MSE Observatory Science Requirements Document

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1 Purpose

This is the MSE Science Requirements Document (SRD). It represents the highest level of requirements that the MSE facility must meet, and every requirement described herein is traced directly to a key science driver for the facility. The key science drivers are described in the Detailed Science Case (DSC), which provides a narrative describing the scientific importance of MSE to address fundamental questions regarding the nature of stars, galaxies and the Universe.

It is fully expected that the scientific scope and impact of MSE that is currently envisioned and described in the DSC is incomplete; the key science questions naturally and continually evolve or change dramatically as our understanding advances and new discoveries are made. To ensure that the design of MSE will be best optimized to address a broad range of transformational science during its lifetime, the DSC describes a suite of "Science Reference Observations" (SROs) that together constitute a "Design Reference Mission" for the facility. The SROs have been identified by the international science team as specific science goals that are high impact, transformational – i.e., will provide a highly important and significant increase in our understanding of the field – and which are *uniquely possible with MSE.* They have been developed in considerable detail, with particular focus on implementation issues such as the origin of pre-imaging, the luminosity distribution of targets, their space density and the survey region required, the specific spectral features that must be observed, the quality of the measurement that is required, the observing cadence, any special calibration measurements, and related issues.

Science requirements are then defined as the capabilities that the MSE system must have in order to make the measurements necessary to successfully carry out the programs described by the SROs.

At science commissioning for MSE, and during its first decade of operations, many of the observing programs that MSE will undertake may address directly the science described by the SROs. Quite possibly, a more contemporary set of observations will be conducted. Nevertheless, it is expected that the capabilities that are captured by the science requirements will ensure that MSE becomes the premier international facility for multiplexed spectroscopy, enabling a vast range of high-impact science programs.

All science requirements describe system-level performance at the end-user level. This point is important and worth expounding. At the level of the science requirements, distinctions between major sub-systems such as the telescope, fiber-system, and spectrographs, are unnecessary and may impede the design of the optimal system. We therefore make explicit the distinction between a *science requirement*, and a *design solution that meets the science requirement*. A good example is "sensitivity". At the level of the science requirements, what is important is the observed signal to noise ratio per resolution element for a given spectral resolution as a function of wavelength. This might be achieved with a relatively small aperture and high throughput optics, or it might be achieved with a design that has a larger aperture to allow for more leeway in other aspects of the optical design. Both are satisfactory solutions, and care has been taken to ensure the science requirements are described in a way that does not explicitly assume a design solution.

2 Related Documents and Drawings

2.1 Reference Documents

Reference	Document title	Date	Document ID
[RD-01]	MSE Detailed Science Case (DSC)	2002-11-01	Not yet in existence

2.2 Applicable Documents

Reference	Document title	Date	Document ID

3 Science Requirements

The science requirements are summarized at various points throughout this document. In case of any inconsistencies in the text, the requirements and descriptions given in Section 3.2 take precedence.

3.1 Summary of MSE Science Capabilities

Table 1 provides a summary of the major, high level, science-enabling characteristics for MSE as defined directly by the science requirements. MSE will conduct multi-object spectroscopy for astrophysical objects located anywhere in three-quarters of the entire sky. It will operate at three different spectral resolutions spanning from R~2500 to ~40000, and will obtain spectra stretching from blue-optical wavelengths to the near-infrared. With an etendue equivalent to at least a 10-m class facility with a 1.5 square degree field of view, MSE will obtain at least 3200 spectra per exposure at low and moderate resolutions, and ~1000 spectra per exposure at high resolution. It will conduct surveys that include millions of targets spread over potentially several tens of thousands of square degrees. During its lifetime it will be able to support a multi-object IFU capability to allow for spatially resolved studies of extended sources. The data that MSE will produce over its >20 year lifetime will be calibrated to a high level of accuracy and repeatability. Overall, these science-enabling capabilities will provide for transformational scientific discoveries spanning a very broad range of astronomical topics.

Table 1: Summary of MSE science capabilities

Accessible sky	30000 sq. degrees (airmass<1.55)			
Etendue = A x Omega	≥ (10m effective diameter x 1.5 square degrees)			
Modes	**Low**		**Moderate**	**High**
Wavelength range	0.36 - 1.0 µm	J, H bands	0.36 - 1.0 µm	0.36 - 1.0 µm
Spectral resolutions	2500 – 3000	≥3000 (5000)	5000 – 7000	38000 – 42000
Multiplexing	≥3200		≥3200	≥1000
Spectral windows	Full		≥0.25um	TBD
Sensitivity	m=24*		m=23.5*	m=20.0♮
Velocity precision	20km/s		9km/s	100m/s
Relative spectrophotometry	3%		N/A	N/A

* SNR/resolution element = 2

♮ SNR/resolution element = 10

All science requirements are traceable to RD-01, the DSC. Each requirement emerges either from consideration of specific or multiple SROs described in that document. The science requirements are listed below, divided into major sub-groupings. The relationship between the science requirements and the SROs is summarized by the Science Traceability Matrix, shown in Figure 1.

Table 2: Summary of MSE science requirements

Requirements relating to Spectral Resolution:	
REQ-SRD-011	Low spectral resolution
REQ-SRD-012	Moderate spectral resolution
REQ-SRD-013	High spectral resolution
Requirements relating to the Focal Plane Input:	

REQ-SRD-021	Etendue
REQ-SRD-022	Multiplexing at low resolution
REQ-SRD-023	Multiplexing at moderate resolution
REQ-SRD-024	Multiplexing at high resolution
REQ-SRD-025	Spatially resolved spectra
Requirements relating to Sensitivity	
REQ-SRD-031	Spectral coverage at low resolution
REQ-SRD-032	Spectral coverage at moderate resolution
REQ-SRD-033	Spectral coverage at high resolution
REQ-SRD-034	Sensitivity at low resolution
REQ-SRD-035	Sensitivity at moderate resolution
REQ-SRD-036	Sensitivity at high resolution
Requirements relating to Calibration	
REQ-SRD-041	Velocities at low resolution
REQ-SRD-042	Velocities at moderate resolution
REQ-SRD-043	Velocities at high resolution
REQ-SRD-044	Relative spectrophotometry
REQ-SRD-045	Sky subtraction, continuum
REQ-SRD-046	Sky subtraction, emission lines
Requirements relating to Lifetime Operations	
REQ-SRD-051	Accessible sky
REQ-SRD-052	Observing efficiency
REQ-SRD-053	Observatory lifetime
Requirements relating to Data Management and Processing	
REQ-SRD-061 ++	

3.2 Individual Requirements

Each science requirement is described in detail in this section. Each requirement contains the following information: (i) the ID for the requirement identification number

(ii) the name of the requirement (iii) the details for the requirement (iv) the justification of the requirement with explicit description of its scientific origin, and reference to the relevant SRO(s) and/or the appropriate section of the DSC (by definition, every science requirement is traceable to the DSC) (v) any other relevant information pertaining to the requirement in order to provide a complete understanding of its intent.

3.2.1 REQ-SRD-011 Low spectral resolution

[REQ-SRD-011] MSE shall provide a mode with an average spectral resolution of 2500 <= R <= 3000 at optical wavelengths (lambda<950nm, TBC), with a minimum resolution of R>2000 in this range, and a minimum spectral resolution of at least R=3000 (*Goal: R=5000*) at near infrared wavelengths (lambda>950nm, TBC).

Justification: Resolution set by measurement of redshifts and by AGN reverberation mapping case with nominal velocity of 100km/s. Resolution needed in the NIR to observe between the bright sky lines.

Notes: (i) Spectral resolution is defined as lambda/d(lambda). d(lambda) is the full width at half maximum of a Gaussian fitted to an unresolved spectral line on the extracted spectrum that has a wavelength of lambda. (ii) At optical wavelengths, this spectral resolution refers to an average value. At NIR wavelengths (lambda > ~950nm), this spectral resolution refers to a minimum value (R>3000 needed to observe between bright sky lines in the NIR). (iii) This mode will hereafter be referred to as "low". It is a key mode of operation that will account for most of the dark time science.

3.2.2 REQ-SRD-012 Moderate spectral resolution

[REQ-SRD-012] MSE shall provide a mode with an average spectral resolution of 5000 <= R < = 7000 in each wavelength window, with a minimum spectral resolution within the window of R>4500.

Justification: Resolution set by need to get velocities of stars in local group, stellar population analysis of nearby galaxies science cases, and by study of the IGM.

Notes: (i) Spectral resolution is defined as lambda/d(lambda). d(lambda) is the full width at half maximum of a Gaussian fitted to an unresolved spectral line on the extracted spectrum that has a wavelength of lambda. (ii) The spectral resolution refers to an average value in each wavelength window. (iii) It is expected that this mode will be used during bright time and dark time depending on the science. (iv) This mode will hereafter be referred to as "moderate".

3.2.3 REQ-SRD-013 High spectral resolution

[REQ-SRD-013] MSE shall provide a mode with an average spectral resolution of 38000 <= R <= 42000 in each wavelength window, with a minimum spectral resolution within the window of R>35000.

Justification: Resolution set by stellar chemistry and Galactic archaeology science cases, in particular the ability to measure weak lines and to resolve lines in the blue (where blending is significant).

Notes: (i) Spectral resolution is defined as lambda/d(lambda). d(lambda) is the full width at half maximum of a Gaussian fitted to an unresolved spectral line on the extracted spectrum that has a wavelength of lambda. (ii) This mode will hereafter be referred to as "High". It is a key mode of operation that will account for a large fraction of the bright time science.

3.2.4 REQ-SRD-021 Etendue

[REQ-SRD-021] MSE shall have an effective etendue equal to or greater than 117m^2degrees^2, and a science field of view from which targets can be selected that has a shape that can be tiled in a regular pattern and which has an area not less than 1 square degree.

Justification: MSE must conduct surveys spanning areas of up to several tens of thousands of square degrees, thus a large field of view and large etendue are essential.

Notes: (i) There is flexibility in the acceptable field of view so long as the field is sufficiently large to allow a large area to be covered. (ii) A regular shaped FoV is required in order to facilitate survey planning/tiling. (iii) An etendue of 117m2degrees2 corresponds to an effective circular aperture of 10m and an effective FOV of 1.5 square degrees. (iv) The phrase "from which targets can be selected" specifically implies that any target at any point in the FoV is potentially accessible for observing.

3.2.5 REQ-SRD-022 Multiplexing at low resolution

[REQ-SRD-022] In low resolution mode, MSE shall be able to obtain spectra for the greater of (a) 3200 objects, or (b) the equivalent of 0.593 objects/sq.arcmin, averaged over the field of view from which targets can be selected, per exposure.

Justification: Low resolution mode will be primarily used in dark time to study galaxies. The source density of galaxies at z<0.2 brighter than i=23 is 2100/sq.degree (with a variance of ~30%), or 3150 per 1.5 square degrees (Balogh's SRO). However, without any pre-selection, the galaxy source density at i<23 is high, and this drives us to as high a degree of multiplexing as possible. Therefore the stated multiplexing is a minimum value and higher values are preferable (as close to 1 per sq. arcmin as possible).

Notes: (i) 0.593 spectra/sq.arcmin corresponds to 3200 spectra in a 1.5 square degree field of view. In reality, sources are not smoothly distributed. Some potential targets will be close to each other, and the ability to observe targets close together in the same exposure will increase efficiency. (ii) Without any pre-selection, the galaxy source density at i<23 is high, and this drives us to as high a degree of multiplexing as possible. Therefore the stated multiplexing is a minimum value and higher values are preferable (as close to 1 per sq. arcmin as possible). (iii) Sky fibers (and other calibration fibers) are not explicitly included in the multiplexing requirement. It is envisioned, however, that for almost all viable multiplexing solutions, 100% of fibers will not be able to be assigned to science targets. Thus, these fibers will be allocated to sky.

3.2.6 REQ-SRD-023 Multiplexing at moderate resolution

[REQ-SRD-023] At moderate resolution, MSE shall be able to obtain spectra for the greater of (a) 3200 objects, or (b) the equivalent of 0.593 objects/sq.arcmin, averaged over the field of view from which targets can be selected, per exposure.

Justification: The source density of galaxies at z<0.2 brighter than i=23 is ~2100/sq.degree (with a variance of ~30%), or ~3150 per 1.5 square degrees.

Notes: (i) Moderate resolution will be used for both galaxy stellar populations and resolved stars in the nearby Universe. Galaxies set the higher multiplexing constraint. (ii) 0.593 spectra/sq.arcmin corresponds to 3200 spectra in a 1.5 square degree field of view. In reality, sources are not smoothly distributed. Some potential targets will be close to each other, and the ability to observe targets close together in the same exposure will increase efficiency. (iii) Without any pre-selection, the galaxy source density at i<23 is high, and this drives us to as high a degree of multiplexing as possible. Therefore the stated multiplexing is a minimum value and higher values are preferable (as close to 1 per sq. arcmin as possible. (iv) Sky fibers (and other calibration fibers) are not explicitly included in the multiplexing requirement. It is envisioned, however, that for almost all viable multiplexing solutions, 100% of fibers will not be able to be assigned to science targets. Thus, these fibers will be allocated to sky.

3.2.7 REQ-SRD-024 Multiplexing at high resolution

[REQ-SRD-024] At high resolution, MSE shall be able to obtain spectra for the greater of (a) 1000 objects, or (b) the equivalent of 0.185 objects/sq.arcmin, averaged over the field of view from which targets can be selected, per exposure.

Justification: MSE must be able to obtain spectra of millions of stars. The source density of thick disk and halo stars at high Galactic latitude in the magnitude range 17<g<21 is ~700 sq/deg, or ~1000 per 1.5 square degree (Besançon model)

Notes: (i) The bright magnitude limit ensures that all targets for MSE are too faint to be studied using 4m-class facilities. (ii) MSE focuses on studies of the thick disk and halo since excellent studies of the thin disk can be accomplished using 4m-class facilities. (iii) 0.185 spectra/sq.arcmin corresponds to 1000 spectra over a 1.5 sq.degree field of view (iv) Sky fibers (and other calibration fibers) are not explicitly included in the multiplexing requirement. It is envisioned, however, that for almost all viable multiplexing solutions, 100% of fibers will not be able to be assigned to science targets. Thus, these fibers will be allocated to sky.

3.2.8 REQ-SRD-025 Spatially resolved spectra

[REQ-SRD-025] During the lifetime of MSE, MSE shall be able to provide a multi-object integral field capability, to obtain spatially resolved spectral data on targets that subtend many arcseconds on the sky, with parameters TBD.

Justification: MSE will have the capability to provide multi-object Integral Field Units to address key science cases for spatially resolved targets.

Notes: (i) The IFU mode requires detailed analysis to decide upon the optimal arrangement (especially, number of spectra per target versus number of targets).
(ii) The IFU mode is not anticipated as a first light capability, but allowance must be made for including this capability at a future point in the design.

3.2.9 REQ-SRD-031 Spectral coverage at low resolution

[REQ-SRD-031] In the low resolution mode, MSE shall provide the following two, critically-sampled, spectral coverage options: (a) continuous spectral coverage from 360nm to 1300nm, in a single exposure (the “J-band” mode), and (b) continuous coverage from 360nm to 950nm (TBC) and from 1500 to 1800nm in a single exposure (the “H-band” mode).
(Goal and lifetime requirement: optical + J-band + H-band simultaneously)

Justification: (i) MSE must have good sensitivity to OII3727A (numerous extra-galactic science cases). (ii) A large number of chemical species have lines shortward of 400nm, and sensitivity to these features is important for estimates of the metallicity. (iii) In the low resolution mode, MSE must be able to derive redshifts and identify the same features in galaxies at a range of redshifts. The NIR cut-off is therefore set by the redshift out to which certain features can be identified. In practice, the cut-off is set by technical and financial limitations, not by clear science thresholds. (iv) J and H are required for the high redshift objects. Ideally, both bands will be observed simultaneously, although at first light it is acceptable if only a single band is observable at once.

Notes: (i) Due to the difficulties of optimisation of optics to 360nm, and the inevitable compromises this will entail for performance at other wavelengths, MSE will be sensitive to 360nm but its performance will be optimised for wavelengths longer than 370nm. MSE will conduct its primary scientific analysis on wavelengths longer than 370nm, with some limited science analysis occurring for wavelengths between 360 - 370nm. (ii) The long wavelength cut-off of MSE (~1.8um) is not a hard limit, and some small variation around this number is potentially acceptable.

[Comments: During the Conceptual Design the feasibility of including the H-band (or some fraction thereof) will be examined. Once the cost and risk of this capability are known, changes in this requirement may be sought, if necessary]

3.2.10 REQ-SRD-032 Spectral coverage at moderate resolution

[REQ-SRD-032] In the moderate resolution mode, MSE shall provide coverage in one or more spectral windows selected from the range 360 – 950 (TBC) nm that together provide a total bandwidth of at least 250nm and that contain the wavelength interval 845 – 885nm.

Justification: (i) Moderate spectral resolution is required for stellar population analyses of unresolved (brighter) galaxies and for chemical abundance and radial velocity studies of faint stars. (ii) Broad wavelength coverage is required in order to access as many spectral features as possible to support these analyses. (ii) The region from 845 - 885 nm is required to access the CaII Triplet region [8498, 8542, 8662A], MgI 8806 (gravity-sensitive), and a large number of Fe lines and alpha elements, necessary for nearby resolved stellar population analysis.

Notes: (i) Due to the difficulties of optimisation of optics to 360nm, and the inevitable compromises this will entail for performance at other wavelengths, MSE will be sensitive to 360nm but its performance will be optimised for wavelengths longer than 370nm. (ii) The wavelength coverage need not be contiguous.

3.2.11 REQ-SRD-033 Spectral coverage at high resolution

[REQ-SRD-033] In the high resolution mode, MSE shall provide critically sampled spectral coverage in at least two *(Goal >= three)* wavelength windows selected from the range 360 – 900nm that can be adjusted over the lifetime of MSE.

Justification: In the high resolution mode, MSE must be able to measure the abundances of a large number of chemical species and multiple wavelength windows are required in order to sample a range of chemical species.

Notes: (i) In the high resolution mode, all major scientifically interesting features at high resolution are at wavelengths shorter than 900nm. (ii) The sizes of the wavelength windows have not been specified to allow for latitude in the design. However, it is expected that the windows will be as large as is possible given large format detectors.

[Comments: During the Conceptual Design Phase, the spectral coverage per arm and the cost per arm will be investigated. Once known, the Science Team will advise on the number of arms that are required for that design and the Project Office will decide if this requirement should be modified.]

3.2.12 REQ-SRD-034 Sensitivity at low resolution

[REQ-SRD-034] In the low resolution mode, an extracted spectrum from MSE taken in the observing conditions described below shall have a signal to noise ratio per resolution element at a given wavelength that is greater than or equal to two for a 1 hour observation of a point source with a flux density of 9.1 x 10^-30 ergs/sec/cm2/Hz at that wavelength, for all wavelengths longer than 400nm. Between 370 - 400nm, the SNR shall not be less than one at any wavelength. The observing conditions in which this requirement shall be met correspond to a sky brightness of 20.7mags/sq.arcsec in the V-band and a natural seeing condition of 0.8 arcseconds in the r band, at an airmass of 1.2.

Justification: Accurate redshifts require a signal to noise ratio of a few. The ability to measure a redshift of an i=24 target in a period of 1 hour is necessary for efficiently completing several of the high redshift SROs (especially, highz-SRO1).

Notes: This requirement corresponds to an observation of an astrophysical source with a monochromatic AB magnitude of m=24.

Relevant data files:

Optical sky background:
http://www.gemini.edu/sciops/ObsProcess/obsConstraints/atm-models/skybg_50_10.dat

Near IR sky background:

http://www.gemini.edu/sciops/telescopes-and-sites/observing-condition-constraints/ir-background-spectra#Near-IR-short (data files are mk_skybg_zm_16_10_ph.dat, mk_skybg_zm_16_15_ph.dat, mk_skybg_zm_16_20_ph.dat)

Atmospheric extinction:

http://www.gemini.edu/sciops/telescopes-and-sites/observing-condition-constraints/extinction

Near IR transmission spectra:

http://www.gemini.edu/sciops/telescopes-and-sites/observing-condition-constraints/ir-transmission-spectra

3.2.13 REQ-SRD-035 Sensitivity at moderate resolution

[REQ-SRD-035] In the moderate resolution mode, an extracted spectrum from MSE taken in the observing conditions described below shall have a signal to noise ratio per resolution element at a given wavelength that is greater than or equal to two for a 1 hour observation of a point source with a flux density of 1.4 x 10^-29 ergs/sec/cm2/Hz at that wavelength, for all wavelengths longer than 400nm. Between 370 - 400nm, the SNR shall not be less than one at any wavelength in the relevant window. The observing conditions in which this requirement shall be met correspond to a sky brightness of 20.7mags/sq.arcsec in the V-band and a natural seeing condition of 0.8 arcseconds in the r band, at an airmass of 1.2.

Justification: Accurate redshifts require a signal to noise ratio of a few. The ability to measure a redshift of an i=23.5 target in a period of 1 hour is necessary for efficiently completing several SROs.

Notes: This requirement corresponds to an observation of an astrophysical source with a monochromatic AB magnitude of m=23.5.

Relevant data files:

Optical sky background:
http://www.gemini.edu/sciops/ObsProcess/obsConstraints/atm-models/skybg_50_10.dat

Near IR sky background:

http://www.gemini.edu/sciops/telescopes-and-sites/observing-condition-constraints/ir-background-spectra#Near-IR-short (data files are mk_skybg_zm_16_10_ph.dat, mk_skybg_zm_16_15_ph.dat, mk_skybg_zm_16_20_ph.dat)

Atmospheric extinction:

http://www.gemini.edu/sciops/telescopes-and-sites/observing-condition-constraints/extinction

Near IR transmission spectra:

http://www.gemini.edu/sciops/telescopes-and-sites/observing-condition-constraints/ir-transmission-spectra

3.2.14 REQ-SRD-036 Sensitivity at high resolution

[REQ-SRD-014] In the high resolution mode in any wavelength window observed over the lifetime of MSE, an extracted spectrum from MSE taken in the observing conditions described below shall have a signal to noise ratio per resolution element at a given wavelength that is greater than or equal to ten for a 1 hour observation of a point source with a flux density of 3.6 x 10^-28 ergs/sec/cm2/Hz at that wavelength, for all wavelengths in the relevant window longer than 400nm. Between 370 – 400nm, the SNR shall not be less than five at any wavelength in the relevant window. The observing conditions in which this requirement shall be met correspond to a sky brightness of 19.5mags/sq.arcsec in the V-band and a natural seeing condition of 0.8 arcseconds in the r band, at an airmass of 1.2.

Justification: High SNR are required for faint targets in order to robustly derive chemical abundance information.

Notes: This requirement corresponds to an observation of an astrophysical source with a monochromatic AB magnitude of m=20.

Relevant data files:

Optical sky background:
http://www.gemini.edu/sciops/ObsProcess/obsConstraints/atm-models/skybg_50_10.dat

Near IR sky background:

http://www.gemini.edu/sciops/telescopes-and-sites/observing-condition-constraints/ir-background-spectra#Near-IR-short (data files are mk_skybg_zm_16_10_ph.dat, mk_skybg_zm_16_15_ph.dat, mk_skybg_zm_16_20_ph.dat)

Atmospheric extinction:

http://www.gemini.edu/sciops/telescopes-and-sites/observing-condition-constraints/extinction

Near IR transmission spectra:

http://www.gemini.edu/sciops/telescopes-and-sites/observing-condition-constraints/ir-transmission-spectra

3.2.15 REQ-SRD-041 Velocities at low resolution

[REQ-SRD-041] For any object with a known velocity, observed at multiple epochs by MSE with up to a 5 year cadence with a signal to noise ratio per resolution element of 5 at low spectral resolution, the contribution from MSE to the rms difference between the known velocity of the object and the measured velocity of the object shall be less than or equal to 20km/s, and shall have no systematic dependence on the wavelength region of the spectrum that is used to the level of 5km/s (TBC) (provided suitable features exist, i.e., any strong absorption or emission lines).

Justification: Accurate redshifts of galaxies at high z.

Notes: This velocity accuracy is the intrinsic velocity of this mode at this SNR and requires that there are no systematic errors in the wavelength calibration across the wavelength range.

3.2.16 REQ-SRD-042 Velocities at moderate resolution

[REQ-SRD-042] For any object with a known velocity, observed at multiple epochs by MSE with up to a 5 year cadence with a signal to noise ratio per resolution element of 5 at moderate spectral resolution, the contribution from MSE to the rms difference between the known velocity of the object and the measured velocity of the object shall be less than or equal to 9km/s, and shall have no systematic dependence on the wavelength region of the spectrum that is used to a level of 1km/s (TBD) (providing suitable features exist, i.e., any strong absorption or emission line).

Justification: Accurate velocities for stars in the Local Group.

Notes: This velocity accuracy is the intrinsic velocity of this mode at this SNR and requires that there are no systematic errors in the wavelength calibration across the wavelength range.

3.2.17 REQ-SRD-043 Velocities at high resolution

[REQ-SRD-043] For a radial velocity standard star, observed at multiple epochs by MSE with up to a 5 year cadence with a signal to noise ratio per resolution element of 30 at high spectral resolution, the contribution from MSE to the rms difference between the known velocity of the object and the measured velocity of the object shall be less than or equal to 0.1km/s (TBC).

Justification: This velocity accuracy allows us to distinguish if stars are velocity variable, potentially indicating the presence of a companion (either a binary star or planet).

Notes: (i) This velocity accuracy is higher than the "intrinsic" accuracy of this mode (~3E5/30000) / 30 = 333m/s and will rely on the use of multiple lines simultaneously to derive velocities. (ii) Need a better science case to demonstrate importance of high resolution velocity accuracy

3.2.18 REQ-SRD-044 Relative spectrophotometry

[REQ-SRD-044] For a spectrophotometric standard star, observed in the low resolution mode at multiple epochs by MSE with up to a 5 year cadence with a signal to noise ratio per resolution element of 30, the rms variation in the ratio of fluxes measured in any two wavelength intervals shall be less than 3% of the mean measured value.

Justification: This requirement is specifically necessary for AGN reverberation mapping studies; spectrophotometry is also required for stellar population studies of nearby galaxies at low and moderate spectral resolution. It is anticipated that meeting this specific requirement will also allow MSE to satisfy the spectrophotometric needs of this additional science case.

Notes: (i) Relative spectrophotometry is defined as the ratio between two fluxes. (ii) We anticipate testing this requirement by observing many spectrophotometric standards in many fields over multiple epochs. After a relative flux correction, the rms variation of the difference between the actual relative flux of the target and the measured relative flux values should be less than or equal to 3%.

3.2.19 REQ-SRD-045 Sky subtraction, continuum

[REQ-SRD-045] In wavelength intervals free from airglow emission-line contamination and strong telluric absorption, MSE shall allow for removal of (100 +/- 0.5)% of the sky flux **(TBC).**

Justification: (i) This is pushing the limits of the best sky subtraction using fibers that can currently be achieved. (ii) Requires advanced analysis (e.g. PCA); See Sharp & Parkinson 2010.

3.2.20 REQ-SRD-046 Sky subtraction, emission lines

[REQ-SRD-046] MSE shall achieve a sky subtraction accuracy for atmospheric airglow emission-lines such that the mean residual error for spectral pixels, within 1 resolution element of known atmospheric emission-lines, is **<N.n** times **(TBD)** the Poisson limit indicated by the propagated variance spectrum for each resolution element.

Justification: (i) This is pushing the limits of the best sky subtraction using fibers that can currently be achieved. (ii) Requires advanced analysis (e.g. PCA); See Sharp & Parkinson 2010.

3.2.21 REQ-SRD-051 Accessible sky

[REQ-SRD-051] MSE shall conduct its primary science objectives on astrophysical targets located at declinations greater than -30 degrees, with a limited number of science observations occurring for astrophysical targets located at declinations between -30 and -40 degrees.

Justification: MSE must be able to access a large fraction of the southern hemisphere to follow up survey facilities based in the south.

Notes: Declination of -40 corresponds to airmass of 2, and declination of -30 degrees corresponds to an airmass of ~1.55.

3.2.22 REQ-SRD-052 Observing efficiency

[REQ-SRD-052] Excluding adverse weather conditions, MSE shall spend at least 90% (TBC) of the night observing science targets (open shutter time).

Justification: TBC

Notes: NEED INPUT FROM OPERATIONS

3.2.23 REQ-SRD-053 Observatory lifetime

[REQ-SRD-053] MSE shall be able to operate for at least 20 years.

Justification: TBC

Notes: NEED INPUT FROM OPERATIONS

3.2.24 REQ-SRD-061++ Data processing and management

Figure 1: Science traceability matrix cross referencing science requirements to science reference observations (SROs). In addition to the notes in each cell, the colors indicate the level of importance for each SRO (green=very important, yellow = some importance, white = not important). [Template only]