THE CONCEPTUAL DESIGN OF SCAL:
A FACILITY CALIBRATION SYSTEM FOR THE MAUNAKEA SPECTROSCOPIC EXPLORER

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ABSTRACT

The Maunakea Spectroscopic Explorer is designed to obtain >4000 simultaneous spectra from the optical to NIR over a 1.5 square degree field of view at multiple resolutions and with unprecedented sensitivity (m=24). A robust facility science calibration system (SCal) will be required to achieve the desired precision over many observations spaced across months or years with minimal impact to the observing efficiency. We describe the major hardware components required to perform sensitivity and wavelength calibrations, removal of sky background and other stray light or ghost signals, line spread function calibration, and detection of any spurious contamination sources.

Introduction & Requirements

The SCal conceptual design has drawn inspiration from several large-scale fiber positioner spectroscopic survey projects such as 4MOST[1], PFS[2], and DESI[3] that are at a later stage of development than MSE. To achieve the stated MSE goals (m=24 sensitivity limit, sky subtraction to better than 0.1%) over many targets in each field, and survey observations over the course of several years represent a significant challenge.

The MSE Science Calibration Unit (SCal) is comprised of light sources, fiber bundles, projectors, and optical systems required to focus, collimate, or otherwise modify the calibration light to maximize system efficiency. This system also includes means of detecting spurious contamination, such as LEO satellites crossing an individual fiber. Top level considerations are maximizing efficiency to minimize the calibration overhead and ensure the majority of observing time is spent collecting scientific spectra, not performing calibration. Likewise minimizing moving parts and utilizing commercially available hardware where possible helps improve reliability and reduces the overall cost of SCal.

This study was primarily concerned with identifying possible hardware solutions to the expected calibration tasks and those areas where hardware development activities may be required to achieve the MSE goals. A holistic study of the science requirements, data reduction pipeline, and calibration hardware has not yet taken place, but is planned prior to preliminary design. A requirements document was generated based on the existing calibration plans and will be updated during preliminary design.

LIGHT BOX

The heart of SCal is an enclosure that houses both broadband and wavelength calibration sources that are then fed into fiber bundles to transport the calibration light to either the projectors for injection into the telescope, or directly to the spectrographs. An Energetiq fiber output Laser Driven Light Source provides high brightness and extremely broadband output that can alternatively be fed directly for broadband calibration, or a Fabry-Perot etalon may be inserted to generate regularly spaced interference peaks that can be used for wavelength calibration in each spectrograph. Due to the temperature, pressure, and angular sensitivity of an etalon, light from a hollow cathode lamp will be mixed to provide an absolute wavelength reference. Due to the broad wavelength coverage (360 – 1800 nm) of MSE, reflective optics will be used, and potentially dual etalons will be utilized to balance the required line spacing for the various spectrograph resolutions with etalon performance. Optical layouts are shown in Figure 2 for the light box as well as the dual etalon option.

LINESPREAD FUNCTION CHARACTERIZATION

Variations in the line spread function (LSF) across both wavelength and spectrum position on the detector require characterization of the LSF in order to ensure precise subtraction of the sky background. A relatively small number of fibers (~10%) will be devoted to recording sky spectra and the resulting spectra must be deconvolved from the LSF before applying it to a science target spectrum or differences in the LSF as a function of spectrum position on the detector will result in residual errors. Two possible methods require further investigation, either tuning the etalons to microstep the etalon peaks across the detector and sample the LSF, or injection of a tunable laser that can be stepped through the range of wavelengths. A tunable laser has the additional benefit of characterization of scattered light (single wavelength light should only land at specific locations on the detector, any light at another position is the result of stray light).

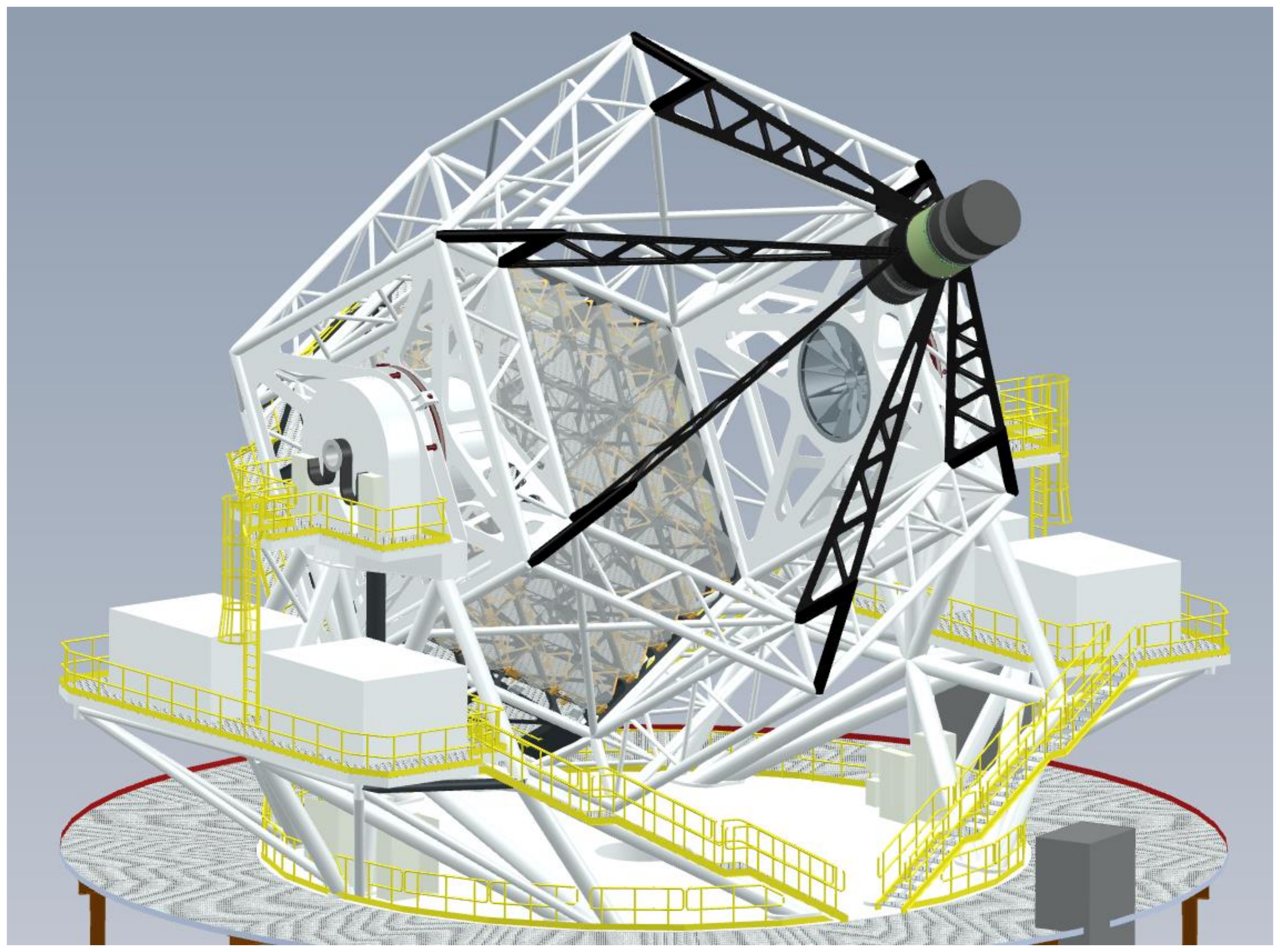

Figure 1. The Maunakea Spectroscopic Explorer telescope. Low and Moderate resolution spectrographs are located on the platforms on either side of the telescope.

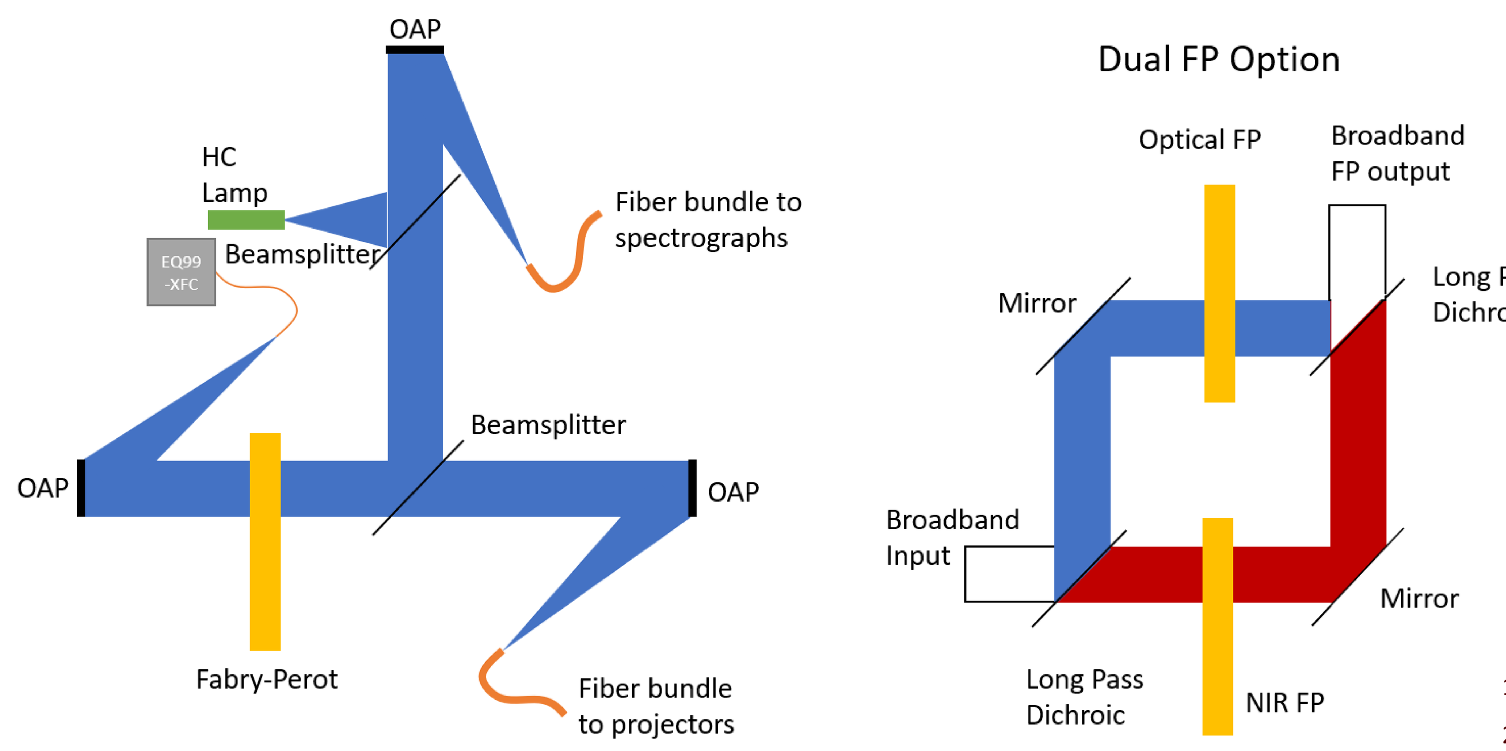

Figure 2. SCal light box optical layout is on the left. An option for splitting and then recombining light for optical and NIR optimized etalons is shown on the right.

PROJECTORS

Due to the small amount of clearance between the front of the telescope and the inside of the dome, mounting and illuminating a traditional calibration screen will be challenging. Additionally, illumination of the telescope pupil with a wider range of angles due to the Lambertian reflectance profile of a screen could result in a different spectrograph pupil illumination when compared to that expected from the sky. Projectors located on the underside of the spider will directly illuminate the primary mirror. The projectors will consist of laser etched linear diffuser fibers with beam spread constrained by baffles rather than lenses or mirrors for a completely achromatic system. The projectors can be sparsely distributed along the spiders, relying on azimuthal scrambling in the fibers to completely fill the spectrograph pupil.

SPURIOUS CONTAMINATION

The wide field of view and stated sensitivity goals (24th magnitude) require a transient detection system to identify contaminating sources such as meteors, airplanes, satellites, and other phenomena that could contaminate a science spectrum. This system would then interface with the data pipeline to flag spectra with possible contamination. There is a trade between resolution (needed to reliably identify which fibers may be impacted) and sensitivity (set by the pixel crossing time and brightness of typical events). A 300mm f/2.8 commercial lens and 2k x 2k pixel sCMOS detector is able to image the entire field of view continuously (20ms read time) with a resolution of 7.5"/px and reach almost 12th magnitude during the pixel crossing time of a typical LEO satellite. A similar system optimized for the NIR will enable monitoring of the entire MSE expected wavelength coverage.

Next Steps

Additional details and a full discussion of the considered solutions are included in the paper. After a "Calibration Feasibility" study is completed, which includes revising the current calibration plan, complete flow down of the MSE Science Requirements, and an updated data reduction pipeline plan, the SCal hardware design can be updated and the preliminary design phase can begin.

[1]de Jong et al. (2019) doi:10.18727/0722-6691/5117
[2]Sugai et al. (2015) doi:10.1117/1.Jatis.1.3.035001
[3]DESI Collaboration (2016) arXiv:1611.00036. Retrieved from https://ui.adsabs.harvard.edu/abs/2016arXiv161100036D

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