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GIRAFFE

User's Requirements for BLDR Software

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Contents

1   INTRODUCTION

1.1   Scope of this document

The present document (UR-BLDRS) describes the astronomer's view of the Base-line Data Reduction Software (BLDRS), part of the Data Reduction Software (DRS), for the Giraffe Spectrograph which is a part of the VLT Multi Object Fiber Facility (called FLAMES) at UT2 telescope. The main purpose is to give moderately technically-oriented overview of the data reduction, identify the specific critical issues and external dependencies. The *BLDRS Technical Specifications* will probably be a more appropriate name.

This document served as a basis for developing the more detailed *Functional Specifications* (FS). **In case of discrepancies between the UR (this document) and the FS, the latter is to be considered as the up-to-date reference.**

The basic instrument is the fibre unit pick-up feeding the high resolution (10000-40000) spectrographs. The fibres may be fed by the light of individual objects (MEDUSA mode), a single resolved object (ARGUS) or several small resolved objects (IFU). The spectrographs could be Giraffe (132 objects 308 elements of image) or UVES (8 objects).

The BLDRS should account for all instrumental effect and produce the flux and wavelength calibrated spectra in all observing modes.

The BLDRS will be complemented (not covered by this document) by the Ancillary Data Analysis Software (ADAS) which will provide the Data Analysis tools specific to the instrument such as High-precision Radial velocity package and image reconstruction in a given passband (ARGUS and IFU modes). However, at least crude image reconstruction will be provided by the BLDRS and by the Quick-Look Software for Argus and IFU modes, since the observers will need to check how far their objects are correctly centered (see Section 4).

1.2   Relation with other giraffe definition documents

- The calibration and operation

  Though the calibration and operation of GIRAFFE and FLAMES will be the subject of another document, some aspects necessary to define the BLDRS are discussed in the present document and may be subject to major modifications according to the final calibration and operation plan.

- The entry interface

  The entry interface to the BLDRS is the output from the Data Flow Software (DFS) which includes the data produced by the DFS as well as some pieces of SW necessary to handle these. It is important to recall that the structure to be handled during the DRS are lists of objects with several important attributes (position in the field, magnitude, object class and color) and that the user expects to find the same facility to navigate within lists with comfort all through the observing and data reduction process.

- The quick-look software

  The Quick-look or acquisition pipeline data analysis will be an easy-to-use and fast subset of the reduction package providing the means to perform all basic calibrations and assess the quality of the data. If necessary for technical reason (speed of execution, robustness toward ill-conditioned data) a special version of commands will be created for the purpose of the quick-look (QLS). **Otherwise the QLS will be identical with the DRS.**

1.3   Implementation requirements

The VLT standard requires:

- The DRS SW should be implemented in ANSI C and in the MIDAS environment (Specs)

- It is recommended to develop the DRS SW as independently as possible from any specific Data Reduction system/environment (MIDAS included)

- The whole code should be available, including the third-party or public domain SW

1.4   Basic philosophy of the implementation

1.4.1   Introductory remarks

Any development of the DRS for a new instrument faces four main challenges:

1. Use as much as possible the existing expertise on similar existing instruments

2. Develop, test and validate as much as possible of the DRS before the instrument is available

3. Design the DRS in a way to make the final laboratory acceptance and adaptation necessary during the commissioning period efficient, fast and safe

4. facilitate the integration of new contributed SW

While the implementation of the first two principles is quite straightforward, the last two could be fulfilled in many different (and even contradictory) ways. Moreover, since several aspects of the design are already defined by AD1, the DRS designer has not much freedom to modify the general scheme. The following guidelines for the DRS should therefore be understood as what the authors consider as a minimum requirement to a system that should be able, after the period of 6 months of the on-site commissioning, to be left to the care of the ESO staff in a rather complex and very likely still changing environment for the maintenance, adaptation, housekeeping and distribution.

1.4.2   Implementation requirements

SW modules should be linked in a way to make it possible to run them independently, chained in a step-by-step execution or fully automatically. Though the goal is a fully-automatic Data Reduction Process, it should be possible to examine and modify the intermediate data, re-run the reduction from a specific step, and skip options. Whenever possible, the communication between modules should proceed through data only without direct interaction with the environment. The interface to the image display, graphics and data editors should be well localized in order to make the integration of personal tools and adaptation for new tools possible.

In order to make the automated processing possible and efficient, all options and controls should be fully parametrised. A subset of comprehensible and widely accepted *classical* main parameters should be put in evidence separately in order to facilitate the handling by technically inexpert user (with necessary astronomical background).

1.5   The I/O Data

Only the standard data formats should be used, the FITS files for images and ASCII files for any tables, keywords, descriptors and all kinds of parameter files. All parameters resulting from the data processing will be cumulatively added progressively as FITS keywords to the FITS data files including also all relevant input data. Tools will be provided to extract FITS keywords to a set of single or several ASCII tables. The deviation from this principle should be thoroughly justified.

The adopted syntax for ASCII files should be straightforward and easy to use.

1.6   The installation validation set, the tutorial, help and documentation

A basic tutorial running at a reasonable speed on realistic but not necessarily full sized data should be available. Also a full-fledged validation run within the tutorial should provide the extensive diagnostic of the installation validation. This facility should help when the installation is attempted on unsupported platforms (normally the HP and SUN platforms are supported).

A well structured (index, searches) on-line html help/documentation should be available.

A FRAMEMAKER format using the standard VLT template is required by ESO

1.7   APPLICABLE DOCUMENTS

AD1   INS-SPE-ESO-13730-1657,1.0 – GIRAFFE Technical Specifications
AD2   VLT-SPE-ESO-10000-0004,1.0 – VLT Specification Environmental Conditions
AD3 * VLT-TRE-ESO-13740-1681   – GIRAFFE SPECTROGRAPH Optical Final Design
AD4   VLT-PLA-ESO-13700-1788,1.0 – FLAMES IOCP - Instrument Operation and Calibration Plan

1.8   REFERENCE DOCUMENTS

RD1 VLT-PLA-ESO-00000-0006,2.0 21/05/92 – VLT Software Management Plan
RD2 VLT-PRO-ESO-10000-0228,1.0 10/03/93 – VLT Software Programming Standard
RD3 2dF User Manual, J. Bailay, K. Glazebrook, May 29, 1998
RD4 VLT-TRE-VIRG-14616-0058,1.0 16/06/98 – VIMOS Final Design Review
RD5 Australis Concept Study Report, The Australis Consortium), K. Taylor, M. Colless et al.,
       27 Sept. 1996
RD6 GIR-TRE-OPM-XXXXX,1.0 – Qualité d'image en bord de ferrule, D. Jocou (OP), 27 July 1999

1.9   ABBREVIATIONS AND ACRONYMS

ADAS	GIRAFFE Ancillary Data Analysis Software
ADU	CCD Analog-to-digital Unit conversion factor
ARGUS	GIRAFFE Integral Field Spectroscopy mode
AUSTRALIS	Australian project
BLDR	GIRAFFE Base Line Data Reduction
BLDRS	GIRAFFE Base Line Data Reduction Software
CRH	Cosmic Ray Hit
DFS	GIRAFFE Data Flow Software
DRS	GIRAFFE Data Reduction Software
FLAMES	VLT Multi Object Fiber Facility
FITS	Flexible Image Transport System
FSFF	*Full-Slit* Flat Field
FoV	Field of View at the Nasmyth focus
GIRAFFE	Spectrograph, part of FLAMES
IFU	Integral Field Unit
IOCP	Instrument Operation and Calibration Plan
MEDUSA	Multi-Object Spectroscopy mode
MIDAS	Munich Image Data Analysis System
MOS	VLT Multi-object slit spectrograph
NFF	*Narrow* Flat Field
OGL	Observatoire de Genève et l'Université de Lausanne
OP	Observatoire de Paris
PHFF	"Photometric" Flat Field, i.e. relative to a wide bandpass
PSF	Point Spread Function
QLS	GIRAFFE Quick-Look Software
RON	Read-Out Noise
SEWC	Separate Wavelength Calibration
SIWC	Simultaneous Wavelength Calibration
SLM	Scattered Light Model
SNR	Signal to Noise Ratio
SW	SoftWare
TBC	To Be Confirmed
TBD	To Be Defined
UR	GIRAFFE User's Requirements
UVES	U-V Echelle Spectrograph
WLC	Wavelength Calibrations
SPECIAL REQUIREMENT	Requirements not foreseen in Calibration Plan

1.10   GLOSSARY

N/A

1.11   Typing conventions

In order to make discussion more precise, we will give as often as possible the formulae to be implemented. In order to make the reading easy, the adopted notation is a rather simple one and may lack precision in some cases (sub/super-scripts omitted whenever possible, only the discussion relevant parameters

appearing in the formulae, ...).

The following types of objects will be referenced:

typing/symbol	explanation
$o(\mathbf{X}, \mathbf{Y})$	2D object (light distribution) in the focal plane
$o(x,y)$	2D image from the detector (with $x \parallel$ dispersion direction)
$\{o_n(x)\}$	Set of n 1D extracted uncalibrated spectra
$\{\mathbf{O}_n(x)\}$	Set of n 1D flux calibrated spectra
$\{o_n(\lambda)\}$	Set of n 1D wavelength calibrated spectra
$\{\mathbf{O}_n(\lambda)\}$	Set of n 1D flux and wavelength calibrated spectra
$\langle o(x,y) \rangle$	Optional term within an expression
$\overline{o(x,y)}$	Average value (a number)
$\overline{o}(x,y)$	Average image
$A \cup B$	Logical "or" element-by-element of common part of matrix A and B

1.12 Structure of the document and release notes

The 1.xx releases will evolve into the final document 2.xx. In the versions 1.xx and 2.0x, we keep in the text the traces of not yet properly addressed problems/questions. We believe this way to proceed spares unnecessary extra works to other people involved. Obviously the WORKING REMARKS are optionally *removable* during the document formatting.

2 CALIBRATIONS

A specific document (AD4) is dedicated to the calibration strategy. Since many points are yet to be clarified and the present version of AD4 does not give the detailed description of the calibration procedures, the calibration-related part of the BLDRS foresees in some cases several possibilities. In this aspect the goal of UR-BLDRS is *not to miss* any important User's requirement of the BLDRS.

2.1 The CCD detector calibration: bias, dark and static defaults

- The bias will be determined using two methods (subject to discussion with the supplier of the detector - ESO CCD group)

    - Constant bias.
      The actual bias is obtained from the overscan of the science image (sigma-clipped average of all points in overscan). The overscan will also be used to monitor the read-out noise.

    - Spatially varying bias.
      If low frequency uncorrected drift is present in CCD electronics, the bias may exhibit some repeatable features at the 1 photo-electron level. In this case the actual bias is taken from the current average bias exposure.

- The standard average dark $dark(x, y) = \overline{dark}(x, y)$ will be used with monitoring of the dark evolution at the specified time-scale (week/month) and after each important (TBD) out-of-operating-conditions temperature excursion.

- The numerical mask badpixel(x,y) of the *bad pixels* will be constructed and maintained. The analysis software will support *flagged* pixels all through the analysis. Alternatively the possibility to replace flagged-pixel at any stage of the data reduction will be implemented.

2.2 Wavelength Calibrations (WLC)

The high standard of the instrument mechanical stability (AD1) will insure that the actual position of the spectra on the detector and actual Wavelength Solution will be very close to the standard ones. Both the positioner and GIRAFFE will be equipped with Th-Ar and Neon lamps (AD4). The following modes of Wavelength Calibration should be implemented (AD1):

- The Separate Wavelength Calibration (SEWC) exposure through all fibres, using the calibration lamp of the positioner, as well as the calibration lamp of the 5 SIWC fibres . This will probably be used routinely only for UVES observation where simultaneous wavelength calibration is not available. Of course it has to be done for GIRAFFE too, but not necessarily on a daily basis.

- The Simultaneous Wavelength Calibration (SIWC) exposure through 5 dedicated fibres (GIRAFFE only). In this mode, a set of calibration spectra will be taken during the science exposure, in order to measure and compensate the instrumental drift and obtain excellent quality radial velocities. The flux of these light-sources is adjustable (using neutral filters) since the simultaneous calibration spectra must be taken in the same time-interval as the scientific ones and must insure close-to-optimal SNR (AD4). The SIWC is done for all observations with Giraffe and is, by far, the best method to insure the high-precision WLC necessary for radial-velocity measurements.

- The (Possibly) Simultaneous Wavelength Calibration exposure using the sky emission lines in the red (the telluric emission lines; see Osterbrock et al. 1996[1], 1997[2]). A minimum number of lines per spectral domain is required in order to be sure that there is only a shift and not a variation in the dispersion function (TBD in the calibration plan).

  The stability of the telluric lines in terms of radial velocity seems excellent, according to the experience of Campbell (1983)[3] and of Smith (1982[4], 1983[5]): it is within about 10 $m\,s^{-1}$, even on timescales of several nights, the limiting factor being telluric winds. Smith (1982) estimates that the O_2 lines are stable to within 6-8 $m\,s^{-1}$, while the H_2O lines may be less stable. In any case, the telluric lines seem to provide a reference which is an order of magnitude more stable than the 150 $m\,s^{-1}$ required in the Technical Specifications, which fully justifies their use for the simultaneous wavelength calibration.

2.3   Flat fielding - The detector and spectrograph response

Several types of FF will be available.

1. **Illumination of the detector through all fibres:** A set of continuous absolute calibrated spectra of an incandescent lamp (AD1) uniformly illuminating the entrance of all fibres. We call such a frame *narrow* FF (NFF), by contrast to *full–slit* FF (FSFF) where the whole slit is uniformly illuminated. It is assumed that all fibres will be packed together in a parking position where their entrance can be illuminated in a uniform way ("FP Calibration", AD4).

   Alternatively, we may illuminate the whole FoV with fibres in the observing position (TBD) with a continuum source of a known spatial distribution using the Nasmyth screen. This could only be done at night, so it is considered as a backup option only (AD4).

   These FF calibration spectra fall, on the detector, at the same places as the science spectra (within the short-term stability of the spectrograph), allowing thus a good preliminary localization. Since the incandescent lamp is calibrated in terms of absolute flux at all wavelengths, the overall efficiency is established, including the effects of the transmission of the fibres and spectrograph and the sensitivity of the CCD detector (the way in which this calibration will be done is yet TBD in the Calibration Plan), provided that the transmissions of the fibres do not vary with the position in the FoV more than the specified tolerance. This may be the case at the $\pm 2\%$ level but not at the $\pm 1\%$ one (see remark below). This NFF frame will also be used to allow the localization of the five spectra dedicated to the simultaneous wavelength calibration. Then the simultaneous wavelength calibration system should contain a continuum lamp (TBC), but uniform illumination of the fibres is not necessary, since an accurate knowledge of the transmissions of these fibres is not necessary for the data reduction.

   The NFF does not allow to map the pixel sensitivity over the whole surface of the detector, since the inter-spectrum regions will not be illuminated. However, experience with other instruments has shown that this is not required (except, perhaps, for large SNRs, typically $S/N > 300$), and that it is better to do the FF correction *after* the extraction than before, in the sense that the resulting SNR is slightly larger. Therefore, in general the NFF will be used not only for determining the

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[1]Osterbrock D.E., Fulbright J.P., Martel A.R., Keane M.J., Trager S.C., 1996, PASP 108, 277

[2]Osterbrock D.E., Fulbright J.P., Bida T.A., 1997, PASP 109, 614

[3]Campbell B., 1983, PASP 95, 577

[4]Smith M.A., 1982, ApJ 253, 727

[5]Smith M.A., 1983, ApJ 265, 325

localization and low spatial frequencies of the efficiency, but also for the high frequencies of the efficiency, i.e. the relative pixel sensitivity along the x axis, after extraction.

2. **Full slit illumination:** The relative pixel sensitivity may be determined, optionally, using an FF exposure made by illuminating the whole slit (AD4). This FSFF exposure will only be done as a back-up solution, since it will not be used in the standard reduction. Using this option implies that negligible scattered light is assumed, and the optical design is indeed optimized in this regard (AD3). The main reason for dropping this option is the presence of fringes on the CCD, mostly in the red. Those fringes will have different locations and/or patterns for FSFF exposures on the one hand, and for exposures made through the fibres on the other hand, due to different optical paths.

3. **Illumination through a few fibres only** (AD4, pp. 21-22): a series of FF exposures made through each individual fibres, a few at a time, in order to detect and possibly model the ghosts and the diffuse background light linked with each individual fibre. This can be done only in the MEDUSA mode for which a few selected fibres well separated on the slit can be illuminated by the continuum lamps. For Argus and IFU modes, one can envisage to illuminate only the 5 SIWC fibres with an incandescent lamp, and/or the sky fibres; other solutions are discussed in Section 4.

4. **"Photometric" FF:** a series of PHFF exposures made through each of the filters used for order selection but not through the spectrograph, may be useful in order to measure the relative pixel sensitivity in the case of scattered light (see Section 3.1). This will be done as laboratory tests only, not as a routine operation. This calibration is not mentioned yet in the IOCP.

2.4 Description of a typical night

The purpose of this subsection is to describe what will happen in practice during a typical night, including the calibrations which will be made in the preceding afternoon. In this way the succession of operations is clarified, and the data flow better identified.

1. **Afternoon calibrations:** these calibration exposures and processing are carried out for most spectral ranges scheduled for the next night, but not necessarily for all of them, if many are foreseen. Indeed, the calibrations are so time consuming that they will be possible for a limited number of set-ups only. For any additional set-up, archive calibrations will generally be used, at least for the automatic pipeline reduction; the calibrations may be done the following morning, but then the reduction should be done again and off-line. The same situation holds for an unforeseen observation (e.g. for a "target of opportunity") done in some other spectral range than those calibrated in the afternoon. The observer will be warned not to use more than n set-ups (TBD) in one night, if he wants the pipeline reduction to operate in best conditions.

   Such day-time calibrations are the normal, standard ones. In some special cases, where one wants either to check the wavelength solution through all fibres in the science configuration, or to estimate very precisely the transmission of the fibres in their science configuration, calibrations will be done during the night with the Nasmyth screen.

   FSFF exposures may be done from time to time to measure the relative pixel sensitivity, but this is only a back-up solution. In general, only NFF frames will be used.

   Long "dark" exposures to obtain the *darkstandard* frame (see next chapter) will not be done daily, but only e.g. once a month. This is why they are not listed below.

- **Acquisition:**

  (a) A series of NFF exposures (typically 10, TBD) through all fibres put in the parking position, in order to
    - calibrate the mutual fibre transmissions
    - define the positions of the spectra

    Note that the IOCP should propose a proper set-up procedure, including the optimal exposure time and/or neutral filter density for each spectral range.

  (b) A single ThArNe exposure with optimal SNR (same remark as above applies) **through all fibres** in parking position, including the 5 fibres dedicated to simultaneous calibration (these fibres cannot be put on the plate, but will have to be illuminated at the same time as the others, from their own separated calibration lamps).

    Note that the focus of the spectrograph is expected to be done by measuring the width of the ThArNe lines (see Chapter 5).

- **Processing:** the tables and coefficients of the calibrations are defined anew and become the "current" ones. The previous current tables and coefficients remain available through access to the Instrument database (VLT archive).

  The new tables and coefficients are systematically compared with the previous ones, and warnings are issued as soon as a significant difference is found. The exact strategy to be followed remains TBD in the IOCP.

  (a) The NFF frames are combined using a median average which simultaneously eliminates the CRH

  (b) The new localization becomes the current one

  (c) The average NFF spectra are extracted

  (d) The total flux summed over all pixels of each NFF spectrum is computed and compared with the flux from the last previous NFF exposure in order to monitor the fibre transmission

  (e) The wavelength solution for all fibres is computed on the basis of the SEWC and becomes the current one

  Then, in the MEDUSA and IFU modes, the whole procedure should be repeated with the second set of fibres, since the latter will necessarily be used as well during the night.

- **Science and calibration exposures during the night:**

  - **Normal science exposure:**
    * A standard science exposure is taken, with simultaneous λ calibration through 5 fibres
    * The DRS will process the exposure as follows:

    (a) preprocessing

    (b) the localization of the spectra is adjusted (with a limited number of parameters), using the 5 calibration spectra

    (c) Spectra extraction

    (d) the wavelength solution based on the afternoon calibration is adjusted, using the 5 calibration spectra

    (e) the extracted science spectra are FF corrected (for both low and high spatial frequencies), i.e. divided by the average extracted NFF spectra (afternoon calibrations)

– **Science exposure with *in situ* separate wavelength calibration:**

(a) A separate ThArNe exposure (SEWC) through all fibres is taken, but unlike the afternoon exposure, this one makes use of the Nasmyth screen: the fibres are not in the parking position, but "in situ" in their science configuration and are illuminated by the Nasmyth screen. At the same time, the 5 simultaneous calibration fibres are illuminated by their own calibration lamp, in such a way that the exposure level is approximately the same as for the other fibres.

(b) The science exposure (including the simultaneous calibration through 5 fibres) and configuration of the other plate are made

(c) Either of these possibilities is adopted:
- The DRS processes the science frame as above, but instead of using the current wavelength solution, it computes a new one from the ThArNe exposure just taken and applies it. The exact strategy to be adopted regarding the use of the 5 SIWC spectra remains TBD in the Final Design: they can be used in the standard way to adjust the Nasmyth SEWC solution, or just serve as a check, the SEWC solution being used without adjustment if no significant difference is found.
- Another separate ThArNe exposure is taken using the Nasmyth screen, and the DRS uses the average of the wavelength solutions computed on both ThArNe frames to process the scientific exposure. The same remark as above applies, regarding the 5 SIWC spectra.

(d) The coherence of the localizations obtained from the ThArNe frames with the Nasmyth screen on the one hand, and from the 5 SIWC spectra on the other hand, can be tested. The comparison can be made also with the current localization, and a decision as to which localization should be adopted must be made (TBD in the Final Design).

(e) The remaining steps of the processing are carried out as for normal science exposures.

(f) **After this calibration, the current wavelength solution (based on the afternoon calibrations) is adopted again for the following normal science exposures.**

– ***In situ* calibration of the fibre transmission using the Nasmyth screen (MEDUSA mode):**
NFF exposures are taken as in the afternoon, but with the fibres in their science configuration and illuminated by the Nasmyth screen, just before (or after, or both, optionally) the science exposure. In this way, any subtle dependences of the fibre transmission on the fibre position is taken into account. The processing is then the following:

(a) Localization of the spectra using the filtered median of all NFF frames taken with the Nasmyth screen; this localization can be checked using the 5 calibration spectra, and possibly adjusted if needed (TBD in the detailed design).

(b) **Fibre transmission with fibres in the science configuration:** The averaged NFF spectra are extracted.

(c) They are divided by the illumination map of the Nasmyth screen (i.e. a table giving INC(X,Y,x(λ)), the intensity of the incandescent lamp reflected on the screen, and which depends both on position and wavelength; it should be normalized so that its mean value is unity.)

(d) The NFF spectra (which implicitly include the relative transmission curves of the fibres and the transmission of the Nasmyth corrector) are defined for this particular

science exposure. **For the following normal science exposures, the current NFF spectra will be used again**.

3   General reduction in both MEDUSA and ARGUS/IFU mode

The Baseline Data Reduction (BLDR) consists in *removing the instrument's signature from the data*. The output of BLDR is a set of flux and wavelength calibrated sky-subtracted spectra.

It is assumed that all the necessary *registration data* maintained by **Data flow** such as the coordinates and identification of all objects measured, together with the identification of the respective fibres are available.

The processing will be the same in both low (5'000) and high (15'000) resolution modes. We separate the Data Reduction in the *pre-processing* which will apply with a few exceptions to all CCD frames and in the *Extraction and Calibration* with which all science and some calibration exposures will be further processed.

With a few exceptions the MEDUSA, ARGUS and IFU data will be reduced using the same Baseline SW. The SW described in this section applies directly and without exception to the MEDUSA mode. The specific aspects of the ARGUS and IFU data reduction are given in Chapter 4.

Through the whole data flow, the following minimum list of parameters characterizing the objects and the observation has to be transmitted:

(a) object running number

(b) object identification

(c) coordinate α

(d) coordinate δ

(e) epoch of the coordinates

(f) magnitude with its designation (V, R or other)

(g) color index with its designation (B-V, V-R or other) if available, or spectral type (for stars)

(h) object morphology (star-like or extended)

(i) usage of the object:

- MEDUSA object
- IFU object
- Argus object
- UVES object
- sky background sample

2. for IFU and Argus modes: position angle of a reference axis (e.g. the long axis) for each IFU button, or for the Argus array

This list is the minimum input list the observer has to provide for each object. Other items may be included but are not mandatory:

- diameter for extended object
- priority (allows possible rejection of the object on a statistical basis)
- category:
  - objects of a given category should or should not be measured in the same exposure
  - objects in a special category must be included in all exposures of a given area

- forced assignment: a specific fibre (number given) should be used for this object
- reference S/N: If this parameter is present, the object may be referenced for the computation of the exposure time. In such a case this information supersedes the exposure time which must, in any case, be indicated by the observer. In any case the indicated SNR will be used by the DRS to assess the quality of the data, by comparison with the real SNR obtained.

In addition to these input data, other information must of course be added to them as the data are being processed. Some of these added data are mentioned here, just as examples of essential information which must be kept; that list cannot be exhaustive at this stage and should be rather defined in the IOCP.

- attributed fibre (and spectrum) number
- coordinates α and δ of the field center
- airmass of the field center, and extreme airmasses in the field
- extinction coefficients
- average seeing during the exposure

3.1 Data Pre-processing

The order of steps may depend on the calibration plan and some steps may be merged together for the sake of efficiency. For legibility we adopt the *running* notation where the same name is used through the image pre-processing though the *object* undergoes progressive changes. We also do not show the use of *masks* except where essential for the understanding of the specific step. At each step the resulting parameters are stored as FITS descriptors on the processed object and added to the processing logfile. The following steps of pre-processing will be carried out:

(a) **Get and subtract bias**:
The bias and read-out noise are obtained as the average value of the *overscan* during the data acquisition as

$$bias = bias(x,y) = \overline{object(x,y)}_{overscan\ area}$$

Nevertheless it could be recomputed using a different set of configuration parameters (such as area used, sigma-clipping, number of iterations) during the pre-processing. The bias to be subtracted is a single number accompanied by the standard error.

$$object(x,y) = object(x,y) - bias$$

(b) **Check and subtract the dark current**:
- Check: The dark correction is applied only if the expected dark is significant and if not explicitly required otherwise by the user. (PAR: darkNegligible = 1 ADU)

$$darkexpected = t_{exposure} \cdot nominaldark[ADU/sec] > darknegligible$$

- Subtraction:
The scaled (with exposure time and CCD gain factors) current standard mean dark is subtracted from the current image:

$$object(x,y) = object(x,y) - t_{exposure} \cdot \overline{darkstandard}(x,y)$$

(c) **Bad pixel flagging**

Pixels located using the standard *bad pixel* mask, and pixels affected by the cosmic ray hits will be flagged. The different flagging will be used for each different purpose. The processing software recognizes flagged pixels and implements options to process or not the flagged pixels (keeping them flagged). The initial current mask is set to a standard $badpixel(x, y)$ mask which will be determined during the technical set-up of the detector together with the photometric flat-filed $PHFF(x, y)$:

$$maskko(x, y) = badpixel(x, y)$$

(d) **Cosmic ray detection**

Pixels affected by the cosmic ray hits (CRH) are recognized and flagged. The flagging is implemented in a way to identify the reason of point rejection by value of the mask, while the mask itself will be used as a logical operand (points with value greater than 0 are rejected).

What is proposed here is to clean the 2-d images of their CRH, which has the advantage that the interspectrum region can, then, be used to estimate properly the scattered light. In any case the CRH will be removed during the extraction, but this is a way to clean only the extracted 1-d spectra, not the 2-d images.

Two methods will be implemented with the option to use one of them or both combined

- **Single image detection: FSFF spectrum, or NFF spectra in the MEDUSA mode**

  It will localize CRH using the data of the current image and based on local estimates (operators $\mathcal{VS}$) of pixel value and standard error.

  $$[estimateobject(x, y), estimatesigmaobject(x, y), image\ statistics] = \mathcal{VS}(object(x, y))$$

  Decision operator $\mathcal{D}$ will produce the mask for the CRH and the current mask will be updated. An example of $\mathcal{D}$ could be to accept points within a few local sigmas.

  $$maskcrh(x, y) = \mathcal{D}(estimateobject(x, y), estimatesigmaobject(x, y), parameters)$$

  $$maskko(x, y) = maskko(x, y) \cup maskcrh(x, y)$$

  Note that *parameters* may include image statistics (see RD4, pp. 46-47). The FF spectra in the MEDUSA mode are smooth in the dispersion direction and well sampled enough in the direction perpendicular to it to allow a local operator to work correctly. Wavelength calibration spectra contain emission lines which may be confused with cosmic rays

- **Detection using several images taken in the same configuration: FSFF spectrum, or NFF spectra in the MEDUSA mode; NFF spectra in the IFU-Argus mode**

  The detection and suppression of the CRH is made simultaneously with the computation of an average image. The latter is computed by attributing to each of its pixels the median value of all images for this particular pixel. Then the individual images are scaled in intensity by computing their differences from the average image, and by performing a linear LSQ fit between the differences and the average intensities. The points lying farther than some threshold TBD from the regression line are rejected, and the whole process is iterated once or more (TBD). This is equivalent to a scaling by integrated

flux, but it could be generalized to a localized flux scaling. Furthermore, this method may be applied to any set of frames, whether they have been bias and dark subtracted or not. Since the frames are obtained in rapid succession, no significant instrumental drift has occurred between the first and the last exposure, which is true to better than $1/100$ of the resolution element in the x direction and to better than $1/200$ of the fibre projection in the y direction, i.e. 0.02 pixels or 0.3 μm, assuming the whole duration of all exposures will be less than half an hour (AD1). This means that the PSF will not be displaced by more than one percent of the FWHM, which is negligible.

(e) **Replace the flagged pixels (optional)**

Flagged pixels could be optionally replaced by the estimated value. This operation is implemented at various stages of the data reduction and could be merged with the previous step.

$$object(x,y) = maskkobin(x,y) * estimateobject(x,y) \cup (1 - maskkobin(x,y)) * object(x,y)$$

where

$$maskkobin(x,y) = maskko(x,y) \quad \text{if} \quad maskko(x,y) = 0$$

$$= 1 \qquad \qquad \text{if} \quad maskko(x,y) \geq 1$$

(f) **Adjust the scattered light**

The scattered light, unlike the light-pollution due to the cross-talk, does not follow the general wavelength equation, therefore the spectroscopic flat-field does not help in its removal. The separate modeling uses the portion of the image where the scattered light is the only possible source (or after the subtraction of all light from other sources). Such locations could be in practice difficult to find and an iterative reduction may be the only possible way to get around. It is therefore one of the important optical constraints to the design of the spectrograph to efficiently eliminate the scattered light. In many cases, the scattered light could be neglected and this is the reason why this and following steps are optional.

The contribution due to the adjacent spectra to the light in the interspectra region could be negligible only in the MEDUSA mode, so that only in this mode can the interspectrum regions be representative of the scattered light. In the IFU-Argus mode, the scattered light will have to be determined by iterations simultaneously with the extraction of the spectra, thanks to a very good knowledge of the PSF

Nevertheless, there will be wider interspectra regions between sub-slits (every 21 or 22 spectra) in the IFU-Argus mode, so that a method similar to that used for MEDUSA could also be used for IFU-Argus. The only difference is that the sampling of the SL will be much coarser in the IFU-Argus mode than in MEDUSA, since only the regions between sub-slits will be used.

The complete discussion of the IFU-Argus case is in Section 4

We fit the parameters of an analytical model of a smooth spatial distribution of the scattered light (SLM, form TBD) using the data in inter-spectra regions $[x_{is}, y_{is}]$ where the contamination by the cross-talk is negligible. The model may be of the form

$$slm(x,y) = \sum_{i,j} c_{ij} x^i y^j$$

or

$$slm(x, y) = \frac{\sum_{i,j} a_{ij} x^i y^j}{\sum_{m,n} b_{mn} x^m y^n}$$

The only difference between the above method, where the SL is subtracted during the pre-processing, and the extraction with simultaneous modeling of the SL, is that in the former, the SL model is a *continuous* function in both directions while in the latter, it is continuous only in the direction perpendicular to dispersion. If the SL is determined simultaneously with the extraction process, then removal of the scattered light will be excluded from the "preprocessing" stage. If the SL is removed during the preprocessing, then the background fitted during the extraction (Equ. 1) should be close to zero; this is a useful check.

Optionally, the model may be built on the photometrically flat-fielded scattered light. This will be used if the detector uniformity is not good enough. It will require the uniformity calibration flat-fields of the detector $PHFF(x, y)$ in all passbands used.

$$object(x_{is}, y_{is}) \langle / PHFF(x_{is}, y_{is}) \rangle = scatter.model(x_{is}, y_{is}, parameters)$$

Then the full image of the scattered light is constructed from the model with, optionally, the transform back to the unflatfielded image.

$$scatter(x, y) = scatter.model(x, y) \langle * PHFF(x, y) \rangle$$

Note that we do not account for ghosts due to optical reflections or secondary orders (TBC optical group). In principle during a second optional iteration it could be possible to construct the SLM from the FF exposures taken through single individual fibres and first iteration reduced spectra but this will probably be an overkill.

This and following steps should be carried out before the spectroscopic FF since the FF correction includes both the non-uniformity and wavelength dependence of the detector response.

(g) **Remove the scattered light**

The SLM is subtracted from the current image.

$$object(x, y) = object(x, y) - scatter(x, y)$$

(h) **Back-up option, not performed in the standard reduction: Spectroscopic FF correction for pixel-to-pixel sensitivity**

The current image is divided by the normalized map of pixel sensitivity obtained from the Full Slit Flat-Field.

$$object_{FF}(x, y) = object(x, y) / FSFF(x, y)$$

Note that slow variation of the CCD, spectrograph and fibre response is not removed in this process.

Here ends the preprocessing which will give for each processed image the following data:

- $object(x, y)$ - zero subtracted raw image (optionally corrected for high FF frequencies)
- $maskko(x, y)$ - mask with bad pixels set to value > 0

3.2 Localization and Extraction

(a) **Localization of spectra using the NFF (Calibration)**

Since the long-term set-up repeatability is within 3 pixels in the direction perpendicular to dispersion, (see AD1, subsection 3.2.1.3, p. 16, point 5) the localization will start from a set of preliminary parameters which are already close to the final values. The localization will therefore be very robust. For the case of unknown preliminary position, problems encountered, or for test purposes, a user-assisted localization will be available.

The most recent NFF exposure using the same set-up is used. The NFF exposure is necessary to determine the position of the spectra at least to a first approximation, because the SNR must be good, and in most cases the science exposures will lack homogeneity to be used for this purpose. Even the SNR of a well exposed science spectrum will not be high at all wavelengths (consider e.g. the case of planetary nebulae, the flux of which is important only in a few emission lines); it will surely be rather low in the case of the 20 sky spectra. The five spectra of the calibration lamp made simultaneously with the science spectra are not the best solution for defining the exact location of all spectra because of their small number; furthermore, there are only very few lines in some wavelength ranges, especially in the deep red. But these calibration spectra may be used to determine a shift between the location deduced from the NFF and the real one. When using the NFF exposure we rely first on the short term set-up repeatability of the spectrograph (which is better than 0.3 pixels in the y direction on time scales shorter than one day, see AD1), but we can adjust more precisely the localization using the 5 calibration spectra.

The accurate positions and shapes of all spectra on the CCD detector is determined as follows:

- Get the preliminary localization.
  The approximate localization mask defining the region to be used for the precise localization is defined. The mask is computed through the analytical expressions

$$\{y_c = \mathcal{Y}(x, y_n)\}$$

  and

$$\{w_y = \mathcal{W}(x, y_n)\}$$

  based on the spectrograph optical design (y_n is the position of the center of the nth spectrum along the y axis). $\mathcal{Y}(x, y_n)$ is the function giving the mean y position of the nth spectrum as a function of x, while $\mathcal{W}(x, y_n)$ is the spectrum half-width at that position. The latter is assumed to be slowly varying along the x and y directions, and the $\mathcal{W}(x, y_n)$ function will probably have to be determined empirically because it is difficult to predict it on the basis of the optical design. If necessary, a few parameters may be left free for the preliminary technical adjustment. Each $maskloc(x, y)_n$ is set to unity for

$$x, \ y \text{ such as that } \mathcal{Y}(x, y_n) - \mathcal{W}(x, y_n) \leq y \leq \mathcal{Y}(x, y_n) + \mathcal{W}(x, y_n)$$

  Note, that though for clarity the $maskloc(x, y)_n$ is mathematically the matrix of the full-size image, technically it will be implemented as a small object containing only the strip with one spectrum and localized through the image *ydirection* offset (world coordinates).

- Get the y position of the centroid yc_n in each x element of each spectrum n (according to $maskloc(x, y)_n$); only the significant points (i.e. those with a SNR larger than some critical limit) are retained here.

$$\{yc_n(x)\} = \frac{\sum_y y \cdot maskloc(x,y)_n \cdot NFF(x,y)}{\sum_y maskloc(x,y)_n \cdot NFF(x,y)}$$

- Get the y-half-width $yw_n(x)$ in each x element of each spectrum n (according to $maskloc(x,y)_n$).
  In order to improve the SNR for faint exposures (simplified localization on science exposure), this step could be carried on several spectral elements at once, using either the 2-D PSF or the X-direction *extruded* (i.e. the 1-D Y-direction profile replicated along the X-axis) 1-D PSF.
  This step is optional and may be skipped. If so, the standard half-width obtained from the PSF will be used.
  The profile in the direction perpendicular to dispersion will be parameterized using the optical design TBD, during the early stage of Giraffe laboratory calibration. We expect that the *half-width* will be the only free parameter that will require the adjustment. It will be done by LSQ fit to the profile function. Technically, the centroid and half-width adjustment could be done in a single step. In the absence of precise specifications, a standard PSF, yet TBD, will be fitted.

$$\{yw_n(x)\} = TBD$$

- In order to insure the continuity of the localization solution we LSQ fit the parameterized optical models $\mathcal{Y}(x,y_n)$ on $\{yc_n(x)\}$ and $\mathcal{W}(x,y_n)$ on $\{yw_n(x)\}$ (for the model see for example Baranne et al. 1996[6]).
  Unfortunately, the $\mathcal{W}(x,y_n)$ function cannot be continuous in y_n, because of the orientation of the sub-slits which implies a PSF variation within each sub-slit, at least near both ends of the slit (RD6). It will have to be a superposition of a function which is continuous in both x and y_n, and of another function which is continuous in x but discontinuous in y_n (TBD).
  The global parameters valid for all n spectra (allowing to skip one or more spectra) will be preferred to n independent sets of parameters.
  As a result we have fully analytical expressions for both position and profile-half-width in the direction perpendicular to the dispersion.

(b) **Adjustment of the localization using the SIWC spectra**

It will be possible to use the five simultaneous calibration spectra of the science exposure for the localization, both as a check of the current NFF localization or instead of it. In the latter case the profile *half-width* adjustment will be skipped and a standard half-width will be used. Another possibility offered by the simultaneous wavelength calibration is to use the 2-D localization of those 5 spectra to adjust the current full localization (see detailed discussion of how to model a geometrical image transformation in a separate OP document). **This implies that the 5 calibration spectra have to be uniformly distributed on the CCD**.

Using the science spectra themselves might be possible, but not in every case (e.g. emission nebulae with only a few lines), while the calibration spectra are stable and always the same for a given wavelength set-up, so they will provide a good security. This is why using the science spectra as well is probably useless.

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[6]Baranne et al., 1996, *ELODIE: A spectrograph for accurate radial velocity measurements*, Astronomy and Astrophysics Supplement, v.119, p.373-390

(c) **Spectra extraction**

At that stage the spectra are accurately localized through the position $y_c = \mathcal{Y}(n, x)$ and half-width $\mathcal{W}(n, x)$ functions. The model of the complete pre-processed image could be written as a sum of PSFs over all X_{max} spectral elements of all N spectra of the PSFs known through the optical design $PSF_n^{x_c}(x - x_c, y - y_c)$ multiplied by the unknown intensity of the spectral elements $object_n(x_c)$ so that:

$$modelobject(x, y) = bg(x, y) + \sum_{n=1}^{N} \sum_{x_c=1}^{X_{max}} PSF_n^{x_c}(x - x_c, y - y_c) \cdot object_n(x_c) \qquad (1)$$

We completed the expression by the optional residual background of low spatial frequency which can be interpreted as anything between the low frequency noise in the detector electronics and imperfect (or skipped) subtraction of the scattered light. Normally this term should not differ significantly from zero.

For several reasons, however, it is preferable to handle the problem separately for each spectral bin:

- First of all, the user may not want to do the deconvolution in the dispersion direction at that stage. If carried on badly conditioned data it may introduce a systematic error which depends critically on the mismatch between the fitted PSF and the actual (unknown) PSF. It is much better to leave the spectral deconvolution to Data Analysis phase.

- The global deconvolution assumes a perfect removal of the scattered light. Even though there should be very little scattered light (AD3), this may be too optimistic.

- Technically, the *per/bin* solution is much easier to implement and control. Specifically, the rejection and replacement of *bad* pixels which requires iteration is less CPU time consuming since it does not affect all data. In our specific example approximately 1ms of CPU time per x-bin is necessary on the SUN UltraSparc at 270 Mhz.

We assume then, that the shape of the PSF in y direction ($-$ to the dispersion) is well known and described by a set of analytical functions $FY_n(x, y)$ which make use of the parameters supplied by the localization. The image could now be described as a linear combination of FY's multiplying the spectral elements $object_n(x_c)$ which we want to extract:

$$modelobject(x_c, y) = bg(x_c, y) + \sum_{n=1}^{N} object_n(x_c) FY_n(x_c, y - y_c) \qquad (2)$$

The extraction is carried out for each x-bin through the LSQ fit of pre-processed data $object(x_c, y)$ to the equation 2. Each pixel $object(x_c, y)$ is weighted, for the LSQ fit, by the inverse of its variance

$$W(x_c, y) = (object(x_c, y) + RON^2 + N_{dark})^{-1}$$

so that the quantity to be minimized is

$$\chi^2 = \sum_{i=1}^{2048} W(x_c, y_i)(object(x_c, y_i) - modelobject(x_c, y_i))^2$$

In the limiting case of a single, isolated spectrum, this is exactly equivalent to Horne's (1986[7]) optimal extraction. Equation 2 is a generalization to the case where the spectra

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[7]Horne K., 1986, PASP 98, 609

are not strictly independent due to the cross-talk. In addition, the SL has to be determined simultaneously. We assume here that the background – essentially the SL – is a slowly varying function of y:

$$bg_n(x_c, y) = \sum_k a_k(x_c)y^k$$

so that eqn. 2 is a linear system of equations.

This method is well adapted to spectra taken in the Argus and IFU modes where the inter-spectra contamination is severe. In the MEDUSA mode, this method is applicable too, but optionally one can use pure Horne's method, assuming the SL can be reliably measured in the interspectrum region:

$$object_n(x_c) = \frac{\sum_i W_H(x_c, y_i)object(x_c, y_i)/FY_n(x_c, y_i - y_c)}{\sum_i W_H(x_c, y_i)}$$

where the SL has already been subtracted, and

$$W_H(x_c, y_i) = FY_n^2(x_c, y_i - y_c)/\sigma^2(object(x_c, y_i))$$

Simple summation along a virtual slit may also be offered as an option for the MEDUSA mode.

The result of the extraction is a set of uncalibrated spectra $object_n(x)$ (format *packed spectra* - image of size $X.N_{max}$) and optionally:

- $sigma_n(x)$ - standard deviation
- clean.object(x,y) - pre-processed 2-D image with flagged points replaced during the extraction

General remarks on the extraction process:

- **Flagged points:**
  During the extraction, the flagged points are not used for the fit. Since in the extraction step all data are used in a global model, this is the optimal opportunity to replace flagged points in the original image by the modeled points and have at disposal a *cleaned* raw input image. This is normally not necessary since all further processing will be done on the extracted spectra, but it could be useful if the user wants to iterate the extraction process.

- **Point Spread Function:**
  The PSF is a necessary input information which we expect either in the form of coefficients of an analytical function or as a data-cube of the size $N \cdot X_{max} \cdot N_{PSFcoeff}$. This information can be obtained via an engineering simulator before laboratory tests. If the PSF is not given, the rectangular function or Gaussian profile of the half-width determined by the *localization* step will be used.

- **Sigma clipping - point rejection:**
  Possibility to reject points too far from the fitted PSF will be implemented. A specific flavor of Horne's method of optimal extraction (1986[7]) as described in Baranne et al. (1996[8]) will be implemented.

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[8]Baranne et al., 1996, *ELODIE: A spectrograph for accurate radial velocity measurements*, A. & A. Supplement, v.119, p.373-390

- **Error estimate:**
  The standard error σ of the flux at each pixel of the extracted spectrum is estimated during the extraction process and saved. From this, one can compute an internal SNR for each pixel. This provides an independent estimate of the overall error for each spectral element which could be compared to the shot-noise limit. This will be useful at the level of the *Ancillary Analysis*.

- **Flat-fielding:**
  The relative pixel sensitivity is assumed to be uniform enough to make the localization and extraction processes possible. The high spatial frequency component of the inhomogeneities in the relative pixel sensitivity will be treated as a small additional noise in these processes. Nevertheless, the possibility to correct for the high spatial frequency component of the detector non-uniformity *before* the extraction is offered as an option, for the off-line reduction. In general, both high and low spatial frequencies will be corrected for *after* extraction using the NFF frames.

3.3 Wavelength calibration and rebinning

The wavelength calibration operates in two steps which are not necessarily both carried out:

- Get Wavelength Solution $\Lambda(x, y)$ or $\Lambda(x, n)$ which associates a wavelength vector $\lambda_n(x)$ to each raw extracted spectrum $object_n(x)$ in a way that $\lambda_n(x)$ gives the wavelength for the x-th bin of the n-th spectrum

- Carry out rebinning of $object_n(x)$ or $OBJECT_n(x)$ so that the $object_n(\lambda)$ or $OBJECT_n(\lambda)$ is equally spaced in λ

(a) Wavelength Solution
This is a 2-D polynomial expansion of the grating equation in the [x,y] space (or the exact analytical model, TBD).

   i. An initial solution, if no valid current solution exists, is obtained from the optical design, the localization and optionally (technical set-up) the residual initial offset by interactively pointing a few lines.

   ii. A list of lines (based on the FEROS line list, in the case of instrumental calibration) is associated to each source of the calibration spectra (thorium/argon/neon source, sky). We expect that after preliminary set-up, this list will be *cleaned* in order to avoid unnecessary systematic rejections during the step 2(a)iv. The number of lines available is currently being determined.

   iii. A line profile (provisionally Gaussian) is fitted to each line and the $\Lambda(x, y)$ polynomial is adjusted to [x,y] positions. Though the full degree of the polynomial will always be used, the list of fitted coefficients will depend on the calibration spectra used (see below).

   iv. The sigma clipping is implemented to eliminate a few lines which do not fit the model.

   v. Optionally (technical set-up) the control of elimination/iteration will include access to all parameters in order to *tune* the process. We expect, that routinely the Wavelength Solution will be fully automatically adjusted.

   vi. The final Wavelength Solution is checked by computing the cross-correlation between the wavelength-calibrated spectrum and the standard calibration spectrum built from the list of lines of the FEROS spectrograph (O. Stahl, private communication).

(b) Rebin the spectra from x to λ space

Optionally the rebinning will be done to obtain the $OBJECT_n(\lambda)$ spectra using an interpolation method. Since the choice of the best interpolation method may depend on the nature of the data and the scientific objective of the actual observation, several interpolation methods will be implemented (linear, cubic spline, TBD).

The Wavelength Solution could be determined using various sources/methods

- **Separate calibration through all fibres (systematically with UVES, occasionally with GIRAFFE)**: This is normally a day-time calibration but could be, in well justified situations (time overhead), made also during the night time. All parameters of the $\Lambda(x,n)$ polynomial are fitted and the solution becomes the current *standard solution*. Such solution could be used *alone* without the simultaneous calibration for e.g. abundance or rotation analysis, but not for high precision radial velocities. For UVES, this is the only wavelength calibration available. Note that the time overhead in case of 8 fibres of UVES is only moderate.

- **simultaneous calibration on 5 fibres (GIRAFFE only)**: The method as described in the report of Pasquini et al. (1998[9]) is used together with the current *standard solution*. The standard or most recent calibration is used, to fit some parameters of the $\Lambda(x,y)$ polynomial (probably a simple constant shift, TBD) using the simultaneous calibration made in fibres dedicated to the calibration source. Although 5 fibres may appear a rather small number, it should be sufficient. The simultaneous calibration removes all instrumental drift inside the spectrograph and only the relative motion of fibres within the spectrograph slit (in the direction perpendicular to the slit) translates directly in wavelength error. Mechanically, these motions are expected to be negligible, and only very small displacements are expected in the direction along the slit (translating to no more than 0.1 pixel on the CCD). Typically, 5 spectra uniformly distributed on the CCD detector and with at least 20 lines each (see AD2) provide 100 pairs of data points which should suffice to constrain the parameters of a simple geometrical transformation of the actual wavelength solution against the *standard solution*. One may expect, to first order, a combination of a translation, a rotation and a dilatation, the former being linked with optical alignment and the latter with a change of focal length. One can show that these three elementary transformations may be summarized as the combination of a homothety and of a rotation, which involve only 4 parameters: 2 for the coordinates of the center of homothety, 1 for the scale factor and 1 for the rotation angle.

- **simultaneous calibration on the telluric emission lines (in the yellow and red only)**: Conceptually this is just the variant of the simultaneous calibration, where the source of light is the night *sky* instead of calibration lamp. However, since the entrance tips of the 5 fibres dedicated to the SIWC are physically attached to the calibration light-source, the sky fibres are used instead.

  - More than 5 fibres could be used (GIRAFFE) for the wavelength calibration
  - A crude SIWC could be implemented also for UVES using 1-2 out of 8 fibres

  In the red, we may use directly the telluric emission lines in the sky spectra to make a good wavelength calibration (Osterbrock et al. 1996, 1997). We are limited to wavelengths above 5200Å and there are very few lines below 5860Å. In the red, depending on the precise

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[9]L. Pasquini, G. Avila, B. Delabre, H. Kostlowski, G. Hess, J.L. Lizon,S. Moreau, *WIDE Field Fibre Facility (WF[3])* *GIRAFFE Fibre System and Spectrograph*, March 31, 1998

wavelength range used, it may be possible to do a complete calibration on the basis of telluric lines using the ~ 20 sky spectra. This will not be possible in all wavelength ranges, nor for any exposure time, since high SNR sky lines will show up only in long exposures. But in the latter cases, the SIWC obtained from the sky lines may well prove superior to that provided by the calibration lamp, which display only very few intense lines in some red domains. In many cases, however – according to the wavelength range, and especially when the exposure time is not very long – the emission sky lines will allow to adjust only the zero point of the wavelength calibration; then, the simultaneous instrumental calibration through 5 fibres will remain useless to provide a check of the stability of all coefficients of the dispersion function. Of course the instrumental SIWC remains strictly necessary in the blue, green and yellow where no important telluric line is present.

3.4   Correction for the blaze function, individual fibre transmission and CCD spectral response-Flux Calibration

In this step the extracted spectra are corrected for spectrograph and detector response, as well as for individual fibre transmission. The high-frequency correction is applied at this step. Both scientific spectra and calibration Narrow Flat-Fields $(nff(x, y))$ have been pre-processed in the same way and therefore both are sets of uncalibrated spectra. The extracted spectra could be written:

$$object_n(x) = OBJECT_n(x(\lambda)) \cdot Tfibre_n(x(\lambda)) \cdot Tspectro(x(\lambda)) \cdot QE_n(x)$$

$$nff_n(x) = NFF(x(\lambda)) \cdot Tfibre_n(x(\lambda)) \cdot Tspectro(x(\lambda)) \cdot QE_n(x)$$

Note that the $NFF(x(\lambda))$ is considered as unique (independent of n), which assumes the uniform illumination of all fibres during the calibration exposure. If it is not the case, it should be written $NFF_n(x(\lambda))$.

The ratio of the two equations above gives the Flux-calibrated input spectra $OBJECT_n(x(\lambda))$ modulated by the spectrum of the calibration source

$$\frac{object_n(x)}{nff_n(x)} = \frac{OBJECT_n(x(\lambda))}{NFF(x(\lambda))}$$

Optionally, fibre-position-dependent $TRELfibre_n(X, Y, x(\lambda))$ correction which takes into account the relative variation of the individual fibre transmission when moved over the [X,Y] focal plane could be applied. The above equations then become:

$$object_n(x) = OBJECT_n(x(\lambda)) \cdot Tfibre_n(x(\lambda)) \cdot TRELfibre_n(X_{obj}, Y_{obj}, x(\lambda)) \cdot Tspectro(x(\lambda)) \cdot QE_n(x)$$

$$nff_n(x) = NFF(x(\lambda)) \cdot Tfibre_n(x(\lambda)) \cdot TRELfibre_n(X_{nff}, Y_{nff}, x(\lambda)) \cdot Tspectro(x(\lambda)) \cdot QE_n(x)$$

And the ratio obtained is more complex:

$$\frac{object_n(x) \cdot TRELfibre_n(X_{nff}, Y_{nff}, x(\lambda))}{nff_n(x) \cdot TRELfibre_n(X_{obj}, Y_{obj}, x(\lambda))} = \frac{OBJECT_n(x(\lambda))}{NFF(x(\lambda))}$$

Note that the calibration work necessary to measure and monitor such corrections accurately enough may require a substantial effort (TBD Calibration Plan). Normally, since the nff spectra will be taken in the nominal parking position, we expect that $TRELfibre_n(X_{nff}, Y_{nff}) \equiv 1$

3.5 Sky modeling and subtraction

3.5.1 Build a model of the sky spectrum in the wavelength space

This step is crucial for faint objects. Note that the accuracy of the subtraction is fully dependent on the accuracy of the measurement and stability of the fibre transmission.

In order to be able to directly subtract an extracted sky spectrum from an extracted object spectrum, one has to assume that both are strictly comparable. In reality, this is not granted, essentially because the PSF, and therefore the resolution, varies according to the position on the detector. This effect may be very important, especially for the sky emission lines, as experienced by Viton & Milliard[10] in the case of the Norris multifibre spectrograph attached to the Hale 5m telescope. Indeed, the center of an emission line will be more intense in the case of a narrow PSF than in the case of a broad one, while the wings of the same line will give a smaller flux, at a given pixel, for the narrow PSF than for the broad one. So, if the FWHM or shape of the PSF varies not only as a function of wavelength but also as a function of x, y (i.e. spectra position on the CCD) then one cannot subtract the sky spectrum directly.

There are two possible remedies to the above problems:

(a) Knowing how the PSF varies along each of the spectra, degrade the resolution of all spectra in such a way that the resolution of all spectra is the same, though varying with wavelength.

(b) Adopt a method similar to that of Viton & Milliard (1999). All sky spectra are extracted and rebinned to a constant wavelength step. To each spectrum, a mean y position is associated. Then, for each fixed x an independent polynomial in y is LSQ fitted to the data of all sky spectra. This method has the advantage to maintain the original spectral resolution (except for problems linked with the rebinning), but it assumes that the PSF varies in a continuous way with the position on the CCD. This method also rests on the assumption that the sky spectrum does not depend on the **X, Y** position in the FoV.

Since in general this is not the case, a preliminary normalization of the spectra to the same integrated intensity will be necessary. The hypothesis then, is that of a constant shape of the energy distribution, the amplitude being allowed to vary.

TBD:

- Can the energy distribution of the sky vary over the FoV?

- Several components with different spatial dependencies ? (e.g. emission sky lines + continuous spectrum of scattered moonlight)

The model of the sky spectrum can only be built in the spaces of flux-and-wavelength calibrated spectrum since a minor mismatch both in intensity or wavelength between the actual object spectra and the sky spectra modeled at the object position could give rise to spurious features on the sky-subtracted object. However, the model built from flux-and-wavelength calibrated spectra could be *de-calibrated* back to the raw extracted spectra and therefore the subtraction itself could be carried out in both flux-and-wavelength calibrated and raw pre-processed data space.

The input data are spectra $SKY_n(\lambda)$ where the index n defines the position $[X_n, Y_n]$ in the focal plane, as well as the running number of the corresponding spectrum on the focal plane. The output data is a model of the sky spectra $SKYMODEL(X_n, Y_n, \lambda)$. We distinguish two cases:

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[10]Viton & Milliard (LAS, Marseille), 1999, private communication

(a) **The sky is smoothly varying over the FoV**

The output sky model $SKY(\lambda, X, Y)$ should have the following properties:

- Be continuous in λ in a similar way the sky spectra are.
- Vary smoothly with the position $[X, Y]$ within the FoV.
- Provide optionally the check to enable the rejection of ill-conditioned or locally anomalous $SKY_n(\lambda)$

The first property implies, as remarked above, that the sky model must take into account the variation of the PSF, hence of the resolution, as a function of both λ and y (y being the mean position of the spectrum on the CCD). Therefore, the model must take into account not only the position of the spectrum on the CCD, but also the corresponding spatial position in the FoV. To take into account these two aspects, the following steps must be carried out:

Flux normalization

i. Each sky spectrum is corrected for the light distribution in the FoV (Nasmyth corrector); we assume that there is no vignetting in the FoV.

ii. Each sky spectrum is corrected for the relative fibre response, in order to make its overall amplitude comparable to the others.

iii. The integrated light is computed for each flux calibrated sky spectrum

$$\mathbf{INTSKY}_n = \int_{\lambda_{min}}^{\lambda_{max}} \mathbf{sky}_n(\lambda)d\lambda$$

where λ_{min} and λ_{max} are the borders of the wavelength range

iv. Each corrected sky spectrum is normalized so that its integrated intensity is unity:

$$\mathbf{NORMSKY}_n(\lambda) = \frac{\mathbf{sky}_n(\lambda)}{\mathbf{INTSKY}_n}$$

This step will allow to interpolate the sky spectra in the y direction on the CCD detector for each spectral element of the x axis, in order to remove the differential effects of a PSF which varies along the spectra.

Sky modeling

i. A model is fitted to the integrated sky intensities obtained, $intsky_n$, using by default a 2-d polynomial form:

$$FITINTSKY(X, Y) = \sum_{i,j=0}^{I,J} sint_{ij} X^i Y^j$$

where I and J are the polynomial degrees adjusted automatically depending on the number of sky fibres and significance of coefficients, and $sint_{ij}$ are the fitted coefficients. This fitted model provides a continuous description of the sky spectra all over the field. Alternatively, other models can be used, applicable to a specific spatial variation of the sky, such as the cases of axial symmetry (R-defendant law) or of de Vaucouleur's law ($I = I_0 \exp\left[-kr^{0.25}\right]$, e.g. in the case of globular clusters around an elliptical galaxy). At the level of the BLDRS, it is irrelevant to foresee any interactivity: the system is expected to go through the pipeline without human intervention. On the other hand, one may provide options which will be decided upon by the observer at the level of the P2PP: if a special form of spatial dependency is needed, it may be provided by the observer at the P2PP.

ii. The residuals are computed, and the sky intensity – or intensities – which differs by more than $3\,\sigma$ from the fitted function is excluded and the fit is iterated.

PSF correction: implementation of the Viton-Milliard method, assuming the PSF to be a continuous function of y (probably sufficient for MEDUSA):

i. In this step, the flux normalized sky spectrum is corrected for the PSF variation of extracted spectra: for each spectral element (pixel) on the λ axis, a 1-d polynomial in y is fitted to the normalized sky spectra **NORMSKY**$_n$. The polynomial fit is constrained in a way to take into account the known properties of the PSF variation and the level of the signal. This initial knowledge could be based on SEWC frames, for both MEDUSA and IFU/Argus modes. The result may be written as

$$NORMCSKY_n(\lambda) = \sum_{k=1}^{K} snor_k(\lambda)y_n^k$$

where K will be small and where $snor_k(\lambda)$ are the fitted coefficients. $NORMCSKY_n(\lambda)$, then, can be compared with any object spectrum lying at the position y on the CCD, except for the amplitude which is defined in the following step.

ii. **Back transformation to the original intensity:**
The amplitude of the PSF corrected sky is then transformed back to the original intensity using the model defined in step 2(a)i:

$$SKYMODEL(X_n, Y_n, \lambda) = NORMCSKY_n(\lambda) \times FITINTSKY(X, Y)$$

PSF correction: implementation of a modified Viton-Milliard method, taking into account a discontinuous PSF variation (probably necessary for IFU-Argus):

Since the PSF does not vary smoothly on the whole y axis, but only on small portions of it corresponding to the size of the sub-slits, the Viton-Milliard method cannot be applied as such when the PSF of the spectrograph alone is not much smaller than the image of the fibre. Indeed, there is only one sky fibre per sub-slit in the IFU-Argus mode, and it lies at an extremity of it; so a fit of a low-degree polynomial in y cannot make sense for all spectra, but only for those corresponding to fibres lying at the center of each sub-slit (the only ones which are exactly on the focal surface).

The modified method we propose is the following:

i. Just like in the original method, we use the normalized sky spectra, and fit them at each λ value by a 1-d polynomial. But instead of using y as the independent variable, we adopt the width of the PSF along the dispersion direction (as given by the SEWC spectra):

$$NORMCSKY_n(\lambda) = \sum_{k=1}^{K} snormodif_k(\lambda)width_n^k(\lambda)$$

where $snormodif_k(\lambda)$ are the fitted coefficients and $width_n(\lambda)$ is the width of the PSF

(b) **The sky is strongly heterogeneous over the FoV:**
We mean here the *astronomical* sky, linked with e.g. emission or diffusion nebulae, or continuous but strongly irregular stellar background. This is the worst case, where the only way to subtract the sky is to measure it close to every object. Up to half of the fibres (excluding

those possibly dedicated to simultaneous wavelength calibration) should then be dedicated to the sky measurement. Each object spectrum will have an associated sky spectrum.

In this case, only the flux normalization and PSF correction above are performed, since sky modeling is skipped, while the last point may be written

$$SKYMODEL(X_n, Y_n, \lambda) = NORMCSKY_n(\lambda) \times INTSKY_m(X_m, Y_m)$$

where m and n are such that

$$\sqrt{(X_m - X_n)^2 + (Y_m - Y_n)^2} = Min(\sqrt{(X_i - X_j)^2 + (Y_i - Y_j)^2}), \vee i \neq j$$

The cases 2a and 2b may be mixed: we build a model of sky after rejection of the strongly deviant measurements and consider it as valid for all objects, except those which lie very close to the rejected skies.

3. **subtract the model sky spectrum** from all object spectra

The subtraction could be made both in the spaces of flux-and-wavelength calibrated spectra $OBJECT_n(\lambda)$ or in the space of raw extracted spectra $object_n(x)$ (the user may not want to go through the flux calibration for faint objects). In the first case, the model is subtracted directly:

$$OBJECT_n(\lambda) = OBJECT_n(\lambda) - SKYMODEL(X_n, Y_n, \lambda)$$

In the second case, the SKY model must be rebinned back from λ to x space and transformed from the flux calibrated $SKYMODEL(X_n, Y_n, x)$ to the raw extracted $skymodel(X_n, Y_n, x)$. Optionally the position-dependent fibre transmission $TRELfibre_n(X, Y, x(\lambda))$ could be taken into account.

$$objet_n(x) = objet_n(x) - SKYMODEL(X_n, Y_n, x) \cdot \frac{nff_{n_{sky}}(x)}{NFF(x)} \cdot \langle \frac{TRELfibre_n(X_{sky}, Y_{sky}, x(\lambda))}{TRELfibre_n(X_{nff}, Y_{nff}, x(\lambda))} \rangle$$

Each object spectrum is then correlated with the corresponding sky model spectrum. If a significant correlation for a zero shift is seen, either in absorption or in emission, it means that the sky subtraction process was not completely successful.

3.6   Flux spectrophotometric calibration

The main issue here is the accuracy of the knowledge of the actual PSF of the optical image on the fibre entrance in the focal plane. In the first approximation the standard PSF provided by the guiding probe could be used, but the position relative to the fibre axis is known only within the accuracy given by specifications (TBD). Typically with the seeing of FWHM=0.7" and the fibre collection diameter of 1" the decentering of 0.25" generates an extra loss of 25% of the flux collected with the centered image. Obviously any spectrophotometric calibration is excluded if no information on the actual PSF and centering of individual object is available. We therefore consider that this topic concerns only the IFU mode, and postpone the discussion to Section 4.

4   Specific aspects of the data reduction in Argus-IFU modes

4.1   Data Pre-processing

Most of the data pre-processing will be identical to the one described in 3.1. The exceptions follow from:

1. Smaller inter-spectra gap because of the larger number of spectra on the same detector (308 for ARGUS, 132 for MEDUSA) leading to the poor separation between adjacent spectra.

2. Better spatial sampling on the sky leads to the smaller PSF and therefore lower *redundancy* of the data within a single spectral element.

In general the bias and dark subtraction and bad pixel flagging with optional flagged pixel replacement will not differ. However, for some programs the cosmic ray detection methods described in 3.1.4 may be difficult to apply because of 2. In such a case only the method using the multi-exposure cosmic removal could be efficient.

Because of 1, the adjustment of the scattered light could prove difficult since the pollution of the inter-spectra gap by the PSF and to some extent by the physical fibre cross-talk (TBC by optical group) will be higher than in MEDUSA mode. Two situations could be distinguished:

- The scattered light presents only a diffuse component with smooth variations and its intensity is a function of one variable - the total light entering in the entrance slit (see Lissandrini and Cristiani, 1994[11]) as described for Optopus.

  In this case a small number of pollution-free points available in the large *inter-bundle* gap could be used to build the smooth model of scattered light. The difference, compared to the MEDUSA data reduction resides only in the number and location of points where the scattered light is sampled.

- The scattered light is more complex and the points in the inter-spectra gaps must be taken into account.

  In such a case, in the first step the spectra are extracted from raw pre-processed image assuming a zero-level scattered light, which is therefore included in the background components. We obtain a set of $bg(x_c, y)$ (one function per spectral element) which describes in a discontinuous way the residual light. We use these functions to fit a global model of the scattered light and subtract it from the original raw pre-processed image. The extraction is then repeated on this scattered-light-subtracted image. The operation could be iterated till the noise-level background is achieved.

In both cases the unpolluted FF for a few individual fibres should be available, such as described for MEDUSA mode in 2.3 item 3.

SPECIAL REQUIREMENT: Since the ARGUS and IFU fibre entrance could not be split into individual fibres (as in MEDUSA mode), some provision should be made to make possible the acquisition of FF where only some fibres, mutually distant enough on the slit, are illuminated at once. The minimum requirement will be to provide such an FF through a one-time laboratory calibration, but it is highly desirable to foresee some optical or mechanical arrangement which could be used also during the maintenance at the VLT site.

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[11]Lissandrini C. and Cristiani S., 1994, PASP 106, 1157

4.2   Localization and Extraction

1. **Localization of spectra**

   The positions and shapes of all spectra on the CCD could be determined in the same way as in the MEDUSA mode. However, since the slit geometry differs for MEDUSA, ARGUSes and IFUs, different preliminary localization masks should be used for each slit. This regards both the spectra positions and half-widths.

   Like for scattered light determination, the smaller inter-spectra gap could make the adjustment of the actual PSF difficult.

   SPECIAL REQUIREMENT: In order to obtain the FF with well separated spectra a special FF exposure will be made with illumination of sky fibre of each IFU (one sky fibre per IFU) and five fibres dedicated to the simultaneous wavelength calibration only.

2. **Spectra extraction**

   Due to the lower sampling of the PSF on the CCD device (between 2 and 3 pixels for the FWHM in the y direction) and to the lower inter-spectra distance compared to the MEDUSA mode, the spectra extraction can only be achieved by an LSQ fit with a known PSF model and by varying the intensity.

   The method presented in Chapter 3 par. 3.2 item 2c will be used with all the options proposed and the PSF deduced from the last step.

   Optionally, Horne's method may be used as such even in the Argus-IFU modes by neglecting the cross-talk, especially in cases of low S/N data on extended objects with a low spatial contrast. If the PSF is not very well known (especially its wings), the result may even be better than with Equation 2, which introduces severe biases when the PSF is poorly known.

4.3   Correction for the blaze function, individual fibre transmission and CCD spectral response-Flux Calibration

This step will be specific to the Argus-IFU modes concerning the blaze function correction since the fibre size and therefore the resolutions are not the same as in MEDUSA mode.

Compared to the MEDUSA mode, variation of the fibre transmission with position should be reduced for IFU mode since relative fibre positions within the bundle do not change. For the Argus mode there is no need to monitor the transmission versus the position. Any trend of transmission variation during long time period or for other reasons will be checked from FF exposures.

4.4   Wavelength calibration and rebinning

The same methods and algorithms will be used for searching the wavelength solution and rebinning the spectra. The resolution are not the same as for MEDUSA mode but the difference is not large enough to require different treatment.

4.5   Sky modeling and subtraction

Compared to MEDUSA mode ARGUS and IFU data reduction could be characterized by:

1. Since in both ARGUS and IFU modes independent fibres for sky are available, methods described for MEDUSA apply without restriction.

2. Both ARGUS and IFU modes provide a continuous spatial sampling of the observed region of the sky. Therefore for objects *smaller than the observed field* the local sky could be obtained directly and with better accuracy from the field data.

In case 2 during the data analysis the extra *sky fibres* selected either automatically or after the inspection of the ARGUS/IFU data, will be added to the *sky-dedicated fibres* and then the sky modeling will be done in the standard way described for MEDUSA.

4.6　Flux spectrophotometric calibration

The Flux calibration is done either using spectrophotometric standard star(s) measured simultaneously, or using a model of transmission of atmosphere + telescope (the latter case will probably be far more frequent, since most spectrophotometric standards are relatively bright and would saturate the detector).

In both cases, the actual loss factor due to the PSF for each object $loss_i(\lambda)$ is obtained first. This geometrical loss factor, though low, is not negligible (with a seeing of FWHM=0.7" and decentering of 0.4" of the IFU with the dimension of 2 by 3", several percent of light of a point source are lost, depending on the direction of decentering). To obtain the PSF corrected flux of a point source, the flux-and-wavelength calibrated spectra of each IFU should be summed over I IFU fibres and multiplied by the loss factor

$$OBJECT_i(\lambda) = loss_i(\lambda) \cdot \sum_{n=N1_i}^{N2_i} OBJECT_n(\lambda)$$

where $loss_i(\lambda) > 1$. Then the PSF corrected fluxes should be calibrated using the source which apply.

- **spectrophotometric standard:**

  The ratio of absolute fluxes $ABSOLUTE.SPST(\lambda)$ over the observed ones $SPST(\lambda)$ is computed for one (or possibly several) spectrophotometric standard star, taking into account the airmass $M(z)$.

  $$RABS(\lambda) = \frac{ABSOLUTE.SPST(\lambda)}{SPST(\lambda)} \cdot e^{-\kappa(\lambda)M(z)}$$

  where z is the zenital distance and $\kappa(\lambda)$ is the atmospheric absorption coefficient.

  Then all observed fluxes are multiplied by this ratio, which should essentially reflect the atmospheric and telescope transmission, since the correction for the overall fibre and spectrograph sensitivity has already been applied.

  $$OBJECT_i(\lambda) = OBJECT_i(\lambda) \cdot RABS(\lambda) \cdot e^{\kappa(\lambda)M(z_i)}$$

- **no standard available:**

  The calibration lamp then plays the role of the standard star. Since we already took the absolute spectrum of the calibration source into account during the calibration step 3.4, only the atmosphere $e^{-\kappa(\lambda)M(z)}$ and Telescope transmission models $TRANSVLT(\lambda)$ should be included so that

  $$OBJECT_i(\lambda) = \frac{OBJECT_i(\lambda)}{TRANSVLT(\lambda)} \cdot e^{\kappa(\lambda)M(z_i)}$$

  External data required:

  - Atmospheric transmission updated by the extinction monitor (TBC ESO)
  - telescope transmission as a function of wavelength

4.7 Image reconstruction, visualization and analysis

Image reconstruction is specific to the Argus and IFU modes only; but in the MEDUSA mode and after the pipeline reduction is finished, it will be possible to visualize the observed field and get the observed spectrum by a click on the corresponding object. In Argus and IFU modes, a standard image reconstruction is implemented within the pipeline (using the flux integrated either on the whole wavelength range observed, or on a range specified in advance by the observer).

4.7.1 Data format

This is relevant both for Argus and IFU observations for which data products after baseline reduction (in the pipeline) will be datacubes. For each exposure in the IFU and Argus mode, a table will give the correspondence between the fibre number on the slit and two spatial coordinates (the position of the corresponding fibre on the sky in α, δ or on the focal plane in X, Y). This table will allow to build a data-cube by arranging the data-set into a 3-D matrix with two spatial dimensions (α and δ or X and Y), the third dimension being the wavelength. The only difference is the output format for the two spatial coordinates X and Y:

- for Argus mode, the X size will be 22 pixels and the Y size 14 pixels since the Argus array is included in a rectangle of 22×14 channels with two channels removed at each of the four corners. Each exposure will give one datacube.

- for IFUs mode, the X size will be 6 pixels and the Y size 4 pixels since an IFU array is included in a rectangle of 6×4 pixels with one channel removed at each of the four corners. Each exposure will give 15 independent datacubes (one per IFU).

4.7.2 Visualization and analysis

The global field visualization for IFU mode will be possible, as well as for the Medusa mode, considering IFU object positions only.

After obtaining the datacube, the integral of the flux in a given wavelength interval will be computed for all spectra. This 2-D image will be displayed and called a reconstructed image. Tools like centroid determination and PSF fitting after window specification, will allow centering verification and image quality analysis.

5   Validation of the reduction, quality control

5.1   Quality control

Virtually all reduction steps return parameters that could be used for the quality control. At each step of the data processing, some quality control is foreseen. It consists in comparing the results with what is expected from nominal parameters in Instrument database (VLT archive). We expect that such nominal parameters will be provided as a FITS KWs with the data frames.

The quality control level 0 (QC0) is a part of the normal data reduction processing. This is done for all processed frames including the science frames in the DFS pipeline. With the exception of the FF calibration exposures, any GIRAFFE frame includes 5 optimally exposed spectra used for the simultaneous wavelength calibration. This is the exceptional opportunity for a full check of the actual instrument performances compared to the nominal ones:

1. read-out noise, CCD offset and average dark

2. number of cosmic hits and detector defects

3. proportion of the scattered light

4. spectra localization stability

5. instrument throughput (integrated light per spectrum/calibration illumination)

6. wavelength solution stability and spectral resolution

The quality control level 1 (QC1) detecting trends and producing the average certified calibration data should be done using the access to the Instrument database (VLT Archive) in the of-line version of the BLDRS.