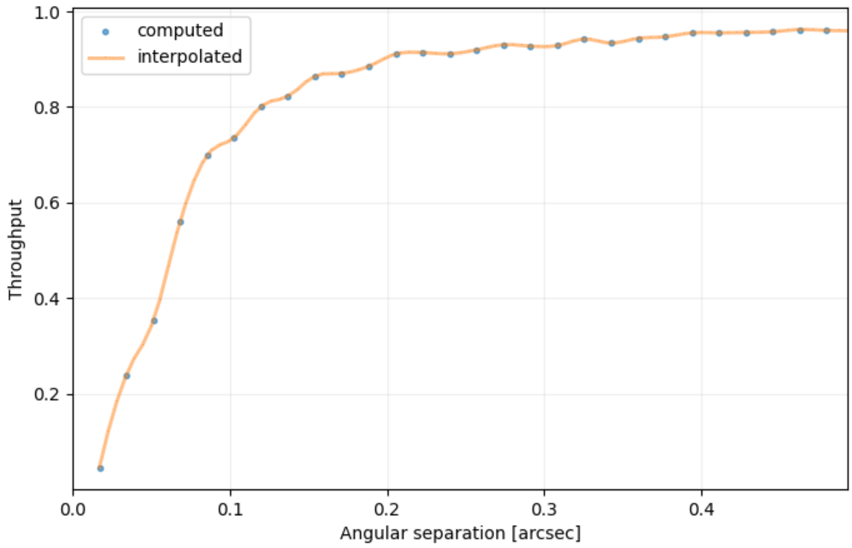


Figure 80: Efficiency of ADI algorithm in retrieving inserted point sources as a function of angular separation.

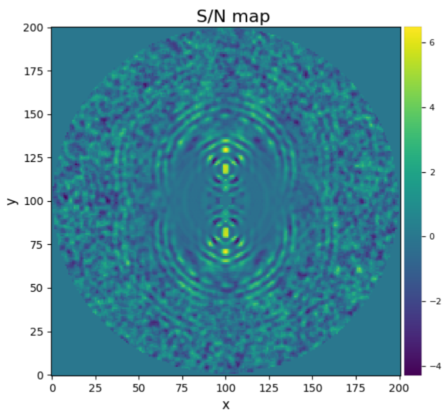


Figure 81: Two dimensional ADI map of post ADI signal to noise of point sources. Two point sources that were inserted at 100 mas are seen.

11 QC PARAMETERS

The following placeholders are used in the QC parameter names:

- `det` is a placeholder for either `LM`, `N`, or `IFU`
- `cgrph` is a placeholder for one of the coronographs
- `nn` is a placeholder for a numerical index

11.1 Calibration

11.1.1 QC PERSIST COUNT

Name	`QC PERSIST COUNT`
Class	header
Context	QC
Type	int
Value	%i
Unit	n/a
Default	None
Range	None
Created by	`metis_apply_persistence_correction`
Description	Number of pixels heavily affected by persistence
Comment	

11.1.2 QC DARK MEAN

Name	`QC DARK MEAN`
Class	header
Context	QC
Type	double
Value	%.3f
Unit	n/a
Default	None
Range	None

Created by	metis_det_dark
Description	Mean level of the dark frame
Comment	

11.1.3 QC DARK MEDIAN

Name	QC DARK MEDIAN
Class	header
Context	QC
Type	double
Value	%.3f
Unit	n/a
Default	None
Range	None
Created by	metis_det_dark
Description	Median level of the dark frame
Comment	

11.1.4 QC DARK RMS

Name	QC DARK RMS
Class	header
Context	QC
Type	double
Value	%.3f
Unit	n/a
Default	None
Range	None
Created by	metis_det_dark
Description	RMS level of the dark frame
Comment	

11.1.5 QC DARK NBADPIX

Name	QC DARK NBADPIX
Class	header
Context	QC
Type	double
Value	%.3f
Unit	n/a
Default	None
Range	None
Created by	metis_det_dark
Description	Number of bad pixels in the image maxk
Comment	

11.1.6 QC DARK NCOLDPIX

Name	QC DARK NCOLDPIX
Class	header
Context	QC
Type	double
Value	%.3f
Unit	n/a
Default	None
Range	None
Created by	metis_det_dark
Description	Number of cold pixels in the image maxk
Comment	

11.1.7 QC DARK NHOTPIX

Name	QC DARK NHOTPIX
Class	header

Context	QC
Type	double
Value	%.3f
Unit	n/a
Default	None
Range	None
Created by	metis_det_dark
Description	Number of hot pixels in the image maxk
Comment	

11.1.8 QC LM MASTERFLAT RMS

Name	QC LM MASTERFLAT RMS
Class	header
Context	QC
Type	double
Value	%.3f
Unit	n/a
Default	None
Range	None
Created by	metis_lm_img_flat
Description	RMS of the master flat
Comment	

11.1.9 QC LM MASTERFLAT NBADPIX

Name	QC LM MASTERFLAT NBADPIX
Class	header
Context	QC
Type	double
Value	%.3f
Unit	n/a

Default	None
Range	None
Created by	metis_lm_img_flat
Description	Number of bad pixels in the image mask
Comment	

11.1.10 QC LM FLAT MEAN

Name	QC LM FLAT MEAN ##
Class	header
Context	QC
Type	double
Value	%.3f
Unit	n/a
Default	None
Range	None
Created by	metis_lm_img_flat
Description	Mean value of a single flat field image
Comment	

11.1.11 QC LM FLAT RMS

Name	QC LM FLAT RMS ##
Class	header
Context	QC
Type	double
Value	%.3f
Unit	n/a
Default	None
Range	None
Created by	metis_lm_img_flat
Description	RMS value of a single flat field image

Comment	

11.1.12 QC N MASTERFLAT RMS

Name	QC N MASTERFLAT RMS
Class	header
Context	QC
Type	double
Value	%.3f
Unit	n/a
Default	None
Range	None
Created by	metis_n_img_flat
Description	RMS of the master flat
Comment	

11.1.13 QC N MASTERFLAT NBADPIX

Name	QC N MASTERFLAT NBADPIX
Class	header
Context	QC
Type	double
Value	%.3f
Unit	n/a
Default	None
Range	None
Created by	metis_n_img_flat
Description	Number of bad pixels in the image mask
Comment	

11.1.14 QC N FLAT MEAN

Name	`QC N FLAT MEAN ##`
Class	header
Context	QC
Type	double
Value	%.3f
Unit	n/a
Default	None
Range	None
Created by	`metis_n_img_flat`
Description	Mean value of a single flat field image
Comment	

11.1.15 QC N FLAT RMS

Name	`QC N FLAT RMS ##`
Class	header
Context	QC
Type	double
Value	%.3f
Unit	n/a
Default	None
Range	None
Created by	`metis_n_img_flat`
Description	RMS value of a single flat field image
Comment	

11.2 Imaging mode

11.2.1 QC LIN GAIN MEAN

Name	QC LIN GAIN MEAN
Class	header
Context	QC
Type	double
Value	%.3f
Unit	e/adu
Default	None
Range	None
Created by	metis_det_lingain
Description	Mean value of the gain
Comment	None

11.2.2 QC LIN GAIN RMS

Name	QC LIN GAIN RMS
Class	header
Context	QC
Type	double
Value	%.3f
Unit	e/adu
Default	None
Range	None
Created by	metis_det_lingain
Description	Root mean square of the gain values
Comment	None

11.2.3 QC LM IMG STD BACKGD RMS

Name	QC LM IMG STD BACKGD RMS
Class	header
Context	QC
Type	double
Value	%.3f
Unit	n/a
Default	None
Range	None
Created by	metis_lm_img_std_process
Description	RMS of the background of the standard star photometry
Comment	

11.2.4 QC LM STD PEAK CNTS

Name	QC LM STD PEAK CNTS
Class	header
Context	QC
Type	double
Value	%.3f
Unit	n/a
Default	None
Range	None
Created by	metis_lm_img_std_process
Description	peak counts of the standard star
Comment	

11.2.5 QC LM STD APERTURE CNTS

Name	QC LM STD APERTURE CNTS
Class	header

Context	QC
Type	double
Value	%.3f
Unit	n/a
Default	None
Range	None
Created by	metis_lm_img_std_process
Description	aperture counts of the standard star
Comment	

11.2.6 QC LM STD STREHL

Name	QC LM STD STREHL
Class	header
Context	QC
Type	double
Value	%.3f
Unit	n/a
Default	None
Range	None
Created by	metis_lm_img_std_process
Description	strehl ratio of the standard star
Comment	

11.2.7 QC LM STD FWHM

Name	QC LM STD FWHM
Class	header
Context	QC
Type	double
Value	%.3f
Unit	pixels

Default	None
Range	None
Created by	metis_lm_img_std_process
Description	FWHM of the standard star PSF
Comment	

11.2.8 QC LM STD ELLIP

Name	QC LM STD ELLIP
Class	header
Context	QC
Type	double
Value	%.3f
Unit	n/a
Default	None
Range	None
Created by	metis_lm_img_std_process
Description	Ellipticity of the standard star PSF
Comment	

11.2.9 QC LM STD FLUXCONV

Name	QC LM STD FLUXCONV
Class	header
Context	QC
Type	double
Value	%.3f
Unit	n/a
Default	None
Range	None
Created by	metis_lm_img_std_process

Description	Flux conversion to physical units, determined from the standard star
Comment	

11.2.10 QC LM STD AIRMASS

Name	QC LM STD AIRMASS
Class	header
Context	QC
Type	double
Value	%.3f
Unit	n/a
Default	None
Range	None
Created by	metis_lm_img_std_process
Description	Airmass of the standard star observation
Comment	

11.2.11 QC LM SENSITIVITY

Name	QC LM SENSITIVITY
Class	header
Context	QC
Type	double
Value	%.3f
Unit	n/a
Default	None
Range	None
Created by	metis_lm_img_std_process
Description	Sensitivity of point source detections
Comment	

11.2.12 QC LM AREA SENSITIVITY

Name	QC LM AREA SENSITIVITY
Class	header
Context	QC
Type	double
Value	%.3f
Unit	n/a
Default	None
Range	None
Created by	metis_lm_img_std_process
Description	Sensitivity extended source detections
Comment	

11.2.13 QC N STD PEAK CNTS

Name	QC N STD PEAK CNTS
Class	header
Context	QC
Type	double
Value	%.3f
Unit	n/a
Default	None
Range	None
Created by	metis_n_img_std_process
Description	peak counts of the standard star
Comment	

11.2.14 QC N STD APERTURE CNTS

Name	QC N STD APERTURE CNTS
Class	header

Context	QC
Type	double
Value	%.3f
Unit	n/a
Default	None
Range	None
Created by	metis_n_img_std_process
Description	aperture counts of the standard star
Comment	

11.2.15 QC N STD STREHL

Name	QC N STD STREHL
Class	header
Context	QC
Type	double
Value	%.3f
Unit	n/a
Default	None
Range	None
Created by	metis_n_img_std_process
Description	strehl ratio of the standard star
Comment	

11.2.16 QC N STD FWHM

Name	QC N STD FWHM
Class	header
Context	QC
Type	double
Value	%.3f
Unit	pixels

Default	None
Range	None
Created by	metis_n_img_std_process
Description	FWHM of the standard star PSF
Comment	

11.2.17 QC N STD ELLIP

Name	QC N STD ELLIP
Class	header
Context	QC
Type	double
Value	%.3f
Unit	n/a
Default	None
Range	None
Created by	metis_n_img_std_process
Description	Ellipticity of the standard star PSF
Comment	

11.2.18 QC N STD FLUXCONV

Name	QC N STD FLUXCONV
Class	header
Context	QC
Type	double
Value	%.3f
Unit	n/a
Default	None
Range	None
Created by	metis_n_img_std_process

Description	Flux conversion to physical units, determined from the standard star
Comment	

11.2.19 QC N STD AIRMASS

Name	QC N STD AIRMASS
Class	header
Context	QC
Type	double
Value	%.3f
Unit	n/a
Default	None
Range	None
Created by	metis_n_img_std_process
Description	Airmass of the standard star observation
Comment	

11.2.20 QC N SENSITIVITY

Name	QC N SENSITIVITY
Class	header
Context	QC
Type	double
Value	%.3f
Unit	n/a
Default	None
Range	None
Created by	metis_n_img_std_process
Description	Sensitivity of point source detections
Comment	

11.2.21 QC N AREA SENSITIVITY

Name	QC N AREA SENSITIVITY
Class	header
Context	QC
Type	double
Value	%.3f
Unit	n/a
Default	None
Range	None
Created by	metis_n_img_std_process
Description	Sensitivity extended source detections
Comment	

11.2.22 QC LM IMG MEDIAN

Name	QC LM IMG MEDIAN
Class	header
Context	QC
Type	double
Value	%.3f
Unit	n/a
Default	None
Range	None
Created by	metis_lm_img_basic_reduce
Description	Median level of the LM image
Comment	

11.2.23 QC LM IMG STANDARD DEVIATION

Name	QC LM IMG STANDARD DEVIATION
Class	header

Context	QC
Type	double
Value	%.3f
Unit	n/a
Default	None
Range	None
Created by	metis_lm_img_basic_reduce
Description	Standard deviation of the LM image
Comment	

11.2.24 QC LM IMG PEAK

Name	QC LM IMG PEAK
Class	header
Context	QC
Type	double
Value	%.3f
Unit	n/a
Default	None
Range	None
Created by	metis_lm_img_basic_reduce
Description	Peak value the LM image
Comment	

11.2.25 QC LM IMG BKG MEDIAN

Name	QC LM IMG BKG MEDIAN
Class	header
Context	QC
Type	double
Value	%.3f
Unit	n/a

Default	None
Range	None
Created by	metis_lm_img_background
Description	Median value of the background removed LM image
Comment	

11.2.26 QC LM IMG BKG MEDIAN DEVIATION

Name	QC LM IMG BKG MEDIAN DEVIATION
Class	header
Context	QC
Type	double
Value	%.3f
Unit	n/a
Default	None
Range	None
Created by	metis_lm_img_background
Description	Median deviation of the background removed LM image
Comment	

11.2.27 QC LIN NUM BADPIX

Name	QC LIN NUM BADPIX
Class	header
Context	QC
Type	int
Value	%i
Unit	None
Default	None
Range	None
Created by	metis_det_lingain
Description	Number of bad pixels as derived in metis_det_lingain.

Comment	None

11.3 IFU mode

11.3.1 QC IFU STD FWHM

Name	QC IFU STD FWHM
Class	header
Context	QC
Type	double
Value	%.3f
Unit	"pixels" (spaxel)
Default	None
Range	None
Created by	metis_ifu_std_process
Description	FWHM of the standard star PSF averaged over central wavelength bins
Comment	

11.3.2 QC IFU STD ELLIP

Name	QC IFU STD ELLIP
Class	header
Context	QC
Type	double
Value	%.3f
Unit	n/a
Default	None
Range	None
Created by	metis_ifu_std_process
Description	Ellipticity of the standard star PSF averaged over central wavelength bins
Comment	

11.3.3 QC IFU WAVECAL LINE WIDTH

Name	QC IFU WAVECAL LINE WIDTH
Class	header
Context	QC
Type	double
Value	%.3f
Unit	pix
Default	None
Range	None
Created by	metis_ifu_wavecal
Description	The width (FWHM) of the laser line is measured by fitting a Gaussian to it.
Comment	This fulfills METIS-6073

11.4 Long-slit spectroscopy mode

11.4.1 QC LM LSS RSRF MEAN LEVEL

Name	QC LM LSS RSRF MEAN LEVEL
Class	header
Context	QC
Type	double
Value	%.3f
Unit	n/a
Default	None
Range	None
Created by	metis_LM_lss_rsrf
Description	Mean level of the RSRF
Comment	

11.4.2 QC LM LSS RSRF MEDIAN LEVEL

Name	QC LM LSS RSRF MEDIAN LEVEL
Class	header
Context	QC
Type	double
Value	%.3f
Unit	n/a
Default	None
Range	None
Created by	metis_LM_lss_rsrf
Description	Median level of the RSRF
Comment	

11.4.3 QC LM LSS RSRF INTORDR LEVEL

Name	QC LM LSS RSRF INTORDR LEVEL
Class	header
Context	QC
Type	double
Value	%.3f
Unit	n/a
Default	None
Range	None
Created by	metis_LM_lss_rsrf
Description	Flux level of the interorder background
Comment	Determined outside the trace

11.4.4 QC LM LSS RSRF NORM STDEV

Name	QC LM LSS RSRF NORM STDEV
Class	header

Context	QC
Type	double
Value	%.3f
Unit	n/a
Default	None
Range	None
Created by	metis_LM_lss_rsrf
Description	Standard deviation of the normalised RSRF
Comment	None

11.4.5 QC LM LSS RSRF NORM SNR

Name	QC LM LSS RSRF NORM SNR
Class	header
Context	QC
Type	double
Value	%.3f
Unit	n/a
Default	None
Range	None
Created by	metis_LM_lss_rsrf
escription	SNR of the normalised RSRF
Comment	None

11.4.6 QC LM LSS TRACE LPOLYDEG

Name	QC LM LSS TRACE LPOLYDEG
Class	header
Context	QC
Type	int
Value	%i
Unit	n/a

Default	None
Range	None
Created by	metis_LM_lss_trace
Description	Degree of the polynomial fit of the left order edge
Comment	"Left" edge means the order edge closer to left detector edge

11.4.7 QC LM LSS TRACE LCOEFF<i>

Name	QC LM LSS TRACE LCOEFF<i>
Class	header
Context	QC
Type	double
Value	%.3f
Unit	n/a
Default	None
Range	None
Created by	metis_LM_lss_trace
Description	*i*-th coefficient of the polynomial of the left order edge
Comment	"Left" edge means the order edge closer to left detector edge

11.4.8 QC LM LSS TRACE RPOLYDEG

Name	QC LM LSS TRACE RPOLYDEG
Class	header
Context	QC
Type	int
Value	%i
Unit	n/a
Default	None
Range	None
Created by	metis_LM_lss_trace
Description	Degree of the polynomial fit of the right order edge

Comment	"Right" edge means the order edge closer to right detector edge

11.4.9 QC LM LSS TRACE RCOEFF<i>

Name	QC LM LSS TRACE RCOEFF<i>
Class	header
Context	QC
Type	double
Value	%.3f
Unit	n/a
Default	None
Range	None
Created by	metis_LM_lss_trace
Description	i-th coefficient of the polynomial of the right order edge
Comment	"Right" edge means the order edge closer to right detector edge

11.4.10 QC LM LSS TRACE INTORDR LEVEL

Name	QC LM LSS TRACE INTORDR LEVEL
Class	header
Context	QC
Type	double
Value	%.3f
Unit	n/a
Default	None
Range	None
Created by	metis_LM_lss_trace
Description	Flux level of the interorder background
Comment	Determined outside the order

11.4.11 QC LM LSS WAVE POLYDEG

Name	QC LM LSS WAVE POLYDEG
Class	header
Context	QC
Type	int
Value	%i
Unit	n/a
Default	None
Range	None
Created by	metis_LM_lss_wave
Description	Degree of the first guess polynomial
Comment	None

11.4.12 QC LM LSS WAVE COEFF<i>

Name	QC LM LSS WAVE COEFF<i>
Class	header
Context	QC
Type	double
Value	%.3f
Unit	n/a
Default	None
Range	None
Created by	metis_LM_lss_wave
Description	i-th coefficient of the polynomial
Comment	None

11.4.13 QC LM LSS WAVE NLINES

Name	QC LM LSS WAVE NLINES
Class	header

Context	QC
Type	int
Value	%i
Unit	n/a
Default	None
Range	None
Created by	metis_LM_lss_wave
Description	Number of detected (laser) lines; should be constant
Comment	None

11.4.14 QC LM LSS WAVE LINEFWHMAVG

Name	QC LM LSS WAVE LINEFWHMAVG
Class	header
Context	QC
Type	double
Value	%.3f
Unit	n/a
Default	None
Range	None
Created by	metis_LM_lss_wave
Description	Average of the FWHM of the detected lines (should be widely constant)
Comment	None

11.4.15 QC LM LSS WAVE INTORDR LEVEL

Name	QC LM LSS WAVE INTORDR LEVEL
Class	header
Context	QC
Type	double
Value	%.3f

Unit	n/a
Default	None
Range	None
Created by	metis_LM_lss_wave
Description	Flux level of the interorder background
Comment	None

11.4.16 QC LM LSS STD BACKGD MEAN

Name	QC LM LSS STD BACKGD MEAN
Class	header
Context	QC
Type	double
Value	%.3f
Unit	n/a
Default	None
Range	None
Created by	metis_LM_lss_std
Description	Mean value of background
Comment	None

11.4.17 QC LM LSS STD BACKGD MEDIAN

Name	QC LM LSS STD BACKGD MEDIAN
Class	header
Context	QC
Type	double
Value	%.3f
Unit	n/a
Default	None
Range	None
Created by	metis_LM_lss_std

Description	Median value of background
Comment	None

11.4.18 QC LM LSS STD BACKGD STDEV

Name	QC LM LSS STD BACKGD STDEV
Class	header
Context	QC
Type	double
Value	%.3f
Unit	n/a
Default	None
Range	None
Created by	metis_LM_lss_std
Description	Standard deviation value of background
Comment	None

11.4.19 QC LM LSS STD SNR

Name	QC LM LSS STD SNR
Class	header
Context	QC
Type	double
Value	%.3f
Unit	n/a
Default	None
Range	None
Created by	metis_LM_lss_std
Description	Signal-to-noise ratio of flux standard star spectrum
Comment	None

11.4.20 QC LM LSS STD NOISELEV

Name	QC LM LSS STD NOISELEV
Class	header
Context	QC
Type	double
Value	%.3f
Unit	n/a
Default	None
Range	None
Created by	metis_LM_lss_std
Description	Noise level of flux standard star spectrum
Comment	None

11.4.21 QC LM LSS STD FWHM

Name	QC LM LSS STD FWHM
Class	header
Context	QC
Type	double
Value	%.3f
Unit	n/a
Default	None
Range	None
Created by	metis_LM_lss_std
Description	FWHM of flux standard spectrum
Comment	None

11.4.22 QC LM LSS STD INTORDR LEVEL

Name	QC LM LSS STD INTORDR LEVEL
Class	header

Context	QC
Type	double
Value	%.3f
Unit	n/a
Default	None
Range	None
Created by	metis_LM_lss_std
Description	Flux level of the interorder background
Comment	None

11.4.23 QC LM LSS STD AVGLEVEL

Name	QC LM LSS STD AVGLEVEL
Class	header
Context	QC
Type	double
Value	%.3f
Unit	n/a
Default	None
Range	None
Created by	metis_LM_lss_std
Description	
Comment	None

11.4.24 QC LM LSS STD WAVECAL DEVMEAN

Name	QC LM LSS STD WAVECAL DEVMEAN
Class	header
Context	QC
Type	double
Value	%.3f
Unit	n/a

Default	None
Range	None
Created by	metis_LM_lss_std
Description	Mean deviation from the wavelength reference frame
Comment	None

11.4.25 QC LM LSS STD WAVECAL FWHM

Name	QC LM LSS STD WAVECAL FWHM
Class	header
Context	QC
Type	double
Value	%.3f
Unit	n/a
Default	None
Range	None
Created by	metis_LM_lss_std
Description	Mean FWHM of the atmospheric lines used for wavelength calibration
Comment	None

11.4.26 QC LM LSS STD WAVECAL NIDENT

Name	QC LM LSS STD WAVECAL NIDENT
Class	header
Context	QC
Type	int
Value	%i
Unit	n/a
Default	None
Range	None
Created by	metis_LM_lss_std

Description	Number of identified lines
Comment	None

11.4.27 QC LM LSS STD WAVECAL NMATCH

Name	QC LM LSS STD WAVECAL NMATCH
Class	header
Context	QC
Type	int
Value	%i
Unit	n/a
Default	None
Range	None
Created by	metis_LM_lss_std
Description	Number of lines matched between catalogue and spectrum
Comment	None

11.4.28 QC LM LSS STD WAVECAL POLYDEG

Name	QC LM LSS STD WAVECAL POLYDEG
Class	header
Context	QC
Type	int
Value	%i
Unit	n/a
Default	None
Range	None
Created by	metis_LM_lss_std
Description	Degree of the polynomial
Comment	None

11.4.29 QC LM LSS STD WAVECAL POLYCOEFF<n>

Name	QC LM LSS STD WAVECAL POLYCOEFF<n>
Class	header
Context	QC
Type	double
Value	%.3f
Unit	n/a
Default	None
Range	None
Created by	metis_LM_lss_std
Description	n-th coefficient of the polynomial
Comment	None

11.4.30 QC LM LSS SCI SNR

Name	QC LM LSS SCI SNR
Class	header
Context	QC
Type	double
Value	%.3f
Unit	n/a
Default	None
Range	None
Created by	metis_LM_lss_sci
Description	Signal-to-noise ration of science spectrum
Comment	None

11.4.31 QC LM LSS SCI NOISELEV

Name	QC LM LSS SCI NOISELEV
Class	header

Context	QC
Type	double
Value	%.3f
Unit	n/a
Default	None
Range	None
Created by	metis_LM_lss_sci
Description	Noise level of science spectrum
Comment	None

11.4.32 QC LM LSS SCI FLUX SNR

Name	QC LM LSS SCI FLUX SNR
Class	header
Context	QC
Type	double
Value	%.3f
Unit	n/a
Default	None
Range	None
Created by	metis_LM_lss_sci
Description	Signal-to-noise ration of flux calibrated science spectrum
Comment	None

11.4.33 QC LM LSS SCI FLUX NOISELEV

Name	QC LM LSS SCI FLUX NOISELEV
Class	header
Context	QC
Type	double
Value	%.3f
Unit	n/a

Default	None
Range	None
Created by	metis_LM_lss_sci
Description	Noise level of flux calibrated science spectrum
Comment	None

11.4.34 QC LM LSS SCI INTORDR LEVEL

Name	QC LM LSS SCI INTORDR LEVEL
Class	header
Context	QC
Type	double
Value	%.3f
Unit	n/a
Default	None
Range	None
Created by	metis_LM_lss_sci
Description	Flux level of the interorder background
Comment	None

11.4.35 QC LM LSS SCI WAVECAL DEVMEAN

Name	QC LM LSS SCI WAVECAL DEVMEAN
Class	header
Context	QC
Type	double
Value	%.3f
Unit	n/a
Default	None
Range	None
Created by	metis_LM_lss_sci
Description	Mean deviation from the wavelength reference frame

Comment	None

11.4.36 QC LM LSS SCI WAVECAL FWHM

Name	QC LM LSS SCI WAVECAL FWHM
Class	header
Context	QC
Type	double
Value	%.3f
Unit	n/a
Default	None
Range	None
Created by	metis_LM_lss_sci
Description	Measured FWHM of lines
Comment	None

11.4.37 QC LM LSS SCI WAVECAL NIDENT

Name	QC LM LSS SCI WAVECAL NIDENT
Class	header
Context	QC
Type	int
Value	%i
Unit	n/a
Default	None
Range	None
Created by	metis_LM_lss_sci
Description	Number of identified lines
Comment	None

11.4.38 QC LM LSS SCI WAVECAL NMATCH

Name	QC LM LSS SCI WAVECAL NMATCH
Class	header
Context	QC
Type	int
Value	%i
Unit	n/a
Default	None
Range	None
Created by	metis_LM_lss_sci
Description	Number of lines matched between catalogue and spectrum
Comment	None

11.4.39 QC LM LSS SCI WAVECAL POLYDEG

Name	QC LM LSS SCI WAVECAL POLYDEG
Class	header
Context	QC
Type	int
Value	%i
Unit	n/a
Default	None
Range	None
Created by	metis_LM_lss_sci
Description	Degree of the wavelength polynomial
Comment	None

11.4.40 QC LM LSS SCI WAVECAL POLYCOEFF<n>

Name	QC LM LSS SCI WAVECAL POLYCOEFF<n>
Class	header

Context	QC
Type	double
Value	%.3f
Unit	n/a
Default	None
Range	None
Created by	metis_LM_lss_sci
Description	n-th coefficient of the polynomial
Comment	None

11.4.41 QC N LSS RSRF MEAN LEVEL

Name	QC N LSS RSRF MEAN LEVEL
Class	header
Context	QC
Type	double
Value	%.3f
Unit	n/a
Default	None
Range	None
Created by	metis_N_lss_rsrf
Description	Mean level of the RSRF
Comment	

11.4.42 QC N LSS RSRF MEDIAN LEVEL

Name	QC N LSS RSRF MEDIAN LEVEL
Class	header
Context	QC
Type	double
Value	%.3f
Unit	n/a

Default	None
Range	None
Created by	metis_N_lss_rsrf
Description	Median level of the RSRF
Comment	

11.4.43 QC N LSS RSRF INTORDR LEVEL

Name	QC N LSS RSRF MEDIAN LEVEL
Class	header
Context	QC
Type	double
Value	%.3f
Unit	n/a
Default	None
Range	None
Created by	metis_N_lss_rsrf
Description	Flux level of the interorder background
Comment	Determined outside the trace

11.4.44 QC N LSS RSRF NORM STDEV

Name	QC N LSS RSRF NORM STDEV
Class	header
Context	QC
Type	double
Value	%.3f
Unit	n/a
Default	None
Range	None
Created by	metis_N_lss_rsrf
Description	Standard deviation of the normalised RSRF

Comment	None

11.4.45 QC N LSS RSRF NORM SNR

Name	QC N LSS RSRF NORM SNR
Class	header
Context	QC
Type	double
Value	%.3f
Unit	n/a
Default	None
Range	None
Created by	metis_N_lss_rsrf
escription	SNR of the normalised RSRF
Comment	None

11.4.46 QC N LSS TRACE LPOLYDEG

Name	QC N LSS TRACE LPOLYDEG
Class	header
Context	QC
Type	int
Value	%i
Unit	n/a
Default	None
Range	None
Created by	metis_N_lss_trace
Description	Degree of the polynomial fit of the left order edge
Comment	"Left" edge means the order edge closer to left detector edge

11.4.47 QC N LSS TRACE LCOEFF<i>

Name	QC N LSS TRACE LCOEFF<i>
Class	header
Context	QC
Type	double
Value	%.3f
Unit	n/a
Default	None
Range	None
Created by	metis_N_lss_trace
Description	*i*-th coefficient of the polynomial of the left order edge
Comment	"Left" edge means the order edge closer to left detector edge

11.4.48 QC N LSS TRACE RPOLYDEG

Name	QC N LSS TRACE RPOLYDEG
Class	header
Context	QC
Type	int
Value	%i
Unit	n/a
Default	None
Range	None
Created by	metis_N_lss_trace
Description	Degree of the polynomial fit of the right order edge
Comment	"Right" edge means the order edge closer to right detector edge

11.4.49 QC N LSS TRACE RCOEFF<i>

Name	QC N LSS TRACE RCOEFF<i>
Class	header
Context	QC
Type	double
Value	%.3f
Unit	n/a
Default	None
Range	None
Created by	metis_N_lss_trace
Description	*i*-th coefficient of the polynomial of the right order edge
Comment	"Right" edge means the order edge closer to right detector edge

11.4.50 QC N LSS TRACE INTORDR LEVEL

Name	QC N LSS TRACE INTORDR LEVEL
Class	header
Context	QC
Type	double
Value	%.3f
Unit	n/a
Default	None
Range	None
Created by	metis_N_lss_trace
Description	Flux level of the interorder background
Comment	Determined outside the order

11.4.51 QC N LSS STD BACKGD MEAN

Name	QC N LSS STD BACKGD MEAN
Class	header
Context	QC
Type	double
Value	%.3f
Unit	n/a
Default	None
Range	None
Created by	metis_N_lss_std
Description	Mean value of background
Comment	None

11.4.52 QC N LSS STD BACKGD MEDIAN

Name	QC N LSS STD BACKGD MEDIAN
Class	header
Context	QC
Type	double
Value	%.3f
Unit	n/a
Default	None
Range	None
Created by	metis_N_lss_std
Description	Median value of background
Comment	None

11.4.53 QC N LSS STD BACKGD STDEV

Name	QC N LSS STD BACKGD STDEV
Class	header

Context	QC
Type	double
Value	%.3f
Unit	n/a
Default	None
Range	None
Created by	metis_N_lss_std
Description	Standard deviation value of background
Comment	None

11.4.54 QC N LSS STD SNR

Name	QC N LSS STD SNR
Class	header
Context	QC
Type	double
Value	%.3f
Unit	n/a
Default	None
Range	None
Created by	metis_N_lss_std
Description	Signal-to-noise ration of flux standard star spectrum
Comment	None

11.4.55 QC N LSS STD NOISELEV

Name	QC N LSS STD NOISELEV
Class	header
Context	QC
Type	double
Value	%.3f
Unit	n/a

Default	None
Range	None
Created by	metis_N_lss_std
Description	Noise level of flux standard star spectrum
Comment	None

11.4.56 QC N LSS STD FWHM

Name	QC N LSS STD FWHM
Class	header
Context	QC
Type	double
Value	%.3f
Unit	n/a
Default	None
Range	None
Created by	metis_N_lss_std
Description	FWHM of flux standard spectrum
Comment	None

11.4.57 QC N LSS STD INTORDR LEVEL

Name	QC N LSS STD INTORDR LEVEL
Class	header
Context	QC
Type	double
Value	%.3f
Unit	n/a
Default	None
Range	None
Created by	metis_N_lss_std
Description	Flux level of the interorder background

Comment	None

11.4.58 QC N LSS STD AVGLEVEL

Name	QC N LSS STD AVGLEVEL
Class	header
Context	QC
Type	double
Value	%.3f
Unit	n/a
Default	None
Range	None
Created by	metis_N_lss_std
Description	
Comment	None

11.4.59 QC N LSS STD WAVECAL DEVMEAN

Name	QC N LSS STD WAVECAL DEVMEAN
Class	header
Context	QC
Type	double
Value	%.3f
Unit	n/a
Default	None
Range	None
Created by	metis_N_lss_std
Description	Mean deviation from the wavelength reference frame
Comment	None

11.4.60 QC N LSS STD WAVECAL FWHM

Name	QC N LSS STD WAVECAL FWHM
Class	header
Context	QC
Type	double
Value	%.3f
Unit	n/a
Default	None
Range	None
Created by	metis_N_lss_std
Description	Mean FWHM of the atmospheric lines used for wavelength calibration
Comment	None

11.4.61 QC N LSS STD WAVECAL NIDENT

Name	QC N LSS STD WAVECAL NIDENT
Class	header
Context	QC
Type	int
Value	%i
Unit	n/a
Default	None
Range	None
Created by	metis_N_lss_std
Description	Number of identified lines
Comment	None

11.4.62 QC N LSS STD WAVECAL NMATCH

Name	QC N LSS STD WAVECAL NMATCH
Class	header
Context	QC
Type	int
Value	%i
Unit	n/a
Default	None
Range	None
Created by	metis_N_lss_std
Description	Number of lines matched between catalogue and spectrum
Comment	None

11.4.63 QC N LSS STD WAVECAL POLYDEG

Name	QC N LSS STD WAVECAL POLYDEG
Class	header
Context	QC
Type	int
Value	%i
Unit	n/a
Default	None
Range	None
Created by	metis_N_lss_std
Description	Degree of the polynomial
Comment	None

11.4.64 QC N LSS STD WAVECAL POLYCOEFF<n>

Name	QC N LSS STD WAVECAL POLYCOEFF<n>
Class	header

Context	QC
Type	double
Value	%.3f
Unit	n/a
Default	None
Range	None
Created by	metis_N_lss_std
Description	n-th coefficient of the polynomial
Comment	None

11.4.65 QC N LSS SCI SNR

Name	QC N LSS SCI SNR
Class	header
Context	QC
Type	double
Value	%.3f
Unit	n/a
Default	None
Range	None
Created by	metis_N_lss_sci
Description	Signal-to-noise ration of science spectrum
Comment	None

11.4.66 QC N LSS SCI NOISELEV

Name	QC N LSS SCI NOISELEV
Class	header
Context	QC
Type	double
Value	%.3f
Unit	n/a

Default	None
Range	None
Created by	metis_N_lss_sci
Description	Noise level of science spectrum
Comment	None

11.4.67 QC N LSS SCI FLUX SNR

Name	QC N LSS SCI FLUX SNR
Class	header
Context	QC
Type	double
Value	%.3f
Unit	n/a
Default	None
Range	None
Created by	metis_N_lss_sci
Description	Signal-to-noise ration of flux calibrated science spectrum
Comment	None

11.4.68 QC N LSS SCI FLUX NOISELEV

Name	QC N LSS SCI FLUX NOISELEV
Class	header
Context	QC
Type	double
Value	%.3f
Unit	n/a
Default	None
Range	None
Created by	metis_N_lss_sci
Description	Noise level of flux calibrated science spectrum

Comment	None

11.4.69 QC N LSS SCI INTORDR LEVEL

Name	QC N LSS SCI INTORDR LEVEL
Class	header
Context	QC
Type	double
Value	%.3f
Unit	n/a
Default	None
Range	None
Created by	metis_N_lss_sci
Description	Flux level of the interorder background
Comment	None

11.4.70 QC N LSS SCI WAVECAL DEVMEAN

Name	QC N LSS SCI WAVECAL DEVMEAN
Class	header
Context	QC
Type	double
Value	%.3f
Unit	n/a
Default	None
Range	None
Created by	metis_N_lss_sci
Description	Mean deviation from the wavelength reference frame
Comment	None

11.4.71 QC N LSS SCI WAVECAL FWHM

Name	QC N LSS SCI WAVECAL FWHM
Class	header
Context	QC
Type	double
Value	%.3f
Unit	n/a
Default	None
Range	None
Created by	metis_N_lss_sci
Description	Measured FWHM of lines
Comment	None

11.4.72 QC N LSS SCI WAVECAL NIDENT

Name	QC N LSS SCI WAVECAL NIDENT
Class	header
Context	QC
Type	int
Value	%i
Unit	n/a
Default	None
Range	None
Created by	metis_N_lss_sci
Description	Number of identified lines
Comment	None

11.4.73 QC N LSS SCI WAVECAL NMATCH

Name	QC N LSS SCI WAVECAL NMATCH
Class	header

Context	QC
Type	int
Value	%i
Unit	n/a
Default	None
Range	None
Created by	metis_N_lss_sci
Description	Number of lines matched between catalogue and spectrum
Comment	None

11.4.74 QC N LSS SCI WAVECAL POLYDEG

Name	QC N LSS SCI WAVECAL POLYDEG
Class	header
Context	QC
Type	int
Value	%i
Unit	n/a
Default	None
Range	None
Created by	metis_N_lss_sci
Description	Degree of the wavelength polynomial
Comment	None

11.4.75 QC N LSS SCI WAVECAL POLYCOEFF<n>

Name	QC N LSS SCI WAVECAL POLYCOEFF<n>
Class	header
Context	QC
Type	double
Value	%.3f
Unit	n/a

Default	None
Range	None
Created by	metis_N_lss_sci
Description	n-th coefficient of the polynomial
Comment	None

11.4.76 QC LM DISTORT RMS

Name	QC LM DISTORT RMS
Class	header
Context	QC
Type	float
Value	%.3f
Unit	pixels
Default	None
Range	None
Created by	metis_lm_img_distortion
Description	RMS of deviation of the distortion fit from expected values
Comment	None

11.4.77 QC N DISTORT RMS

Name	QC N DISTORT RMS
Class	header
Context	QC
Type	float
Value	%.3f
Unit	pixels
Default	None
Range	None
Created by	metis_n_img_distortion
Description	RMS of deviation of the distortion fit from expected values

Comment	None

11.4.78 QC LM DISTORT NSOURCE

Name	QC LM DISTORT NSOURCE
Class	header
Context	QC
Type	int
Value	%i
Unit	None
Default	None
Range	0 to number of pinholes
Created by	metis_lm_img_distortion
Description	number of positions used to fit the distortion polynomial
Comment	None

11.4.79 QC N DISTORT NSOURCE

Name	QC N DISTORT NSOURCE
Class	header
Context	QC
Type	int
Value	%i
Unit	None
Default	None
Range	0 to number of pinholes
Created by	metis_n_img_distortion
Description	number of positions used to fit the distortion polynomial
Comment	None

11.5 HCI

11.5.1 QC det cgrph SCI FWHM nn

Name	QC det cgrph SCI FWHM nn
Class	header
Context	QC
Type	double
Value	%.3f
Unit	pixels
Default	None
Range	None
Created by	metis_img_adi_cgrph
FWHM of the PSF in frame nn	
Comment	None

11.5.2 QC det cgrph SCI NEXPOSURES

Name	QC det cgrph SCI NEXPOSURES
Class	header
Context	QC
Type	integer
Value	%d
Unit	none
Default	None
Range	None
Created by	metis_img_adi_cgrph
Effective number of exposures used to create the ADI data products	
Comment	None

11.5.3 QC det cgrph SCI SNR MEAN

Name	QC det cgrph SCI SNR MEAN
Class	header
Context	QC
Type	double
Value	%.3f
Unit	none
Default	None
Range	None
Created by	metis_img_adi_cgrph
Mean value in ADI SNR map	
Comment	None

11.5.4 QC det cgrph SCI SNR PEAK

Name	QC det cgrph SCI SNR PEAK
Class	header
Context	QC
Type	double
Value	%.3f
Unit	none
Default	None
Range	None
Created by	metis_img_adi_cgrph
Peak value in ADI SNR map	
Comment	None

11.5.5 QC det cgrph SCI CONTRAST RAW LAMD

Name	QC det cgrph SCI CONTRAST RAW LAMD
Class	header
Context	QC
Type	double
Value	%.3f
Unit	mag
Default	None
Range	None
Created by	metis_img_adi_cgrph
Raw Contrast curve value at separation LAMD LDD	
Comment	None

11.5.6 QC det cgrph SCI CONTRAST ADI LAMD

Name	QC det cgrph SCI CONTRAST ADI LAMD
Class	header
Context	QC
Type	double
Value	%.3f
Unit	mag
Default	None
Range	None
Created by	metis_img_adi_cgrph
Post-ADI Contrast curve value at separation LAMD LDD	
Comment	None

11.5.7 QC det APP SCI FWHM nn

Name	QC det APP SCI FWHM nn
Class	header
Context	QC
Type	double
Value	%.3f
Unit	pixels
Default	None
Range	None
Created by	metis_lm_adi_app
FWHM of the PSF in frame nn	
Comment	None

11.5.8 QC det APP SCI NEXPOSURES

Name	QC det APP SCI NEXPOSURES
Class	header
Context	QC
Type	integer
Value	%d
Unit	none
Default	None
Range	None
Created by	metis_lm_adi_app
Effective number of exposures used to create the ADI data products	
Comment	None

11.5.9 QC det APP SCI SNR MEAN

Name	QC det APP SCI SNR MEAN
Class	header
Context	QC
Type	double
Value	%.3f
Unit	none
Default	None
Range	None
Created by	metis_lm_adi_app
Mean value in ADI SNR map	
Comment	None

11.5.10 QC det APP SCI SNR PEAK

Name	QC det APP SCI SNR PEAK
Class	header
Context	QC
Type	double
Value	%.3f
Unit	none
Default	None
Range	None
Created by	metis_lm_adi_app
Peak value in ADI SNR map	
Comment	None

11.5.11 QC det APP SCI CONTRAST RAW LAMD

Name	QC det APP SCI CONTRAST RAW LAMD
Class	header
Context	QC
Type	double
Value	%.3f
Unit	mag
Default	None
Range	None
Created by	metis_lm_adi_app
Raw Contrast curve value at separation LAMD LDD	
Comment	None

11.5.12 QC det APP SCI CONTRAST ADI LAMD

Name	QC det APP SCI CONTRAST ADI LAMD
Class	header
Context	QC
Type	double
Value	%.3f
Unit	mag
Default	None
Range	None
Created by	metis_lm_adi_app
Post-ADI Contrast curve value at separation LAMD LDD	
Comment	None

11.5.13 QC IFU cgrph SCI FWHM nn

Name	QC IFU cgrph SCI FWHM nn
Class	header
Context	QC
Type	double
Value	%.3f
Unit	pixels
Default	None
Range	None
Created by	metis_ifu_adi_cgrph
FWHM of the PSF in frame nn	
Comment	None

11.5.14 QC IFU cgrph SCI NEXPOSURES

Name	QC IFU cgrph SCI NEXPOSURES
Class	header
Context	QC
Type	integer
Value	%d
Unit	none
Default	None
Range	None
Created by	metis_ifu_adi_cgrph
Effective number of exposures used to create the ADI data products	
Comment	None

11.5.15 QC IFU cgrph SCI SNR MEAN

Name	QC IFU cgrph SCI SNR MEAN
Class	header
Context	QC
Type	double
Value	%.3f
Unit	none
Default	None
Range	None
Created by	metis_ifu_adi_cgrph
Mean value in ADI SNR map	
Comment	None

11.5.16 QC IFU cgrph SCI SNR PEAK

Name	QC IFU cgrph SCI SNR PEAK
Class	header
Context	QC
Type	double
Value	%.3f
Unit	none
Default	None
Range	None
Created by	metis_ifu_adi_cgrph
Peak value in ADI SNR map	
Comment	None

11.5.17 QC IFU cgrph SCI CONTRAST RAW LAMD

Name	QC IFU cgrph SCI CONTRAST RAW LAMD
Class	header
Context	QC
Type	double
Value	%.3f
Unit	mag
Default	None
Range	None
Created by	metis_ifu_adi_cgrph
Raw Contrast curve value at separation LAMD LDD	
Comment	None

11.5.18 QC IFU cgrph SCI CONTRAST ADI LAMD

Name	QC IFU cgrph SCI CONTRAST ADI LAMD
Class	header
Context	QC
Type	double
Value	%.3f
Unit	mag
Default	None
Range	None
Created by	metis_ifu_adi_cgrph
Post-ADI Contrast curve value at separation LAMD LDD	
Comment	None

12 DEVELOPMENT PLAN

This section describes the development plan for the METIS DRS to comply with the the specifications and standards of the ESO data reduction libraries given in the ESO dataflow deliverables standards document ([AD5]). The development of the DRS is a team effort lead by A* (Vienna and Innsbruck) with contributions from Uppsala and ASIAA ([RD32], [RD33]).

The test and validation procedures for the pipeline software are described in [RD1], fulfilling METIS-6062. Test data are are required for the pipeline software development, including the development of pipeline recipes, workflows and for pipeline testing and validation. The sources of test data are:

- Simulated data using the ScopeSim software tool
- Archive data from similar instruments (e.g. VISIR, SPHERE, ERIS)
- Laboratory data obtained during the AIT phase

Further details are given in [RD1].

The time schedule is subject to regular updates and review in close cooperation with

- AIT team: coordination of the pipeline implementation schedule
- ICS team: coordination with ICS implementation schedule to test the dataflow between ICS and pipeline and check consistency of FITS keywords
- Detector group: coordination when detector characteristics become available
- Calibration Scientist: check consistency of pipeline calibration data products, coordinate the population of the calibration database
- Instrument Scientist: check consistency of FITS keywords, QC parameters, pipeline data products and coordination of the end-to-end tests of the pipeline
- ESO: check consistency of FITS keywords, QC parameters, coordinate required input to software recipe development (detector persistence, ...) and coordinate the pipeline implementation schedule

Tables 5, 6 and 7 provide an overview of the milestone schedule for the METIS pipeline development.

12.1 FDR to PAE development plan

It is planned to monitor the status of pipeline software implementation in regular progress meetings, where, if necessary, specific action items can be defined. Starting after FDR the implementation of the development schedule (Table 5) will be carried out in the subsequent steps:

1. The baseline for the pipeline development environment regarding the use of the EDPS framework and of pyCPL needs to be established.

Table 5: Milestones of the METIS pipeline software development schedule from FDR to PAE

Date_start	Date_end	Task	Reference
25.11.2023	25.11.2023	Release of FDR board report = FDR	1
		Baseline for PIP software development defined (EDPS, pyCPL)	
		Updated detector characteristics LM & N imager received	
25.05.2024	25.05.2025	PR2 Simulated raw data, processed data = FDR+6m	2
25.11.2024	25.11.2024	PR3 DRS Chain Skeleton = FDR+12m	2
		OP3 Microservice modules and User Manual for Obs.Preparation = FDR+12m	2
03.03.2025	03.03.2025	Updated characteristic data of HCI sub-system received	
02.01.2025	23.09.2025	SysAIV Phase D2 AB - CRY/ICS/CFO/WCU	3
02.05.2025	02.05.2025	Updated characteristic data of IMG sub-system received	
24.10.2025	23.04.2026	SysAIV Phase D2 CD - CRY/ICS/CFO/WCU/LMS/DET/PIP	3
24.10.2025	24.10.2025	First dataflow system products ready for SysAIV:	4
		PIP interface to ICS	
		Detector characterisation	
14.11.2025	23.04.2026	LMS testing:	3
		Basic background subtraction (LMS & IMG/LSS modes)	
		LMS cube reconstruction	
01.12.2025	01.12.2025	Updated characteristic data of LMS received	
05.06.2026	09.07.2027	SysAIV Phase D2 E - CRY/ICS/CFO/WCU/IMG/LMS/SCAO	3
26.06.2026	26.10.2026	IMG testing (IMG & LSS modes):	3
		Wavelength calibration	
		Distortion correction	
26.10.2026	26.10.2026	Updated characteristic data LM & N imaging, LMS, HCI, LSS	
27.10.2026	15.09.2027	Further dataflow system products:	4
		Processing of LMS, LSS & IMG data	
		Processing of HCI data	
		QC parameters	
16.09.2027	16.09.2027	Pipeline Test Readiness Review = PAE-3m	
04.11.2027	04.11.2027	Pipeline end-to-end simulation =PAE-6w	
18.11.2027	18.11.2027	PAE deliverables =PAE-4w	2
		DC3 PAE Test and Calibration Data	
		DR3 Data Reduction Library v1.0 & Test Report	
		DR3 Pipeline/QC User Manual v1	
		DT2 DRL Validation and Test Plan v2	
		ET3 Instrument Description Data v1.0	
		OP4 Observation Preparation Tool v1.0	
		IP3 Instrument Package v1.0	
16.12.2027	16.12.2027	Preliminary Acceptance Europe PAE	3

1 ESO-456292 METIS FDR Plan
2 ESO-037611 Dataflow for ESO Observatories Deliverables Standard
3 E-PLA-NOVA-MET-1225_4-0 METIS Project schedule
4 E-TNT-NOVA-MET-1292 METIS PIP Capabilities needed for AIT
5 E-PLA-MPIA-MET-1046_2-0 Commissioning Plan
6 ESO-257874_2 Statement of Work for the Construction of METIS

2. Review and adapt the schedule for the pipeline software development after successful PIP FDR in compliance with the METIS DRL Validation and Test Plan ([RD1]). A priority list for the implementation of the PIP capabilities will be agreed with the AIT team. It will

categorize high, medium and low priorities of pipeline modules for subsystem and system level AIT. The priority list will be reviewed in regular intervals in progress of AIT.

High priority tasks of the pipeline development (at start of Phase D):

- The interface with ICS has to be set up in order to create proper FITS files
- Recipes needed for the detector characterisation

These modules should be ready at the start of system AIT phase CD to support the integration of the detectors.

Medium priority tasks to support the integration of LMS, LSS and IMG modes:

- Processing of LMS, LSS and IMG data which includes in particular background subtraction, wavelength calibration recipes for the spectroscopic modes and LMS cube reconstruction
- Additional recipes needed: Distortion map, RSRF calibration, contrast curve
- Support of stray light analysis tools

Following the outline of the system AIT plan, LMS-related modules will be first available for the cold instrument verification, followed later by LSS and IMG-related modules which will be ready for the cold functional tests.

Low priority tasks:

- Processing of HCI data (pupil imaging)
- Slit-loss calibration
- Fringing calibration recipe
- Characterisation of various background subtraction methods
- Quality control parameters

The time table for receiving the characteristic data of the instrument modes necessary for the pipeline software development will finalized at the same time. These data include in particular raw data from the detectors, calibration data from the WCU and laboratory data for the instrument modes obtained resulting from functional and verification tests at (sub-) system level during the AIT phase.

Further on, a detailed schedule will be set up with ESO regarding updated versions of pipeline package.

3. Simulated and processed data at T_{FDR} + 6 months: the package includes raw data, intermediate data and science data products for each instrument mode. The emphasis will be on the correct data structures and relevant data flow system keywords. Where applicable, the raw and intermediate data will be simulated with the ScopeSim tool. The simulated

data will be used to test the data flow system, in particular for cross-checking the output of the DRS chain skeleton to be delivered at T_{FDR} + 12 months.

4. Delivery of the DRS chain skeleton at T_{FDR} + 12 months: The pipeline skeleton consists of the recipes *shells*, i.e. the executable code that takes the expected inputs and parameters and produces output files, albeit without actually performing any reductions; pixel values of input and outputs are just dummy values at this stage. The purpose of chain skeleton is to demonstrate the data flow but is otherwise empty from the algorithmic point of view. Depending on the release status of the EDPS, the chain can be assembled with it. Otherwise a simple software integration environment of the METIS data flow team will be used for this purpose.

5. Updated versions of the pipeline package in previously agreed intervals consisting of:
   - Updated version of the DRL document
   - Reports on tests performed at the level of pipeline recipes
   - Test and calibration data
   - Updated version of the pipeline/QC user manual
   - Report describing the status of the DRL implementation
   - List of action items

   The updates will be maintained in a shared repository to allow ESO to monitor the work progress. The pipeline development and implementation will be done in close collaboration with ESO.

12.2 METIS Preliminary Acceptance in Europe (PAE)

PAE completes the METIS AIT phase. At this stage, the pipeline software has reached a maturity level where all components are fully developed and integrated. It is expected that at this point also all necessary lab data from the AIT phase will be available for test and validation purposes in addition to the simulated test data package. The pipeline PAE will consist of 3 phases: a test readiness review, an end-to-end test of the data flow and the PAE review phase.

12.2.1 Test Readiness Review

The pipeline package will be carefully reviewed to check its compliance to [AD5] approximately 3 months before the PAE review. The review requires:

- The METIS instrument has been fully assembled, aligned and all tests at subsystem level have been performed
- Both simulated data and lab data obtained during the AIT phase are available for verification purposes to cover all relevant instrument modes

- Full unit tests have been implemented at the algorithmic level to check requirement compliance
- Full error propagation has been implemented to check requirement compliance
- A science use case has been assigned to each observing mode

The review will be carried out in close cooperation with ESO pipeline experts to prepare the integration of the pipeline at the observatory. This includes functionality checks of the data reduction pipeline in the QC0/QC1/QC2 operational environments.

12.2.2 End-to-End tests of the data flow system

The scope of the data flow end-to-end test is to validate the full process of pipeline data management and processing. The process will consist of

- One science case per observing mode will be used as demonstrator
- Raw data will be processed in final data products
- Check that that the input raw data are correctly organized
- Check that recipes are executed in the correct order in the dataflow
- Check that intermediate data products are passed correctly in the data flow
- Final consistency checks on the data flow system (FITS keywords, QC parameters, ...)
- Final check on relevant documents (user manuals)

Further details are specified in [RD1].

12.2.3 PAE review phase

The PAE review phase will consist of the formal approval of the PAE deliverables described in [AD5] (see also table 5). The reports of the Test Readiness Review and the data flow end-to-end simulation will be attached to them.

12.3 METIS instrument commissioning

It is planned that the commissioning period will be divided in three sections (see also table 6).

12.3.1 Commissioning period 1 (COM1)

The aim of the COM1 period is to test the interface of METIS with the ELT and the characterization of the instrument performance including the data reduction pipeline software. COM1 will consist of several observing runs to perform all necessary tests, observations and calibrations. This includes also the preparation of the data flow science operation system. The prerequisites for the data reduction pipeline are

Table 6: Milestones of the METIS pipeline software development schedule from First Light to PAC

Date_start	Date_end	Task	Reference
01.11.2028	01.11.2028	First Light	3
17.04.2029	17.04.2029	ET4 Instrument Description Data v1.1 =COM1-6w	2
01.05.2029	01.05.2029	Deliverables COM1-4w DR4 Data Reduction Library v1.1 & Test Report DF4 Observation Preparation Tools v1.1 IP4 Instrument Package v1.1	2
22.05.2029	22.05.2029	DR5 Pipeline v0.5 =COM1-1w	2
29.05.2029	14.11.2029	Commissioning TBC	3
29.05.2029	10.07.2029	COM1 TBC	5
11.07.2029	10.10.2029	Performance Assessment Period PAP TBC	5
07.08.2029	07.08.2029	DC4 Instrument Commissioning Data = COM1+4w	2
16.08.2029	16.08.2029	Deliverables COM2-8w Microservice modules for Obs.Prepration User Manual for Obs.Prepration	2
13.09.2029	13.09.2029	Deliverables COM2-4w IP4 Instrument Package v1.x OP6 Observation Preparation Tools v1.x ET6 Exposure Time Calculator v1.0	2
20.09.2029	20.09.2029	DR6 Data Reduction Library v1.2 & Test Report =COM2-3w	2
11.10.2029	22.11.2029	COM2 TBC	5
25.10.2029	25.10.2029	Deliverables COM2+2w DC5 Calibration Plan v1 DC6 Science Test Data DR7 Pipeline v1.0	2
TBD	TBD	Observation Preparation Tools v2.0 =CFP-6w	2
TBD	TBD	Deliverables CFP-4w ET6 Exposure Time Calculator v1.1 IP5 Instrument Package v2	2
TBD	TBD	CFP Proposals (Phase 1) Preliminary TBD	2
03.10.2029	03.10.2029	ET7 Instrument Description Data v1.x =PAC-6w	2
17.10.2029	17.10.2029	Deliverables PAC-4w DR8 Data Reduction Library v1.x & Test Report DR8 DRL Validation and Test Plan v3 DR8 Data Reduction Library Design v2	 2
14.11.2029	14.11.2029	Preliminary Acceptance Chile PAC	3

1 ESO-456292 METIS FDR Plan
2 ESO-037611 Dataflow for ESO Observatories Deliverables Standard
3 E-PLA-NOVA-MET-1225_4-0 METIS Project schedule
4 E-TNT-NOVA-MET-1292 METIS PIP Capabilities needed for AIT
5 E-PLA-MPIA-MET-1046_2-0 Commissioning Plan
6 ESO-257874_2 Statement of Work for the Construction of METIS

- METIS has been fully integrated at the ELT
- METIS passed the instrument functional hardware and software tests
- The data reduction pipeline has been fully integrated and validated

The COM1 deliverables are specified in [AD5].

Table 7: Milestones of the METIS pipeline software development schedule covering the Guarantee Period until Final Acceptance

Date_start	Date_end	Task	Reference
15.11.2029	14.11.2031	Guarantee period	2
TBD	TBD	ET8 Exposure Time Calculator v1.x =PH2-4w	2
TBD	TBD	PH2 Observation Preparation Phase 2	2
TBD	TBD	IP6 Package v2.x =SO1-16w	2
TBD	TBD	Deliverables SO1-4w DR10 Pipeline v1.x DR10 Pipeline/QC User Manual v2	2
TBD	TBD	SO1 Science Operations (1st observation period)	2
TBD	TBD	Deliverables SO1+8w DR11 DRL Validation and Test Plan v4 DR11 Data Reduction Library Design v3 DC7 Calibration Plan v2	2
TBD	TBD	SO2 Science Operations (2nd observation period)	2
TBD	TBD	Deliverables SO2+8w DR12 Pipeline/QC User Manual v3	2
14.11.2031	14.11.2031	Final Acceptance = PAC+24m TBD	6

1 ESO-456292 METIS FDR Plan
2 ESO-037611 Dataflow for ESO Observatories Deliverables Standard
3 E-PLA-NOVA-MET-1225_4-0 METIS Project schedule
4 E-TNT-NOVA-MET-1292 METIS PIP Capabilities needed for AIT
5 E-PLA-MPIA-MET-1046_2-0 Commissioning Plan
6 ESO-257874_2 Statement of Work for the Construction of METIS

12.3.2 Performance Assessment Period (PAP)

The test results of COM1 will be analyzed and the instrument commissioning data will be released. The pipeline team will support this activity. This includes a full check of the data reduction pipeline functionality in the QC0/QC1/QC2 operational environments.

12.3.3 Commissioning period 2 (COM2)

The scope of COM2 is to establish the science operation readiness of METIS integrated at the ELT. This includes in particular the full data flow system and data reduction pipeline functionality with a first version of a completely populated calibration data base. The COM2 deliverables are specified in [AD5] (see also table 6).

12.4 METIS Preliminary Acceptance in Chile

At the time of PAC the final version of the Data Reduction Library package will be available. Data from the ESO Archive will be processed with the data reduction pipeline which have to comply with ESO standards on data formats and data products. THe functionality of the pipeline wil be checked in the QC0/QC1/QC2 operational environments. The PAC deliverables are specified in [AD5] (see also table 6). Upon successful completion of PAC, the two-year guarantee period will start as defined in the Statement of Work.

12.5 METIS science operations

MEITS science operations will consist of two observation periods, SO1 and SO2 respectively. SO1 will start upon successful completion of PAC. The data reduction pipeline will support the scientific data analysis with the METIS pipeline software team providing support to ESO. The SO1 deliverables are specified in [AD5] (see also table 7).

SO2 will be used to further refine the data reduction pipeline package based upon feedback from SO1. This should be the final consolidation of the pipelines software and all relevant documentation and user manuals. The SO2 deliverables are specified in [AD5] (see also table 7).

A FITS KEYWORDS

The below lists of keys make up the interface to the ICS, in compliance with METIS-6081. Section A.1 gives an overview on the Data Products (DPR) keywords and their connection to the respective recipes, Section A.2 lists FITS keywords used within the recipes. The subsection A.3 provides a list of header keywords used in the FITS files of METIS data items, both raw and processed, for which the values are used as parameters in the processing.

A.1 DPR keywords

DPR.CATG	DPR.TECH	DPR.TYPE	DO.CATG	Recipes
CALIB	IFU	DARK	DARK_IFU_RAW	metis_det_dark
CALIB	IFU	DARK,WCUOFF	IFU_WCU_OFF_RAW	metis_det_lingain
CALIB	IFU	DETLIN	DETLIN_IFU_RAW	metis_det_lingain
CALIB	IFU	DISTORTION	IFU_DISTORTION_RAW	metis_ifu_distortion
CALIB	IFU	PSF,OFFAXIS	IFU_OFF_AXIS_PSF_RAW	metis_ifu_adi_cgrph
CALIB	IFU	RSRF	IFU_RSRF_RAW	metis_ifu_rsrf
CALIB	IFU	RSRF	IFU_RSRF_RAW	metis_ifu_rsrf
CALIB	IFU	SKY	IFU_SKY_RAW	metis_ifu_sci_process
CALIB	IFU	STD	IFU_STD_RAW	metis_ifu_std_process
CALIB	IFU	WAVE	IFU_WAVE_RAW	metis_ifu_wavecal
CALIB	IMAGE,LM	CHOPHOME	LM_CHOPPERHOME_RAW	metis_img_chophome
CALIB	IMAGE,LM	DARK	DARK_2RG_RAW	metis_det_dark
CALIB	IMAGE,LM	DARK,WCUOFF	LM_WCU_OFF_RAW	metis_det_lingain
"	"	"	"	metis_lm_img_distortion
"	"	"	"	metis_lm_adc_slitloss
CALIB	IMAGE,LM	DETLIN	DETLIN_2RG_RAW	metis_det_lingain
CALIB	IMAGE,LM	DISTORTION	LM_DISTORTION_RAW	metis_lm_img_distortion
CALIB	IMAGE,LM	FLAT,LAMP	LM_FLAT_LAMP_RAW	metis_lm_img_flat
CALIB	IMAGE,LM	FLAT,TWILIGHT	LM_FLAT_TWILIGHT_RAW	metis_lm_img_flat

Continued on next page

Table 8 – continued from previous page

DPR.CATG	DPR.TECH	DPR.TYPE	DO.CATG	Recipes
CALIB	IMAGE,LM	PSF,OFFAXIS	LM_OFF_AXIS_PSF_RAW	metis_img_adi_cgrph
"	"	"	"	metis_lm_adi_app
CALIB	IMAGE,N	DARK	DARK_GEO_RAW	metis_det_dark
CALIB	IMAGE,N	DARK,WCUOFF	N_WCU_OFF_RAW	metis_det_lingain
"	"	"	"	metis_n_img_distortion
"	"	"	"	metis_n_adc_slitloss
CALIB	IMAGE,N	DETLIN	DETLIN_GEO_RAW	metis_det_lingain
CALIB	IMAGE,N	DISTORTION	N_DISTORTION_RAW	metis_n_img_distortion
CALIB	IMAGE,N	FLAT,LAMP	N_FLAT_LAMP_RAW	metis_n_img_flat
CALIB	IMAGE,N	FLAT,TWILIGHT	N_FLAT_TWILIGHT_RAW	metis_n_img_flat
CALIB	IMAGE,N	PSF,OFFAXIS	N_OFF_AXIS_PSF_RAW	metis_img_adi_cgrph
CALIB	LSS,LM	FLAT,LAMP	LM_LSS_RSRF_RAW	metis_LM_lss_rsrf
CALIB	LSS,LM	FLAT,LAMP,PINH	LM_LSS_RSRF_PINH_RAW	metis_LM_lss_trace
CALIB	LSS,LM	SLITLOSS	LM_SLITLOSSES_RAW	metis_lm_adc_slitloss
CALIB	LSS,LM	STD	LM_LSS_STD_RAW	metis_LM_lss_std
CALIB	LSS,LM	WAVE	LM_LSS_WAVE_RAW	metis_LM_lss_wave
CALIB	LSS,N	FLAT,LAMP	N_LSS_RSRF_RAW	metis_N_lss_rsrf
CALIB	LSS,N	FLAT,LAMP,PINH	N_LSS_RSRF_PINH_RAW	metis_N_lss_trace
CALIB	LSS,N	SLITLOSS	N_SLITLOSSES_RAW	metis_n_adc_slitloss
CALIB	LSS,N	STD	N_LSS_STD_RAW	metis_N_lss_std
SCIENCE	IFU	OBJECT	IFU_SCI_RAW	metis_ifu_sci_process
SCIENCE	IMAGE,LM	OBJECT	LM_IMAGE_SCI_RAW	metis_lm_img_basic_reduce
SCIENCE	IMAGE,N	OBJECT	N_IMAGE_SCI_RAW	metis_n_img_chopnod
SCIENCE	LSS,LM	OBJECT	LM_LSS_SCI_RAW	metis_LM_lss_sci
SCIENCE	LSS,N	OBJECT	N_LSS_SCI_RAW	metis_N_lss_sci
TECHNICAL	PUP,M	PUPIL	LM_PUPIL_RAW	metis_pupil_imaging
TECHNICAL	PUP,N	PUPIL	N_PUPIL_RAW	metis_pupil_imaging

Table 8: DPR keywords table

A.2 List of FITS header keywords used in imaging and spectroscopy recipes

All FITS files with raw exposures will have the same set of header keywords. The following header keywords are mandatory for the data processing to function:

- CDELTn
- CRPIXn
- CRVALn
- CTYPEn

- `CUNITn`
- `DET.DIT`
- `DET.READOUT`
- `DPR.CATG`
- `DPR.TECH`
- `DPR.TYPE`
- `EXPTIME`
- `INS.FILTi.NAME`
- `INSTRUME`
- `MJD-OBS`
- `OBS.TPLNO`
- `OCS.PXSCALE`
- `TPL.EXPNO`
- `TPL.START`

A.3 Specification of FITS header keywords used in imaging and spectroscopy recipes

A.3.1 DET*n*.ID

Name	DET*n*.ID
Class	header
Context	Template
Type	double
Value	%.3f
Unit	none
Comment	keyword to identify detector 2RG = Hawaii 2RG from the IMG/LSS GEO = Geosnap detector from the IMG/LSS IFU: IFU detectors
Default	1.0
Range	0.0..3600.0

Description	Detector integration time (average when NDIT > 1)

A.3.2 DET*n*.DIT

Name	DET*n*.DIT
Class	header
Context	Template
Type	double
Value	%.3f
Unit	s
Comment	*n*=1: LM IMG/LSS detector (Hawaii2RG)
	n=2: N IMG/LSS detector (Geosnap)
	n=3: IFU detectors
Default	1.0
Range	0.0..3600.0
Description	Detector integration time (average when NDIT > 1)

A.3.3 DET*n*.NDIT

Name	DET*n* NDIT
Class	header
Context	Template
Type	integer
Value	%i
Unit	None
Comment	*n*=1: LM IMG/LSS detector (Hawaii2RG)
	n=2: N IMG/LSS detector (Geosnap)
	n=3: IFU detectors
Default	1
Range	1..10
Description	Number of detector integrations

A.3.4 DPR.CATG

Name	DPR CATG
Class	header|template
Context	Template
Type	string
Value	%.50s
Unit	None
Comment	Set by ICS
Default	None
Range	CALIB SCIENCE TEST
Description	Raw data product category

A.3.5 DPR.TECH

Name	DPR TECH
Class	header|template
Context	Template
Type	string
Value	%.50s
Unit	None
Comment	Set by ICS
Default	None
Range	Depending on the observing mode
Description	Raw data product technique

A.3.6 DPR.TYPE

Name	DPR TYPE
Class	header|template
Context	Template
Type	string

Value	%.50s
Unit	None
Comment	Set by ICS
Default	None
Range	Depending on the observing mode
Description	Raw data product type

A.3.7 EXPTIME

Name	EXPTIME
Class	header
Context	FITS
Type	double
Value	%.3f
Unit	s
Comment	Integration time
Default	None
Range	None
Description	The integration time for a single observation (in the infrared this corresponds to DIT. Note that this does not represent the photon statistics).

A.3.8 INS.OPTI3.NAME

Name	INS OPTI3 NAME
Class	header
Context	INS
Type	string
Value	%.50s
Unit	None
Comment	Name of the LSS slit
Default	None
Range	A_19 B_29 C_38 D_57 E_114

Description	LSS slit name

A.3.9 INS.OPTI9.NAME

Name	INS OPTI9 NAME
Class	header
Context	INS
Type	string
Value	%.50s
Unit	None
Comment	LM-LSS Mask/Grism name
Default	None
Range	open GRISM-L GRISM-M
Description	LM-LSS Mask/Grism name

A.3.10 INS.OPTI10.NAME

Name	INS OPTI10 NAME
Class	header
Context	INS
Type	string
Value	%.50s
Unit	None
Comment	LM-LSS Filter name
Default	None
Range	None
Description	LM-LSS Filter name

A.3.11 INS.OPTI11.NAME

Name	INS OPTI11 NAME
Class	header
Context	INS
Type	string
Value	%.50s
Unit	None
Comment	Name of the neutral density filter
Default	None
Range	OPEN ND1 ND2 ND3 ND4 ND5
Description	ND Filter name

A.3.12 INS.OPTI12.NAME

Name	INS OPTI12 NAME
Class	header
Context	INS
Type	string
Value	%.50s
Unit	None
Comment	N-LSS Mask/Grism name
Default	None
Range	open GRISM-N
Description	N-LSS Mask/Grism name

A.3.13 INS.OPTI13.NAME

Name	INS OPTI13 NAME
Class	header
Context	INS
Type	string

Value	%.50s
Unit	None
Comment	N-LSS Filter name
Default	None
Range	full_N
Description	N-LSS Filter name

A.3.14 INS.OPTI14.NAME

Name	INS OPTI14 NAME
Class	header
Context	INS
Type	string
Value	%.50s
Unit	None
Comment	ND Filter name
Default	None
Range	OPEN ND1 ND2 ND3 ND4
Description	ND Filter name

A.3.15 INS.OPTI20.NAME

Name	INS OPTI20 NAME
Class	header
Context	INS
Type	string
Value	%.50s
Unit	None
Comment	Pinhole mask inserted?
Default	None
Range	LM-pinhole
Description	WCU FP2.1 mask wheel

A.3.16 PRO.CATG

Name	PRO CATG
Class	header
Context	Pipeline
Type	string
Value	%.50s
Unit	None
Comment	Set by recipes
Default	None
Range	None
Description	Processed data product category

A.3.17 PRO.TECH

Name	PRO TECH
Class	header|template
Context	Template
Type	string
Value	%.50s
Unit	None
Comment	Set by ICS
Default	None
Range	Depending on the observing mode
Description	Copied from DPR.TECH of main input

A.3.18 DET.READOUT

Name	DET READOUT
Class	header
Context	INS
Type	string

Value	%.50s
Unit	None
Comment	Readout mode of the detector
Default	CDS
Range	CDS TLI RRR
Description	Readout mode of the detector

A.3.19 CDELTn

Name	CDELTn
Class	header
Context	FITS
Type	double
Value	%.8f
Unit	
Comment	Increment in <axis direction>
Default	None
Range	None
Description	Increment of coordinate specified by CTYPEn for each pixel step at CRPIXn. Possible values for <axis direction> are: rows (1), columns (2), frame(3) For RA and DEC the unit is degree. In this case, the comment field includes the value expressed in seconds of arc. In the proposed WCS system it should be replaced by CDn_m

A.3.20 CDn_ms

Name	CDn_ms
Class	header
Context	FITS
Type	double
Value	%f
Unit	

Comment	Coordinate translation matrix element
Default	None
Range	None
Description	Gives the translation from array axis n to coordinate axis m. For images the comment should read SS.ss arcsec per pixel

A.3.21 CRPIXn

Name	CRPIXn
Class	header
Context	FITS
Type	double
Value	%.1f
Unit	
Comment	Ref pixel in <axis direction>
Default	None
Range	None
Description	Pixel position of the reference point in axis n. Possible values for <axis direction> are: rows (1), columns (2), frame (3) By convention the center of the pixel is pix.0, pix.5 gives the right edge of the pixel. Reference pixel is also used to identify the pointing centre (with respect to the WCS transformation, i.e. the optical axis).

A.3.22 CRVALn

Name	CRVALn
Class	header
Context	FITS
Type	double
Value	%.5f
Unit	
Comment	Coordinate at reference pixel in <axis direction>

Default	None
Range	None
Description	Coordinate value as specified by CTYPEn at reference pixel CRPIXn. Possible values for <axis direction> are: rows (1), columns (2), frame (3) If world coordinates are used (i.e. CTYPEn is either RA—TAN and DEC–TAN), the comment field includes the value expressed in hours, minutes and seconds (RA) or degrees, minutes, and seconds (DEC). The unit has to be degrees, if RA and DEC are used as world coordinates.

A.3.23 CTYPEn

Name	CTYPEn
Class	header
Context	FITS
Type	string
Value	%s
Unit	
Comment	Coordinate system of <axis direction>
Default	None
Range	None
Description	Name of the coordinate represented by axis n. Possible values for <axis direction> are: rows (1), columns (2), frame (3) Examples for values are "PIXEL", "RA—TAN", "DEC–TAN"

A.3.24 CUNITn

Name	CUNITn
Class	header
Context	FITS
Type	string
Value	%s
Unit	

Comment	Unit of coordinate translation
Default	None
Range	None
Description	Unit of the coordinate in n axis n

A.3.25 EXTINCT

Name	EXTINCT
Class	header
Context	PRO
Type	double
Value	%.3f
Unit	mag
Comment	Extinction of the observation
Default	0.0
Range	None
Description	Extinction of the observation

A.3.26 GAIN

Name	GAIN
Class	header
Context	Detector
Type	double
Value	%.3f
Unit	e/adu
Comment	Gain of the detector
Default	1.0
Range	None
Description	Gain of the detector

A.3.27 ICCOEFi

Name	ICCOEFi
Class	header
Context	PRO
Type	double
Value	%.3f
Unit	None
Comment	Illumination Correction Coefficient
Default	0.0
Range	None
Description	Illumination Correction Coefficient

A.3.28 INS.DROT

Name	INS DROT
Class	header
Context	INS
Type	double
Value	%.3f
Unit	degree
Comment	Derotator angle
Default	0.0
Range	None
Description	Derotator angle

A.3.29 INS.FILT.NAME

Name	INS FILT NAME
Class	header
Context	INS
Type	string

Value	%.50s
Unit	None
Comment	Filter name
Default	None
Range	None
Description	Filter name

A.3.30 INS.FILTi.NAME

Name	INS FILTi NAME
Class	header
Context	INS
Type	string
Value	%.50s
Unit	None
Comment	Filter name
Default	None
Range	None
Description	Filter name

A.3.31 INS.MODE

Name	INS MODE
Class	header
Context	INS
Type	string
Value	%.50s
Unit	None
Comment	Instrument Mode
Default	NODEFAULT
Range	IMAGING SPEC PUP
Description	Instrument Mode

A.3.32 INS.READMODE

Name	INS READMODE
Class	header
Context	INS
Type	string
Value	%.50s
Unit	None
Comment	Readout mode of the detector
Default	CDS
Range	CDS TLI RRR
Description	Readout mode of the detector

A.3.33 INSTRUME

Name	INSTRUME
Class	header
Context	FITS
Type	string
Value	%s
Unit	
Comment	Instrument used
Default	None
Range	None
Description	ESO acronym for the instrument used.

A.3.34 MJD-OBS

Name	MJD-OBS
Class	header
Context	FITS
Type	double

Value	%.8f
Unit	
Comment	Obs start
Default	None
Range	None
Description	Modified Julian Day of the start of the exposure. The MJD is related to the Julian Day (JD) via the formula: MJD = JD-2400000.5 The comment includes a civil representation of the date and time. 8 decimals are required for a precision of one millisecond, 5 decimals for a precision of one second.

A.3.35 OBS.DEC

Name	OBS DEC
Class	header
Context	Template
Type	double
Value	%.3f
Unit	deg
Comment	Declination
Default	0.0
Range	-90.0..90.0
Description	Declination

A.3.36 OBS.RA

Name	OBS RA
Class	header
Context	Template
Type	double
Value	%.3f
Unit	deg
Comment	Right Ascension

Default	0.0
Range	0.0..360.0
Description	Right Ascension

A.3.37 OBS.TPLNO

Name	OBS TPLNO
Class	header
Context	Template
Type	integer
Value	%i
Unit	None
Comment	Number of the template of this exposure in an Observing-Block
Default	0
Range	0..1000
Description	Number of the template of this exposure in an Observing-Block

A.3.38 OCS.PXSCALE

Name	OCS PXSCALE
Class	header
Context	INS
Type	double
Value	%.3f
Unit	arcsec/pix
Comment	Pixel scale
Default	0.004
Range	None
Description	Pixel scale

A.3.39 PVn_ks

Name	PVn_ks
Class	header
Context	FITS
Type	double
Value	%f
Unit	
Comment	Coordinate projection parameter
Default	None
Range	None
Description	Describes the parameter k for the axis n. Required for certain coordinate types

A.3.40 TPL.EXPNO

Name	TPL EXPNO
Class	header
Context	Template
Type	integer
Value	%i
Unit	None
Comment	Number of this exposure in a Template
Default	0
Range	0..1000
Description	Number of this exposure in a Template

A.3.41 TPL.START

Name	TPL START
Class	header|template
Context	Template

Type	double
Value	%.8f
Unit	None
Comment	Start time of template
Default	None
Range	None
Description	Start time of template

A.3.42 ZEROPNT

Name	ZEROPNT
Class	header
Context	PRO
Type	double
Value	%.3f
Unit	mag
Comment	Zeropoint of the observation
Default	0.0
Range	None
Description	Zeropoint of the observation

A.3.43 INS.FILT1.NAME

Name	INS FILTi NAME
Class	header
Context	INS
Type	string
Value	%.50s
Unit	None
Comment	Filter name
Default	None
Range	None

Description	Filter name

A.3.44 INS.FILT2.NAME

Name	INS FILTi NAME
Class	header
Context	INS
Type	string
Value	%.50s
Unit	None
Comment	Filter name
Default	None
Range	None
Description	Filter name

A.3.45 INS.SLIT.NAME

Name	INS SLIT NAME
Class	header
Context	INS
Type	string
Value	%.50s
Unit	None
Comment	Slit name
Default	None
Range	provided at PAE
Description	Slit name

A.4 Spectroscopic FITS header keyword values

B Earth's Atmosphere Transmission

INS.SLIT.NAME	INS.FILT.NAME	Description	Spectral setup
SHORT	SPEC_IJ	short 16mas×3" slit	IzJ
BROAD	SPEC_IJ	broad 48mas×3" slit	IzJ
BROAD	SPEC_HK	broad 48mas×3" slit	HK
LONG	SPEC_J	long 20mas×15" slit	J
LONG	SPEC_HK	long 20mas×15" slit	HK
SHORT_SH	SPEC_IJ	shifted 16mas×3" slit	IzJ
BROAD_SH	SPEC_IJ	shifted 48mas×3" slit	IzJ
BROAD_SH	SPEC_HK	shifted 48mas×3" slit	HK
LONG_SH	SPEC_J	shifted 20mas×15" slit	J
LONG_SH	SPEC_HK	shifted 20mas×15" slit	HK
PINH	all	pinhole slit	all
PINH_SH	all	shifted pinhole slit	all

Table 9: Values for the FITS keywords INS.FILT.NAME and INS.SLIT.NAME representing the spectrosopic modes

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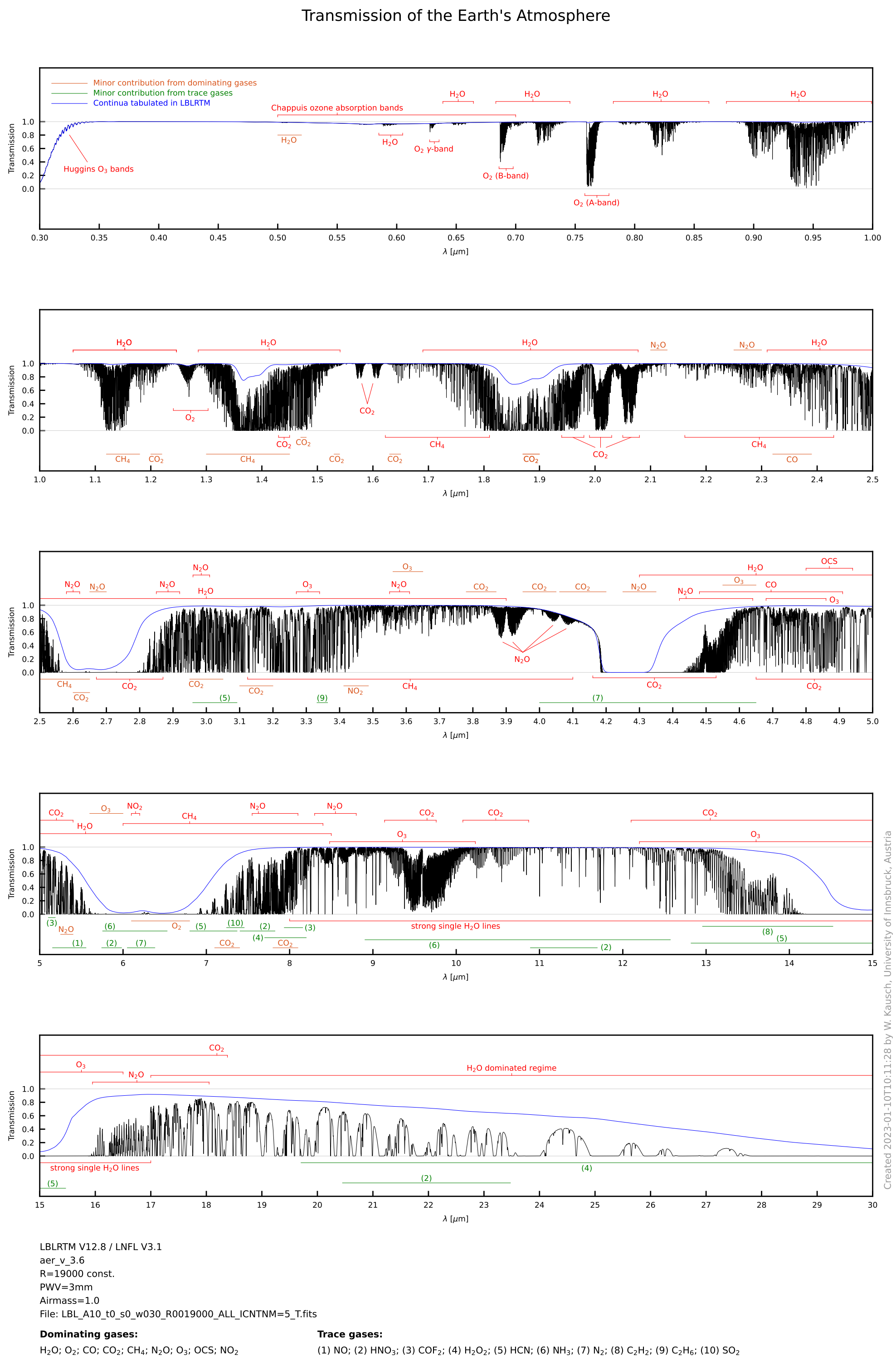

Figure 82: Transmission of the Earth's atmosphere.