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Planning of the Maunakea Spectroscopic Explorer Preliminary Design Phase in an Evolving Astronomy Landscape

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ABSTRACT

The Maunakea Spectroscopic Explorer project's preliminary design phase start coincides with planned and unplanned events in the national and international astronomy landscape. As the decade draws to a close, most MSE participants are undergoing national strategic planning for key future astronomical development. There are processes similar to the Decadal Survey on Astronomy and Astrophysics in the US. Much of the Project Office activities since our last 2018 report have been aligned in supporting these strategic plans. A vital activity related to the Maunakea Observatories (MKO), including the Canada France Hawaii Telescope (CFHT) Corporation and Maunakea Spectroscopic Explorer, is to secure future access to the mountain for astronomy as affected by the current protest over the Thirty Meter Telescope. Much of the MKO activities have been centered on ensuring the long-term success of astronomy on the mountain beyond 2033. However, the most significant unplanned activity has been managing progress through the ongoing COVID pandemic and anticipating its effects on the timeline and efficacy of upcoming national strategic planning recommendations for astronomy among other national priorities.

This paper provides a status report of MSE as it enters the preliminary design phase, and our plan to progress and manage changes in an evolving national and international astronomy landscape.

Keywords: spectroscopic facility, survey facility, Maunakea, observatory, upgrade, fiber, wide field, prime focus

1. INTRODUCTION

Maunakea Spectroscopic Explorer (MSE) is the first of the future generation of massively multiplexed spectroscopic facilities. MSE is designed to enable transformative science, being completely dedicated to large-scale multi-object spectroscopic surveys, each studying thousands to millions of astrophysical objects. MSE uses an 11.25 m aperture telescope to feed 4,332 fibers over a wide 1.52 square degree field of view. It will have the capabilities to observe at a range of spectral resolutions, from $R \sim 3,000$ to $R \sim 40,000$, with all spectral resolutions available at all times and across the entire field. As a dedicated survey facility, MSE is designed to efficiently execute a wide variety of scientific programs at the same time.

In our 2018 paper¹, we described the technical and programmatic status of the project as it emerges from the Conceptual Design Phase (CoDP) and our plan to progress the MSE Observatory design development toward the Preliminary Design Phase (PDP) in order to realize MSE's science ambitions. This paper is a status update of the MSE development as we prepare to enter the next PDP and describes our strategy to advance and manage changes in an evolving national and international astronomy landscape with a broader view of the activities for securing long-term success of astronomy for all observatories on the summit. This paper discusses the considerations and timeline required to support the tangible and regulatory steps being taken by University of Hawaii and MKO toward renewal of the Master Lease in various governmental and public engagements.

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2. OBSERVATORY BASELINE CONFIGURATION

Figure 1 illustrates the baseline observatory configuration at the end of the CoDP. The MSE Observatory is an Alt-Az mount telescope housed inside a calotte style enclosure. The enclosure's ventilation modules and the open-truss telescope structure maximize dome flashing and preserve the excellent free-atmosphere seeing, 0.4 arcseconds median seeing at 500 nm, at the CFHT site. MSE is a large aperture 10-m class facility utilizing a sixty segment primary mirror (M1). M1 delivers a 1.52 square degree, 0.584 m in diameter, focal surface through a wide-field corrector at prime focus. 4,332 tilting spine positioners populate the focal surface, and each carrying an optical fiber. A fiber transmission system feeds light from 1,083 fibers to the high resolution spectrographs in the 2nd floor pier lab Coude room, and 3,249 fibers to the low/moderate resolution spectrographs on the telescope instrument platforms. Both sets of fibers provide full field coverage for all spectral resolutions.

In addition, MSE plans to retrofit and reuse the CFHT facility building, enclosure and telescope piers without disturbing the current summit ground.

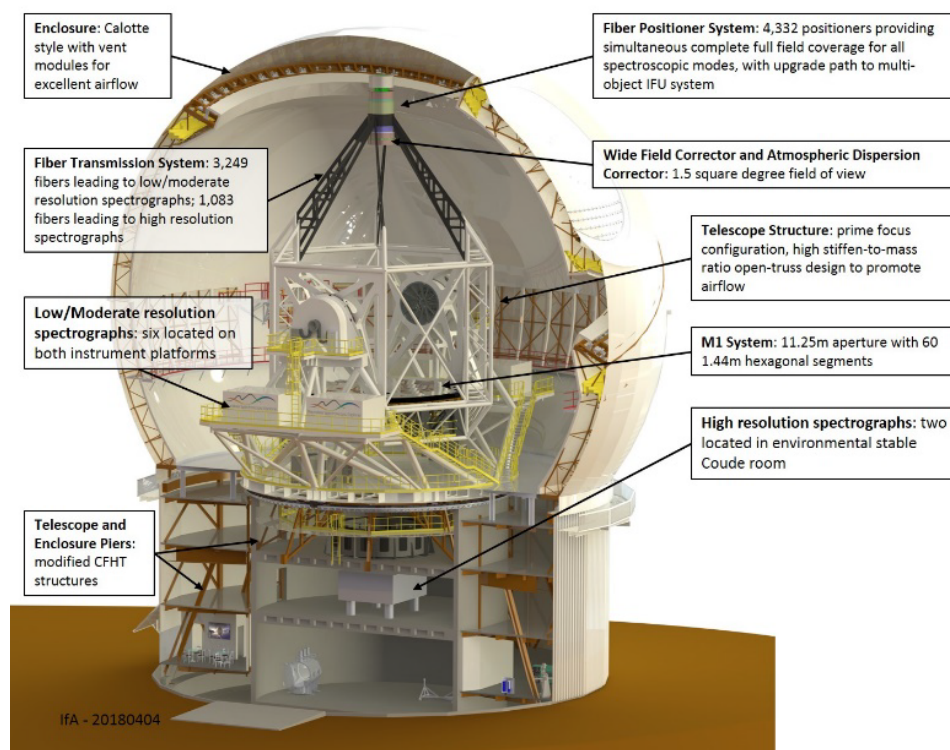


Figure 1 Cutaway-view of MSE Observatory baseline configuration.

Figure 2 is the MSE Work Breakdown Structure (WBS) representing the activities and deliverables to concretize the baseline Observatory, and serves as the pattern to organize MSE design development in the areas of programmatics, science, and engineering. The left most branch is a detailed outline of the Project Office (PO) leadership responsibilities expressed in terms of anticipated work in these three areas, including our effort to facilitate the Master Lease renewal that ultimately safeguards future Maunakea access beyond 2033 for the Maunakea Observatories.

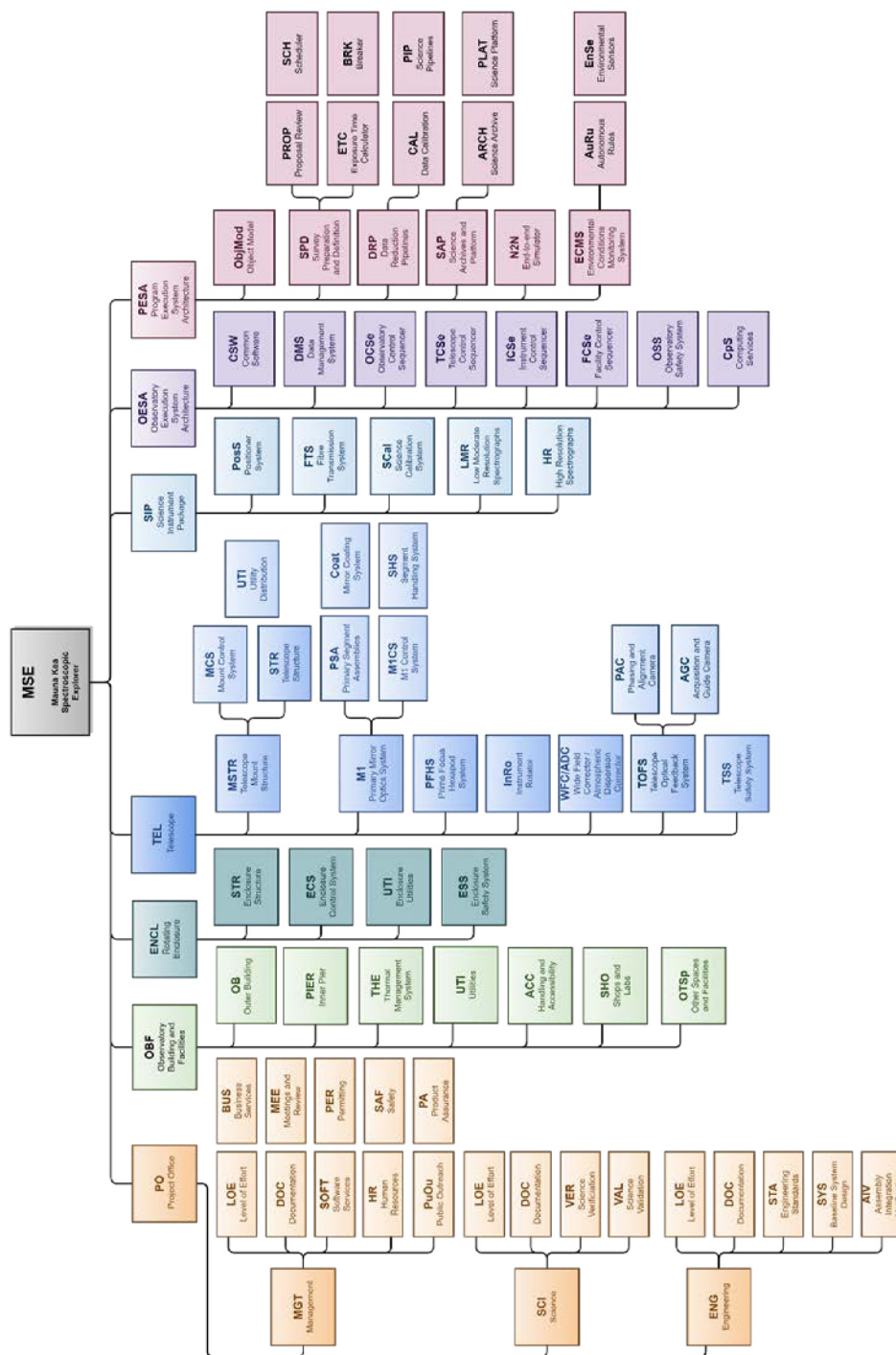


Figure 2 MSE Work Breakdown Structure with seven main blocks that concretizes the baseline Observatory. Every block represents either a collective activity, such as Level of Effort in labour or a deliverable, in order to facilitate cost and duration estimations of the associated work in a hierarchical tree structure. The PESA WBS elements were renamed from those presented in the 2018 project status paper¹

3. MAUNAKEA LAND AUTHORIZATION RENEWAL DEVELOPMENT

3.1 Maunakea Science Reserve Land Authorization Background

The Maunakea Observatories together demonstrably comprise the most scientifically productive astronomical research complex in the world. They are located in the Maunakea Science Reserve (MKSR), see Figure 3, an ~11,000 acre region of land centered on the summit of Maunakea that is leased to the University of Hawaii (UH) from the State designated for the construction and operation of astronomical observatories on Maunakea. Non-UH (internationally) owned observatories on Maunakea operate under separate subleases to a “Master Lease” between the State of Hawaii and UH that was signed in 1968 and has a 65 year duration, so expires at the end of 2033. Securing land authorization through, for example, a new Master Lease by UH is needed to ensure that the Maunakea Observatories have a future beyond 2033. Given various and growing interests in this matter, which span a gamut of perspectives including economic, cultural, scientific, environmental, educational, etc., resolving the current disputes and securing a new Master Lease are complex and important for MSE and the global astronomy.

3.2 Components and Schedule for MKSR Land Authorization

With that as background, we decided from the outset that permits needed to eventually construct MSE at CFHT’s site will not be pursued until a new Master Lease, or equivalent form of Land Authorization, is in place. MSE’s nominal construction schedule is therefore synchronized with Master Lease renewal, noting that a large fraction of the Project development can proceed in advance of securing various construction permits. UH has been preparing various components of the Master Lease “package” for several years, the main components include:

- Approval of UH administrative rules (done)
- Master Plan Update (current plan expires in 2020)
- UH Management Progress Report
- Comprehensive Management Plan (CMP) update
- Completion of Environmental Impact Statement and Governor’s signature as “recipient”
- Negotiation of Master Lease terms and conditions

The first component of the package was completed in January 2020 with the State of Hawaii’s approval of new Administrative Rules for the MKSR. These rules provide a legal framework for important aspects of UH’s management program for the MKSR and in some respects are a prerequisite for approval of the other parts of the overall Master Lease package. At the writing of this paper, the 2020 Master Plan is well advanced and undergoing internal review before public comment is sought in early 2021. This key document outlines UH’s vision for managing the MKSR through ~2040, summarizes planning and development considerations at the summit and mid-level facility (Hale Pohaku), describes future plans for infrastructure including the summit road, fiber, and power, etc. The previous (2000) Master Plan led to the formation of the Office of Maunakea Management, Ranger program, Maunakea Management Board, and Kahu Ku Mauna cultural advisory committee, resulting in an important shift in management of the MKSR locally to Hawaii Island, instead of remotely from Oahu.

Completion of the UH Management Progress Report and CMP update are due in 2021, and the CMP approval by the State Board of Land and Natural Resources (BLNR) is anticipated in 2022. In some ways the CMP update flows from the 2020 Master Plan and UH Management Progress Report, the latter influenced by a recently approved transition

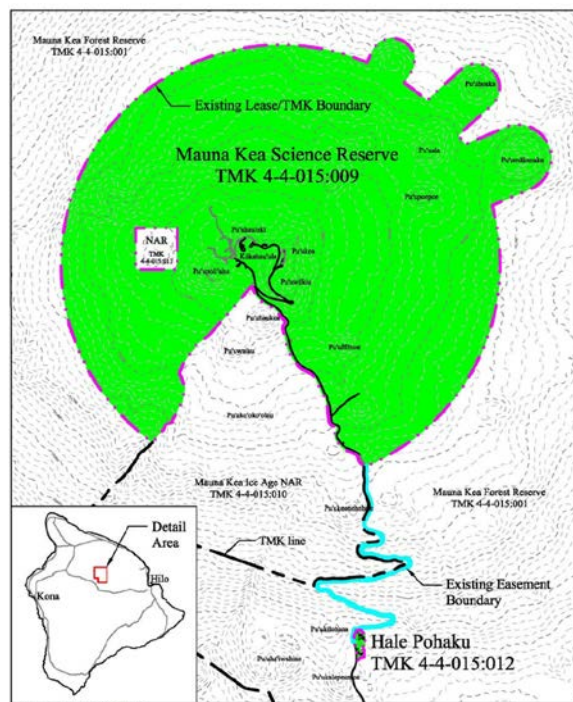


Figure 2 The Maunakea Science Reserve is depicted by the green shaded area in this topographic map of the summit region of Maunakea.

replacing the Office of Maunakea Management with a new Center for Maunakea Stewardship. A new Environmental Impact Statement (EIS) for the MKSR is underway now, with work launched back in 2017. Approval of the new EIS is slated to occur in late 2022, as the last primary component of the new Master Lease package. All components go to BLNR for consideration by 2023 with the anticipated litigation and contested case requests follow. Due to a new statute approved by the Hawaii State Legislature that “fast-tracks” such land disputes straight to the Hawaii State Supreme Court. Given that it took ~2 years to resolve similar disputes pertaining to TMT by the highest court in Hawaii, final resolution of Master Lease renewal is nominally anticipated in 2025. Considering the time needed to decommission the all facilities on the summit and complete site restoration in the event that a new Master Lease is not approved, reaching closure on a new Master Lease mid-decade is about as late as can be tolerated to sustain the existing observatories.

Negotiations for the Terms and Conditions (T&Cs) associated with a new Master Lease and associated subleases are underway. Through these discussions, the baseline T&Cs, which will critically inform the future of the Maunakea Observatories, will be known in 2-3 years and help existing facilities to determine if they would like to seek new subleases under a new Master Lease beyond 2033.

3.3 Community Engagement

While a myriad of activity is underway to support the formal renewal of the Master Lease, because public lands (MKSR) are involved, this process involves public input and ultimately needs public support. Significant opposition within a portion of the Native Hawaiian community has forcefully opposed construction of the Thirty Meter Telescope in recent years, including effective use of roadblock that not only prevented construction equipment from reaching the TMT site on Maunakea but also drew worldwide attention. Because the Master Lease renewal process is entirely administrative, principal avenues of opposition are via BLNR proceedings and legal litigation without physical roadblock. That said, as indicated by public surveys, overall community support for Maunakea astronomy is high. Importantly, the current 500+ staff members of the Maunakea Observatories, and 50+ year history of their operation on Maunakea, have effectively woven the observatories into the Hawaii Island community at all levels.

The aforementioned process of Master Lease renewal includes various forms of community engagement intended to transform and fortify the nature of the relationship of the Hawaii Island community with the Maunakea Observatories going forward. A number of innovative programs are in place to deepen the partnership between the Maunakea Observatories and the community of which they are an integral part. These include programs like Maunakea Scholars and A Hua He Inoa. The former is unique worldwide and provides high school students statewide the opportunity to develop their own astronomy research proposals with mentors principally from the UH Institute for Astronomy graduate program. These research proposals are evaluated by astronomers based on their scientific merit and technical feasibility. The selected proposals are awarded dedicated observing time on the Maunakea observatories. To date >600 students have participated in the Maunakea Scholars program, which is likely the most widely known astronomy education program across the State. A Hua He Inoa (which means to call forth a name in Hawaiian) is led by ‘Imiloa Astronomy Center and is intended to help advance ‘ōlelo Hawai‘i (Hawaiian language), recognizing that indigenous languages are central to the cultures of indigenous populations worldwide. A Hua He Inoa was originally conceived by Hawaiian kupuna (elders) who partnered with the Maunakea Observatories and community members to establish a program through which Hawaiian names are created for important astronomical discoveries from Hawaii based observatories. Hawaiian students, teachers, and language experts have all participated in the program which to date has assigned names to a half dozen major discoveries from Hawaii based telescopes including ‘Oumuamua (the first interstellar asteroid discovered) and Pōwehi (the black hole in M87 imaged by the Event Horizon Telescope). Like Maunakea Scholars, this program is unique and



Figure 3 The first cohort of Maunakea Scholars from Kapolei High School on Oahu is seen on CFHT’s catwalk overlooking the upper ridge of Maunakea.

recognized worldwide by the melding of contemporary science and indigenous cultural ways of knowing, yielding a deeper connection and appreciation between both cultural and scientific communities.

4. SCIENCE DEVELOPMENT

As a testament of its scientific significance, MSE's international Science Team membership grew from 336 members from 31 countries in 2018 to 442 members from 39 countries currently. The MSE science development is organized into eight Science Working Groups (SWGs) supported by selected Science Team members with two co-leads each.

4.1 Participation in National Strategic Planning

Mobilized by the SWG leads, the Science Team members represent and support MSE in their national decadal strategic planning processes for astronomical infrastructure, resulting in:

- Australian mid-term review of its Decadal Plan 2015 stated their top priority remains joining ESO full membership, from current associate member, while MSE or wide-field multi-object spectroscopic facilities were highlighted as potential opportunities.
- Canadian Long Range Plan 2020 released their final finding on astronomical facilities recommending that Canada should play a leading and substantive role in a next-generation wide-field spectroscopic survey facility with MSE as the best option currently.
- US Decadal Survey on Astronomy and Astrophysics (Astro2020), the Science Team submitted 20+ science white papers, and the Project Office submitted a facility white paper and provided programmatic information for the Survey's Technical Risk and Cost Evaluation process. The final report is expected in mid-2021.
- US Snowmass 2021, a.k.a. particle physics community planning exercise, the Science team submitted Letters of Interest in the areas of dark matter and dark energy research, and facility development in support of MSE. Snowmass is a multi-year strategic planning process for setting priorities in US particle physics research for the coming decade.

Though we are optimistic MSE will receive positive recommendations and outcomes from these strategic planning processes, we do not know the actual funding timeline for national support under current political and economic uncertainties due to the COVID pandemic.

4.2 Design Reference Survey

Working with the SWGs, the PO progressed the Design Reference Survey[†] (DRS) by selecting four diverse key science cases from MSE Detailed Science Case² based on their unique and different observing conditions, instrument specifications, and survey planning requirements with respect to field size, target density and observing cadence, etc. In order to observe these science cases contemporaneously and efficiently, the first phase of the DRS study will provide practical insight and understanding on the functional requirements of the survey program Scheduler tool. DRS development is reported in detail by Marshall³ in the *Observatory Operations: Strategies, Processes, and Systems* conference. Her paper also describes the Science Questionnaire the PO used to collect Science Team inputs in order to affirm the spectrographs' design requirements are consistent with their science needs.

5. PROGRAMMATIC DEVELOPMENT

Under the current governance structure, representatives from the MSE participants form the Management Group (MG). It is the MG responsibility to plan the construction and operations phase, and define the corresponding partnership and funding models, and advocate for national resources to support MSE's technical development. MSE observers are potential participants who participate in the MG in order to assess compatibility before formally joining the Project.

[†]DRS represents a step-by-step plan to execute the selected MSE observations, and it informs functionally and operationally if the as-designed baseline Observatory is adequate to complete the observing plan.

5.1 Growth in Management Group

Since 2018, MSE membership has increased from six national institutions from Australia, Canada, China, France, India and Hawaii to ten, with the addition of Texas A&M University and Kyung Hee University (South Korean) as participants and US NSF's NOIRLab and UK university consortium (Cambridge, Durham, Oxford, University College London), led by the Astronomy Technology Centre in Edinburgh, as observers.

5.2 Preparation for Preliminary Design Phase Readiness

Despite the national fund timeline uncertainty, we plan to attain Preliminary Design Phase readiness by early 2022. Programmatically, PDP readiness implies the Project has completed the requisite system-level documents, and have the appropriate processes and procedures in place to lead the subsystem design teams through their preliminary design activities correctly and efficiently. The PDP readiness will be evaluated by an external review panel consists of subject-matter experts. Officially, this is known as the Preliminary Design Phase Readiness Review (PDPRR).

More importantly, PDP readiness is significant to instill confidence in funding agencies that their national investments will be well managed for effective science return. Specifically, the objective of the Review is to demonstrate the PO has met the following expectations:

- There are no outstanding Conceptual Design Phase issues, including
 - Resolution of the Conceptual Design Review recommendations regarding improvement on MSE's (Level 1) fundamental documents[‡], development of DRS, justification of H-band capability, and understanding of on-site assembly, integration and verification procedures during the construction phase
 - Resolution of technical risks raised at the subsystems' conceptual design reviews[§]
 - Resolution of technical risks of those subsystems^{**} highlighted in the last 2018 paper¹ that have not undergone formal conceptual design reviews
- Establishment of effective requirement management tool to maintain traceability and flow-down between Level 0 and Level 1 requirements, including
 - Interpretation of the (Level 0) foundational documents' ^{††} objectives into meaningful and manageable requirements within the (Level 1) fundamental documents
 - Implementation of DOORS requirement management software to perform traceability analysis, etc.
- Enforcement of configuration management and change control process to safeguard the Project baseline regarding its scope^{††}, system performance, overall cost and schedule
- Creation of design, health and safety, and product assurance standards to ensure personnel, equipment and environmental safety

Table 1 Table 2, Table 3 tabulate the 49 deliverables organized into nine groups that the PO will complete and present at the PDPRR. Collectively, the deliverables represent the evidentiary documentation in meeting the PDP readiness expectations by linking the (Level 0) science objectives that reflect MSE stakeholders' aspirations to (Level 1) fundamental observatory architecture to (Level 2) subsystem designs. Detailed descriptions of the PDPRR documents are presented by Szeto³ in the *Modeling, Systems Engineering, and Project Management for Astronomy* conference.

[‡]Including the Observatory Architecture Document, Operation Concepts Document, and Observatory Requirements Document

[§]For both LRM and HR spectrograph optical designs, and the Fiber Transmission System

^{**}Including Observatory Building and Facilities, Primary Mirror (M1) System, Acquisition and Guiding Camera, Phasing and Alignment Camera, Science Calibration System, and Program Execution Software Architecture

^{††}Including the Concept of Operation and Science Requirements Document

^{‡‡}Including established programmatic and technical processes, design and safety standards

Table 1 Level 0 and 0.5 document list - L0 documentation is are science pertinent documents and L0.5 documentations are science and engineering pertinent documents

<u>Level 0 Science Document</u>	<u>Level 0 Science Supplemental Document</u>	<u>Level 0.5 Science/Engineering Document</u>
Detailed Science Case	Science Questionnaires	H-Band Trade Study
Science Requirements Document with Science Reference Observations	High Resolution Science Case	Design Reference Survey Report
Concept of Operations	Low/Moderate Resolution Science Case	Science Calibration Plan

Table 2 Level 1 engineering document list specific to MSE baseline such as system performance budgets and design requirements, and the corresponding design reports and reviews

<u>Level 1 Fundamental Document</u>	<u>System Budgets and Design Requirements Document</u>	<u>Design Report and Review</u>
Observatory Architecture Document	Sensitivity Budget Document	Observatory Building and Facilities Conceptual Design Review
Operations Concept Document	Observing Efficiency Budget Document	M1 System Design Report
Observatory Requirements Document	Supplemental Budgets Document	M1 System Figure Error Budget Review
	Acquisition and Guide Camera Design Requirements Document	Science Calibration System Conceptual Design Review
	M1 System Figure Error Budget	Low/Moderate Resolution Spectrograph delta-Conceptual Design Review
	M1 System Design Requirements Document	High Resolution Spectrograph light-Preliminary Design Review
	Low/Moderate Resolution Spectrograph Design Requirements Document	Program Execution Software Architecture Conceptual Design Review
	High Resolution Spectrograph Design Requirements Document	

Table 3 Level 1 engineering document list specific to project management, systems engineering and project engineering

<u>Programmatic Document</u>	<u>Systems Engineering Document</u>	<u>Project Engineering Document</u>
Management Plan	Systems Engineering Management Plan	Assembly, Integration & Verification Plan
Project Cost Book	Design Requirements Document Template	
Integrated Project Schedule	Interface Description Document and N^2 Diagram	
Hazard Analysis and Risk Assessment Report	Interface Control Document Template	
Issue Tracker	Observatory Safety System Interface Control Document	
Work Breakdown Structure Dictionary	Functional Analysis and Use Case Report	
Configuration Management and Reviews Plan	CAD Management Plan	
Project Risk Register	Digital Mockup	
Project Standards List	DOORS Analysis Report	
Configuration Index Document (CoDP)	Compliance Matrix	
Configuration Index Document (PDP RR)		

6. ENGINEERING DEVELOPMENT

Irrespective of the COVID pandemic lockdown, the Project continued to make technical progress with the international subsystem design teams and resolved the subsystems' technical risks identified during the CoDP. Specifically, risks associated with the Observatory Building and Facilities, M1 System, Acquisition and Guiding Camera, Phasing and Alignment Camera, Science Calibration System, Low/Moderate Resolution (LMR) Spectrograph, High Resolution (HR) Spectrograph, and Program Execution Software Architecture (PESA).

6.1 Observatory Building and Facilities (OBF)

The Observatory Building and Facilities is fundamentally the structural support for the MSE enclosure and telescope. The OBF also provides the science operations infrastructure and houses plant equipment required to support and facilitate daytime and nighttime operations⁵.

The OBF includes the existing five-story steel frame outer building and its concrete ring foundation that supports the enclosure, and the inner concrete pier that supports the telescope. We have completed detailed structural analysis to confirm the OBF's structural capacities are sufficient to support the new MSE enclosure and telescope after the required seismic upgrade. The existing summit equipment and infrastructure will be repurposed wherever possible while meeting the new MSE requirements. The current development priorities are to formalize the MSE OBF design requirements based on the proposed operations concept⁶, especially supporting the service and handling procedures to exchange and recoat mirror segments with the Observatory geometry and the segment coating lab located on the 1st floor of the inner pier. Elements to be considered for the segment servicing procedures are illustrated in Figure 5.

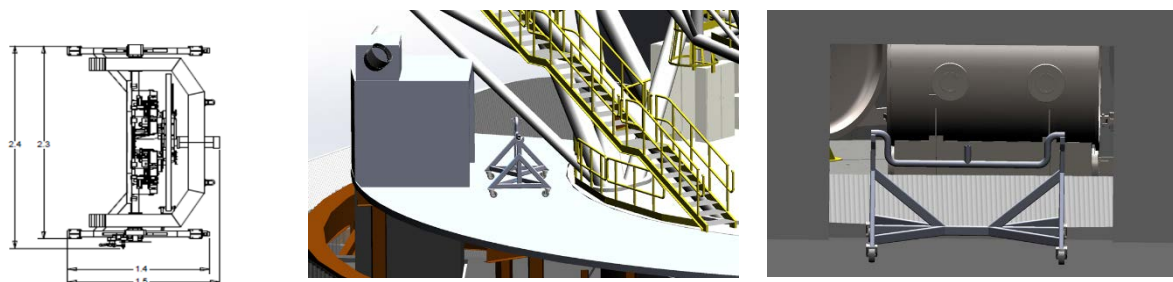


Figure 4 Illustrative CAD segment servicing study to evaluate the optimal method to transport segment on its handling cart (left panel) from the observing floor (middle panel) to the coating lab (right panel).

6.2 Primary Mirror (M1) System

In November 2018, an external review panel confirmed the proposed M1 System development plan is plausible and has a high probability to succeed. After a detailed comparative study of the segmented mirror technologies between the European Southern Observatory (ESO) Extremely Large Telescope (ELT) and the Thirty Meter Telescope, the PO adopted the ESO ELT M1 System as the current baseline. Since then, ESO has granted MSE access to their M1 System IP and supply chain vendors, provisional to the PO will not burden their ELT engineers with additional workload. Currently, the PO is working with the ELT Programme Manager to establish a Non-Disclosure Agreement with a mutually acceptable technology exchange arrangement.

6.3 Acquisition and Guiding Camera (AGC)

A conceptual optical and opto-mechanical design study was completed to confirm feasibility of the proposed three camera AGC system. The study verified the proposed design meets the performance requirements regarding guide star availability and centroid accuracy, and the interface requirements within the limited space at the telescope prime focus station, see Figure 6a. The proposed acquisition and guiding system is reported by Gillingham⁷ in this conference.

6.4 Phasing and Alignment Camera (PAC)

A conceptual optical and opto-mechanical design study was completed to confirm feasibility a combined imaging and Shack-Hartman wavefront sensor (SHWFS) camera system. The proposed camera system is an advancement of the legacy system used at the W. M. Keck Observatory. The study verified the proposed design meets the performance requirements regarding alignment, phasing and figuring of the segmented M1, and the interface requirements within the limited space at the telescope prime focus station, see Figure 6b.



Figure 5 Isometric view of the telescope prime focus station: a) Left panel shows the positioners and AGC cameras share the teal hexagonal support structure housing 4,332 tilting spine positioners, where only a few tilting spines populating the focal surface are shown; and the three CMOS cameras are mounted the blue standoffs; b) Right panel shows the on-axis pickoff optics and the PAC components on an optical bench, with blue SHWFS at the center, fitted within the “ghosted” allowable space envelope.

6.5 Science Calibration (SCal) System

With a holistic approach, the PO continues the development of the science calibration plan that includes considerations for requirements, procedures, operational features, algorithm, software and hardware components. The calibration strategy attains MSE’s science goal in detecting spectral features of faint targets at $mAB=24$ magnitude by facilitating accurate sky subtraction and spectrophotometry. Two classes of calibration are under consideration. The first is Facility Calibration to ensure and maintain all MSE subsystems perform at their required level of performance, and this is the responsibility of individual subsystems. The second is Science Calibration to ensure accurate extraction of science data. This is a set of coherent calibration methodologies at the system-level to ensure the extracted spectra represent the true spectral characteristics of the scientific targets.

The SCal system is an integral part of MSE’s science calibration plan currently under development and reported by Barden⁸ in the *Observatory Operations: Strategies, Processes, and Systems* conference.

6.6 Low/Moderate Resolution (LMR) Spectrograph

Due to their concern on the tight opto-mechanical packaging and complex optics with strong aspheric surfaces, the conceptual design panel recommended a delta-conceptual design for the LMR spectrograph to resolve these technical risks. In parallel, the PO revised the spectrograph design requirements according to the observational needs learned from the Science Questionnaire. Table 4 compares the 2017 CoRP requirements with the latest requirements.

Table 4 Comparison of low and moderate resolution requirements, where increases in optical design difficulties due to spectral resolution and coverage changes are highlighted in red.

Requirement	2017		2020	
	VIS	NIR	VIS	NIR
Spectral Coverage	0.36 – 0.95 μm	0.95-1.3 or 1.5-1.8 μm	0.36 – 1.0 μm	1.0-1.3 and 1.45-1.8 μm
LR Spectral Resolution	$R_{\text{min}} > 2000$ 2500 < $R_{\text{avg}} < 3000$	$R_{\text{min}} > 3000$	$R_{\text{min}} > 2500$ 3000 < $R_{\text{avg}} < 3500$	$R_{\text{min}} > 3000$ 3000 < $R_{\text{avg}} < 3500$
MR Spectral Resolution	$R_{\text{min}} > 4500$ 5000 < $R_{\text{avg}} < 7000$		$R_{\text{min}} > 5000$ 5500 < $R_{\text{avg}} < 6000$	$R_{\text{min}} > 5500$ 6000 < $R_{\text{avg}} < 7000$

The design team proposed to separate the LMR spectrograph design into a visible spectrograph operating at ambient temperature, and a cryogenic NIR, J and H bands, spectrograph operating at $\sim 200^{\circ}\text{K}$. They reckoned it is more economical to build one smaller non-cryogenic visible unit and one smaller cryogenic NIR unit than a single bigger cryogenic unit to accommodate full visible and NIR spectral coverage. The team are currently progressing the NIR optical design, which they deem to be the more challenging than the visible unit. Figure 7 compares the CoDP optical design with the latest NIR optical design, which alleviates the tight opto-mechanical packaging. Detailed description of the LMR spectrograph design development is reported by Jeanneau⁹ in the *Ground-based and Airborne Instrumentation for Astronomy* conference.

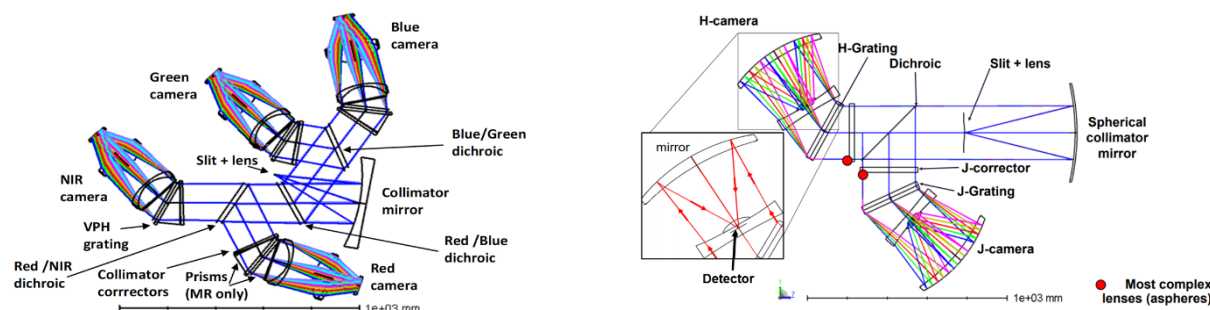


Figure 6 Comparison of LMR spectrograph optical designs: a) Left panel - 2017 conceptual design with three visible, blue, green and red, arms and one NIR, J or H band, arm; b) Right panel - NIR only optical design with two J and H band arms.

The new LMR spectrograph configuration may affect MSE's multiplexing capabilities. It is the PO's responsibility to understand the operational impacts and assess whether the proposed change is acceptable programmatically and scientifically.

6.7 Spectrograph, High Resolution (HR) Spectrograph

Based on the conceptual design review panel's advice, the HR spectrograph team design explores alternate optical designs with alternate disperser solutions. Due to its high line density and large size, the CoDP HR disperser was recognized to have the highest technical risk. In parallel, the PO revised the spectrograph design requirements according to the observational needs learned from the Science Questionnaire. Table 5 compares the 2018 requirements with the current requirements, where the lower R30K spectral resolution is now common among all three spectral arms. Figure 8 compares the 2018 optical design with the latest Echelle grating optical design, which alleviates the previous risk of utilizing large grism with mosaic VPH grating for each arm. Detailed description of the LMR spectrograph design development is reported by Zhang¹⁰ in the *Ground-based and Airborne Instrumentation for Astronomy* conference.

Table 5 Comparison of high resolution requirements, where spectral resolution, coverage and window bandpass were modified.

Designs	HR Design-2018	HR Design-2020
Multiplexing	542 fibers each spectrographs	90 fibers each spectrographs
Spectral Arms	B=360-430nm G=430-510nm R=510-900nm	B=360-420nm G=420-580nm R=580-820nm
Resolution	RB=40K RG=40K RR=20K	RB=30K RG=30K RR=30K
Window Bandpass	B=1/30 G=1/30 R=1/15	B=1/45 - 1/35 G=1/35 - 1/25 R=1/25 - 1/20
Diffraction Grating	Single-order Transmission (m=1) 'Diamond' Grism ($\theta_b=53^\circ$)	Multi-order Reflection (m=98-43) R2.6 Echelle grating ($\theta_b=69^\circ$)
Collimated Aperture	Dc = 300mm	Dc = 245mm

The most significant gain in the current optical design is the ability to modify the window bandpass in each arm independently by adjusting bandpass filter and the camera orientation remotely by motorized mechanism without changing additional optical elements, specifically the disperser. In previous grism designs, a different grism is required

for each window bandpass for each arm. The previous approach incurs much higher cost and longer instrument downtime.

However, the new HR spectrograph configuration has much lower multiplexing capability. It is the PO's responsibility to justify the cost-benefit trade and operational impacts of having more spectrographs, albeit physically simpler and smaller units, and assess whether the proposed change is acceptable programmatically and scientifically.

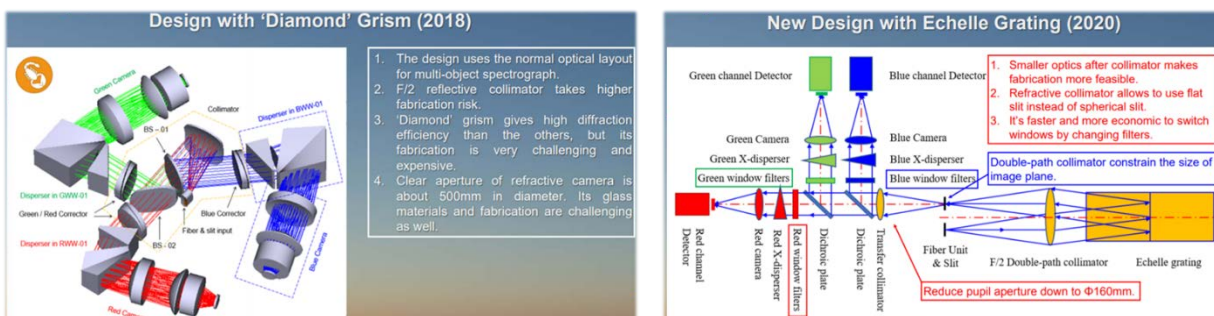


Figure 7 Comparison of HR spectrograph optical designs: a) Left panel - 2018 design with individual large grism disperser with VPH grating for each blue, green and red arm; b) Right panel - Echelle grating design with a single shared disperser for all arms.

6.8 Program Execution Software Architecture (PESA)

PESA is an end-to-end system-level software suite that receives survey proposals and distributes MSE science data products in order to support MSE's plan to distribute fully reduced and validated spectra to its user community. As illustrated by the block diagram in Figure 9, the PESA products are consistent with the customary five-phase observing workflow sequence starting from proposal selection, targets definition, observations, data reduction and validation, and ending with distribution.

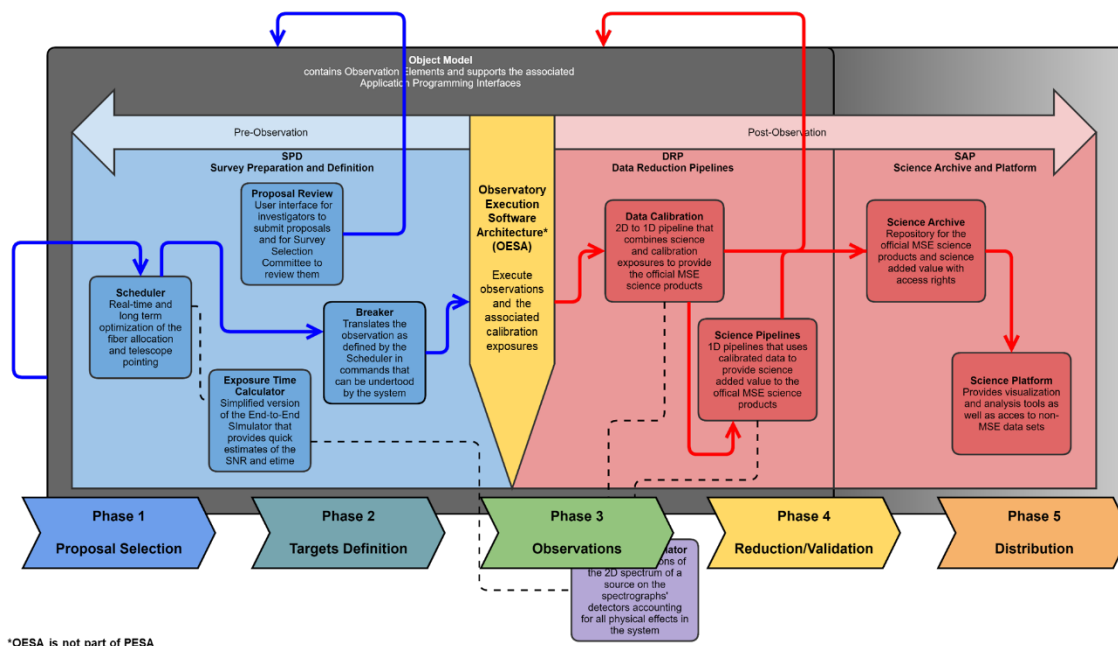


Figure 8 PESA block diagram illustrates the workflow with respect to the observing sequence, and shows the product breakdown functionally and their data flow by the PESA products represented by the rectangular colour blocks, except the Object Model. It is the overarching data structure containing target definitions and their science information from start to finish. The End-to-End Simulator is the purple block partially hidden by the Phase 3 Observations green colour arrow.

Figure 9 shows ten PESA products and they are separated into two operational domains, pre and post observation, separated by an external product Observatory Execution System Architecture (OESA) that contains the observatory control systems, hardware and software, and MSE's IT infrastructure. Organized by their functionalities, the PESA products are divided into three groups: Survey Preparation and Definition (SPD), Data Reduction Pipelines (DRP) and Science Archive and Platform (SAP). The products in the SPD group completes the pre-observing operations where the selected survey proposals are converted into observing commands that are understood by the OESA Observatory Control Sequencer. MSE will observe multiple survey programs contemporaneously from an integrated target list, which contains target definitions managed by the Object Model. SPD encompasses the work of Phase 1 Proposal Selection and Phase 2 Targets Definition. The products in the DRP and SAP groups generate, validate and then deliver the final MSE science data products by processing the spectrographs' science detector readout collected from the Observations phase, Phase 3, via OESA. Independently, DRP contains the work of Phase 4 Reduction/Validation, and SAP contains the work of Phase 5 Distribution.

The functionalities and operations of each PESA product are discussed in detailed by Szeto¹¹ in the *Software and Cyberinfrastructure for Astronomy* conference. The PO plans to conduct a system-level conceptual design to define a common data structure, which facilitates consistent data flow, design requirements and interface definitions prior to commencing conceptual design of individual PESA products.

7. SUMMARY

With respect to our development plan presented at the last SPIE conference in 2018, the PO working with the SWGs and international design team to progress the Project. We have increased the MSE partnership and Science Team, are working to secure MSE's standing in the national strategic planning processes and Maunakea long-term access along with other MKO, and led the international design team to advance the baseline design with scientific oversight and retire technical risks.

On the other hand, the challenges lie ahead for Maunakea astronomy regarding the Master Lease renewal represent valuable opportunities to recast the future of a significant fraction of ground based astronomy worldwide for this century. Through MKO, CFHT/MSE has in many ways led the efforts to not just defend astronomy's interests but broaden opportunities in Hawaii, while recognizing the promise of discovery in modern astronomy extends beyond what we glean from the sky above. Certainly, what happens in Hawaii while striving to ensure there is a future for Maunakea astronomy is beneficial for other research facilities in remote areas that affect indigenous populations. As a long standing member of the Hawaii Island community, we see this once in a century Master Lease renewal process as an important opportunity to strengthen the partnership between the Maunakea observatories and local community for the betterment of all.

Due to COVID and the national funding timeline uncertainties, we have re-planned and adopted an ambitious work schedule to achieve Preliminary Design Phase readiness. The Preliminary Design Phase Readiness Review will demonstrate the programmatic maturity expected for a well-planned project that national funding agencies would recognize. More importantly, the PDPRR document set will serve as a comprehensive guide to achieve MSE's scientific capabilities and safeguard MSE's scope, performance, cost and schedule. Our work plan will lead to a successful PDP and beyond, despite an evolving astronomy landscape worldwide, nationally and internationally.

In conclusion, the Project continues on a positive path scientifically, technically and programmatically. We look forward to the continuous growth of the MSE partnership and the start the next design phase in 2022. We will be at the next (COVID-free) SPIE conference in 2022 to report on our PDP progress.

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