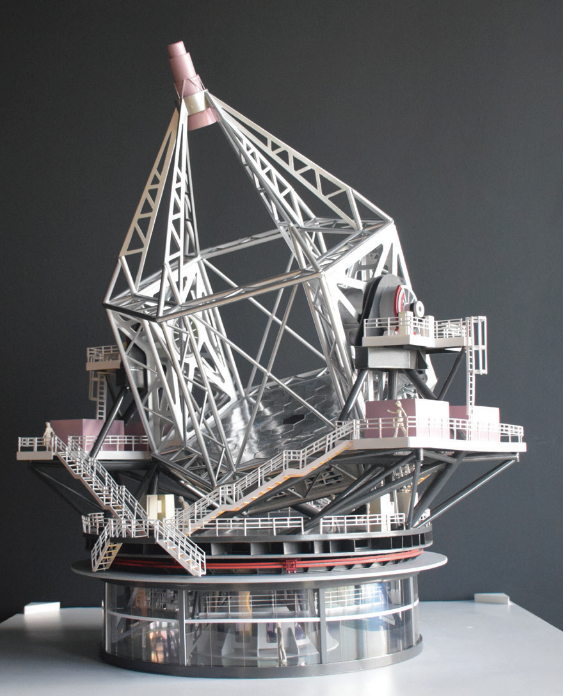
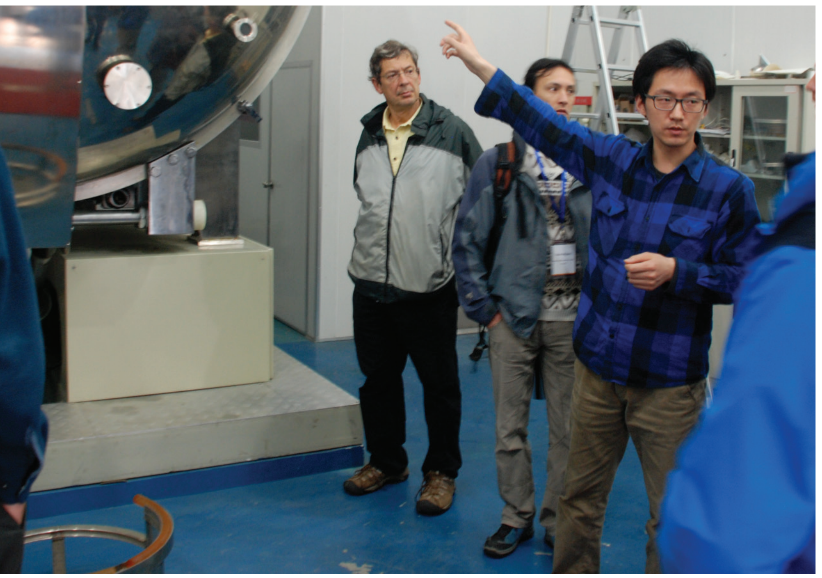
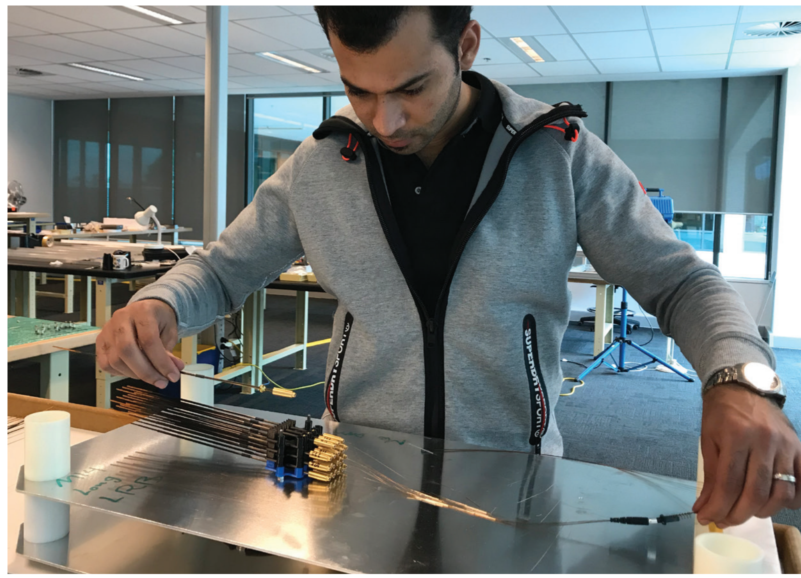
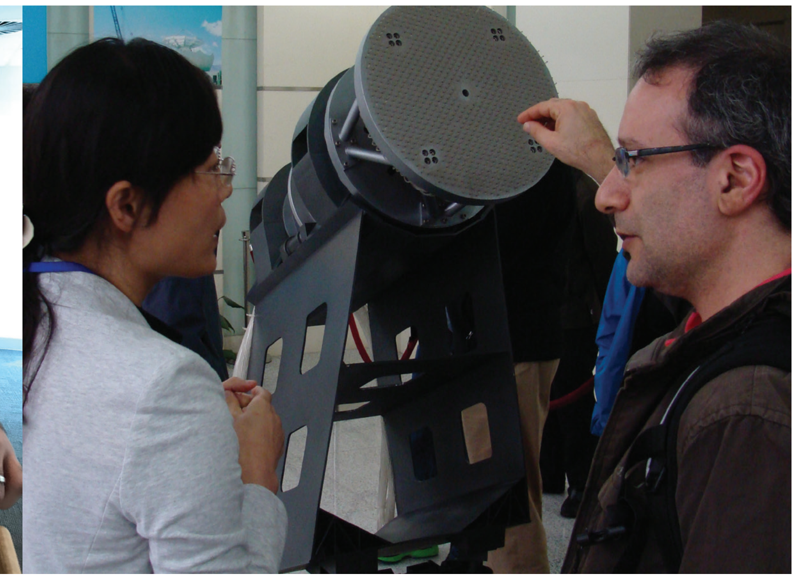
MAUNAKEA SPECTROSCOPIC EXPLORER

Maunakea Spectroscopic Explorer




Maunakea Spectroscopic Explorer

CONTENTS

THE RAINBOW, “THE BRIDGE OF THE GODS”, PROVED TO BE THE BRIDGE TO OUR UNDERSTANDING OF LIGHT .

ISAAC ASIMOV

MAKING RAINBOWS

MSE represents an innovative, comprehensive upgrade of the iconic 3.6m Canada-France-Hawaii Telescope (CFHT), that will tackle the key questions in astronomy in the 2020s and beyond, and operated within an expanded international partnership.

THE UNIVERSE, IN COLOR

Building on the successful legacy of the CFHT – a pioneering 3.6 meter primary mirror telescope perched atop Maunakea, on Hawaii’s Big Island – the Maunakea Spectroscopic Explorer (MSE) will provide the world with a uniquely important research capability.

MSE represents the realization of a long-held aspiration of the international astronomy community: a large optical and near-infrared facility dedicated to obtaining the spectra of many thousands of astronomical targets per hour.

More simply put, MSE spreads the light from every object that it observes into a rainbow of color - and it has the ability to look at thousands of objects simultaneously. Each rainbow (or spectrum), contains information about what that object is made of and how that object is moving.

Through the accumulation of large datasets of spectra, MSE will answer fundamental questions about the formation of stars and galaxies, all by examining the colors in each spectrum in exquisite detail.

From its outset, MSE has been designed to become a world-leading surveyor of the sky, with the capacity to observe nearly 1 million objects per month, every month for the life of the telescope. The potential for new discoveries is immense.

At the same time, MSE leverages its CFHT predecessor’s prime equatorial location – from which it can observe more than three quarters of the entire sky – to observe the Universe from one of the highest quality sites for optical astronomy on the planet.

KEY MSE CAPABILITIES

SURVEY SPEED AND SENSITIVITY: MSE will have the largest primary mirror of telescopes in its class (11.25m) and a very wide field of view (1.5 square degree). These characteristics are essential to enable surveys of the faintest science targets spread over very large areas of the sky.

SPECTRAL PERFORMANCE AND MULTIPLEXING: MSE will be sensitive from ultra-violet, through optical, to near-infrared wavelengths, and it will obtain spectra for over 4,000 objects in a single exposure.

Of these, approximately 1,000 objects are observed at very high wavelength resolution, suitable for probing the composition of stars in our Galaxy, while approximately 3,000 objects are observed at lower wavelength resolution, suitable for probing the composition and velocities of the faintest sources such as distant galaxies.

DEDICATED AND SPECIALIZED OPERATIONS: MSE is designed to do just one thing – obtain spectra – but to do it exceedingly well, and with very high efficiency.

This degree of specialization ensures a level of stability and repeatability that will allow MSE to maximize its scientific output and offers the potential for a vast range of new discoveries.

THE SPECIALIZED TECHNICAL CAPABILITIES PROVIDED BY MSE ENABLE AN ENORMOUS DIVERSITY OF EXCITING SCIENCE, TACKLING QUESTIONS ABOUT STARS AND PLANETS THROUGH TO GALAXIES, COSMOLOGY, AND THE NATURE OF DARK MATTER AND DARK ENERGY. THE MOTIVATING SCIENCE FOR MSE HAS NEVER BEEN MORE COMPELLING THAN IT IS RIGHT NOW.

INSIDE THE SCIENCE

DARK MATTER, BRIGHT FUTURE

The majority of matter in the Universe is not like the stuff that we, or all the objects visible in space, are made of. Rather, most of the matter in the Universe is in the form of what astronomers call 'dark matter'.

Very little is known about dark matter, in large part because it does not emit any light...hence the name. It does, however, interact with normal matter through gravity, and it is here that MSE is poised to play a very powerful role.

MSE will measure the velocities of millions of objects throughout the Universe – from the smallest dwarf galaxies up to the most massive super-clusters of galaxies – all of which are moving under the influence of surrounding dark matter. In this way, MSE will be the ultimate facility to take an astrophysical measure of dark matter, and will literally weigh the Universe.

THE GROWTH OF SUPERMASSIVE BLACK HOLES

At the center of every galaxy lurks a supermassive black-hole, millions or even billions of times larger than the Sun, from which nothing can escape. The formation and growth of these most enigmatic objects are intrinsically linked to the formation and evolution of the surrounding galaxy. MSE will measure the mass of thousands of supermassive black holes in thousands of galaxies – a dramatic increase over the number of current measurements. These data will allow scientists to trace the growth of supermassive black holes through cosmic time, charting the co-evolution of a galaxy and its central black hole "engine".

COSMIC NUCLEOSYNTHESIS AND THE CHEMICAL EVOLUTION OF THE GALAXY

MSE is the premier astronomical facility for understanding the cosmic origins of the elements of the periodic table. It is the only facility that will probe the chemical evolution of the Galaxy at the very earliest times through direct measurements of the chemical abundances of stars in all regions of the Milky Way. The combination of MSE spectroscopy and measurements from the Gaia satellite will have a lasting impact in our understanding of the origins of our Galactic home.

GALAXIES AND THE LARGE-SCALE STRUCTURE OF THE UNIVERSE

Galaxies exist within a vast and complex cosmic web. The structure of this web has been mapped observationally and can be explained with impressive accuracy using modern cosmological theory. However, how can we explain the vast diversity of galaxy types that we observe within this web? MSE will begin a new era in our understanding of the evolution of galaxies, by linking their formation and evolution to the large-scale structure of the Universe.

A NEW GENERATION OF ASTRONOMY FACILITIES IS NOW COMING ONLINE WHICH, TOGETHER, WILL IDENTIFY LITERALLY BILLIONS OF NEW OBJECTS, USING IMAGING CAPABILITIES FROM X-RAY TO RADIO WAVELENGTHS.

STRATEGIC SCIENCE

MSE will perfom a key role in this emerging network of astronomical facilities, serving astronomers as an essential follow-up resource for the current and next generation of multi-wavelength imaging surveys slated to be active throughout the 2020s. These surveys include – but are not limited to! – the Large Synoptic Survey Telescope, Gaia, Euclid, WFIRST, the Square Kilometre Array, and the Next Generation Very Large Array, collectively representing several billions of dollars of investment in astronomy's future.

By providing much needed optical and near-infrared spectroscopy for the plethora of objects detected in next generation imaging surveys, MSE can filter down these enormous datasets, by helping to identify the smaller number of objects exhibiting particularly unusual characteristics. This subset of sources can then be referred for more detailed study by specialized facilities, such as the Thirty Meter Telescope, the Giant Magellan Telescope, and the Extremely Large Telescope.

INSPIRED DESIGNS

ENGINEERING MSE

DESIGN EVOLUTION

MSE will be a state-of-the-art observatory inspired by the latest technical advancements made by other top astronomical facilities around the world. MSE will build on the knowledge and experience gained from CFHT's four decades of successful operation atop Maunakea. This development philosophy minimizes costs and risk, while ensuring an efficient and cohesive design.

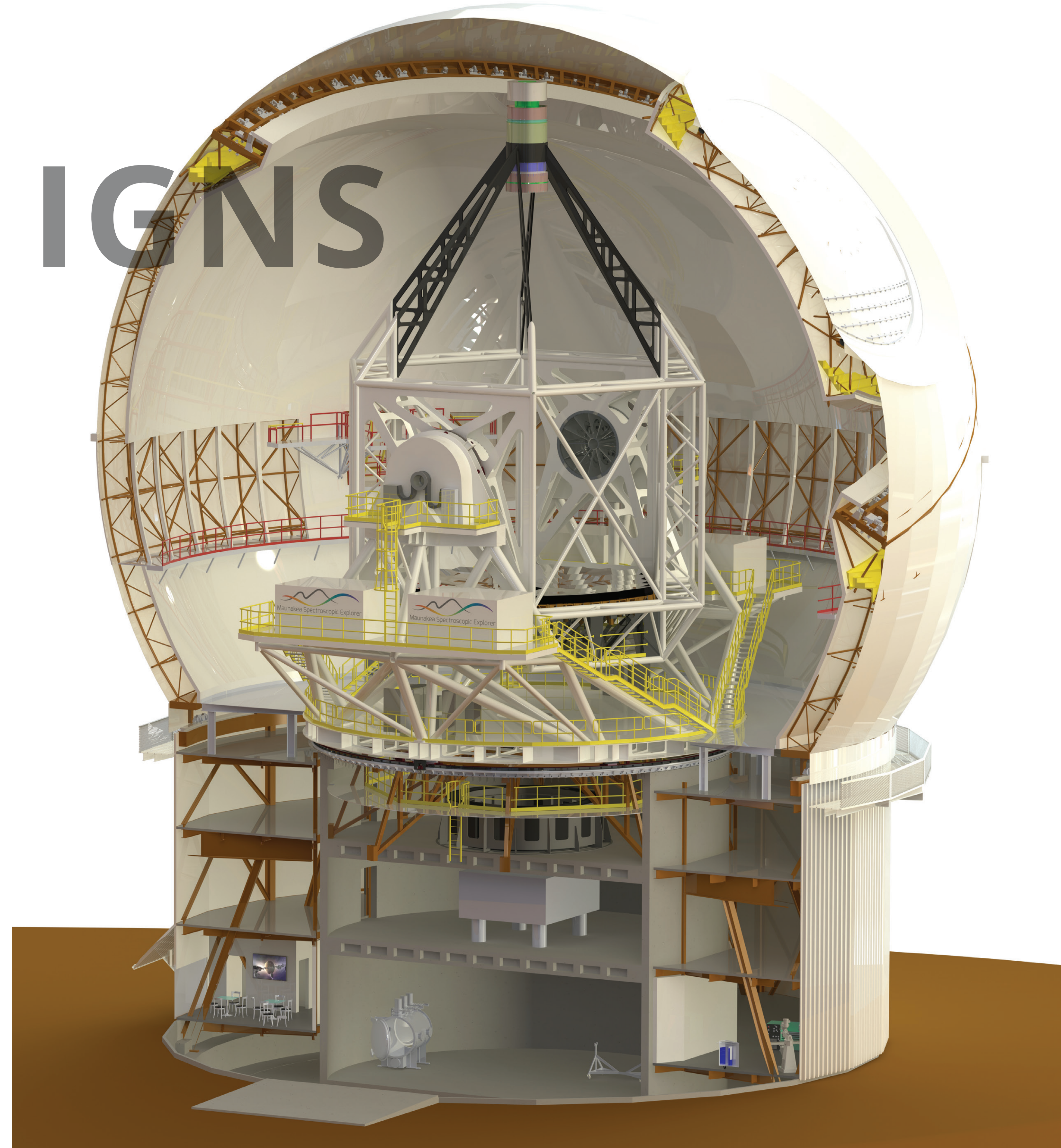
By upgrading the summit facility of CFHT, MSE will continue to use a proven site with well-established infrastructure. The outer building will be reconfigured to improve workflow and facilitate thermal management, while reusing existing equipment to the greatest extent possible. The inner pier remains as the main support structure, providing a stable environment to accommodate the telescope, high resolution spectrographs, and mirror coating laboratory.

THE MAIN STRUCTURE: MSE will be housed in a Calotte style dome enclosure; a design that maximizes strength while minimizing structural mass. The telescope structure is equally efficient due to its high stiffness-to-mass ratio space-frame design. The design promotes ventilation to eliminate the thermally-induced turbulence that would otherwise degrade performance, and thereby maintains the exceptional image quality of the site.

THE TELESCOPE: A prime-focus configuration was adopted after an extensive trade study comparing the merits of four different optical variations. The study examined system level attributes, optical performance, cost and risk. The adopted prime-focus configuration is an Alt-Az segmented mirror telescope with 60 segments and an integrated hexapod that supports the top-end system essential to observing 4,332 targets simultaneously.

The MSE top-end system is composed of a high throughput wide-field corrector, field de-rotator, fibreoptic positioners and fibreoptic bundles. 4,332 positioners provide full-field coverage, and are capable of placing all fibreoptic inputs to within six micron accuracy. The fibreoptic bundles deliver light collected at prime focus to the spectrographs below. The fibre positioning system was selected after an exhaustive down-select process analogous to the telescope optical configuration study.

THE SPECTROGRAPHS: Two sets of spectrographs are required for MSE: one group of six for low/moderate resolution measurements, and a group of two for high-resolution measurements. The spectrograph designs are the result of collaborative efforts between scientists and engineers given challenging constraints on multiplexing, spectral coverage, and detector formats.



CURRENT MSE PARTICIPANTS

THE BENEFITS OF A TEAM: JOINING THE MSE TEAM

MSE IS DESIGNED TO BECOME A KEY TOOL FOR SURVEYING THE COSMOS, OBSERVING THE SPECTRA OF MANY MILLIONS OF ASTRONOMICAL OBJECTS. ALL MSE PARTNERS GAIN ACCESS TO THAT UNIQUE AND RICH DATASET, FOR IMMEDIATE SCIENTIFIC USE BY THE MSE RESEARCH COMMUNITY.

As a partner in MSE, astronomers can participate in defining, proposing, obtaining and analyzing multi-year, legacy datasets. These community-wide programs are expected to be solicited from the partners on a yearly or bi-yearly basis, with a handful of programs under observation at any time.

Smaller, strategic survey programs will also be solicited from partners more frequently, to occupy the remainder of available telescope time. With their more limited scope and shorter duration, these programs will take advantage of MSE's unique capabilities, but without requiring the extensive multi-year allocations of the legacy surveys.

The combination of legacy and strategic programs ensures that MSE partners are always conducting leading edge science defined and led by astronomers in their research community.

A significant proprietary period on all data obtained by MSE prior to worldwide release will ensure the scientific results achieved by astronomers in the MSE partnership are, quite literally, years ahead of their colleagues elsewhere.

Entering the preliminary design phase, the MSE team includes Australia, Canada, China, France, Hawaii and India. Spain also played a key design role in earlier phases of the project.

Numerous work packages and contracts are available to MSE partners. MSE uses advanced systems, opto-mechanical, mechanical and software engineering to deliver a state-of-the-art scientific research facility. The work, taken together, is the design and manufacture of an entire observatory system including environmental, safety, building, enclosure, telescope, instrument and data subsystems.

MSE is being developed through close collaboration between scientists, engineers, academia, government and industry, and it provides cutting edge opportunities for all these sectors.

The budget and scope of MSE are under the exclusive control of the MSE Management Group, a body that ensures all participants in the preconstruction phase of the project have an equal voice in the financial, administrative and oversight aspects of the project.

SOUND SCIENCE

FINANCIAL FEASIBILITY

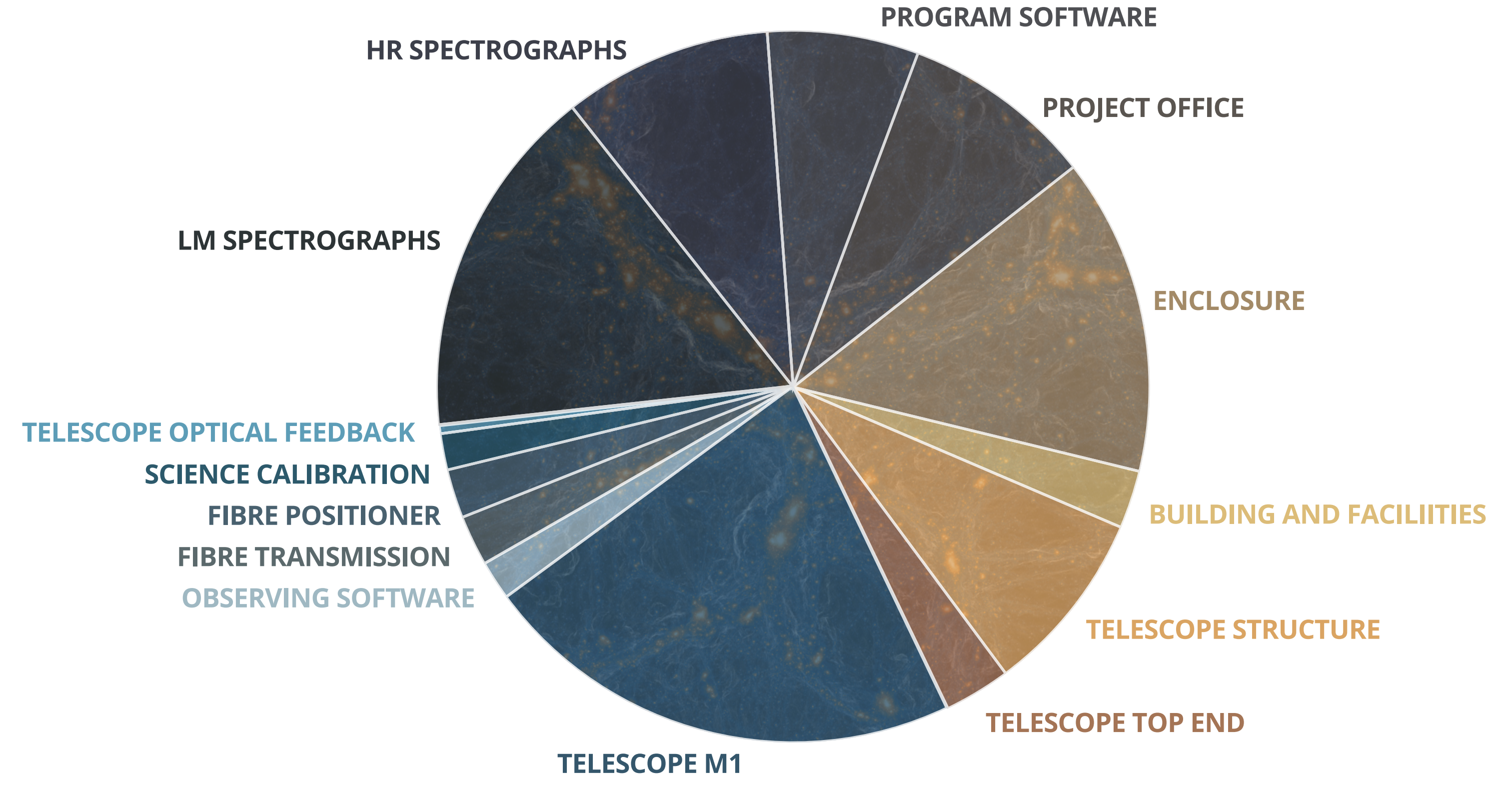
On all matters affecting science capability, the Management Group acts with the advice of the MSE Science Advisory Group, a group of scientists with representation from across the spectrum of MSE participants.

MSE reduces risk via the selection of engineering solutions with proven track records. This core strategy is especially successful for all aspects of the infrastructure of the observatory (the telescope mount, the primary mirror, enclosure, and building).

MSE's main science instruments – the fibreoptic positioners, fibreoptic transmission system, the two main spectrograph systems, and the observing preparation and data reduction software – contains elements that must push the boundaries of their associated technologies in order to meet the challenging science objectives. These elements include the production of high transparency and high numerical aperture fibreoptics, and the design of large, high performance, spectrographs.

Current cost estimates assign nearly half of the total budget to the science instruments of MSE. The MSE team will achieve its engineering objectives through innovative solutions, techniques, and knowledge, being developed and shared between those who join the challenge.

MSE COST ESTIMATE



SCHEDULED FOR SUCCESS

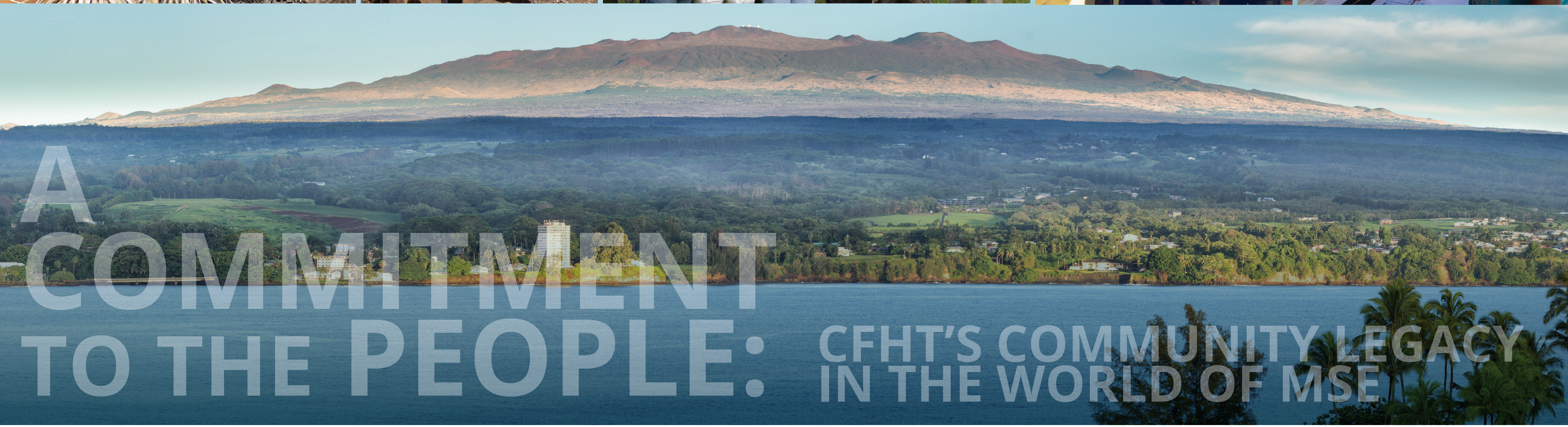
MSE has successfully completed the conceptual design and is actively establishing funding for the preliminary design phase, scheduled for 2019/20. MSE is managed as a cost-capped project (currently $313 million, 2018 economics), with regular cost and scope reviews built into its schedule.

Following the end of preliminary design, the project will transition to the construction phase, including final design and fabrication work for each of the subsystems, followed by the assembly, integration, testing and commissioning (AIVC) on Maunakea.

Two major milestones must first be achieved prior to the construction phase. First, land authorization for long-term continuation of astronomy on Maunakea, under which all Maunakea telescopes operate, must be renewed – a process that is underway now. Second, the MSE partnership must agree to fund and initiate the construction phase. The current schedule anticipates achieving both of these milestones by mid-2021, leading to full science operations commencing in August 2026.







A COMMITMENT TO THE PEOPLE: CFHT'S COMMUNITY LEGACY IN THE WORLD OF MSE

MSE benefits from CFHT's 40 years of experience on Maunakea and a support staff deeply rooted in the Hawaii Island community. By hosting numerous outreach events and activities, CFHT actively engages the local Big Island community to share our understanding of the cosmos and to inspire young people to pursue education in fields of science, technology, engineering and math (STEM).

MSE will continue CFHT's outreach goals and methods, strengthening our ties to the broad community, both locally in Hawaii and across the partnership. MSE will maintain the deep connections CFHT has cultivated with the local educational community and workforce development programs. These connections will help local students, parents and educators to understand the scientific and engineering jobs that exist inside an observatory, with the goal of inspiring Hawaii students to remain in the STEM fields. It is the hope of MSE that these students will stay in Hawaii to work in the observatory community and participate in other high tech industries.

At the same time, MSE will offer ample opportunities for students outside of Hawaii to learn about astronomy by facilitating observatory visits, either in person or remotely. When CFHT staff attend conferences, they make an effort to engage with local students from elementary to graduate level. CFHT offers virtual visits and talks by staff to students and the general public around the world. MSE is committed to expanding these efforts to engage more students and communities within the partnership community. We envisage MSE will host visiting graduate and undergraduate students to work alongside observatory staff on a variety of projects from astronomical research, engineering development to computer science.

In all its endeavours, MSE will remain deeply committed to balancing cultural and environmental considerations, from the design and operation of the observatory itself, in our realization of the new MSE partnership.

Located on the breathtaking summit of Maunakea, CFHT has long enjoyed arguably the best site for optical astronomy on the planet. MSE retains and reuses as much of the existing physical infrastructure as possible, both on the summit and at the headquarters in Waimea.

As much as MSE builds on the same physical infrastructure of CFHT, so too does it build on the successes of CFHT's expert staff and operations. Over the past decade, this staff has been the vanguard for establishing operational procedures optimized for large, multi-year, survey programs. They were the first major optical astronomy facility to move to queue-scheduled observing, greatly increasing the efficiency of the facility and showing the way for other observatories, including MSE.

In tandem with their development of queue-based operational procedures, CFHT realized early on that the staff who operate and maintain instruments are often the best-placed to process the data when it first comes off the telescope. In so doing, the observatory provides science-ready data products to its users. This approach is fundamentally necessary when dealing with the specialized, large datasets that MSE will produce on a nightly basis.

THE LEGACY LIVES ON

Through innovative engineering MSE will fit within the existing envelope of CFHT, enabling revolutionary new science while minimizing any impact to the environment. CFHT will be the first observatory to be recycled in this way and is a leading example of how to apply careful planning and advanced engineering methods to protect sensitive astronomy sites. In the same way CFHT's local workforce will learn and grow with MSE to offer even more outstanding careers and educational opportunities.

MSE celebrates, is thankful for, and will continue the legacy of CFHT.

PHOTO CREDITS:

Page 2: Maunakea Rainbow image: Bryan Carnathan and The-Digital-Picture.com **Page 5:** Hercules A (the image associated with "Supermassive Black Holes"): NASA, ESA, S. Baum and C. O'Dea (RIT), R. Perley and W. Cotton (NRAO/AUI/NSF), and the Hubble Heritage Team (STScI/AURA); Illustris image (the image associated with Dark Matter): The Illustris Collaboration; Gaia density map (image associated with Chemical Evolution): ESA/Gaia/DPAC/CU5/CU8/DPCI/F. De Angeli, D.W. Evans, M. Riello, M. Fouesneau, R. Andrae, C.A.L. Bailer-Jones **Page 7:** LSST facility image: Todd Mason, Mason Productions Inc. / LSST Corporation; Euclid image: Artist impression based on the CAD drawings by Thales Alenia Space, Italy and Airbus (Defence and Space), France.- © ESA; Gaia image: ESA–D. Ducros, 2013; SKA image: SKA Organisation

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Maunakea Spectroscopic Explorer

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https://arxiv.org/abs/1606.00043