# Snowmass2021 - Letter of Interest

# *Enabling precision calibration of massively multiplexed spectroscopic surveys*

**Thematic Areas:** (check all that apply ☐/■)

☐ (CF1) Dark Matter: Particle Like
☐ (CF2) Dark Matter: Wavelike
■ (CF3) Dark Matter: Cosmic Probes
■ (CF4) Dark Energy and Cosmic Acceleration: The Modern Universe
☐ (CF5) Dark Energy and Cosmic Acceleration: Cosmic Dawn and Before
■ (CF6) Dark Energy and Cosmic Acceleration: Complementarity of Probes and New Facilities
☐ (CF7) Cosmic Probes of Fundamental Physics
■ (IF2) Instrumentation: Photon Detectors

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**Collaboration:** Maunakea Spectroscopic Explorer Collaboration

**Abstract:** Massively multiplexed spectroscopic facilities on large aperture telescopes are essential for the next phase in experimental astrophysics. In the era of the Rubin Observatory's Legacy Survey of Space and Time and other wide-field imaging surveys, the spectroscopic follow-up of hundreds of millions of objects with brightnesses comparable to or fainter than the sky background is required to enable precision studies of the nearby and distant universe. In order for these studies to be executed efficiently, thousands of spectra per pointing must be acquired, a feat that can only be accomplished using fiber-fed spectroscopic instruments, which require complicated hardware and control software. A further challenge in executing this science successfully is the careful calibration that is required to disentangle the desired source signal from the background noise due to the sky signal and scattered light caused by the instrumentation. In order to fully assess these noise sources and develop a plan to remove them from the source signal, careful design of the positioner hardware and subsequent in-situ calibration measurements must be made with the fibers as they deliver light to the spectroscopic instruments. These measurements, when coupled with careful acquisition of the survey data as well as application of additional required calibration data through the data reduction process, will enable the full scientific goals of these surveys to be reached. Here we use the Maunakea Spectroscopic Explorer, the most advanced of the next generation of dedicated massively multiplexed spectroscopic facilities, as an example of the need to further develop these considerations in the near future.

**Introduction: Calibration needs of next-generation spectroscopic surveys** Observations from Earth will always be contaminated by emission from our atmosphere. This emission is composed of many components (Rayleigh and aerosol scattering of sunlight reflected by the Moon, atomic and molecular emission lines, etc.) and must be subtracted from a measurement to reveal the true spectrum of a science target. Nearly all targets that will be observed by the next generation of spectroscopic follow-up facilities will be fainter than the sky, so precise and accurate subtraction of sky background will be critical to achieve precise and accurate science results. For example, to understand the structure and distribution of matter in the universe, a requirement will be to measure spectra of tens of millions of galaxies that are roughly 100 times fainter than the sky (the area of the sky that is included in any astronomical measurement is set by a combination of the angular size of the target and the angular size of the image due to atmospheric turbulence). Consequently, to make a 5-$\sigma$ measurement that is accurate and precise to 10% requires removing the sky contribution at a level of roughly 0.1 x (1/100) = 0.1% accuracy and precision. The size of the telescope will ensure excellent precision (by collecting many photons from the sky), but achieving high accuracy will require careful calibration of many effects.

**The Maunakea Spectroscopic Explorer** The Maunakea Spectroscopic Explorer is the first of the future generation of dedicated observational facilities that enable massively multiplexed spectroscopic study of faint astrophysical objects. MSE completed a Conceptual Design of the facility in 2018[1] describing a design that will enable transformative science, being completely dedicated to large-scale multi-object spectroscopic surveys, each studying thousands to millions of objects. MSE will use an 11.25 meter aperture telescope to feed thousands of fibers over a 1.5 square degree field of view and has the capability to observe at optical and near-Infrared wavelengths at a range of spectral resolutions, with all spectral resolutions available at all times across the entire field. MSE will collect more than 10 million fiber-hours of spectroscopic observations every year and is designed to excel at precision studies of large samples of faint astrophysical targets, in most cases objects having brightnesses fainter than the sky background. As a project, MSE has a goal of minimizing the need to develop new technologies to accomplish these science goals and largely relies on proven existing technologies to maximize efficiency and minimize cost and schedule. Two necessary exceptions to this policy are the fiber positioner architecture and the data calibration plan, both of which will require technology development before converging on final hardware and software plans. As described in a companion Snowmass LOI (Marshall et al.), MSE will stand as a premier facility for next-generation experimental astrophysical studies of the nature of dark matter, dark energy, and the universe as a whole.

The MSE science team has recently produced an up-to-date Detailed Science Case[2] that describes a very large number of science cases, most of which would be impossible to execute with current generation instrumentation. Of these, two of the key MSE science cases are of considerable interest to the astroparticle physics community and have been submitted as LOIs to Snowmass2021: *Probing Dark Matter Physics with MSE* (Li, Kaplinghat, & the MSE Science Team) and *Cosmology with MSE* (Yèche, Percival, & the MSE Science Team). These two cases also drive the requirements for careful calibration of the data to enable the planned science, and in the case of the cosmology science case, drive the desire for larger numbers of fibers in MSE's focal plane.

**Next generation fiber positioner systems** The baseline MSE fiber positioner is a piezo-actuated tilting spine technology "Sphinx" positioner system designed by Australian Astronomical Observatory (AAO). This technology has been implemented in several instruments including FMOS-Echidna (Subaru) and 4MOST (VISTA). It represents a mature, low risk, high performance solution to MSE positioner requirements. Figure 1 shows the Conceptual Design of the MSE fiber positioner system.

MSE and other next-generation massively multiplexed spectroscopic surveys would benefit from the ability to more densely pack fibers into the telescope focal plane. As described in another Snowmass LOI submitted by Diehl et al., developing this technology should be pursued in the near future in order to benefit MSE and

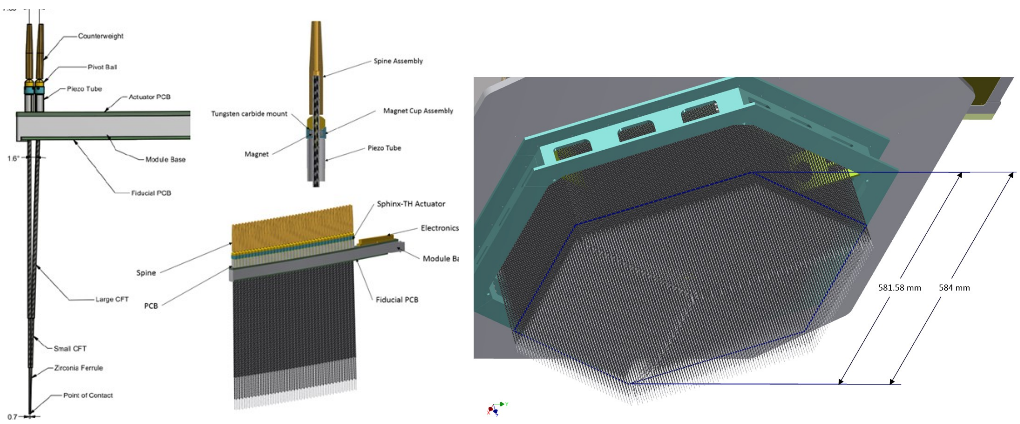

Figure 1: MSE fiber positioner Conceptual Design[1]. *Left:* Sphinx fiber positioner module. Each module carries 76 spines, with 57 LMR and 19 HR fibers (bottom right), two adjacent spine assemblies (left) and a close-up of the piezo actuator (top right). *Right:* 57 Sphinx positioner modules carrying 4,332 MSE fibers, shown mounted at the telescope top end.

other similar future facilities.

**Enabling precision calibration of massively multiplexed spectroscopic surveys** Recently a new fiber testing and characterization facility has been established at Texas A&M University that will allow detailed measurements of fibers that will be incorporated into multi-fiber systems. We will focus on developing techniques to test large numbers of fibers for characteristics that are most relevant to astronomical instrumentation: not only the most commonly considered fiber feature of focal ratio degradation (FRD), but also fiber transmission versus wavelength (spectrophotometric performance and stability), sensitivity to stress/strain in the individual fibers, relevance of fiber profile shape, and injection efficiency as relates to fiber positioner architecture. Eventually, for any massively multiplexed spectroscopic instrument the goal should be to select a group of fibers that will minimize the impact of fiber differences for accurate sky subtraction, to determine a suite of required calibration measurements and techniques to be used once the instrument is deployed on site, and to develop a software technique to apply the measurements to the observations so that the spectroscopic data may be appropriately calibrated. MSE is right now unique amongst massively multiplexed spectroscopic facilities in this regard: the project is currently beginning its Preliminary Design Phase and this is an appropriate stage in the project to integrate the required calibration facilities into the observatory plans.

**Recommendations for Snowmass 2021** Here we have used the MSE project as an example, but all future spectroscopic facilities will benefit from advancing the state of the art of the capabilities described here. We recommend that Snowmass support the development of this hardware and calibration software architecture for future massively-multiplexed spectroscopic facilities planning to study objects fainter than the sky background. Specifically, we recommend:

- Support for the development of fiber positioner technology, in particular the investigation of high density fiber positioner systems.
- Support for testing of fiber system architecture and development of calibration plans.
- Support of the associated software development in tandem with the hardware development.

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[2] The MSE Science Team, Carine Babusiaux, Maria Bergemann, Adam Burgasser, Sara Ellison, Daryl Haggard, Daniel Huber, Manoj Kaplinghat, Ting Li, Jennifer Marshall, Sarah Martell, Alan McConnachie, Will Percival, Aaron Robotham, Yue Shen, Sivarani Thirupathi, Kim-Vy Tran, Christophe Yeche, David Yong, Vardan Adibekyan, Victor Silva Aguirre, George Angelou, Martin Asplund, Michael Balogh, Projjwal Banerjee, Michele Bannister, Daniela Barría, Giuseppina Battaglia, Amelia Bayo, Keith Bechtol, Paul G. Beck, Timothy C. Beers, Earl P. Bellinger, Trystyn Berg, Joachim M. Bestenlehner, Maciej Bilicki, Bertram Bitsch, Joss Bland-Hawthorn, Adam S. Bolton, Alessandro Boselli, Jo Bovy, Angela Bragaglia, Derek Buzasi, Elisabetta Caffau, Jan Cami, Timothy Carleton, Luca Casagrande, Santi Cassisi, Márcio Catelan, Chihway Chang, Luca Cortese, Ivana Damjanov, Luke J. M. Davies, Richard de Grijs, Gisella de Rosa, Alis Deason, Paola di Matteo, Alex Drlica-Wagner, Denis Erkal, Ana Escorza, Laura Ferrarese, Scott W. Fleming, Andreu Font-Ribera, Ken Freeman, Boris T. Gänsicke, Maksim Gabdeev, Sarah Gallagher, Davide Gandolfi, Rafael A. García, Patrick Gaulme, Marla Geha, Mario Gennaro, Mark Gieles, Karoline Gilbert, Yjan Gordon, Aruna Goswami, Johnny P. Greco, Carl Grillmair, Guillaume Guiglion, Vincent Hénault-Brunet, Patrick Hall, Gerald Hand ler, Terese Hansen, Nimish Hathi, Despina Hatzidimitriou, Misha Haywood, Juan V. Hernández Santisteban, Lynne Hillenbrand, Andrew M. Hopkins, Cullan Howlett, Michael J. Hudson, Rodrigo Ibata, Dragana Ilić, Pascale Jablonka, Alexander Ji, Linhua Jiang, Stephanie Juneau, Amanda Karakas, Drisya Karinkuzhi, Stacy Y. Kim, Xu Kong, Iraklis Konstantopoulos, Jens-Kristian Krogager, Claudia Lagos, Rosine Lallement, Chervin Laporte, Yveline Lebreton, Khee-Gan Lee, Geraint F. Lewis, Sophia Lianou, Xin Liu, Nicolas Lodieu, Jon Loveday, Szabolcs Mészáros, Martin Makler, Yao-Yuan Mao, Danilo Marchesini, Nicolas Martin, Mario Mateo, Carl Melis, Thibault Merle, Andrea Miglio, Faizan Gohar Mohammad, Karan Molaverdikhani, Richard Monier, Thierry Morel, Benoit Mosser, David Nataf, Lina Necib, Hilding R. Neilson, Jeffrey A. Newman, A. M. Nierenberg, Brian Nord, Pasquier Noterdaeme, Chris O'Dea, Mahmoudreza Oshagh, Andrew B. Pace, Nathalie Palanque-Delabrouille, Gajendra Pandey, Laura C. Parker, Marcel S. Pawlowski, Annika H. G. Peter, Patrick Petitjean, Andreea Petric, Vinicius Placco, Luka Č. Popović, Adrian M. Price-Whelan, Andrej Prsa, Swara Ravindranath, R. Michael Rich, John Ruan, Jan Rybizki, Charli Sakari, Robyn E. Sanderson, Ricardo Schiavon, Carlo Schimd, Aldo Serenelli, Arnaud Siebert, Malgorzata Siudek, Rodolfo Smiljanic, Daniel Smith, Jennifer Sobeck, Else Starkenburg, Dennis Stello, Gyula M. Szabó, Robert Szabo, Matthew A. Taylor,

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