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Science-based requirements and operations development for the Maunakea Spectroscopic Explorer

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ABSTRACT

MSE is a wide field telescope (1.5 square degree field of view) with an aperture of 11.25m. It is dedicated to multi-object spectroscopy at several different spectral resolutions in the range $R \sim 2500 - 40000$ over a broad wavelength range ($0.36 - 1.8\mu m$). MSE enables transformational science in areas as diverse as exoplanetary host characterization; stellar monitoring campaigns; tomographic mapping of the interstellar and intergalactic media; the in-situ chemical tagging of the distant Galaxy; connecting galaxies to the large scale structure of the Universe; measuring the mass functions of cold dark matter sub-halos in galaxy and cluster-scale hosts; reverberation mapping of supermassive black holes in quasars. Here, we summarize the Observatory and describe the development of the top level science requirements and operational concepts. Specifically, we describe the definition of the Science Requirements to be the set of capabilities that allow certain high impact science programs to be conducted. We cross reference these science cases to the science requirements to illustrate the traceability of this approach. We further discuss the operations model for MSE and describe the development of the Operations Concept Document, one of the foundational documents for the project. We also discuss the next stage in the science based development of MSE, specifically the development of the initial Legacy Survey that will occupy a majority of time on the telescope over the first few years of operation.

Keywords: Astronomical facilities, multiplexing, spectroscopy, operations, requirements

1. INTRODUCTION

The Maunakea Spectroscopic Explorer (MSE) has a unique and critical role in the emerging network of international astronomical facilities. As the largest ground based optical and near-infrared telescope aside from the TMT, the E-ELT and GMT (we refer to these facilities collectively as the Very Large Optical Telescopes, VLOTs), its wide field will be dedicated to highly multiplexed spectroscopy at a broad range of spectral resolutions. MSE is designed to enable transformational science in areas as diverse as tomographic mapping of the interstellar and intergalactic media; the in-situ chemical tagging of thick disk and halo stars; connecting galaxies to their large scale structure; measuring the mass functions of cold dark matter sub-halos in galaxy and cluster-scale hosts; reverberation mapping of supermassive black holes in quasars; next generation cosmological surveys using redshift space distortions and peculiar velocities. MSE is an essential follow-up facility to current and next generations of multi-wavelength imaging surveys, including LSST, Gaia, Euclid, WFIRST, PLATO, and the SKA, and is designed to complement and go beyond the science goals of other planned spectroscopic capabilities like VISTA/4MOST, WHT/WEAVE, AAT/HERMES and Subaru/PFS. It is an essential feeder facility for the VLOTs, namely E-ELT, TMT and GMT, and provides the missing link between wide field imaging and small field precision astronomy. Figure 1 shows some of the main synergies of MSE with other major facilities in the 2020s.

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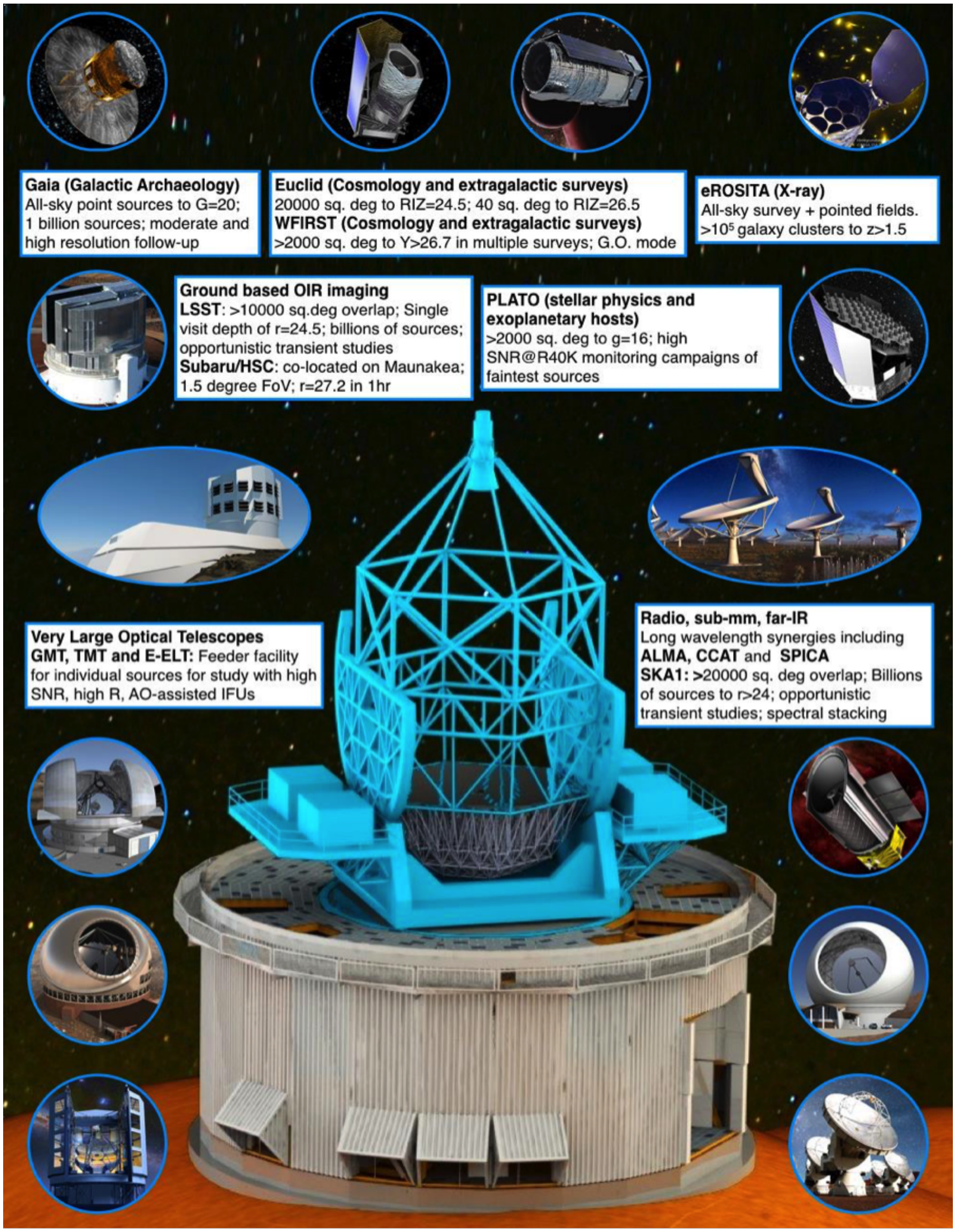

Figure 1. MSE and other prominent astronomical facilities in the 2020s and beyond. The number and type of astrophysical targets accessible to MSE are described in the inset panels.

MSE is the realization of the long-held ambition of the international astronomy community for highly multiplexed, large aperture, optical and near-infrared spectroscopy on a dedicated facility. Such a facility is the most glaringly obvious and important missing capability in the international portfolio of astronomical facilities. MSE is a refurbishment of the CFHT, upgraded to an aperture of 11.25m (for discussion of the redevelopment process, see the presentation by Murowinski et al.[3]) It has a 1.5 square degree field of view that will be fully dedicated

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to multi-object spectroscopy. 3200 or more fibers will feed spectrographs operating at low ($R \sim 2000 - 3500$) and moderate ($R \sim 6000$) spectral resolution, and approximately 1000 fibers will feed spectrographs operating at high ($R \sim 40000$) resolution. At low resolution, the entire optical window from $360 - 950$nm and the near infrared J and H bands will be accessible, and at moderate and high resolutions windows with the optical range will be accessible. The entire system is optimized for high throughput, high signal-to-noise observations of the faintest sources in the Universe with high quality calibration and stability being ensured through the dedicated operational mode of the observatory. The discovery efficiency of MSE is an order of magnitude higher than any other spectroscopic capability currently realized or in development. Figure 2 is a rendering of a cut-away of MSE showing the system architecture and major subsystems.

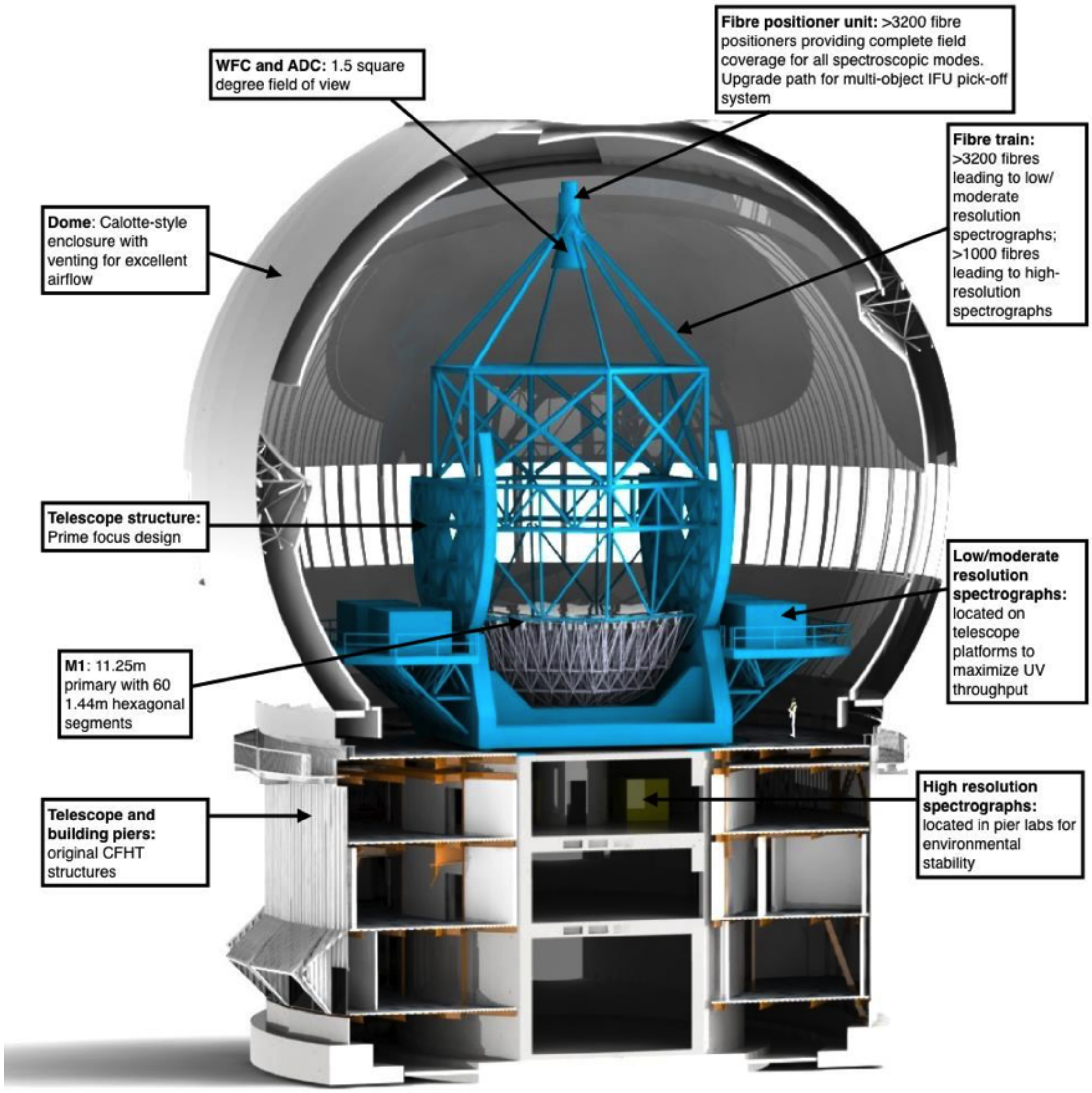

Figure 2. Cut away of MSE revealing the system architecture and major subsystems.

MSE builds on the success of the SDSS concept, but is realized on a facility with ~ 20 times larger aperture located at possibly the world's best telescope site. The diverse science enabled by MSE spans all astronomy, from planet formation, the microphysics of stars and the interstellar medium through to the dynamics of dark matter and the physics of black holes. What are the key capabilities of MSE that facilitate this impact and diversity,

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and how does it compare to other spectroscopic resources? Figure 3 shows the relevant scientific capabilities of MSE. Defining science capabilities include:

Accessible sky	30000 square degrees (airmass<1.55)						
Aperture (M1 in m)	11.25m						
Field of view (square degrees)	1.5						
Etendue = FoV x π (M1 / 2)^2	149						
Modes	**Low**		**Moderate**	**High**			**IFU**
Wavelength range	0.36 - 1.8 µm		0.36 - 0.95 µm	0.36 - 0.95 µm ♯			IFU capable; anticipated second generation capability
	0.36 - 0.95 µm	J, H bands		0.36 - 0.45 µm	0.45 - 0.60 µm	0.60 - 0.95 µm	
Spectral resolutions	2500 *(3000)*	3000 *(5000)*	6000	40000	40000	20000	
Multiplexing	>3200		>3200	>1000			
Spectral windows	Full		≈Half	λ_c/30	λ_c/30	λ_c/15	
Sensitivity	m=24 *		m=23.5 *	m=20.0 ♮			
Velocity precision	20 km/s ♪		9 km/s ♪	< 100 m/s ★			
Spectrophotometic accuracy	< 3 % relative		< 3 % relative	N/A			

♯ Dichoric positions are approximate
* SNR/resolution element = 2
♮ SNR/resolution element = 10
♪ SNR/resolution element = 5
★ SNR/resolution element = 30

Figure 3. Summary of major science capabilities of MSE.

- Survey speed and sensitivity: The etendue of MSE is > 2 larger than its closest 8m competitor (149 vs. 66 $m^2 deg^2$ for Subaru/PFS). MSE's sensitivity allows efficient observation of sub-$L\star$ galaxies to high redshift, and high resolution analysis of stars in the distant Galaxy. The excellent site image quality is essential to observe efficiently the faintest objects and to ensure the spectrograph optics are a reasonable size given the multiplexing demands.
- Dedicated and specialized operations: MSE's specialized capabilities enable a vast range of new science. Specialized observing modes allow time domain programs such as transient targeting, quasar reverberation mapping and precision stellar radial velocity monitoring. These require well-calibrated and stable systems only possible with dedicated facilities.
- Spectral performance: The extensive wavelength coverage of MSE from the UV to H-band uniquely enables the same tracers to be used to study galaxy and black hole growth at all redshifts to beyond cosmic noon. Chemical tagging with MSE can be conducted across the full luminosity range of Gaia targets, and operation at $R = 40000$ enables the identification of weak lines in the blue to access species sampling a diverse range of nucleosynthetic sites.

2. FROM SCIENCE TO REQUIREMENTS: MAPPING THE FLOWDOWN FOR MSE

The Detailed Science Case for MSE[1] provides extensive discussion of the anticipated science objectives of MSE, with the important caveat that it is impossible to predict how astrophysics will evolve over the next decade in response to discoveries and realizations that have not yet been made. It is not the purpose to describe the details of these science cases here, and the reader is referred to the Detailed Science Case for a complete description of the scientific roll that MSE will play in the 2020s and beyond. It is clear that diverse fields of research have converged in requiring dedicated large aperture multi-object spectroscopy, and it is clear that the capabilities of MSE will be a critical component of future lines of astronomical enquiry.

A key aspect of the science development of MSE are "Science Reference Observations" (SROs). These have been identified by the international science team and are defined as specific, detailed, science programs for MSE that are transformative in their fields and which are uniquely possible with MSE. This last point is particularly important given the large number of multi-object spectroscopic surveys current in development, and which are summarised in Figure 4. The SROs have been selected to span the range of anticipated fields in which MSE is expected to contribute, and they have been developed in considerable detail. They include:

- DSC-SRO-1, The characterization and environments of exoplanet hosts

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Class	Facility / Instrument	First light (anticipated)	Aperture (M1 in m)	Field of View (sq. deg)	Etendue	Multiplexing	Wavelength coverage (um)	Spectral resolution (approx)	IFU	Dedicated facility
Comparison	**SDSS I - IV**	Existing	2.5	1.54	7.6	640	0.38 - 0.92	1800	Yes	Yes
4-m	**Guo Shoujing / LAMOST**	Existing	4	19.6	246	4000	0.37 - 0.90	1000 - 10000	No	Yes
	AAT / HERMES	2015	3.9	3.14	37.5	392	windows	28000, 50000	No	No
	WHT / WEAVE	2017	4	3.14	39.5	1000	0.37 - 1.00	5000	Yes	Yes
							windows	20000		
	VISTA / 4MOST	2017	4	2.5	31.4	2400	0.39 - 0.95	5000	No	Yes
							windows	18000		
	Mayall / DESI	2018	4	7.1	89.2	5000	0.36 - 0.98	4000	No	Yes
8-m	**VLT / MOONS**	2018	8.2	0.14	7.4	1000	0.8 - 1.8	4000	No	No
							windows	20000		
	Subaru / PFS	2019	8.2	1.25	66	2400	0.38 - 1.26	2000	No	No
							0.71 - 0.89	5000		
10-m	**MSE**	2024	11.25	1.5	149	3468	0.36 - 1.8	3000	Second generation	Yes
							0.36 - 0.95 50% coverage	6500		
							windows	40000		

Figure 4. Summary of new optical and infrared multi-object spectroscopic instruments and facilities.

- DSC-SRO-2, Rare stellar types and the multi-object time domain
- DSC-SRO-3, Milky Way archaeology and the in situ chemical tagging of the outer Galaxy
- DSC-SRO-4, Stream kinematics as probes of the dark matter mass function around the Milky Way
- DSC-SRO-5, Dynamics and chemistry of Local Group galaxies
- DSC-SRO-6, Nearby galaxies and their environments
- DSC-SRO-7, Baryonic structures and the dark matter distribution in Virgo and Coma
- DSC-SRO-8, Evolution of galaxies, halos and structure over 12Gyrs
- DSC-SRO-9, The chemical evolution of galaxies and AGN over the past 10 billion years (z¡2)
- DSC-SRO-10, Mapping the inner parsec of quasars with MSE
- DSC-SRO-11, Connecting high redshift galaxies to their local environment: 3D tomographic mapping of the structure and composition of the IGM, and galaxies embedded within it
- DSC-SRO-12, Dynamics of the dark and luminous cosmic web during the last three billion years

More detail on individual SROs are available as Appendices to the Detailed Science Case*. The Science Requirements for MSE – i.e., the highest level design requirements for the facility – are defined as the suite of capabilities necessary for MSE to carry out these observations. The MSE architecture and technical requirements flow directly from, and deliver the capability described within, the Science Requirements. Figure 5 shows the science development procedure for MSE, and its relation to the key documents that define the design of MSE.

We expect that many of the identified SROs will be precursors to observing programs that MSE will carry out. However, it is not necessarily the case that this is so, since come first light of the facility, a new set of forefront science topics might have emerged that the users of MSE will want to address. Nevertheless, the suite of capabilities that MSE will have, in response to the SROs, will ensure that MSE is at the cutting edge of astronomical capabilities in 2025 and beyond.

Figure 6 cross references each SRO to each of the high level MSE science requirements. The science requirements are described and discussed in detail in the MSE Science Requirements Document†. The traceability of

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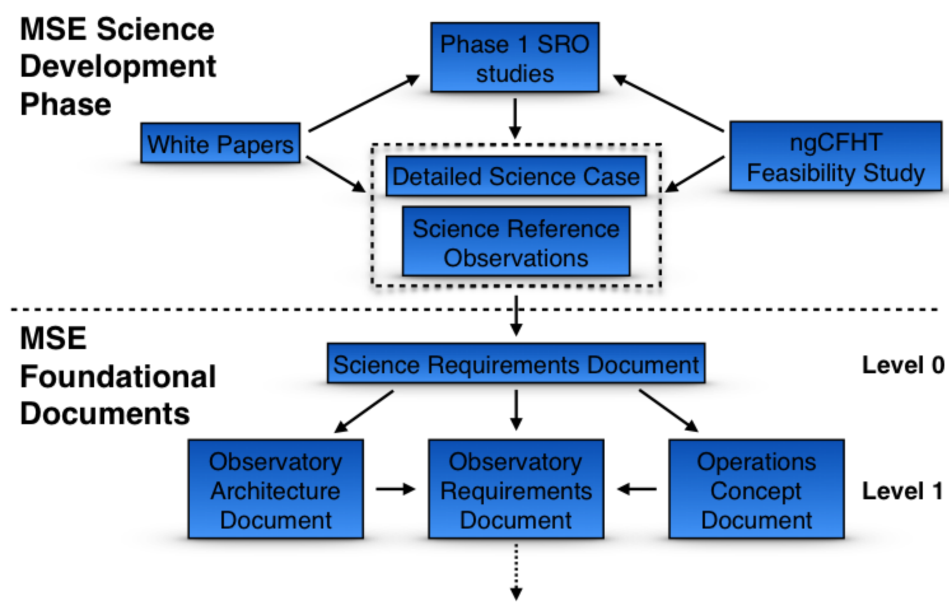

Figure 5. Overview of the science development process to date for MSE, including the relationships to the main documents that define the design of MSE.

the science requirements to individual SROs is essential to facilitate scientifically informed trade studies as the project develops.

MSE outperforms all other facilities by a wide margin for both high and low resolution science given the high level science requirements that define its capabilities, as can be seen from inspection of some of the metrics listed in Figure 4. However, given the uncertainties inherent in attempting to compare a large number of disparate facilities through a single metric, it is illustrative to consider the performance of the instruments listed in Figure 6 as it relates to specific science goals:

- At low resolution, consider DSC-SRO-10, that will map the accretion processes occurring within the inner parsec of quasars through a large-scale reverberation mapping campaign. This program requires good SNR observations of a large number of relatively faint quasars at low/moderate resolution over an extended period of time. 10m class telescopes are therefore essential. At low redshift, many of the diagnostics to be monitored are in the optical region prior to being redshifted into the NIR, and so a large wavelength range is necessary. Only MSE and Subaru/PFS are therefore capable of this science, although the narrower wavelength range of Subaru/PFS means such studies are more limited in redshift space. Critical to this science, however, is accurate spectrophotometry and calibration, to be able to compare observations separated by up to 5 years in duration. Such precise observations are a strength of a dedicated, specialized facility where the entire system is optimized and stable, and is much more difficult to achieve for a facility instrument such as Subaru/PFS that moves on and off the telescope at regular intervals;
- At high resolution, consider DSC-SRO-04 that will measure the cold dark matter sub-halo mass function of the Galaxy through precision velocity measurements of stars in tidal streams in the halo. Such observations

[*] Available at http://mse.cfht.hawaii.edu/docs/
[†] Available at http://mse.cfht.hawaii.edu/docs/

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require high SNR observations of very faint stars ($g > 20$), in order to be able to have the statistics necessary to probe the kinematic substructure of very diffuse and distant structures. Moderate or high resolution observations on 10m class facilities are required, and these additionally provide important metallicity diagnostics in order to isolate the populations of interest. In addition, however, data spanning hundreds or thousands of square degrees are required due to the very extended nature of the streams being probed, and in order to probe multiple streams at different locations in the Galactic halo. Field of view and multiplexing capabilities are essential. MSE is therefore the only instrument that can conduct this science program.

3. THE OPERATIONAL CONCEPT OF MSE

3.1 Development of the Operational Concept Document

As described in Figure 5, the Operational Concept Document (OCD) is a key foundational (Level 1) document in the system design hierarchy of MSE. Fundamentally, the OCD describes all aspects of the top level operational model of the Observatory, covering night-time science operations as well as daytime observatory maintenance. The OCD acts as the prime source for the hardware functional and performance requirements that need to be satisfied to enable the operations mode; will set requirements on the observation preparation software and data management, archiving and delivery system,;and sets the basis for operations cost estimate[‡].

Examples of the level of detail included in the OCD are:

- Description of the observation design process;
- Description of the post-processing, archive, data delivery;
- Description of any time-critical observing or data delivery needs;
- Detailed sequence of steps for gathering all necessary calibration data;
- Description of the sequence of events in a typical night, including but not limited to:
  - Detailed sequence of steps of observing one target field, from the start of slew to target to the start of slew to next target. This information is used to develop specifications on speeds and times;
  - List of metadata collected for the science and calibration data (i.e. FITS header information);
- Description of a typical day at the observatory, including but not limited to:
  - Maintenance procedures, data quality checks, etc.;
  - List of data collected for engineering maintenance;
- First order breakdown of the components of the observatory efficiency budget (i.e. distribute the overall availability into operational (availability, slewing and acquisition, engineering time, etc.);

Figure 7 is a flow-chart that illustrates the envisioned normal nighttime science operation of MSE. It starts at the end of daytime operations in the upper left corner and goes through to sunrise at the bottom of the chart. At this point, the dome is closed and the telescope is parked for the day crew to begin daytime operations. It includes multiple decision points (proceed with observations? select appropriate fields for observing, etc.) and shows the multiple interfaces between the survey teams (through the definition of target databases), data processing and archiving, as well as all the major subsystems of the telescope such as fiber positioners, acquisition and guiding, hexapod, etc.

[‡]In accordance with the adopted systems engineering model, the requirements will be traceable through the Observatory Requirements Document, and the cost estimate itself is part of the Operations Plan, although the OCD is the prime source of all this information.

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3.2 Survey development and data access

The science development activities described in this article and that have thus far been the primary focus of the MSE science team are geared towards definition of the functional and operational *capabilities* of MSE i.e., ensuring MSE has the capabilties to be able to conduct key science demanded by its users. The next phase of science development is now getting underway, and is focused toward design of specific surveys for MSE i.e., implementation of the science programs. This is also clearly linked to the development of operational procedures for the Observatory.

MSE is a dedicated spectroscopic survey facility for operation by its partner communities. The prime deliverable is data, obtained through one or more survey programs. At first light, baseline science operations anticipate a large legacy survey designed by the science team (comprised of a dark - extragalactic - and bright - Galactic - component) that will occupy all available observing time. Once in standard operation, observing time will be made available for additional strategic surveys of flexible scope. The impact, productivity, and allocations of legacy and strategic surveys will be reviewed continually to respond to community needs and science developments. The initial legacy survey to be conducted by MSE will be finalised prior to first light of the facility, with initial work starting in late 2016.

Data will be available immediately to the survey teams that work with the Observatory to provide data products for the MSE community on a short timescale. A significant proprietary period on science data enables the MSE community to use the data for frontline science before their worldwide release. The MSE community is served by their ability to propose for, design and lead ambitious survey programs, and by a rich archive of data accessible to MSE astronomers for scientific exploitation. It is expected that > 5 million astronomical spectra will be ingested into the archive on a yearly basis (roughly equivalent to a SDSS Legacy Survey every $3 - 4$ months). The scientific advantages provided to these communities are therefore significant.

The design of MSE foresees the need to upgrade components or instruments over the long lifetime of the Observatory and to respond to a changing scientific landscape. A multi-object integral field unit is already anticipated, and the top-end is designed to be upgradable to deliver this capability. MSE will remain the world's premier resource for astronomical spectroscopy: a specialized technical capability, and a general purpose science facility.

4. SUMMARY

The Maunakea Spectroscopic Explorer is undertaking an extensive science driven development procedure that ensures it will be a uniquely powerful astronomical facility that will impact diverse science areas from the mapping of the interstellar medium to the growth of supermassive black holes in galaxies. MSE has strong synergies with a plethora of major astronomical facilities that and as such will occupy a critical node in the future international network of astronomical facilities.

Science-based design work to date has resulted in the public release of the Detailed Science Case and the Science Requirements Document, and the Operational Concept Document will shortly be released in draft form. Together with the Observatory Requirements Document and Observatory Architecture Document, these define the foundations of the MSE design. A short 10 page description of MSE designed for the international astronomical community is given in McConnachie et al.[2]

More information on various aspects of MSE are available in these proceedings. Specifically:

1. The status of MSE from the perspective of a major astronomical site redevelopment project can be found in Murowinski et al.;[3]
2. An overview of the engineering development of MSE since the establishment of the Project Office can be found in Szeto et al.;[4]
3. The systems budget architecture of MSE is discussed in Mignot et al.;[5]
4. The calibration procedure and hardware concepts are shown in Flagey et al.;[6]

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5. Work to maximize the throughput of MSE is described in Flagey et al.;[7]
6. A description of the work to reuse the CFHT building and optimize it for MSE is given in Bauman et al.;[8]
7. Various elements of the optical design of MSE are discussed in Saunders et al.;[9]
8. The development of the software required for the MSE observatory is described in Vermeulen et al.;[10]
9. A conceptual design for the high resolution spectrograph is in Zhang et al.[11]

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			Resolved stellar sources					Extragalactic sources						
			DSC-SRO-01 Exoplanet hosts	DSC-SRO-02 Time domain stellar astrophysics	DSC-SRO-03 Chemical tagging in the outer Galaxy	DSC-SRO-04 CDM subhalos and stellar streams	DSC-SRO-05 Local Group galaxies	DSC-SRO-06 Nearby galaxies	DSC-SRO-07 Virgo and Coma	DSC-SRO-08 Halo occupation	DSC-SRO-09 Galaxies and AGN	DSC-SRO-10 The InterGalactic Medium	DSC-SRO-11 Reverberation mapping	DSC-SRO-12 Peculiar velocities
Spectral resolution	REQ-SRD-011	Low spectral resolution		R~2000 (white dwarfs)				R~3000	R~3000	R~2000-3000	R~3000		R~3000	R~1000-2000
	REQ-SRD-012	Intermediate spectral resolution		Any repeat observations	Essential, R~6500	Essential, R~6500	Essential, R~6500	Velocities of low mass galaxies	Velocities of low mass galaxies			R~5000		
	REQ-SRD-013	High spectral resolution	R>=40000	R>=20000	Essential, R~20-40K	Essential	Young stars		Bright globular clusters					
Focal plane input	REQ-SRD-021	Etendue	~2000 sq. deg @g=16	all-sky	1000s sq. deg; g~20.5@	1000s sq.deg, g~22 with high v accuracy	100s sq. deg, g~24	3200 (100) sq.deg, i<23 (24.5)	~100sq.deg, i<24.5	~1000sq.deg, i<24.5	~300 sq.deg, i<25	40 sq.deg, r<24.0	7 sq. deg, 5000 targets to i=23.25	all-sky
	REQ-SRD-022	Multiplexing at lower resolution						~5000 galaxies/sq. deg	100s targets (galaxies/GCs) / sq.deg	>5000 galaxies/sq. deg	770 galaxies/sq. deg		600AGN/deg	1000s galaxies/sq. deg
	REQ-SRD-023	Multiplexing at moderate resolution			1000s stars/sq.deg to g~23	1000s stars/sq.deg to g~23	few - thousands stars/sq. deg					500 galaxies/sq. deg		
	REQ-SRD-024	Multiplexing at high resolution	~100 stars/sq.deg @ g = 16	~1000 stars/sq.deg to g=20.5	~1000 stars/sq.deg to g=20.5	1000s stars/sq.deg to g~23								
	REQ-SRD-025	Spatially resolved spectra						Goal	Goal					Yes
Sensitivity	REQ-SRD-031	Spectral coverage at low resolution						0.37 - 1.5um	0.37 - 1.5um	0.36 - 1.8um	0.36 - 1.8um	0.36 - 1.8um (0.36 -	0.36 - 1.8um	Optical emission lines
	REQ-SRD-032	Spectral coverage at moderate resolution			Strong line diagnostics in optical	CaT essential	CaT essential	Goal: complete	Goal: complete			Goal: complete		
	REQ-SRD-033	Spectral coverage at high resolution	Strong lines for velocities; tagging	Strong lines for velocities	Chemical tagging	Strong lines for velocities								
	REQ-SRD-034	Sensitivity at low resolution						i=24.5	i=24.5	i=25.3	i=25 / H=24		i=23.25	i=24.5
	REQ-SRD-035	Sensitivity at moderate resolution			g>20.5	g~23	i=24	i=24.5	i=24.5			r~24		
	REQ-SRD-036	Sensitivity at high resolution	g=16 @high SNR	g=20.5	g=20.5	g~22								
Calibration	REQ-SRD-041	Velocities at low resolution						v~20km/s	v~20km/s	v~100km/s	v~20km/s		v~20km/s	v~20km/s
	REQ-SRD-042	Velocities at moderate resolution			v~1km/s	v~1km/s	v~5km/s	v~9km/s	v~9km/s			v~20km/s (10km/s goal)		
	REQ-SRD-043	Velocities at high resolution	v<100m/s	v~100m/s	v~100m/s	v<1km/s								
	REQ-SRD-044	Relative spectrophotometry						~4%					Critical:3%	
	REQ-SRD-045	Sky subtraction, continuum	few %	few %	few %	few %	<1%	<1%	<1%	<0.5%	<0.5%	<1%	<1%	<1%
	REQ-SRD-046	Sky subtraction, emission lines				important (CaT region)	important (CaT region)	critical	critical	critical	critical	critical	critical	
Operations	REQ-SRD-051	Accessible sky	Plato footprint (ecliptic)	Gaia footprint (all sky)	Gaia footprint (all sky)	Gaia, PS1, HSC footprint	Northern hemisphere (M31, M33, dec~+40)	LSST overlap useful (10000 sq.deg)	NGVS footprint; dec +12	LSST overlap useful (10000 sq.deg); Euclid (all sky)	LSST overlap useful (10000 sq.deg); Euclid (all sky)	LSST overlap useful (10000 sq.deg); Euclid (all sky)	all sky target distribution	all sky target distribution
	REQ-SRD-052	Observing efficiency	maximise	maximise	maximise	maximise	maximise	maximise	maximise	maximise	maximise	maximise	maximise	maximise
	REQ-SRD-053	Observatory lifetime	Monitoring >=years	Monitoring >=years	Survey >=5 years	Survey >=5 years	Survey ~100s nights	Survey ~ few years	Survey ~100s nights	Survey ~7 years	Survey ~100s nights	Survey ~100s nights	Monitoring ~5 years	Survey ~years

Figure 6. Science Reference Observations cross referenced to Science Requirements. Dark green boxes indicate import impacts of the SRO on the requirement; light green indicates moderate impact of the SRO on the requirement; grey indicates minimal or no impact of the SRO on the requirement.

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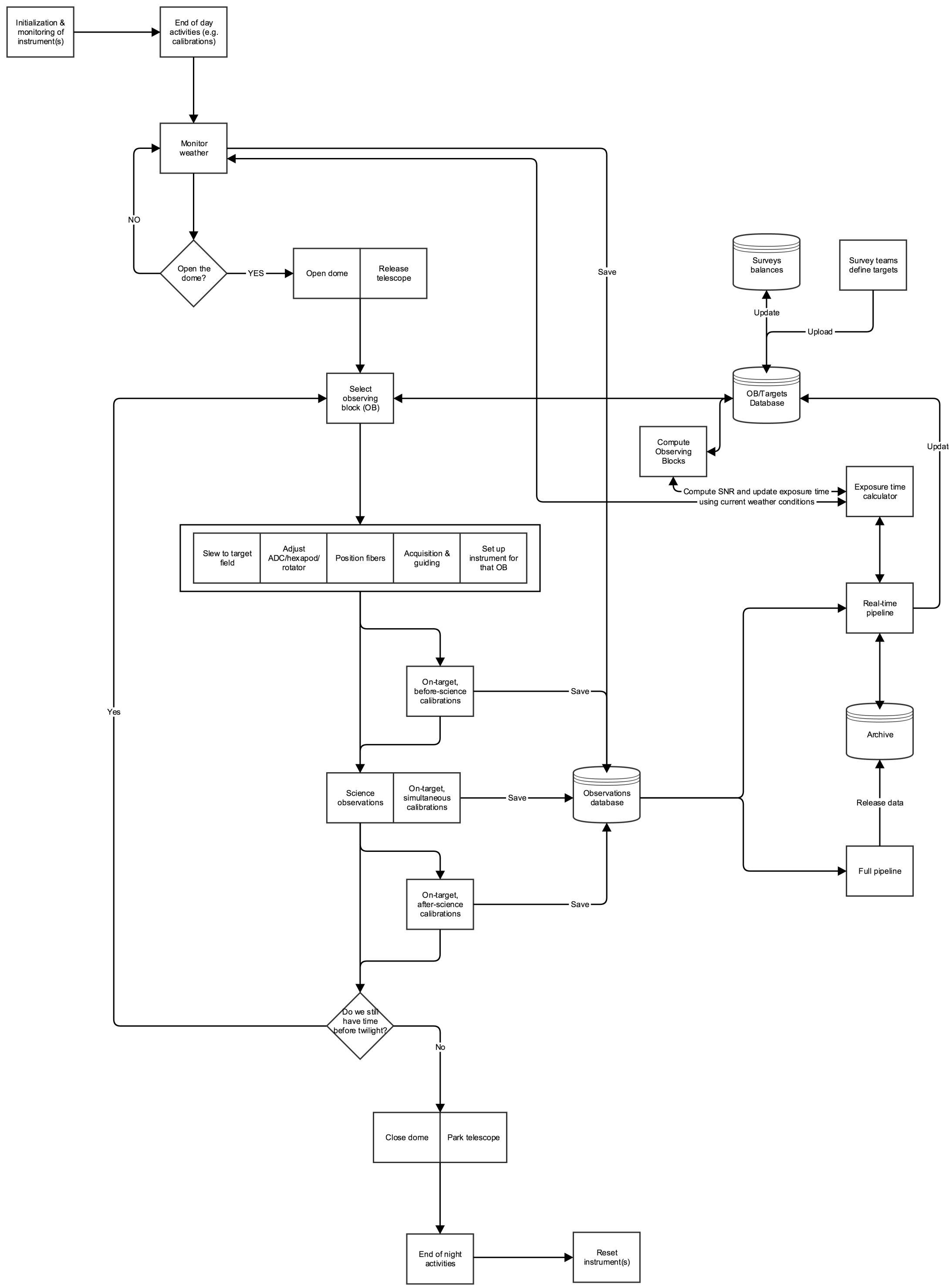

Figure 7. Flowchart showing illustrating the skeleton functional structure of a typical night observing with MSE, that forms the basis for much of the science-driven night-time operations of the Observatory, and which is described in full as a section of the Operational Concept Document.

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