Manual

4MOST User Manual

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1 Scope

This document describes the 4MOST instrument performance as well as how to use the 4MOST facility. It is intended for all actual or potential users of 4MOST, i.e. participating and non-participating surveys.

4MOST operations are differently organised than most other ESO instruments. The survey nature and high multiplex capabilities are most efficiently used if observing strategy and data reduction are handled jointly and not by each observing program separately. ESO has entrusted the 4MOST Consortium to, under ESO's supervision, prepare the observations for all participating surveys and to perform the data reduction to remove the instrumental profile of all observations.

Note that at the time of writing of the current version of this document, some of the necessary tools are still in development (e.g. Exposure Time Calculator) and thus the document is inherently not final yet.

2 Applicable Documents (AD)

The following applicable documents (AD) of the exact issue shown form a part of this document to the extent described herein. In the event of conflict between the documents referenced herein and the contents of this document, the contents of this document are the superseding requirement.

AD ID	Document Title	Document Number	Issue	Date

3 Reference Documents (RD)

The following reference documents (RD) contain useful information relevant to the subject of the present document.

RD ID	Document Title	Document Number	Issue	Date
[RD1]	Template Reference Manual	MST-MAN-PMO-80500-9850-0001	1.00	2018-03-17

4 Definitions

Term	Definition
Observation block	A set of instructions on actions or a process executed by the instrument and the telescope.
Configuration	A uniquely defined set of fibre allocations within one field. Typically, one configuration is one sub-exposure of one OB, but one configuration can be repeated if needed. The equivalent that is unique in time is called a "sub-exposure of a pointing."
Field	Region of the sky that fits within one 4MOST field of view. It is considered the basic observational unit of 4MOST during science operations. The sky is subdivided into fields for observation planning.
Science fibre	Fibre connecting the Fibre Positioner with a spectrograph.
Simultaneous calibration	Calibration light (spectral) from the Calibration System’s light source fed directly into the spectrograph slits. Therefore, simultaneous calibrations don’t suffer from fibre-tilt induced effects, but can be used to correct for them.
Attached calibration	Calibration exposures (generated by the Calibration System illuminating the telescope pupil) that are taken before or after the science exposure, and allow to correct for tilt-induced shifts of the spectrum on the CCD.
Raw data	Data produced by the execution of Observation Blocks.
Fibre hour	The equivalent of the usage of one fibre for one hour during 4MOST operations, including overheads.

5 Participating and non-participating surveys

Participating Surveys: Such surveys are defined as GTO (i.e., consortium) and community surveys, which share the focal surface (parallel observing mode) and are members of the Science Team. 4MOST is conceived as a survey facility that comprises the instrument as well as associated operations services. The largest fraction of the observing time on 4MOST will be allocated within a unique operations concept in which 5-year Public Surveys from both the consortium and the ESO community will be combined and observed in parallel during each exposure. In parallel observing mode, 4MOST will obtain spectra for many different surveys simultaneously. Parallel observing thus enables efficient use of 4MOST for surveys that have complementary observing conditions requirements and/or a target density lower than the 4MOST multiplexing capability. It also implies that surveys have to agree on a common survey strategy and prepare Observation Blocks (OBs) jointly. As a consequence, Participating Surveys will not explicitly choose the atmospheric conditions under which they wish to observe their targets. Rather, the design of the common survey strategy will be driven by observational success criteria. These could, for example, be requirements on the Signal-to-Noise ratio (S/N) per target, or on the sky area to be covered. An additional consideration is that, due to the nature of multi-object spectrographs, the spectra of targets will partially overlap on the detector (cross-talk between neighbouring fibres on the CCD). This implies that all Participating Surveys have to fully share the raw data as well as the calibrated spectra in order to be able to assess and mitigate the impact of this cross-talk effect on their science. Finally, determining the selection/completeness functions of the surveys depend on the joint observing strategy and will be calculated by a joint working group.

The exposure time used by each survey will be calculated on a per target basis. So each hour 4MOST is used there are ~2400 fibre-hours available, shared between the surveys that use fibres for a particular exposure. In case of target duplicates between participating surveys, fibre-hours are shared between respective surveys proportionally to requested exposure time need for this target.

Non-participating surveys: Such surveys are defined as Community surveys which do not share the focal surface, and must prepare Observation Blocks and deliver higher-level data products themselves. 4MOST has been designed to cover the southern hemisphere in a 5-year survey using a parallel mode of observation, thus enabling surveys that would otherwise not be possible. All Consortium Surveys participate in the parallel mode of observations. Yet, 4MOST is also a very powerful instrument to be used in single survey mode if the target density is sufficiently high. In this mode, special thought has to be given to the use of fibres from both low- and high-resolution spectrographs. Proposing community surveys wishing to use 4MOST in single survey mode are called Non-Participating Surveys. They will not become members of the Science Team, and will not be bound by the Science Team Policies. Their time will be allocated in named nights or half nights to enable accurate planning. The consortium Operations System will deliver the software necessary to produce OBs, which Non-Participating Surveys will run themselves. The consortium Data Management System will deliver Level 1 data products to Non-Participating Surveys through the Operational Repository. Non-participating surveys will not have access to the advanced pipelines developed in the 4MOST Science Team. Non-Participating Surveys will have to produce and upload their own Level 2 products to ESO and calculate their own selection/completeness functions.

Non-participating surveys will be allocated full or half nights and will be "charged" the full ~2400 fibre-hours per hour usage, independent whether all or only a few fibres are used for actual targets. Non-participating surveys may have at maximum a 30% target overlap with any and all surveys, and the exposure time will not be shared with other surveys in the case of these duplicates, as these targets will be observed twice independently.

A separate document, describing in detail how to create Observation Blocks, will be published in time for Phase 2.

6 4MOST characteristics and Sub-systems

This section provides a general description of the 4MOST instrument, main system and subsystems technical specifications.

6.1 General description

4MOST is a wide-field, high-multiplex, fibre-fed spectrograph, which will be mounted on the ESO VISTA telescope (Figure 1: Overview of 4MOST on VISTA) and operated in the ESO Paranal Observatory operation environment. 4MOST will be an ESO instrument. The unique concept of 4MOST operations is that it is being designed to carry out multiple surveys simultaneously. 4MOST will be able to observe competitively large sample sizes for different science programs. Its capability of parallel observing makes it possible to observe surveys which otherwise would be too expensive due to the low density of their targets.

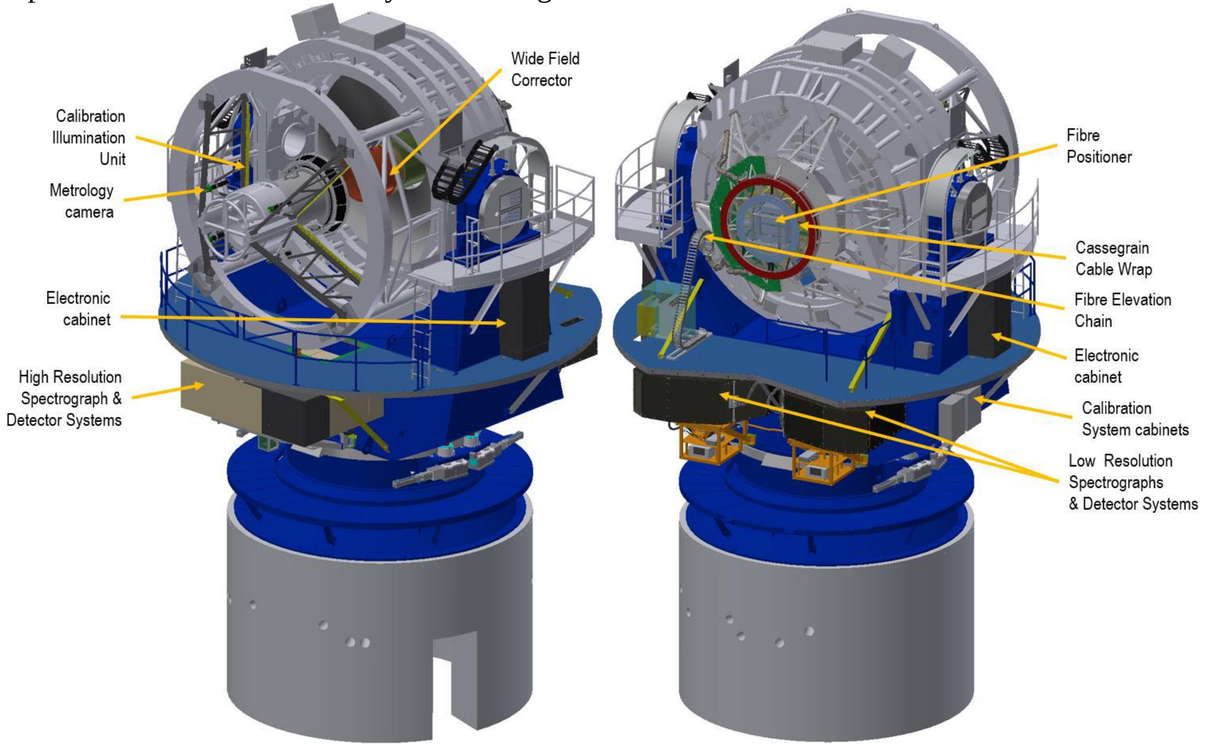

Figure 1: Overview of 4MOST on VISTA

4MOST is being developed to address a broad range of pressing scientific questions in the fields of Galactic archaeology, high-energy astrophysics, galaxy evolution and cosmology. Its design allows tens of millions of spectra to be obtained in a 5-year survey, even for targets distributed over a significant fraction of the sky. The expected lifetime of the instrument is at least 15 years.

While many science cases can be addressed with 4MOST, its design mission is to provide the spectroscopic complements to the large-area surveys coming from key European space missions like Gaia, eROSITA, Euclid and PLATO, and from ground-based facilities like VISTA, VST, DES, LSST and SKA. The first 5 years of 4MOST operations will be used to carry out a pre-approved coordinated GTO program of observations by the 4MOST Consortium. Currently, ten different Consortium Public Surveys are envisaged, taking 70% of the total available fibre-hours. These projects are as follows: Milky Way Halo Surveys (at both low and high spectral resolution); Milky Way Bulge and Disk surveys (at both high and low resolution); a survey of the Magellanic Clouds; an X-ray AGN survey; a Cluster Cosmology Survey; a Cosmology Redshift Survey; a Galaxy Evolution Survey (WAVES), and a Time Domain survey of transients and time-variable sources. The combination of these projects drives both the design of the instrument and the survey strategy, with a goal to provide not only homogenous coverage over very large sky areas (>10^4 deg^2), but also highly complete sampling over smaller specially selected fields. These Consortium surveys will be complemented by a number of "Community" Surveys, which will utilize the remaining 30% of the fibre-hours, and that will have their own science requirements and resultant impacts on survey strategy. Community Survey can be fully integrated together with the 4MOST GTO surveys in a coherent long-term (5-years) program, run and operated by the 4MOST Operations System (OpSys). Alternatively, surveys can be "Non Participating", i.e. these surveys use the 4MOST instrument with all ~2400 fibres for fixed (half-)nights. An adapted mode of operations is foreseen for these Non-Participating Surveys.

6.1.1 Main system technical specifications

The 4MOST instrument design was driven by the science requirements of its key Consortium Surveys. Within a 2 hour observation it has the sensitivity to obtain redshifts of r = 22.5 mag (AB) galaxies and AGN, radial velocities of any Gaia source (G < 20.5 mag (Vega)), stellar parameters and some key elemental abundances with accuracy better than 0.15 dex of G < 18 mag stars, and abundances of up to 15 elements of G < 15.5 mag stars. Furthermore, in a 5-year survey, 4MOST can cover >17,000 deg^2 at least twice and obtain spectra of millions of sources with low (R≈6500) or high (R≈20,000) resolution. The main instrument parameters, enabling these science requirements, are summarized in Table 1.

4MOST will feature a 2.6 degree diameter field-of-view with 2436 science fibres in the focal surface that will be configured by a fibre positioner based on the tilting spine principle. The fibres feed three spectrographs; two thirds of the fibres will go to the low resolution spectrographs, and the remaining 812 fibres to a high resolution spectrograph. Each spectrograph has three channels (red, green, blue). **All three spectrographs are fixed-configuration**.

Parameter	**Design value**
Field of view (hexagon)	>4.2 deg^2 (diameter = 2.6°)
Accessible sky (zenith angle <55°)	>30,000 deg^2
Area density of apertures (# of fibres)	>3 within any circle of 2 arcmin diameter at least 3.5 arcmin from the edge of the FoV

On-sky diameter of aperture	1.45 arcsec circular
Smallest target separation	15 arcsec on any side
Expected on-target fibre-hours per year	LRS: >3,200,000 h/yr, HRS: >1,600,000 h/yr
Multiplex fibre positioner	2436
Operating efficiency (i.e. overheads)	$\leq$ 3.5 minutes for the field acquisition (telescope preset), $\leq$ 4.4 minutes for each science exposure including attached calibrations
(2x) Low Resolution Spectrographs (LRS)	
# Fibres	**812** fibres
Mean sensitivity 6x20min, mean seeing, new moon, *S/N* = 10 Å^{-1} (AB-mag)	400nm: **20.2**$^{\mathbf{m}}$, 500nm: **20.4**$^{\mathbf{m}}$, 600nm: **20.4**$^{\mathbf{m}}$, 700nm: **20.2**$^{\mathbf{m}}$, 800nm: **20.2**$^{\mathbf{m}}$, 900nm: **19.8**$^{\mathbf{m}}$
Spectral resolving power	$R > \lambda*10$ for $400\mathrm{nm} < \lambda < 500\mathrm{nm}$ and $R > 5000$ for $500\mathrm{nm} < \lambda < 885\mathrm{nm}$ (λ = wavelength)
Wavelength range	400-885 nm
Radial velocity calibration accuracy	$\leq$ 1 km/s
Spectral sampling	PSF FWHM $\geq$ 2.5 pixel
(1x) High Resolution Spectrograph (HRS)	
# Fibres	**812** fibres
Mean sensitivity 6x20min, mean seeing, 80% moon, *S/N* = 100 Å^{-1} (AB-mag)	420nm: **15.7**$^{\mathbf{m}}$, 540nm: **15.8**$^{\mathbf{m}}$, 650nm: **15.8**$^{\mathbf{m}}$
Spectral resolving power	$R \geq 18{,}000$
Wavelength range	· 392.6–435.5 nm, · 516–573 nm, · cover 69nm in the 606-681 nm range
Radial velocity calibration accuracy	$\leq$ 1 km/s
Spectral sampling	PSF FWHM $\geq$ 2.5 pixel

Table 1: 4MOST key instrument specifications.

In Table 1, the total throughput for both LRS and HRS includes the throughput from the telescope mirrors to the detectors, i.e. adding fibre-to-target alignment losses, WFC/ADC, coupling efficiency, Fibre Feed and the spectrograph itself.

The expected 4MOST point-source sensitivity is depicted in Figure 2: , for the signal-to-noise per Ångström values and sky conditions indicated in the legend. The solid lines are for a total exposure time of 120 min, whereas the dashed lines are the limits for 20 min exposures. The approximate conversion to *S/N* per pixel is obtained by dividing the HRS values by 3.3 and the LRS numbers by 1.7. For clarity, sky emission lines are removed, which affects results redward of 700 nm mostly. Mean (not median) seeing conditions, airmass values, fibre quality and positioning errors, etc., are used, to ensure that this plot is representative for an entire 4MOST survey, not just for the optimal conditions. Typical science cases for obtaining detailed elemental abundances of stars (orange), stellar parameters and some elemental abundances (dark blue), stellar radial velocities (light blue), and galaxy and AGN redshifts (black: 90% complete / grey: 50% complete) are shown.

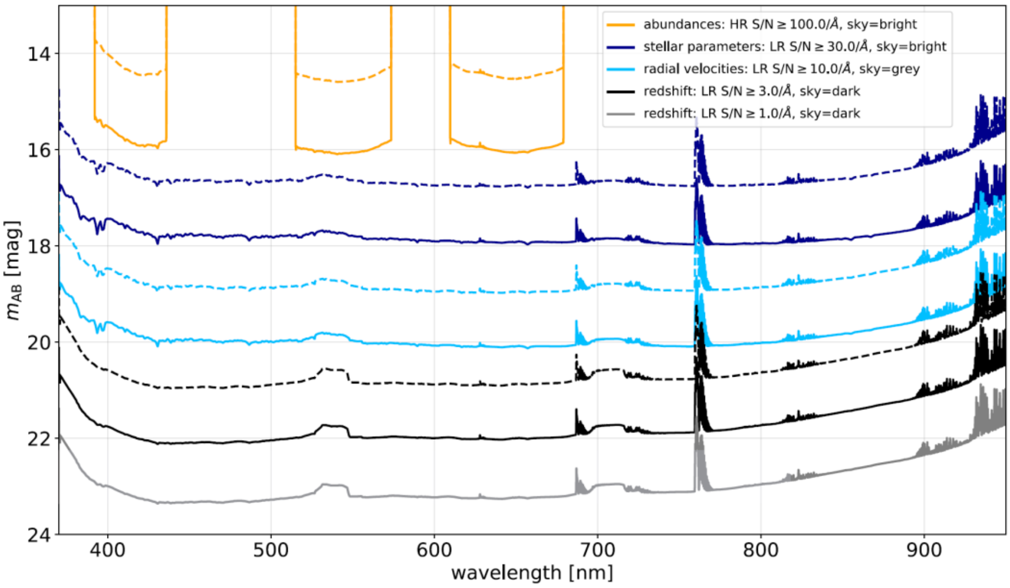

Figure 2: The expected 4MOST point source sensitivities for the signal-to-noise levels and lunar conditions indicated in the legend. The solid lines are for a total exposure time of 120 minutes, whereas the dashed lines are the limits for 20-minute exposures. The approximate conversion to signal-to-noise per pixel is obtained by dividing the HRS values by 3.3 and the LRS values by 1.7. For clarity, sky emission lines are removed — this mostly affects results redward of 7000 Å. Mean (not median) seeing conditions, airmass values, fibre quality and positioning errors, etc., are used, in order to ensure that this plot is representative for an entire 4MOST survey, not just for the optimal conditions.

6.1.2 Subsystems overview

A schematic block diagram of the 4MOST system is presented in Figure 3: 4MOST System Block Diagram. Many of these subsystems, as well as the exposure time, affect the fibre-to-target alignment precision and accuracy. The final fibre-to-target error budget is described in Section 7.6.

The 4MOST system is made of the following subsystems:

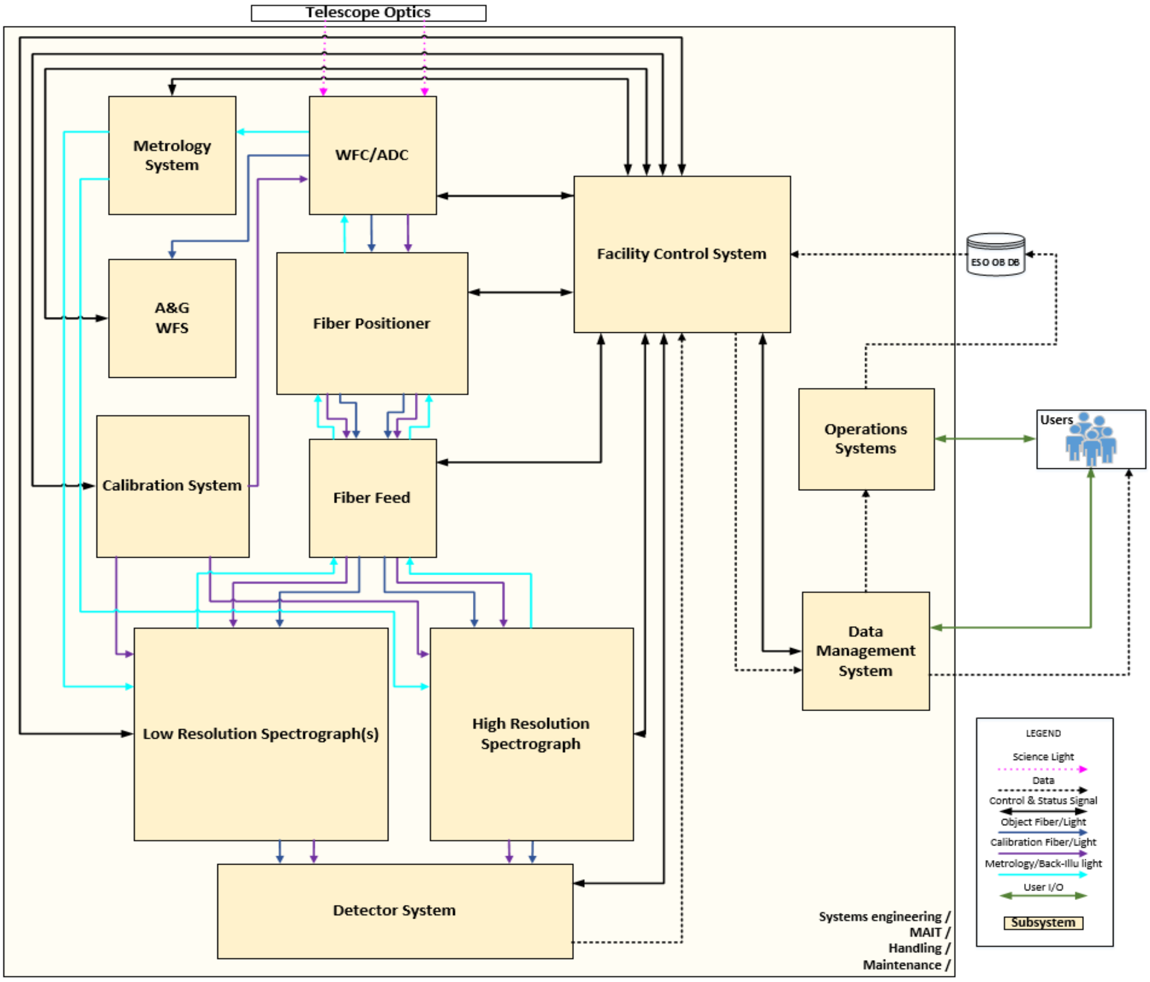

Figure 3: 4MOST System Block Diagram

6.1.2.1 Wide Field Corrector (WFC), with Atmospheric Dispersion Corrector (ADC)

The WFC creates a nearly unvignetted image of 2.6 degrees diameter in the focal surface of the telescope. The ADC corrects for atmospheric dispersion up to 55 degrees zenith distance and hence at larger zenith angles has poorer performance as object light gets dispersed in the focal surface and light at the end of the 4MOST wavelength range may miss the fibre. In simulations, the WFC has a quite homogeneous throughput over the whole field averaging to 84.6%. The plate scale of the WFC is about 59.4µm/arcsec.

6.1.2.2 Acquisition & Guiding (A&G) and Wavefront Sensor system (WFS)

Two A&G cameras will be implemented for redundancy and in order to increase the sky coverage, but only one of them will be active at a time. There are four WFS cameras around the edge of the field of view. Each WFS camera (2048x2048, 13.5µm pixels) will sample a 27.6mm x 27.6mm patch of the field, equivalent to about 7.75´ x 7.75´ (60 arcmin2).

6.1.2.3 Fibre Positioner, AESOP

The AESOP fibre positioning system based on the tilting spine principle can within 2 minutes simultaneously position all the 2436 science fibres that are arranged in a hexagonally shaped grid at the focal surface. The accuracy of fibre positioning is expected to be better than 0.2

arcsec, thanks to the 4-camera metrology system. The tilting spine positioner has the advantage that each fibre has a large patrol area. The pitch between spine tips is 9.542 mm (~161 arcsec) and each spine has a patrol radius of at least 11.8 mm (~200 arcsec). The closest separation that can be achieved between fibres is expected to be about 15 arcsec on any side. Each target in the science field of view can be reached by at least 3 fibres that go to one of the Low-Resolution Spectrographs (LRS) and one or two fibres that go to the High-Resolution Spectrograph (HRS). This ensures a high allocation efficiency of the fibres to targets, even when targets are clustered. Figure 4: Schematic diagram showing the central pitch position (small circles) and the overlapping patrol areas (large circles) of fibres in AESOP going to the LRS (blue) and HRS (yellow) spectrographs. shows the schematic layout and patrol areas of the fibres in AESOP.

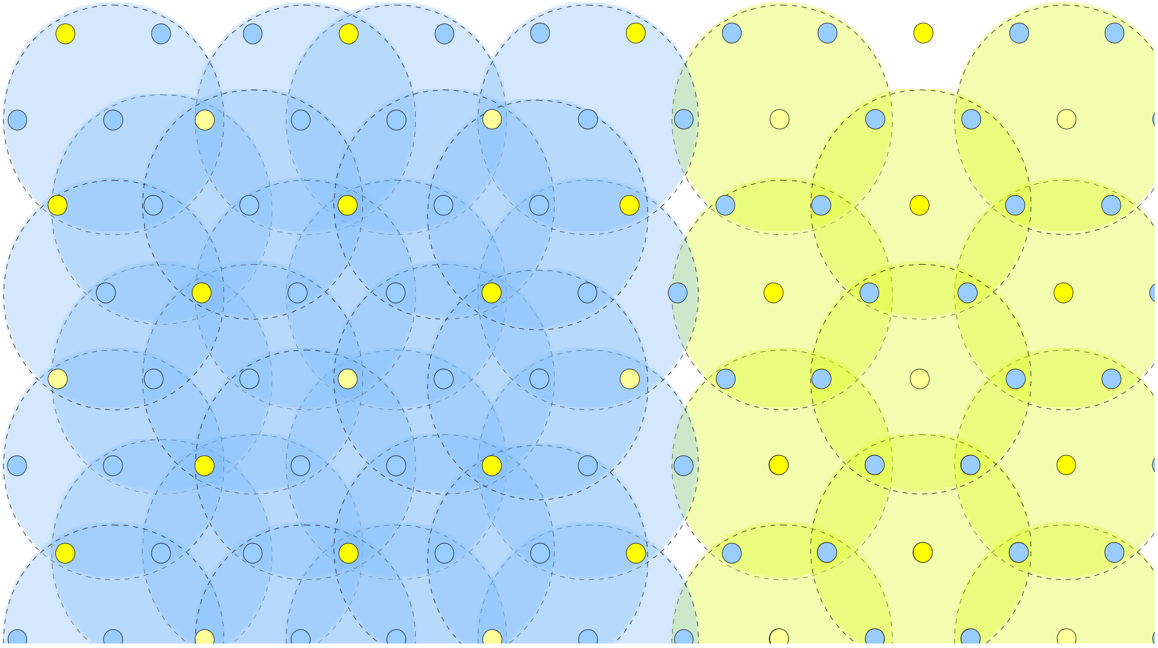

Figure 4: Schematic diagram showing the central pitch position (small circles) and the overlapping patrol areas (large circles) of fibres in AESOP going to the LRS (blue) and HRS (yellow) spectrographs.

6.1.2.4 Metrology System

The Metrology System provides the Fibre Positioner closed loop control with position measurements of the fibres for the setup of an observation. The speed and accuracy of this control loop determines considerably the setup time for an observation configuration and therefore the total 4MOST system efficiency.

6.1.2.5 Fibre Feed

The Fibre Feed subsystem transports light from the focal surface to the slits of the 4MOST spectrographs. It accommodates ±200 degrees rotation to allow for tracking across the sky in an alt-az mounted telescope.

6.1.2.6 Low Resolution Spectrographs (LRS)

The LRS will be installed on the VISTA telescope below its main platform. Unlike the rest of the telescope and the fibre focal plane, the LRS is therefore rather protected from direct outer conditions during observation. Each of the two LRS spectrographs accept 812 science fibres and 6 simultaneous calibration fibres attached to either end of the spectrograph entrance slit. The two LRSs have 3 channels (blue, green, red) each, in fixed configuration, covering three wavelength bands and are temperature controlled for stability.

The three LRS spectral bandwidths will cover a wavelength rage from 370 nm to 950nm: the blue arm will cover from 370 nm to 554nm, the green arm, from 524 nm to 721 nm and the red one from 691 nm to 950 nm. A schematic of the LRS arms is presented in Figure 5.

The covered wavelength range and resolution is depicted in Figure 6: LRS Spectral Resolution. This figure depicts the estimated spectral resolution, including the effects of the CCD flatness, the detector charge diffusion, the scattered light and the thermal effects. The resolution is defined as λ/Δλ, where Δλ is the width of a resolution element (given by the FWHM of a custom fit function to an unresolved line) and λ is the wavelength at which the resolution is determined. The spectra are sampled with ~3 pixels per resolution element.

The flux contamination caused by adjacent fibres (i.e. crosstalk) was computed to be ~0.75%, taking into account the LRS optical design itself, the CCD flatness, the detector charge diffusion, the scattered light, the thermal effect and manufacturing, assembly, and integration errors. The main contributor to the crosstalk is the scattered light.

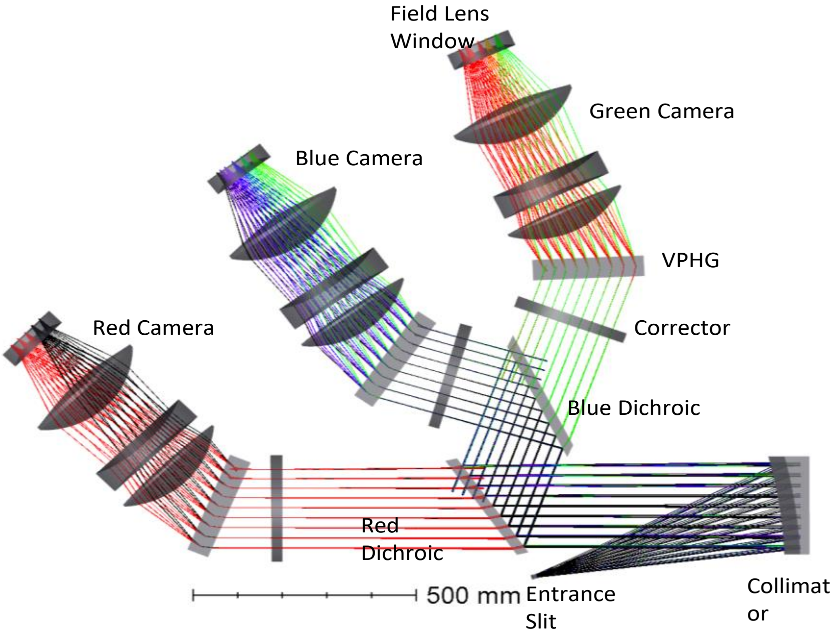

Figure 5: LRS General Overview: Optical layout

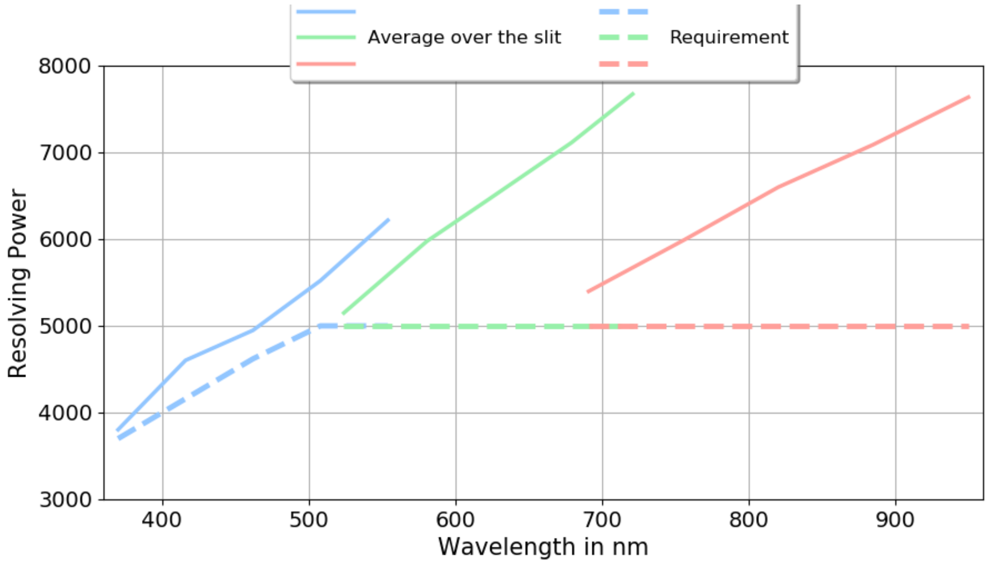

Figure 6: LRS Spectral Resolution, accounting for various effects mentioned in section 6.1.2.6. The dashed lines show the minimum requirement to deliver the desired accuracy for the consortium surveys.

The stability of the spectrograph is affected by thermal variations and different fibre illumination due to fibre tilt. The maximum variation due to temperature changes was estimated to be 2.0µm/°C in Y direction, 1.8µm/°C in X, and 1.1µm/°C in focus. However, taking into account that the LRS is actively controlled at ±0.3°C and assuming a 1°C/h variation, these shifts are limited to 0.6µm in X and Y direction and ±0.33µm in focus. The maximum deviation due to tilt differences is 0.8µm for 1.9° tilt (median tilt) and 1.6µm for 2.7° tilt (maximum tilt). The average case throughput of the LRS is shown in Figure 7: LRS throughput. The LRS expected throughput is 73.8% on average and always greater than 62.8%.

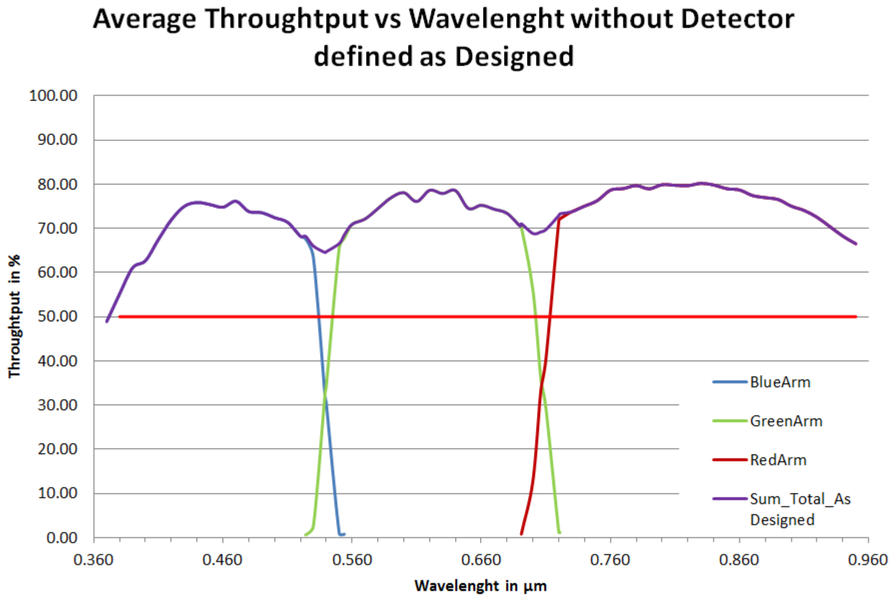

Figure 7: LRS throughput. The horizontal red line is the requirement value, needed to obtain the desired accuracy for the consortium science surveys.

6.1.2.7 High Resolution Spectrograph (HRS)

The HRS will be installed on the VISTA telescope below its main platform. The HRS accepts 812 science fibres and 6 simultaneous calibration fibres attached to either end of the spectrograph entrance slit. Similar to the LRS, the HRS has 3 channels in fixed configuration covering three wavelength bands. These are graphically presented in Figure 8: HRS General Overview: Optical Layout.

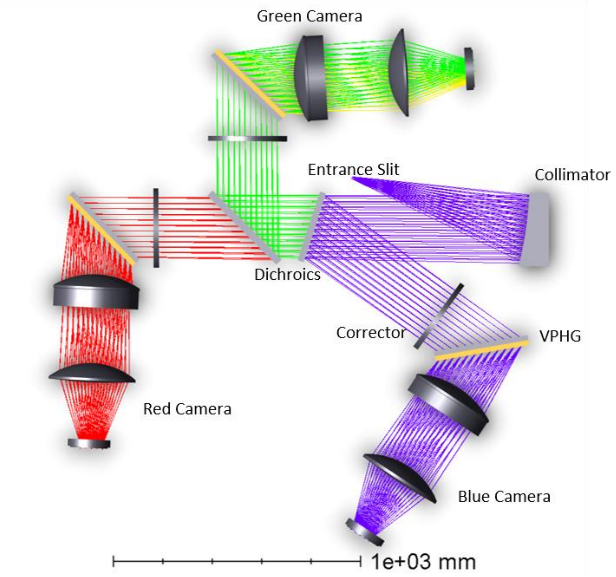

Figure 8: HRS General Overview: Optical Layout

The HRS optical components will be enclosed by a mechanical design that protects the optical components from adverse elements, such as dust or light pollution, and is thermally insulated. The three arms of the HRS will cover the following spectral ranges: from 392.6 nm to 435 nm the blue arm, from 516 nm to 573 nm the green arm and from 610 nm to 679 nm the red arm. The spectral resolution of the HRS, including the effects of the CCD flatness and the detector charge diffusion, is shown in Figure 9: HRS Spectral Resolution. The spectra are sampled with ~3 pixels per resolution element.

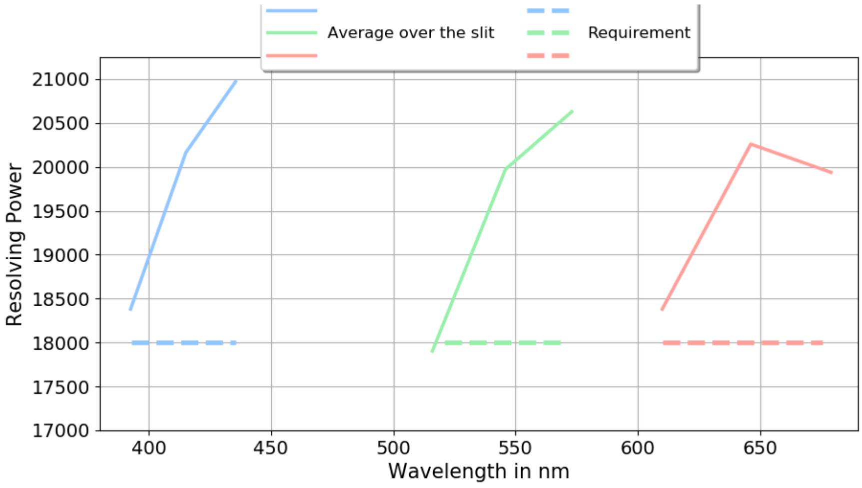

Figure 9: HRS Spectral Resolution, accounting for various effects mentioned in section 6.1.2.7. The dashed

lines show the minimum requirement to deliver the desired accuracy for the consortium surveys.

Crosstalk of the HRS design amounts to 0.57% - 1.28% between adjacent fibres when considering the effect of scattered light.

The stability of the spectrograph is fairly high due to its thermally invariant optical-mechanical design. As the spectrograph is mounted on a stable platform without movement relative to the gravity vector, the main impact to the spectra stability is the temperature change. Assuming a temperature gradient of 1°C/h, the shift of the image centroid is on average lower than 0.8µm/h with a maximum shift of 1.125µm/h. For an exposure of 20min, this translates to an average radial velocity shift of 0.36 km s^{-1} (at λ_{blue}=460nm), 0.28 km s^{-1} (at λ_{green}=620nm), and 0.28 km s^{-1} (at λ_{red}=820nm). For the maximum shift, the corresponding maximum radial velocity shifts are 0.50 km s^{-1} (at λ_{blue}=460nm), 0.40 km s^{-1} (at λ_{green}=620nm), and 0.40 km s^{-1} (at λ_{red}=820nm). The throughput of the HRS for the numbers above is shown in Figure 10: HRS throughput.

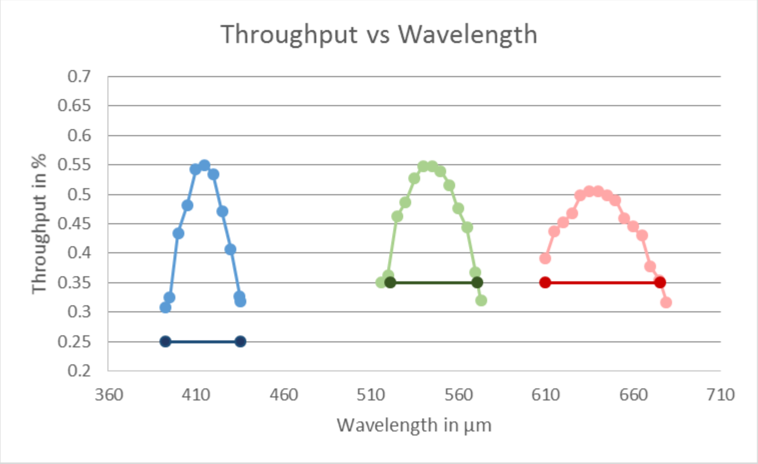

Figure 10: HRS throughput. The horizontal dark line is the requirement value, needed to obtain the desired accuracy for the consortium science surveys.

6.1.2.8 Detector System, Vacuum and Cryogenic System

The three channels (blue, green, red) of the LRS and HRS spectrographs are equipped with identical 6k x 6k CCD E2V detectors with low read-noise (<2.3 electron per read), excellent cosmetic cleanness and with high, broadband quantum efficiency. The pixel size is 15µm. The CCDs need to be operated at stable temperatures below 150K. For this reason, and to protect the detectors against any type of contaminations, they will be enclosed in a vacuum vessel. Two readout modes will be possible: Normal (100 kHz), and Fast (400 kHz). Binning modes of 1×1; 2×1; 1×2; 2×2; 1×4 (spatial × spectral) are available.

6.1.2.9 Calibration System

A calibration system equipped with a continuum source, a Fabry-Perot etalon, and ThAr lamps can feed light both through the telescope plus science fibres combination as well as directly through the simultaneous calibration fibres into the spectrograph slit to ensure accurate wavelength calibration. This will ensure an accuracy on stellar radial velocities better than 1 km/s. Details on Calibration are given in Section Calibration of 4MOST data10.

6.1.2.10 Operations System (OpSys)

When 4MOST is operational, OpSys will provide tools to plan, produce and submit OBs for all observations, including science and calibration. It will also monitor the progress of the 4MOST survey program, and maintain a database. The available tools will be the 4MOST Facility Simulator (4FS), Operations Support Software (OSS), Survey Progress Monitor (SPM), and Operations System Target Database (OSTD). Currently, the OpSys simulates 4MOST operations in order to develop a near-optimal survey strategy.

6.1.2.11 Facility Control System (Hardware and Software)

The subsystems responsible for the control and monitoring of the instrument are the Facility Control Hardware and Facility Control Software.

The Facility Control Hardware is responsible for the hardware devices controlling and monitoring the electronics components used in the other subsystems, from simple temperature and pressure sensors to check the conditions inside the different enclosures, to complex cryogenic control system, passing through motors to move the ADC.

The Facility Control Software is responsible for the high level control of all 4MOST hardware devices (lamps, motors, sensors, etc.). It coordinates the interaction between the Facility Control components and controls the sequence of actions necessary for observations, calibrations, and maintenance. It is also responsible for the development of the algorithms necessary to process the metrology and secondary images in order to provide feedback to the fibre positioner and the primary guiding system respectively.

6.1.2.12 Data Management System

The Data Management System function is to handle the end-to-end data processing, quality control and archiving for the science and related ancillary information from 4MOST.

Data management is composed of a number of major sub components:

- Level 0: basic data quality control checks to be run at the telescope using quick-look processing pipeline
- Level 0: instrument health and quality control checks to be run at ESO headquarters using a processing pipeline
- Level 1: full image processing, spectral extraction and calibration
- Survey progress monitoring including detailed quality control measures
- Archive systems both for internal consortium use and for public access

The 4MOST Data Management System (DMS) is to ensure that all data obtained from the telescope are fully processed into calibrated science data products and made available in a timely manner to both the consortium and the wider ESO community. In addition, it is also responsible for the development of the data distribution and archive elements, and the quick-look pipelines for data quality control and system health monitoring.

7 Observing Operations

7.1 4MOST Operations scheme

The 4MOST Operation scheme is unique for an ESO instrument in that it allows for scheduling many different science cases simultaneously during one observation. To accommodate the range of exposure times required for different targets, the same part of the sky will be observed with multiple exposures and visits. Objects that require longer exposures will be exposed several times until their stacked spectra reach the required signal-to-noise. 4MOST Operations also differ from that of other ESO instruments in that the 4MOST Consortium plays a primary role in planning the observations (Phase 2) and in reducing, analysing and publishing the data (Phase 3). A highly simplified overview of 4MOST operations is shown in Figure 13: Overview of 4MOST operations.

The survey nature of 4MOST operations means that Targets of Opportunity or time constrained observations on scales shorter than a few days cannot be accommodated. However, transients that are numerous enough that they fall in randomly distributed 4MOST pointings can be observed if they can be included into the data stream with a few days lead time. Also, fields that require re-visits with a certain cadence can to some limited extent be accommodated (e.g., do not revisit this field within a year, reobserve this field every 2 weeks ±3 days), in particular in the deep fields with many visits.

Because many targets from different Surveys are observed simultaneously, proposers cannot request certain observing conditions (seeing, moon) on a per target level. To avoid that one has a too wide range in target brightness in one area of the sky and to simplify scheduling, the Surveys have to agree to observe certain areas of the sky under particular conditions. Currently, the Consortium Surveys have identified the disk plane of the Milky Way as the region that will be predominantly be observed during bright time, with the rest of the sky devoted mostly to grey and dark time. This means that targets with a fibre luminosity fainter than that of the bright sky may be hard to schedule at low Galactic latitude, except maybe some areas near the bulge where some dark/grey time will be used. Also the situations when binned or fast readouts will be used need to be agreed upon between the different surveys observing in a particular area.

As mentioned above, observers will not be able to specify seeing conditions for their observations. When necessary, longer exposure times will be used for a field to match the observing conditions. On a larger scale, it is expected that the scheduling algorithm can be tuned such that areas with many background limited, point-like sources or regions that are hard to complete (e.g., high airmass or high Right Ascension (RA) pressure regions) will automatically be assigned better seeing.

NP surveys may choose to be in visitor mode. For Participating surveys, there will be no visitor mode observations. ESO night operators trained to operate 4MOST will perform all observations. The ESO night operator will follow a set of procedures to start up the telescope and the instrument, including opening the dome, changing the state of the instrument from STANDBY to ON, etc. Twilight and dawn calibration OBs will be executed according to the calibration plan. Next, the list of science OBs for the night will be executed, taking moon, airmass, seeing, sky brightness, and wind direction into account. These will be sorted by priority. Each OB contains a set of observing templates with set parameters that are executed in order. The OBs are interpreted by the Facility Control Software (FCS) and low level commands are sent to the instrument, the telescope and the detector. Raw FITS files will be saved at the Paranal archive. The night log will record all OB execution decisions, including at least the prioritization algorithm, invalid OB with reason, and night observer decisions.

7.2 Observation blocks

At ESO, Observation Blocks (OBs) are the smallest schedulable observational unit. Any OB contains templates that describe any action or process executed by the 4MOST instrument and the VISTA telescope. OBs are generated by the OpSys that produces two files: i) the OB

Description (.obd/.obx) file, containing all the templates that need to be executed in that OB plus the values of all variable (user-defined) keywords, and ii) the fibre-configuration file (FIBRE_CONFIG.FITS), containing all AESOP-relevant information (in particular the positions of targets, of blank sky, and of reference stars for secondary guiding). That is, for each acquisition template, there is a unique fibre-configuration file. With 4MOST, a standard science OB, i.e. one intended for night-time science observations, will be constructed of the following templates:

- One or more Acquisition Templates (ACQ) to move the telescope to the intended field position on the sky (defined by the center of the 4MOST FOV) and to rotate the instrument to the required angle. In parallel the template positions the fibres for the first configuration of the OB. In the absence of new telescope coordinates (checked by the FCS), the telescope doesn't move, and only new fibre configurations are acquired.
- One or more Observing Templates (OBSs) to integrate target flux on the CCD detectors.
- Each OBS is accompanied by one or two night-time, attached calibration templates (CAL) to perform a facility fibre wavecal or a facility fibre flatfield or both.

Generally, within one OB each ACQ pairs with one OBS and the "attached" night-time calibrations that precedes the OBS to reduce the overhead (fibre allocation happens in parallel with detector read-out of the calibration frame). Thus, in typical OBs, the template sequence looks like the following:

(Start OB)

ACQ – Move telescope to acquire Field

(in parallel allocate fibres of Configuration 1)

CAL – Take fibre wavecal or fibre flat or both

OBS – Take science exposure of Configuration 1

(During OBS read-out: allocate fibres of Configuration 2)

CAL – Take fibre wavecal or fibre flat or both

OBS – Take science exposure of Configuration 2

(During OBS read-out: update optics, in parallel allocate fibres of Configuration 3)

Continue until last OBS of Configuration N is executed.

(End of OB)

(Start of next OB)

7.3 4MOST observing templates

A template contains a set of the so-called template signature files (extension .tsf), reference files (.ref) and sequence files (.seq). The parameters in those files are not usually set by the user (except for non-participating surveys), and hence only a brief overview is provided here. Further information, with a detailed description of all parameters, can be found in the Template Reference Manual [RD1].

Template signature files contain the parameters (keywords), both variable and fixed, necessary to describe the configuration of the telescope, the instrument and the detector; reference files contain all parameters of the instrument setup that are fixed and cannot be modified or even accessed by the user; and sequence files contain the actual observing sequence (i.e. commands written in Tcl) that is executed by the broker of OBs.

Acquisition Templates (ACQ) move the telescope to the intended field position on the sky and rotate the instrument to the required angle. Observing Templates (OBSs) perform the integration of the target flux on the CCD detectors. Calibration templates (CAL) take the necessary data to perform a facility fibre wavelength calibration, or a facility fibre flatfield, or both.

7.4 Target acquisition

4MOST will point its fibres, each with a 1.45 arcsec field of view, to a field of targets defined by the observation planning. This is a nontrivial task for the very large field of view of 4MOST. Target acquisition has tremendous consequences for the efficiency of the survey and the data quality. Analyses show that a position offset of half an arcsec would lead to a fibre throughput loss of 20%, whereas an offset of a quarter of an arcsec would result in only 5% throughput loss.

7.5 Differential Atmospheric Refraction (DAR)

As the source light passes through the atmosphere the light is refracted by a very significant amount and due to the large FoV there is a significant spatially differential effect across the field. At large zenith distances the effect can reach some 10 arcsec. We assume that we can correct this effect to the 0.5% level, as it is purely differential, and thus make a residual error of 0.05 arcsec. The critical part is the dynamical effect of the refraction as the field changes zenith distance.

To evaluate this effect, we have computed the dynamical differential refraction for a 20min integration time for a field passing close to the zenith (DEC=-25deg) and a field in the southernmost part of the Magellanic Clouds (DEC=-80deg). This effect is demonstrated in Figure 11: DAR effects for a field at DEC=-25deg, where the variation of zenith distance (ZD) is shown as a function of Hour Angle (HA) for a field at DEC=-25deg (upper left) and the change for 20min integration time (upper right). The differential refraction across the 2.5deg FoV as a function of hour angle (lower left) and change during a 20min integration (lower right). The effect of differential atmospheric refraction is substantially decreased for a field in the far south (DEC=-80deg), as shown in DEC=-80deg. It is evident from the plots that the dynamical differential refraction becomes significant at higher hour angles. For the zenith crossing field the effect reaches 0.6 arcsec peak-to-valley at an hour angle of 3hours whereas for the southern field the effect is less dramatic. The effect can be reduced by precomputing the differential refraction to mid-exposure (a factor two), and by observing the field closer to the meridian. Already at an hour angle of 2hours the effect is half of that at 3hours. The ADC corrects for DAR up to 55 deg zenith distance.

7.6 Fibre-to-target alignment error budget

Both static and dynamic effects impact the system throughput and may also lead to spectral distortions. Dynamic effects strongly depend on exposure time and location of the target on sky. The main source of error is the dynamical differential refraction across the large field of view. Currently, the instrument can safely observe for 20 minutes, before the errors become so significant that a reconfiguration of the fibres would be advantageous. Longer exposures can result in targets moving off their fibre position due to differential refraction at certain positions on the sky.

Combining the static and dynamical errors, with integration time of 20min and the field being within ±3hours from the meridian, the standard deviation of centroid movement of all fibres is expected to be s.d.=0.25 arcsec. The same standard deviation can be obtained for a 30min integration within ±2hours of the meridian.

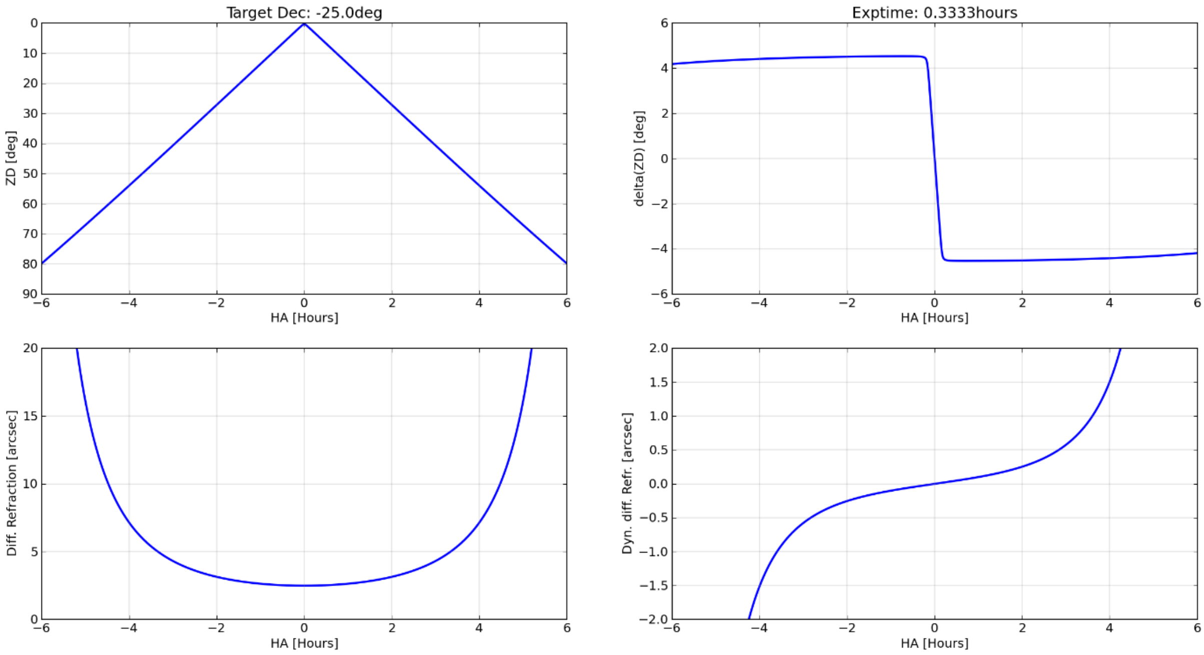

Figure 11: DAR effects for a field at DEC=-25deg

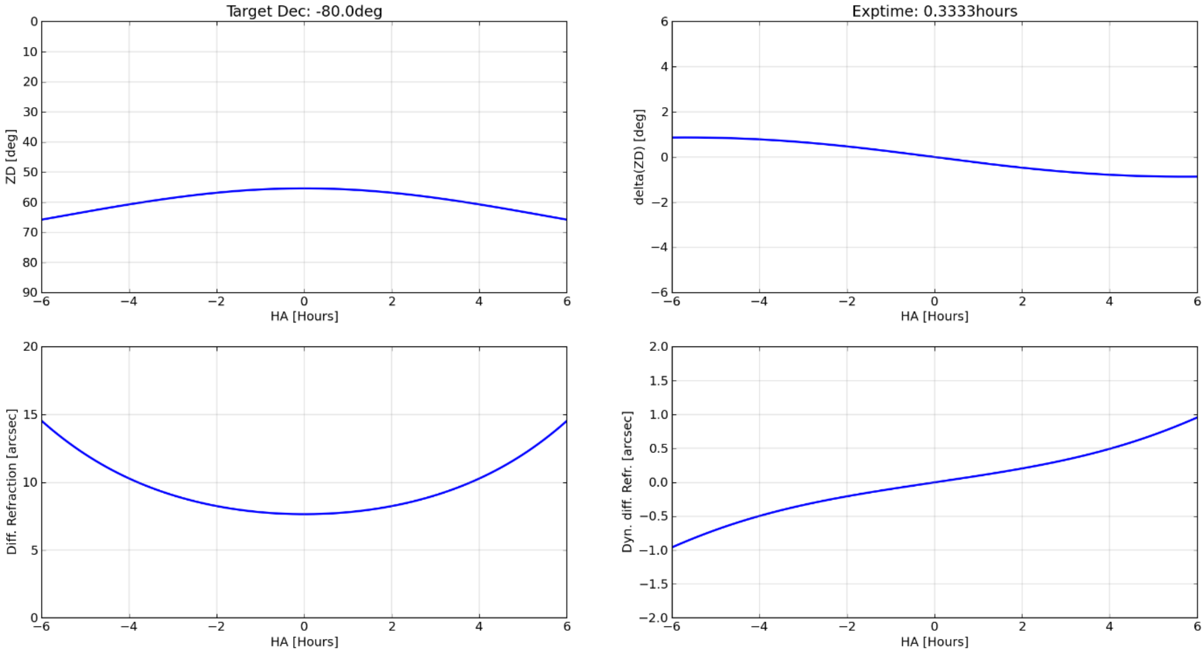

Figure 12: DAR effects for a field at DEC=-80deg

8 Preparing the observations

8.1 Introduction

The following instructions apply to Participating surveys only. The operations of the 4MOST facility are complicated by the need to operate many parallel science surveys with heterogeneous requirements and goals, over an extended time frame. As a result, all Consortium Surveys and most Community Surveys will be integrated fully in a coherent long-term plan, maintained and operated by the 4MOST Opsys. This implies that all aspects of observation, from preparation of observing blocks (OBs), estimating the exposure times, the creation of configurations, optimisation of overheads, etc., to the scheduling of the observations for the optimum observing slot, will be handled by the 4MOST OpSys, and not by the individual survey PIs. These surveys drive operations through submission of target catalogues with precise target coordinates on a common system and by providing analytical formulae that allows calculating the scientific success of a specific observation for their respective survey.

Only Non-participating surveys will be required to prepare OBs themselves.

8.2 Survey strategy parameters

A Spectral Success Criteria (SSC) was defined at target level and is used to set the initial exposure time requirement. The SSC prescribes the S/N requirements in specified wavelength regions of the target spectrum needed for robust scientific output. As an example, to achieve a sufficient precision in the stellar parameters, the median S/N ratios in the continuum over given wavelength ranges have to reach at least a certain value. Such criteria are provided by all individual 4MOST Surveys for all of their targets and depend on their individual scientific goals. 4MOST operations are also expected to include a feedback loop on already observed targets. Surveys must therefore also provide “stop observing” criteria for all targets. These are evaluated after the first exposure(s) of a target have been taken in one Observation Block and may be used to make decisions if subsequent observations in this region of the sky are planned. Examples of stop criteria are: a minimum S/N has been reached (that can be lower than the original request), a redshift has been obtained, or a maximum exposure time has been exceeded.

The Small Scale Merit (SSM) is used by the target scheduling tool that assigns fibres to targets to quantify the success of observations in a small area of the sky. The SSM defines the completeness requirements of a (sub-)survey on a scale of one fibre configuration, i.e., an area covering a 4MOST field-of-view. Indeed, the different Surveys require different completeness in a given local area, with varying numbers of targets. The SSM is then a way to quantify the increment of scientific knowledge we acquire when observing an additional target in one Survey versus another. This allows Surveys to provide many more targets than needed for their science case and, by specifying that only a fraction of targets need to be completed, helps improve the fibre usage efficiency. Using the total observing time assigned to a region and the target exposure times calculated with the SSC, an algorithm is used to assign targets to fibres in a field-of-view in a probabilistic way such that the desired completeness is reached for each Survey, while avoiding unwanted biases in brightness or crowding, for example. The use of probabilities throughout selection and operation decisions will greatly simplify recreating the selection functions that one needs to make statistical inferences on the intrinsic abundances of different types of targets.

In order to coordinate the science goals over a large area of the sky, the Consortium uses the

Large Scale Merit (LSM). The LSM concerns the entire observable sky and is defined by a HEALPix[1] map of scientific priorities as a function of right ascension and declination. The LSM maps are needed to ensure that observations concentrate on areas of higher scientific interest. As an example, Surveys can use the LSM to reduce the priority of regions with high levels of extinction.

In order to obtain an overall measure of 4MOST survey success a Figure of Merit (FoM) is defined by each Survey. This metric ranges from 0.0 to 1.0, and can be a function of, e.g., the successfully observed targets, areas completed with sufficient number of targets, and completeness of individual sub-surveys with special targets. The FoM is defined such that it reaches 0.5 once a Survey has met its requirements (the minimum set of observations to accomplish the core science case) and it reaches 1.0 once it has met all its goals. The goal of the 4MOST observation scheduling software is of course to maximize this FoM for all Surveys, without penalising any of the Surveys. The choice and implementations of these LSM and SSM concepts contribute to the final shape of the 4MOST sky.

8.3 Target catalogues

Catalogues with target coordinates in the Gaia DR2 system need to be provided with accuracy of 0.1 arcsec. Higher coordinate precision is possible with Gaia, however, the fibre-to-target alignment error budget is ~ 0.25 arcsec, and hence more accurate target coordinates will not make much difference. For all targets, and in particular for the guide stars, the following information needs to be provided: (RA, DEC, proper motion (RA), proper motion (DEC), parallax, magnitude, magnitude system, colour).

8.4 4FS Exposure Time Calculator

The 4MOST Facility Simulator (4FS) is a Web Interface, which offers to the 4MOST users the possibility to submit and upload all the data needed to simulate the execution of a survey. This includes the 4MOST Facility Simulator Exposure Time Calculator. A separate User Manual and the ETC web-interface itself can be found at the 4MOST website (https://www.4most.eu/cms/operations/simulations/).

9 Observing Overheads

The overheads depend on the calibration scheme, binning and readout mode. The four possible cases are presented in the tables below. Night-time calibrations are called “attached” calibrations. The presented overheads assume one science exposure, one flatfield, and one wavelength calibration exposure per OB; taking N science exposures of the same field would mean multiplying the second row by N.

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[1] The definition of HEALPix can be found at https://healpix.jpl.nasa.gov/

Overheads for case 1: no night-time (attached) calibrations		
Field acquisition	≤ 270 sec	
Detector readout + WFS stop + M2 update	127 sec	Normal mode + bin 1x1
Overheads per science exposure	≤ 397 sec	

Overheads for case 2: attached flatfield calibrations		
Field acquisition	≤ 270 sec	
Detector readout + WFS stop + M2 update	127 sec	Normal mode + bin 1x1
Flatfield exposure	20 sec	bin 4x1
Flatfield readout	18 sec	Fast mode + bin 4x1
Overheads per science exposure	≤ 435 sec	

Overheads for case 3: attached wavelength calibrations		
Field acquisition	≤ 270 sec	
Detector readout + WFS stop + M2 update	127 sec	Normal mode + bin 1x1
Wavecal. exposure	60 sec	bin 1x1
Wavecal. readout	44 sec	Fast mode + bin 1x1
Overheads per science exposure	≤ 501 sec	

Overheads for case 4: attached flatfield and wavelength calibrations		
Field acquisition	≤ 270 sec	
Detector readout + WFS stop + M2 update	127 sec	Normal mode + bin 1x1
Flatfield exposure	20 sec	bin 4x1
Flatfield readout	18 sec	Fast mode + bin 4x1
Wavecal. exposure	60 sec	bin 1x1
Wavecal. readout	44 sec	Fast mode + bin 1x1
Overheads per science exposure	≤ 539 sec	

10 Calibration of 4MOST data

For 4MOST we distinguish three different types of calibration:

Instrument Calibration deals with all calibration and monitoring efforts that are required to guarantee proper function and operation of the 4MOST instrument (and telescope, where applicable). It is strongly linked to the Operations and Maintenance Plan of 4MOST. The software required to carry out the Instrument Calibration steps is part of the Instrument Control Software.

Data Calibration deals with all calibration and monitoring efforts that are required to remove instrument signature from the scientific exposures during the data-reduction process. It thus provides the necessary calibration files so that the Data Management System (which is part of the 4MOST Facility) performs to specification.

Science Calibration deals with all calibration and monitoring efforts that are required to ensure proper scientific exploitation of the 4MOST data products by the high-level, data analysis pipelines which are not part of the Facility, but are provided by each survey that utilizes 4MOST.

10.1 Participating versus Non-Participating surveys

Participating surveys have access to all day time calibrations, be they instrument or data calibrations, without any charge to their science time. Any night time calibrations will count towards the allocated science time. All science calibrations will also count towards the allocated science time but will be shared among participating surveys in the same OB, thereby reducing the number of science fibre hours surveys spent on such calibration.

NP-surveys also have access to day-time instrument and data calibration files, without any penalty to their science time. Any night time calibrations, and all science calibrations, will come out of the NP-surveys’ allotted science time.

10.2 Instrument Calibration

The instrument calibration includes the Metrology camera, and the Secondary Guiding Camera calibration. For both cameras, bias and flatfield frames will be taken parallel with Daytime Data Calibrations, resulting in no additional overheads. In addition, once per month the linearity of the CCDs will be tested in a series of flat field exposures with increasing exposure times of 1k, 2k, 3k, … 10k, 12k, 14k, … to 60k counts, with one frame at 1k counts in between to guard against remnants, in total 69 frames. These will also happen during daytime, together with Daytime Data Calibrations.

10.3 Data Calibration

In 4MOST, the low-resolution (LRS) and high-resolution spectrographs (HRS) are operated in parallel; hence all data calibrations are carried out simultaneously for both LRS and HRS. Data calibrations will be taken during daytime, with frequency once per week and/or once per month (daytime calibrations), and each night (night-time calibrations).

The daytime calibrations consist of bias (zero exposure time), internal flatfields (calibration lamp), and dark frames (shutter closed). To obtain a dispersion solution and absolute wavelength calibration, 10 fibre wave calibration exposures of 60 seconds will be obtained both during daytime with 0.1 pixel precision. 10 fibre flats of 20 seconds from a continuum source will be obtained, in order to produce a trace mask and determine the wavelength-dependent pixel-to-pixel response. The expected accuracy is 1%. 10 dome screen fibre flats of 60 second exposure time will also be taken to correct the data for effects of the pupil illumination. In addition, attached night time calibrations may be taken for participating surveys, and taken if requested for non-participating surveys.

During morning and evening twilight, 10 high-quality (SNR≥100) sky fibre flats will be taken, in order to serve as pupil-illumination correction of the Dome Screen and Calibration Beam (used for fibre flats and wavelength calibrations) to 5% precision.

The readout mode can be Normal (100 kHz) and Fast (400 kHz), with binning modes 1×1; 2×1; 1×2; 2×2; 1×4 (spatial × spectral). For both bias and flatfields, HRS will normally be operated at “100 kHz, 1×1”, thereby dominating the overheads (1,140 sec).

10.4 Science Calibration

The purpose of science calibrations is to monitor the quality and correctness of the data-reduction process via Radial-velocity (RV) standard stars, spectrophotometric and telluric standard stars. All additional science calibrations are optional, and need to be specifically requested. Examples of the latter are Benchmark stars, targets enabling comparison and cross-calibration between surveys, etc.

Typically, science calibrations are carried out during night time, i.e. targets are queued in the same mode as normal science targets. Some of them (e.g., very bright Benchmark stars, etc.) will be done during late twilight before the night begins so that they don’t affect the available time for science observations.

10.4.1 RV standards

RV standards stars are stars whose absolute RVs are known with high accuracy. Typically, RVs are known from very-high resolution spectroscopy, which normally means that RV standard stars are bright and, thus, sparsely distributed over the sky. ESO is currently working on establishing with HARPS a new catalogue on highly accurate RV standard stars. For G- to K-type stars with magnitudes ≤ 14, Gaia will be able to determine very good RVs ($\sigma_{RV} \approx 1$ km s^{-1}), hence such stars can and will act as secondary RV standards.

10.4.2 Spectrophotometric standards

Spectrophotometric or flux standard stars are stars whose spectral energy distribution (SED) is known in absolute fluxes. Such stars are bright and, thus, sparsely distributed over the sky. There are two major sources used by ESO and Gemini-S that provide a few flux standard stars, Oke (AJ, 99, 1621, 1990, 25 stars) and Hamuy et al. (1994, PASP, 106, 566; declination range $-68° \leq \mathrm{DEC} \leq +11°$; wavelength range 330 to 1030 nm with a step-width of 5 nm).

4MOST will include such flux standards as a function of their visibility, either during nighttime observations or, if the magnitudes are very bright, during dark (astronomical) twilight observations. The data-reduction pipeline will check the approach based on Gaia BP/RP photometry against results obtained with these flux standards stars.

White dwarfs are also used as flux standards; since one of the 4MOST surveys actually is a white-dwarf survey, we will use them as flux standards whenever covered by 4MOST.

10.4.3 Telluric standard stars

We will regularly include telluric standard stars (typically, main-sequence B stars, with F stars and White Dwarfs as more numerous reasonable compromises) in our science fields. These stars offer the opportunity to monitor the quality of the telluric correction done by the data-reduction pipeline.

10.4.4 NP-surveys

All science calibrations in Sections 10.4.1 through 10.4.3 will count towards the allotted science time of the NP-surveys, and must be specifically requested, planned and prepared by each survey, just like any other science observations.

10.5 Calibration Procedures

10.5.1 Daytime calibrations

During daytime, following standard calibrations are taken with the dome closed, the telescope in parking position, and the fibres in nominal zero position:

- With the Calibration System: fibre flatfields and wavecals
- CCD calibrations: zero (bias), dark, and flatfields
- (Technical CCD calibrations: zero (bias), flatfields; part of Instrument Calibration)

10.5.2 Twilight calibrations

During (evening and/or morning) bright (civil) twilight, following standard calibrations are taken with the dome open, the telescope pointing towards the sky, and the fibres in nominal zero position:

- Twilight flatfields

Due to the sky gradient, twilight flats will be taken at varying field rotations.

10.5.3 Night-time calibrations (a.k.a. attached calibrations)

During night-time (i.e., nominal science operations), following standard calibrations are taken with the dome open and both the telescope position and the field rotation and fibre state as the accompanying science exposure:

- With the Calibration System: fibre flatfields and/or wavecals;
- Every science exposure has its own simultaneous wavecals.

We note again that if the integrated FPE spectrum contains enough flux to measure fibre-to-fibre throughput differences with meaningful accuracy (≤0.5-1%, i.e. total counts between 10,000 and 40,000), only an attached wavecals will be taken.

10.5.4 Pipeline output data products

Both Participating and NP surveys will have access to the (L1) pipeline data products, which comprise fully reduced and calibrated science spectra.

The output spectral files will contain all of the spectra for a single observation in a single FITS container. The spectra for a given detector/arm will all appear in a single 2D image extension, with each spectrum occupying a single row in the image; both sky subtracted and pre-sky subtracted spectra will be given. A variance estimate for each spectrum will also be present in the container file together with an extension per arm specifying the conversion to flux units (i.e. ADU/s to ergs/s/cm2/Å). There will be a "fibinfo" table that refers to each set of spectra which will give all of the information about the object covered by each fibre. This will also include relevant information from the metrology table. An outline of the structure of these files is contained in Table 2.

Extn#	**Extension Name**	**Description**
0	Primary	The primary header unit. This will have no data, but will have a full FITS header with information about the observations that went into these science spectra
1	SPECTRA_BLUE	An image extension for the blue arm with wavelength calibrated sky subtracted spectra on a consistent internal flux system in ADUs.
2	IVAR_BLUE	An image extension with the inverse variance array for the above
3	SPECTRA_GREEN	An image extension for the green arm with wavelength calibrated sky subtracted spectra on a consistent internal flux system in ADUs.
4	IVAR_GREEN	An image extension with the inverse variance array for the above
5	SPECTRA_RED	An image extension for the red arm with wavelength calibrated sky subtracted spectra on a consistent internal flux system in ADUs.
6	IVAR_RED	An image extension with the inverse variance array for the above
7	SPECTRA_BLUE_NOSS	An image extension for the blue arm with wavelength calibrated spectra that have not been background sky corrected
8	IVAR_BLUE_NOSS	An image extension with the inverse variance array for the above
9	SPECTRA_GREEN_NOSS	An image extension for the green arm with wavelength calibrated spectra that have not been background sky corrected
10	IVAR_GREEN_NOSS	An image extension with the inverse variance array for the above
11	SPECTRA_RED_NOSS	An image extension for the red arm with wavelength calibrated spectra that have not been background sky corrected
12	IVAR_RED_NOSS	An image extension with the inverse variance array for the above
13	SENSFUNC_BLUE	The sensitivity function for each spectrum in the blue arm – converts ADU/s to ergs/s/cm2/Å
14	SENSFUNC_GREEN	As above but for the green arm
15	SENSFUNC_RED	As above but for the red arm
16	FIBINFO	A fibre information table (see Table 3)

Table 2: The outline structure for the output science spectral file

Fibinfo: A FITS binary table that will include all of the relevant information for each fibre in an observation will be included in each science product. An excerpt of the included information is shown in Table 3.

Column	**Description**
Nspec	The number of the spectrum in extracted order
Fibre_ID	The unique fibre id number used for this object
Slit_pos	Specifies the slit position of the fibre
Target_name	The object name as defined in the raw data fibre information table
Target_UID	Object name formed from the celestial coordinates. This will be used in place of the target name to give a unique identifier. This is formed by splicing the RA in hours, minutes and seconds (to 2 decimal places) and the Dec in degrees, minutes and seconds (to 1 decimal place) together, including a sign for the declination. Thus, an object at $3^h\,40^m\,21.^s767$ and -31° 20' 32.71" will have a UID of 03402177-3120327.
Target_bit	The surveys and sub-surveys the target belongs to
Target_RA	Target RA in decimal degrees
Target_Dec	Target declination in decimal degrees
Fibre_use	O-object, R-reference, S-sky, C-calibration, G-guide, I-inactive
Fibre_status	A-allocated, D-disabled, P-parked
Target_priority	Target relative priority within survey (scale of 1-100)
RMS_arc	The RMS in Angstroms of the wavelength solution for fibre
Helio_cor	The heliocentric correction (km/sec) that was applied to the standard arc solution
Wave_cor	The wavelength offset applied to the standard arc solution (Angstroms) (3 values)
Wave_corrms	The RMS of the wavelength offset correction (Å; 3 values)
Exptime	Total exposure time in seconds for the object (3 values)
SNR	The mean signal/noise ratio for the spectrum (3 values)
Resolution	The mean FWHM of the arc lines for this fibre (Å; 3 values)
Total_flux	Total flux of the extracted object (ADUs; 3 values)
Flux_pixel	Mean flux per pixel of the extracted object (ADUs; 3 values)
Target_mag_blue	Target magnitude estimate for blue arm (e.g. SDSS-like AB g-band)
Targt_mag_blue_err	The error on the above
Target_mag_green	Target magnitude estimate for green arm (e.g. SDSS-like AB r-band)
Target_mag_green_err	The error on the above
Target_mag_red	Target magnitude estimate for red arm (e.g. SDSS-like AB i-band)
Target_mag_red_err	The error on the above

Table 3: Basic specification for the fibinfo table, to be included in the spectral output files

10.6 Additional Information

If you cannot find a specific piece of information in this 4MOST User Manual or in case you have further questions, please contact the 4MOST Helpdesk. They can be reached via an email to help@4most.eu, or via the Helpdesk web-portal, available at https://4mosthelp.freshdesk.com. A list of Frequently Asked Questions and a Glossary of

4MOST related terms are maintained there also.

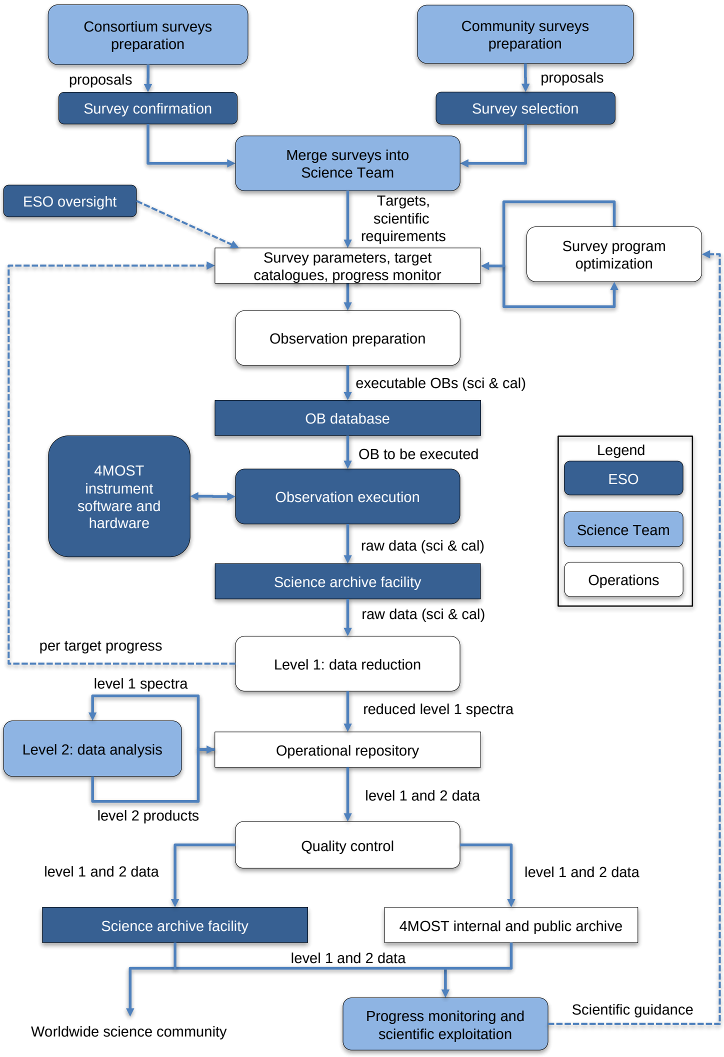

Figure 13: Overview of 4MOST operations

Appendix A List of Acronyms

List of Acronyms	
4MOST	4-metre Multi-Object Spectroscopic Telescope
4FS	4MOST Facility Simulator
4PA	4MOST Public Archive
4OR	4MOST Operational Repository
AIP	Leibniz Institut für Astrophysik Potsdam
AD	Applicable Document
ADC	Atmospheric Dispersion Corrector
AL2	Additional L2 Data
CASU	Cambridge Astronomy Survey Unit
CCD	Charge Coupled Device
CfLoI	Call for Letters of Intent
CfP	Call for Proposals
CRB	Conflict Resolution Board
CWPM	Communications Work Package Manager
DFDR	Data Flow Design Review
DG	Director General
DL2	Deliverable L2 Data
DMS	Data Management System
DWPM	Data Management System Work Package Manager
DXU	Data eXchange Unit

List of Acronyms	
ESO	European Southern Observatory
EST	ESO Survey Team
ETC	Exposure Time Calculator
EWPM	Engineering Support Work Package Manager
EXB	Executive Board
FDR	Final Design Review
FITS	Flexible Image Transport System
FoM	Figure of Merit
FTE	Full Time Equivalent
GTO	Guaranteed Time Observations
GUI	Graphical User Interface
HWPM	Helpdesk Work Package Manager
IC	Infrastructure Coordinator
ICB	Infrastructure Coordination Board
ICD	Interface Control Document
ICS	Instrument Control Software
IoA	Institute of Astronomy
IS	Instrument Scientist
IWG	Infrastructure Working Group
JOG	Joint Operations Group
L0/1/2 data	Level 0/1/2 data
LoI	Letter of Intent
LRU	Line Replaceable Unit

List of Acronyms	
MPE	Max Planck Institut für Extraterrestrische Physik
NP-survey	Non-participating survey
OB	Observation Block
OM	Operations Manager
OMA	Operations Management Assistant
OPC	Observing Programme Committee
OpSys	Operations System
OpSys WPM	Operations System Work Package Manager
P1WG	Phase 1 Working Group
PDR	Preliminary Design Review
PI	Principal Investigator
PS	Project Scientist
PSSP	Public Spectroscopic Survey Panel
PubBoard	Publication Board
QC	Quality Control
QC0/1/2	Quality Control Level 0/1/2
RD	Reference Document
RfW	Request for Waiver
SCB	Science Coordination Board
SoW	Statement of Work
TechSpec	Technical Specification
USD	User Support Department

List of Acronyms	
VISTA	Visible and Infrared Survey Telescope for Astronomy
Wavefront Sensing	WFS
WPM	Work Package Manager