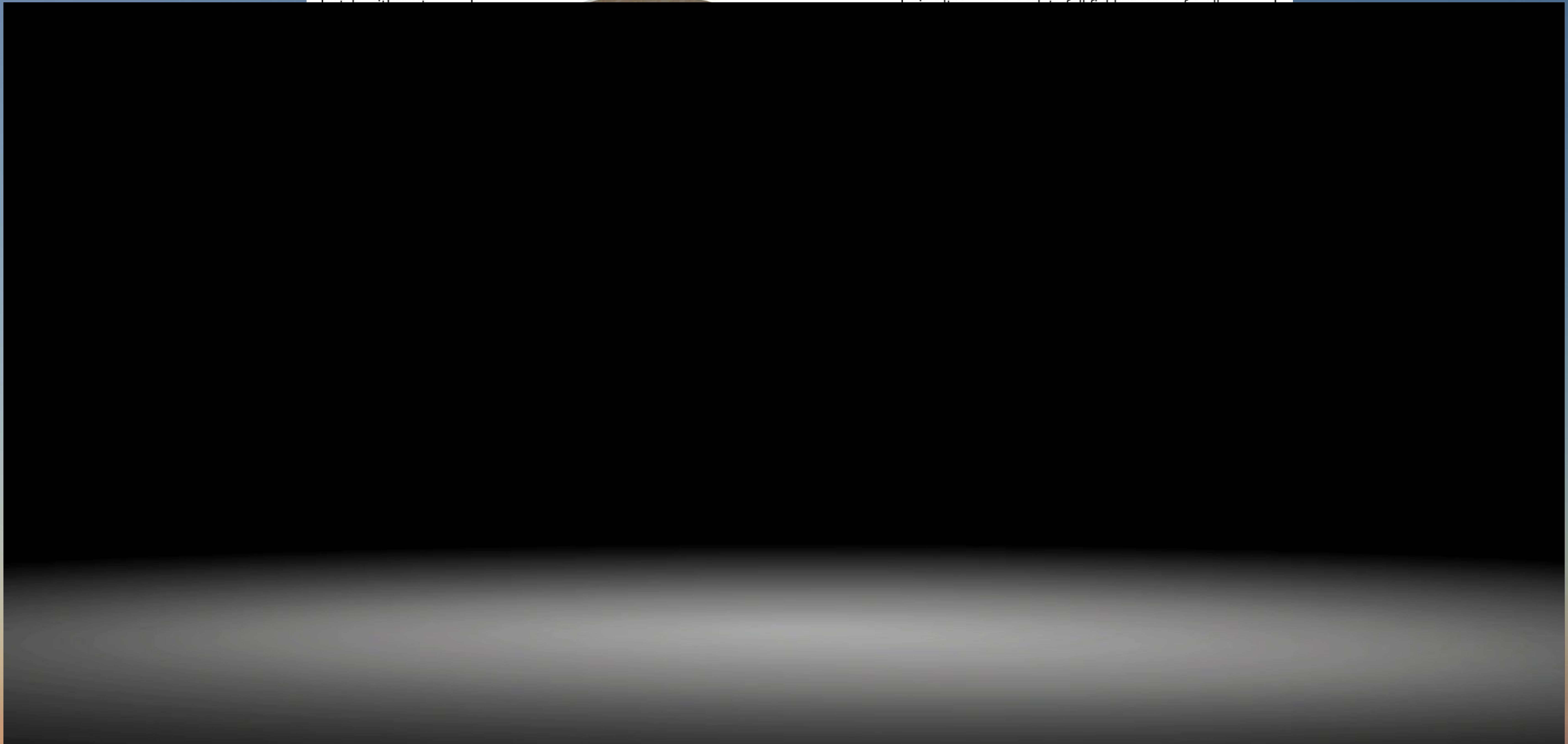
The Maunakea Spectroscopic Explorer

- Jennifer Marshall
- MSE Project Scientist
- Texas A&M University

The Maunakea Spectroscopic Explorer

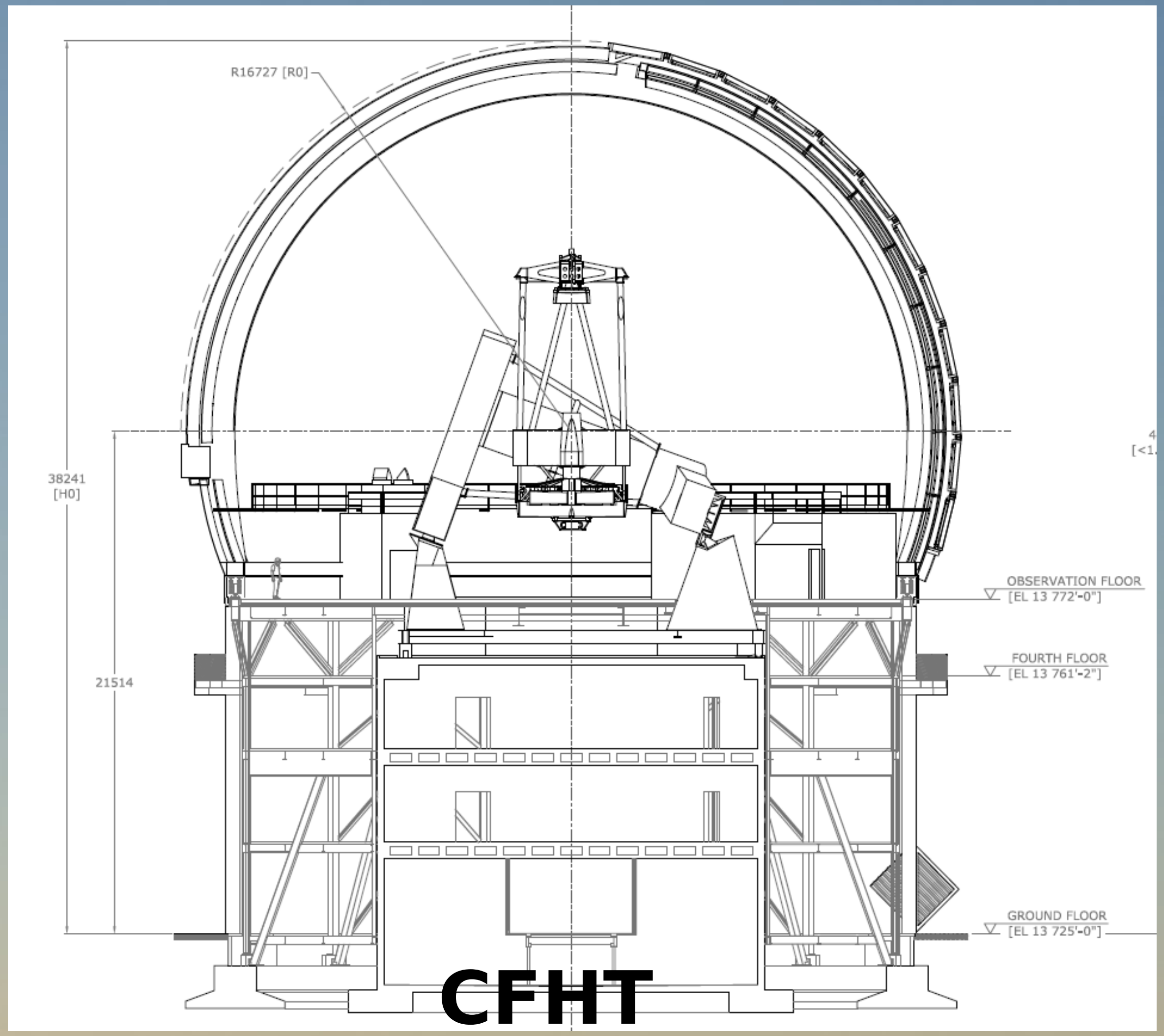


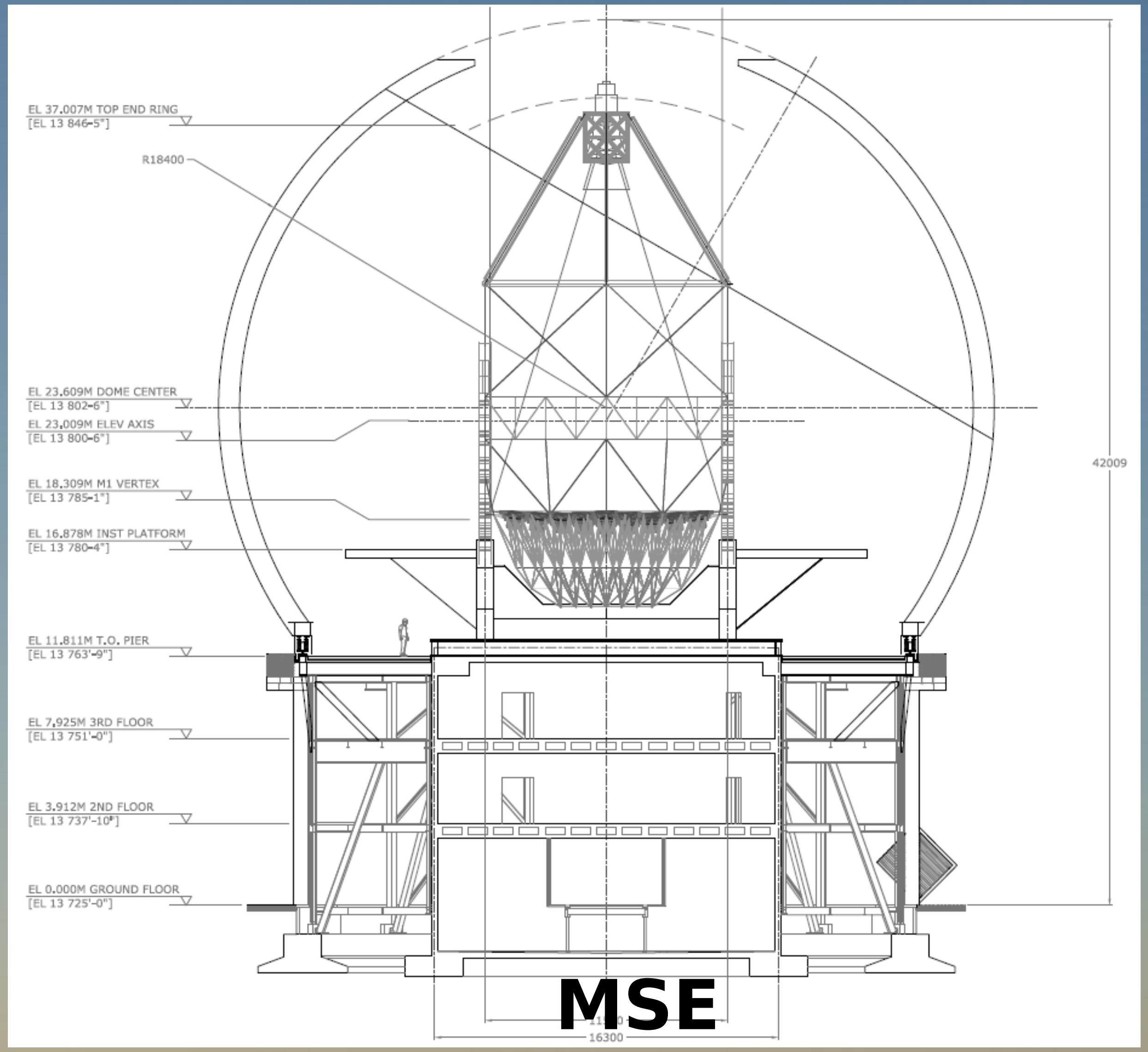
Maunakea Spectroscopic Explorer

Facility transformation

- CFHT has a 40 year history of scientific and outreach leadership on Maunakea
- Out of environmental and cultural respect, a strong desire to preserve the external appearance of CFHT after MSE completion
  - MSE will reuse the CFHT summit building without additional ground disturbances
  - Limiting size increase of the new facility building and enclosure to 10%

Facility transformation



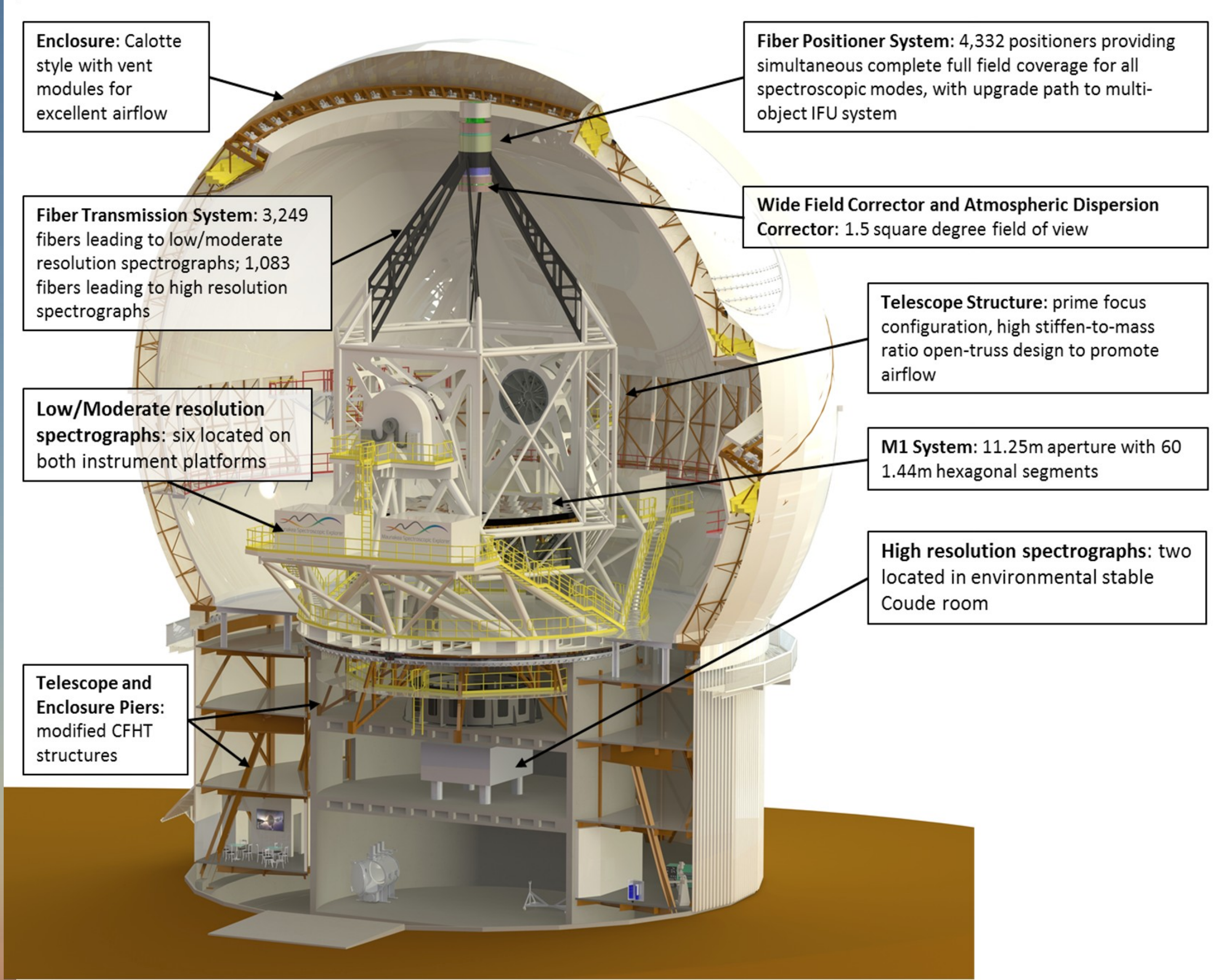


Maunakea Spectroscopic Explorer

Facility transformation

Conceptual Design

- 11.25m diameter telescope
- 1.5 square degree field of view
- 4,332 fiber positioner feed two sets of spectrographs
  - Low resolution: R~3000 / UV to H band / 3249 positioners
  - High resolution: R=40000 / three windows in optical / 1083 positions
- **Completely dedicated survey facility**



Fiber Positioner System

Conceptual Design by AAO (Australian
Astronomical Observatory) Macquarie

-Sphinx design (based on FMOS/Echid

-Hexagonal field of view

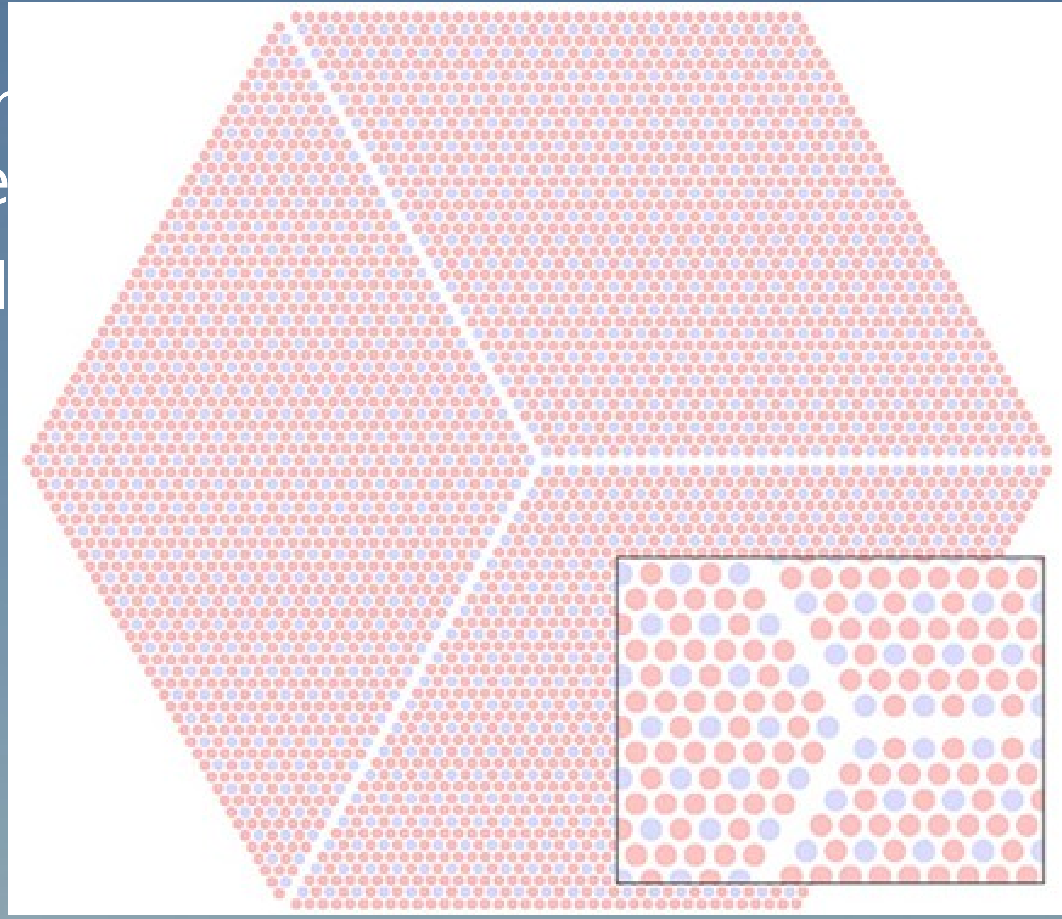
- 4,332 piezo actuator positioners

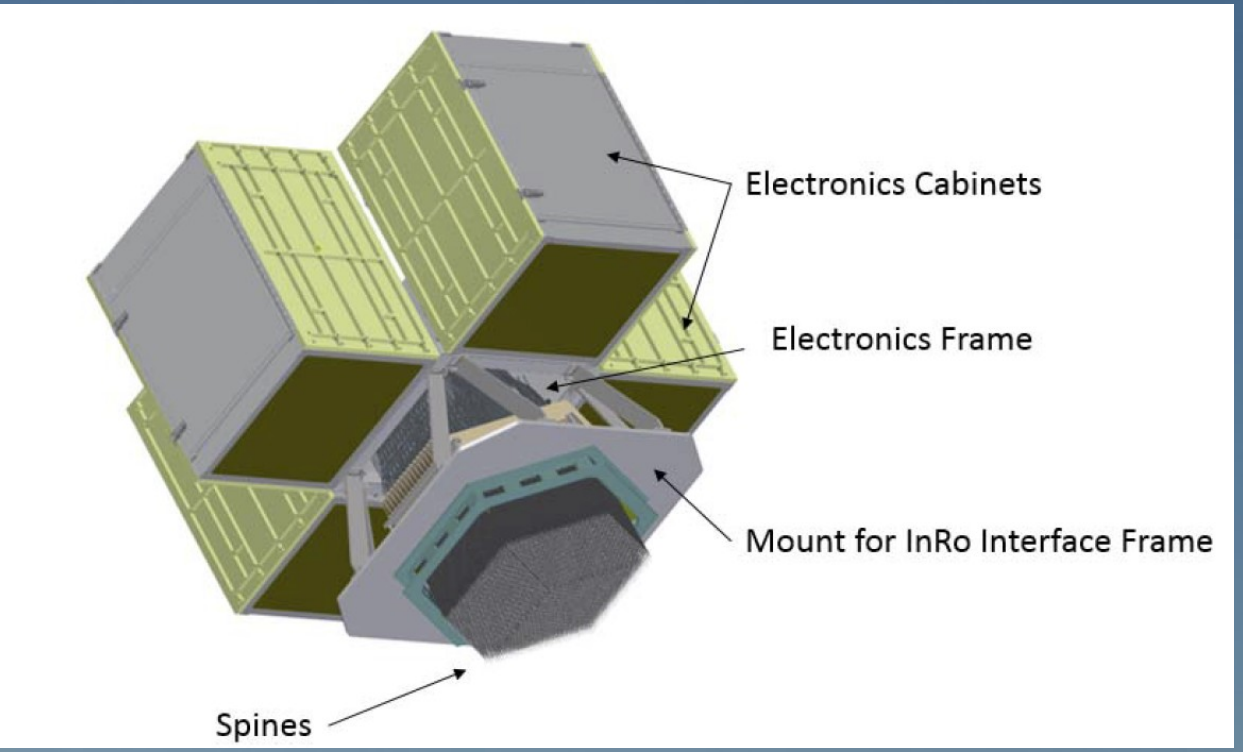
-57 modules/76 positioners each

(57 LMR/19 HR)

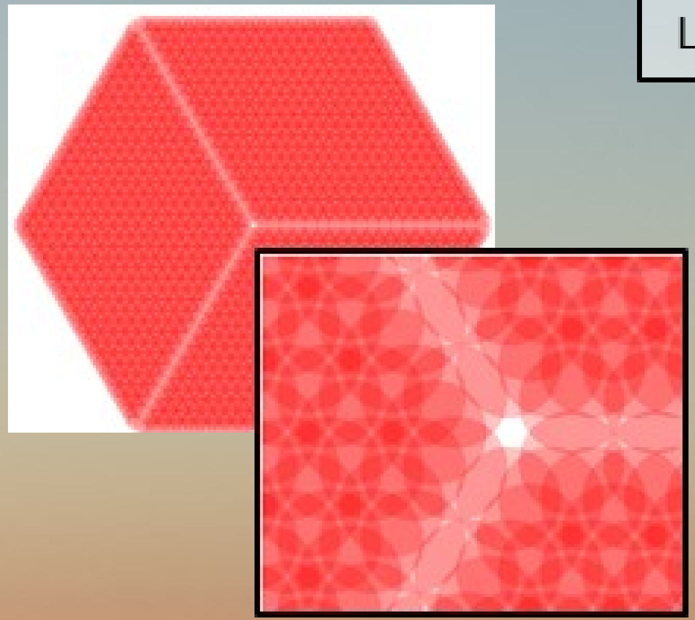
Allows **simultaneous**

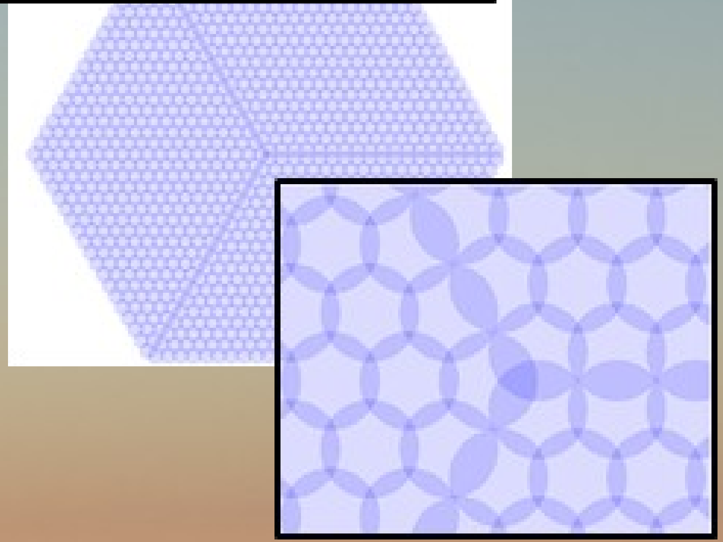
HR and LMR coverage



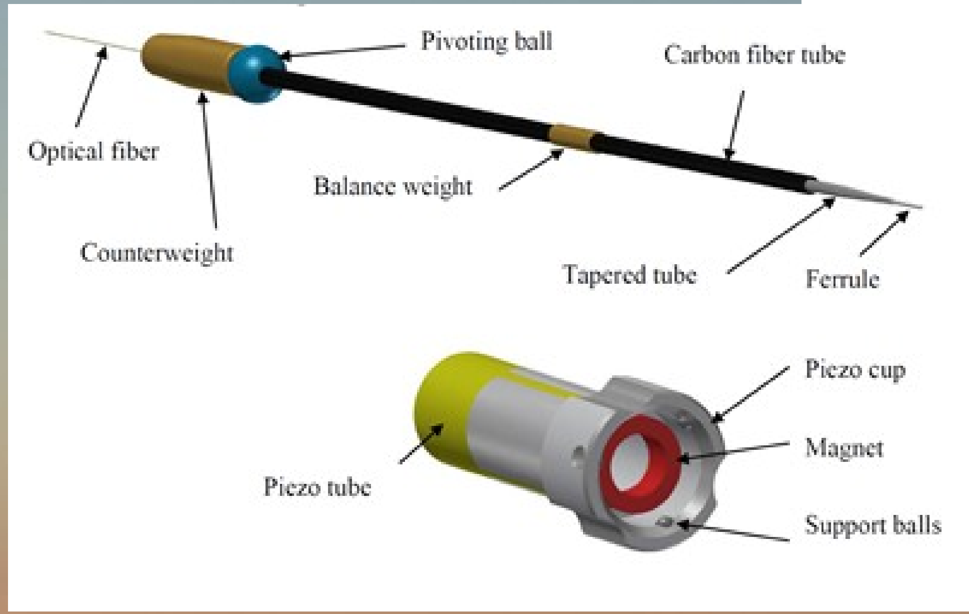


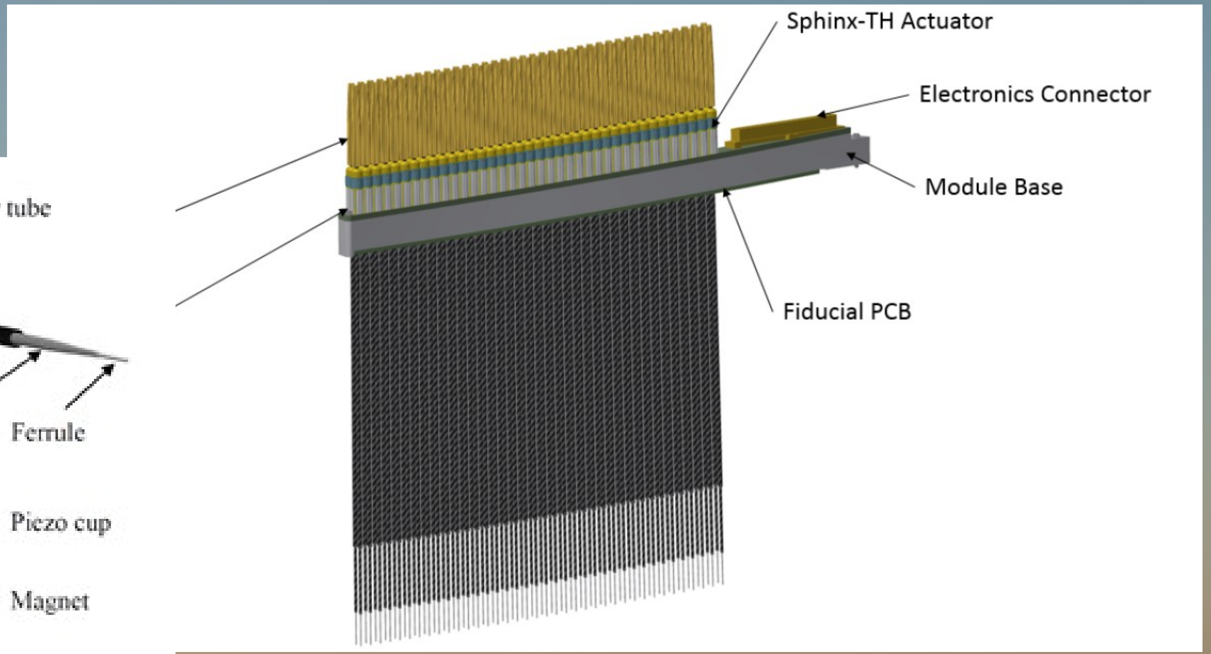
Positioner patrol areas:
LMR (red), HR (blue)





Echidna fiber positioner



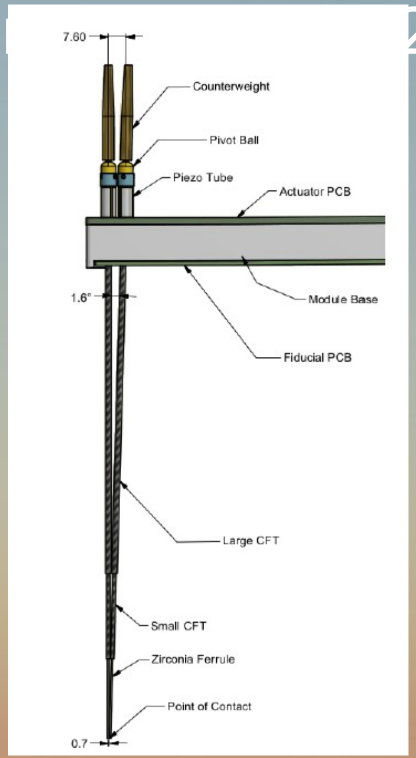


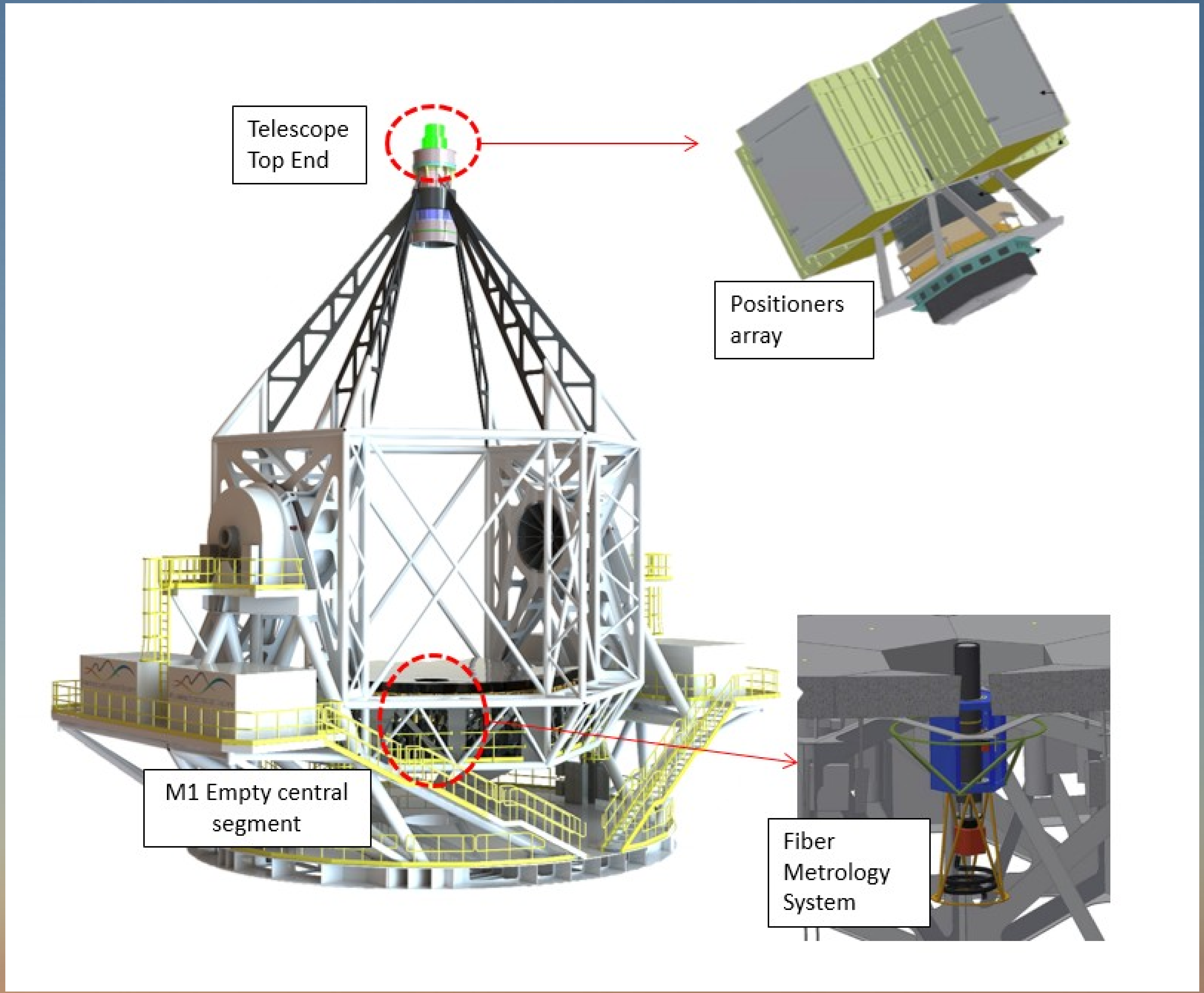
Maunakea Spectroscopic Explorer

Fiber Positioner System

Individual actuators position fibers precisely on sky targets.

- Closed loop with its own metrology, accuracy 0.06 arcsec rms (~6 um)
- Patrol radius 90.3 arcsec (~9 mm)
- Two fibers: closest approach 7 arcsec
- Three fibers: cluster within 9.9 arcsec circle
- Reconfigu[illegible] 2 minutes



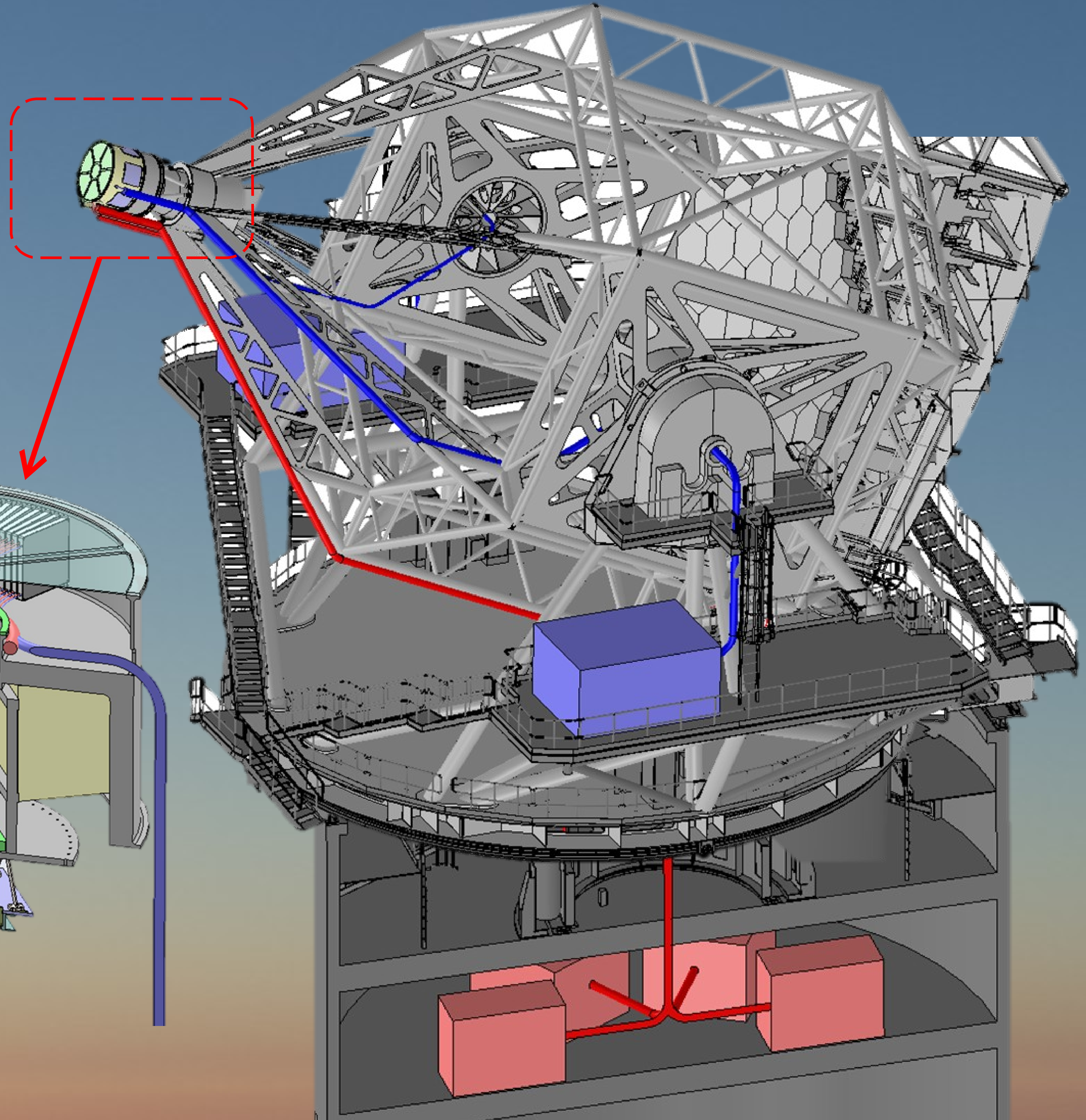


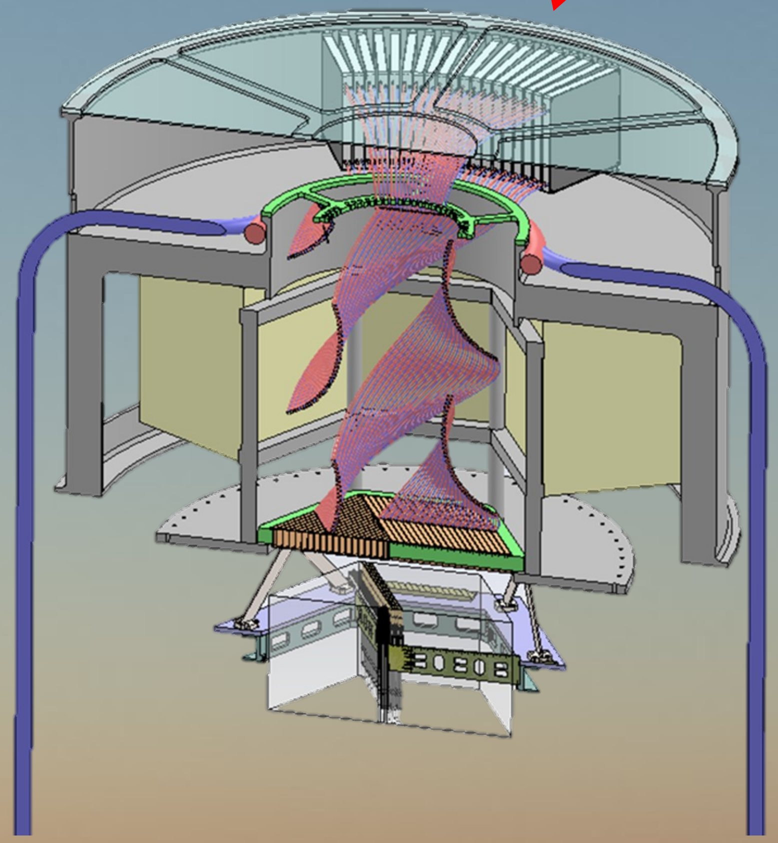
Fiber Transmission System

Conceptual Design by NRC-HAA (Herzberg Astronomy and Astrophysics), Canada

- Continuous fiber end-to-end without connectors
- High Numerical Aperture fibers (0.75” HR, 1.0” LMR)
- No input microlens optics
- High stability and repeatability

- End to end test bench being developed in Canada at University of Victoria

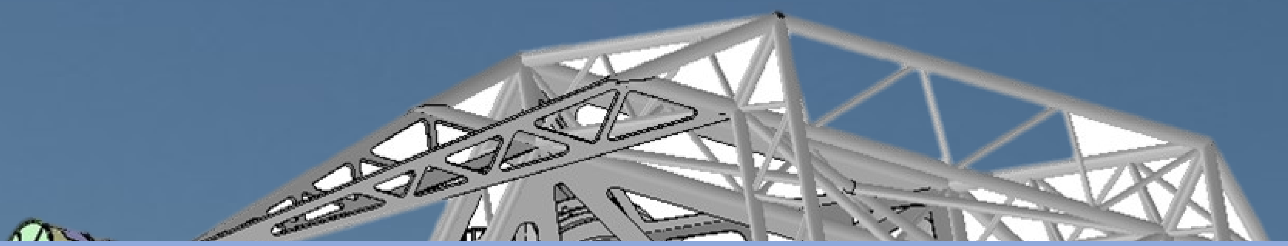




Maunakea Spectroscopic Explorer

LMR Spectrographs

Conceptual Design by CRAL (Centre de Recherche Astrophysique de Lyon), France



Low resolution (LR) spectroscopy				
Wavelength range	360 ≦ λ ≦ 560 nm	540 ≦ λ ≦ 740 nm	715 ≦ λ ≦ 985 nm	960 ≦ λ ≦ 1320 nm
Spectral resolution *(approx. at center of band)*	2,550	3,650	3,600	3,600
Sensitivity requirement *(pt. source, 1hr, zenith, median seeing, monochromatic magnitude)*	m = 24.0 SNR/res. elem. = 2, λ > 400 nm SNR/res. elem. = 1, λ ≦ 400 nm	m = 24.0 SNR/resolution element = 2	m = 24.0 SNR/resolution element = 2	m = 24.0 SNR/resolution element = 2
Moderate resolution (MR) spectroscopy				
Wavelength range	391 ≦ λ ≦ 510 nm	576 ≦ λ ≦ 700 nm	737 ≦ λ ≦ 900 nm	1457 ≦ λ ≦ 1780 nm
Spectral resolution *(approx. at center of band)*	4,400	6,200	6,100	6,000
Sensitivity requirement *(pt. source, 1hr, zenith, median seeing, monochromatic magnitude)*	m = 23.5 SNR/res. elem. = 2, λ > 400 nm SNR/res. elem. = 1, λ ≦ 400 nm	m = 23.5 SNR/resolution element = 2	m = 23.5 SNR/resolution element = 2	m = 24.0 SNR/resolution element = 2

Modes:

- Optical LR + J-band LR
- Optical MR + H-band LR
- All arms of all spectrographs are independently controlled. Possibility of simultaneous LR/MR on different targets in same observing field.

LMR Spectrographs

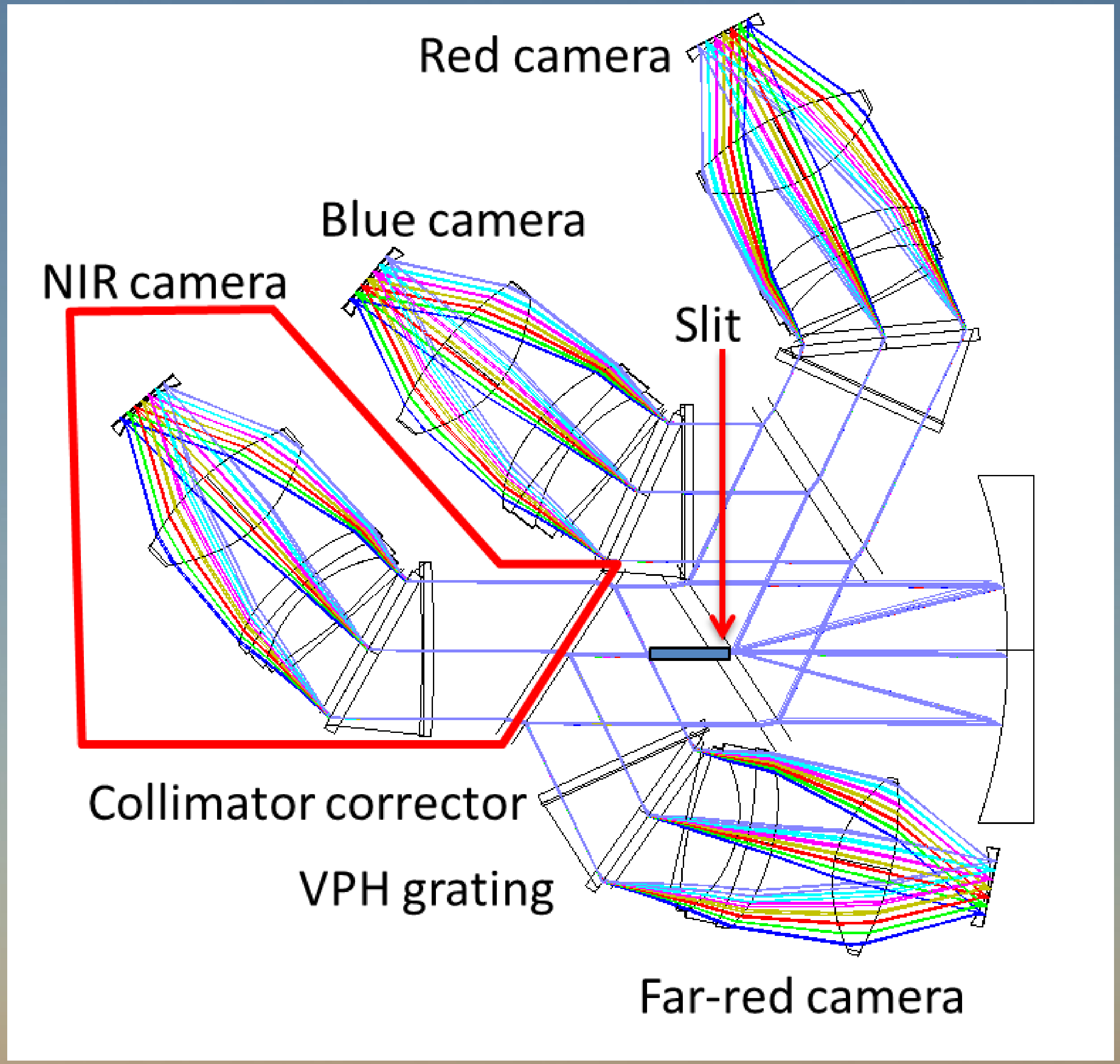
Conceptual Design by CRAL (Centre de Recherche Astrophysique de Lyon), France

H-band use requires cooled slit, hence cooled *optical* arms (210K)

Camera design is f/1.2, transmissive. Good throughput and unobstructed pupil.

Challenging to build –strong aspheres/glued doublets, tight alignment specs. Some options:

- Catadioptric design
- Shrink the fiber size
- Curved CCDs (but not NIR)



Maunakea Spectroscopic Explorer

HR Spectrographs

Conceptual Design by NIAOT (Nanjing Institute of Astronomical Optics & Technology)

Two identical spectrographs:

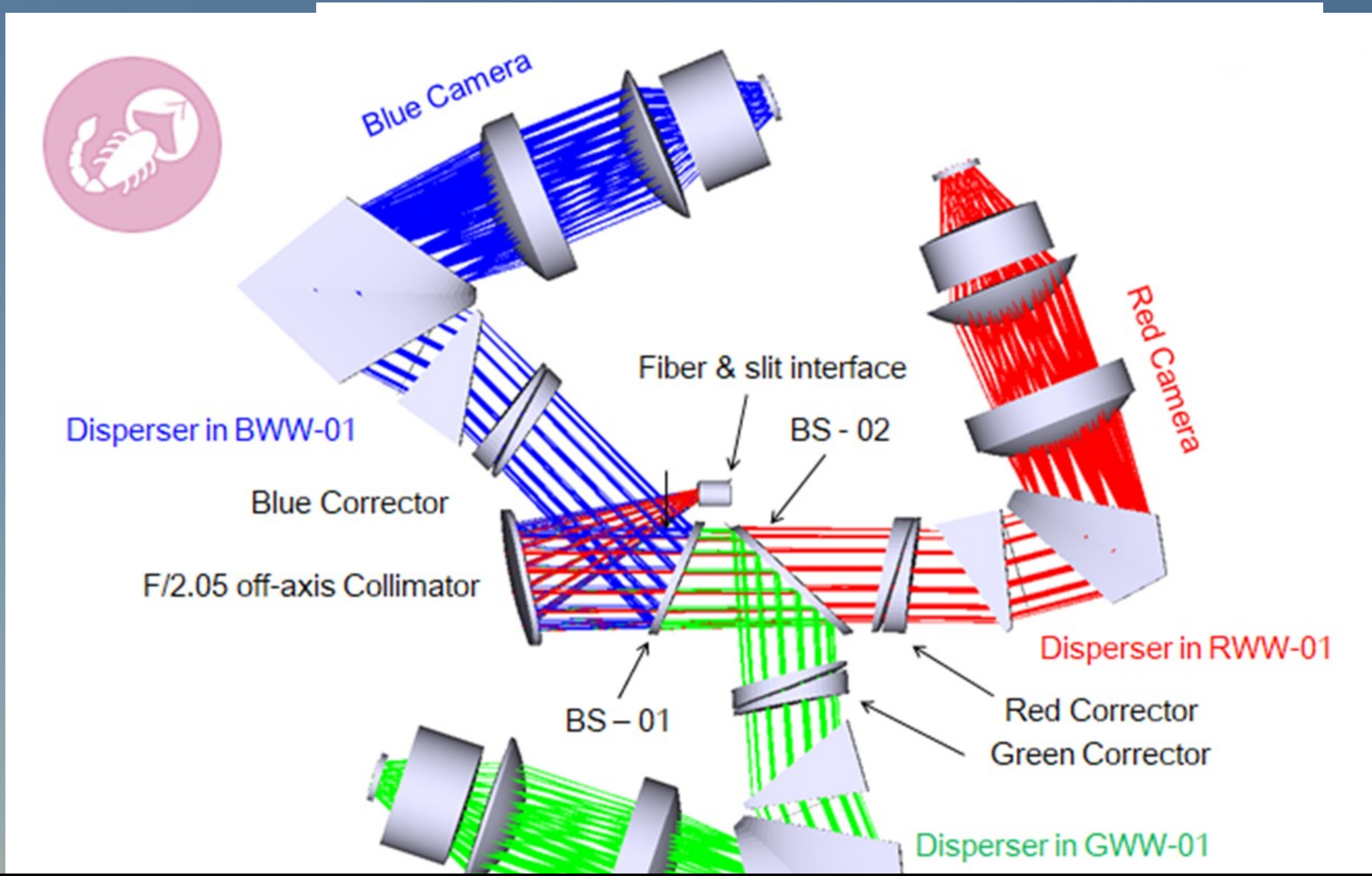
- accept 1083 (0.8” diameter) fibers, from full field of view, divided evenly
- 3x optical arms (360-950), in three spectral channels (blue green and red), a.k.a. wavelength windows

Blue (401-417nm), R=40k, λ/30

Green (471-489nm), R=40k, λ/30

Red (625-674nm), R=20k, λ/15

- Off-axis f/2.05 collimator



High resolution (HR) spectroscopy			
Wavelength range	360 ≤ λ ≤ 460 nm	440 ≤ λ ≤ 620 nm	600 ≤ λ ≤ 900 nm
Wavelength band	λ / 30 [baseline: 401.0 - 415.0 nm]	λ / 30 [baseline: 472.0 - 488.5 nm]	λ / 15 [baseline: 626.5 - 672.0 nm]
Spectral resolution *(approx. at center of band)*	40,000	40,000	20,000
Sensitivity requirement *(pt. source, 1hr, zenith, median seeing, monochromatic magnitude)*	m = 20.0 SNR/resolution element = 10, λ > 400 nm SNR/resolution element = 5, λ ≤ 400 nm	m = 20.0 SNR/resolution element = 10	m = 20.0 SNR/resolution element = 10

Maunakea Spectroscopic Explorer

Preliminary Design Phase

CURRENT MSE PARTICIPANTS

- The PDP starts in 2019 with participants:
  - Australian Astronomical Optics (AAO) Macquarie
  - National Research Council (NRC) of Canada
  - National Astronomical Observatories (NAOC), Chinese Academy of Sciences
  - Centre National de la Recherche Scientifique (CNRS) of France
  - Institute for Astronomy, University of Hawaii
  - India Institute of Astrophysics
  - National Optical Astronomy Observatory, USA and Texas A&M University participate as observers

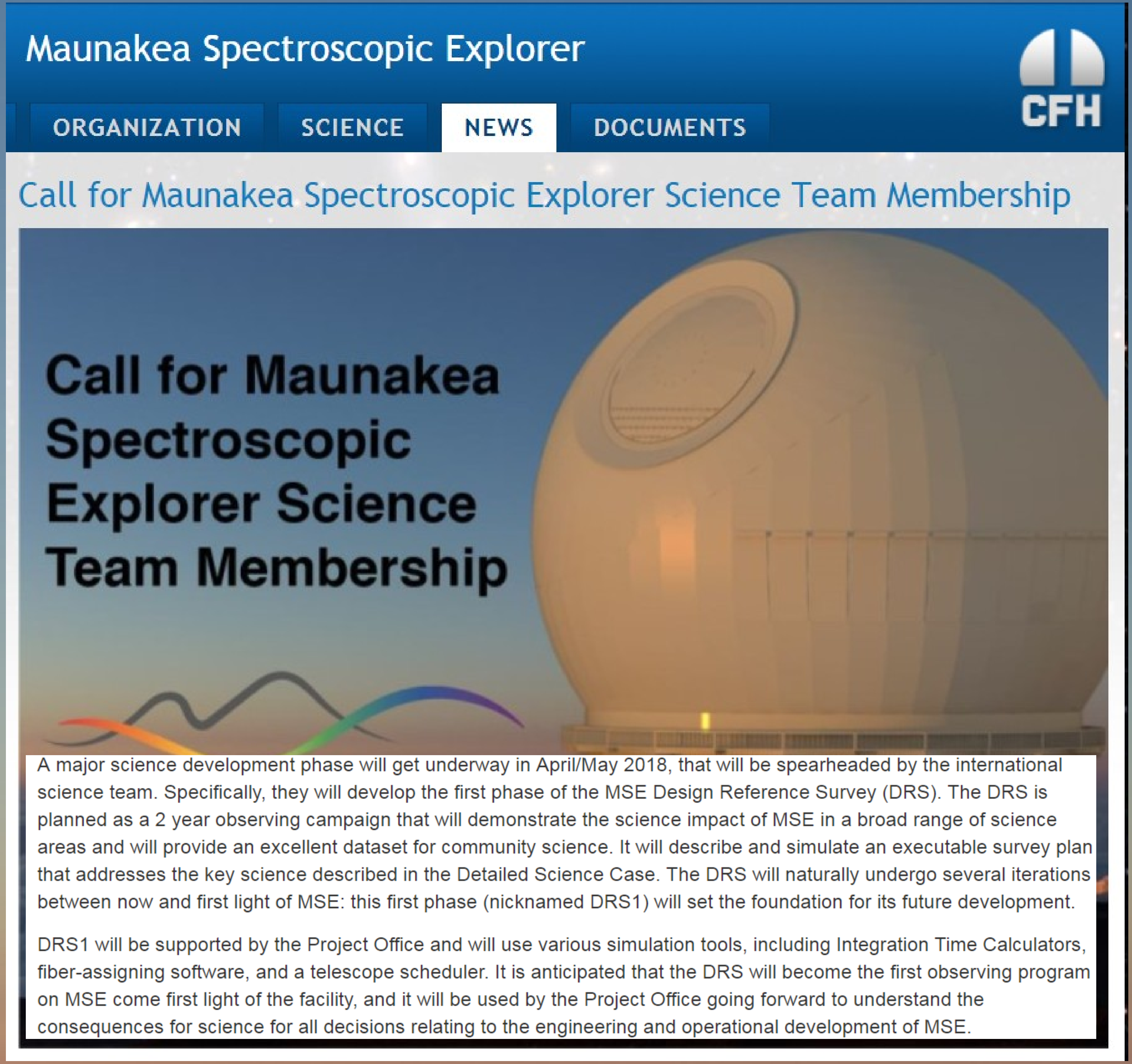
Maunakea Spectroscopic Explorer

Growth of Science Team

- Huge response to March 2018 call for Science Team Membership!
  - Currently 372 members from 36 countries:

    - Australia* – 30
    - Belgium – 7
    - Canada* – 38
    - Chile – 7
    - China* – 32
    - France* – 38
    - Germany – 18
    - India* – 11
    - Italy – 12
    - Spain – 14
    - United Kingdom – 31
    - USA – 93
    - **Brazil – 1**
    - Other – 130

* Current MSE participants


Maunakea Spectroscopic Explorer

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ORGANIZATION SCIENCE NEWS DOCUMENTS

Call for Maunakea Spectroscopic Explorer Science Team Membership

Call for Maunakea Spectroscopic Explorer Science Team Membership

A major science development phase will get underway in April/May 2018, that will be spearheaded by the international science team. Specifically, they will develop the first phase of the MSE Design Reference Survey (DRS). The DRS is planned as a 2 year observing campaign that will demonstrate the science impact of MSE in a broad range of science areas and will provide an excellent dataset for community science. It will describe and simulate an executable survey plan that addresses the key science described in the Detailed Science Case. The DRS will naturally undergo several iterations between now and first light of MSE: this first phase (nicknamed DRS1) will set the foundation for its future development.

DRS1 will be supported by the Project Office and will use various simulation tools, including Integration Time Calculators, fiber-assigning software, and a telescope scheduler. It is anticipated that the DRS will become the first observing program on MSE come first light of the facility, and it will be used by the Project Office going forward to understand the consequences for science for all decisions relating to the engineering and operational development of MSE.

Updated Detailed Science Case

- Over the past few months the Science Team has worked hard to update the MSE Detailed Science Case:

Contents

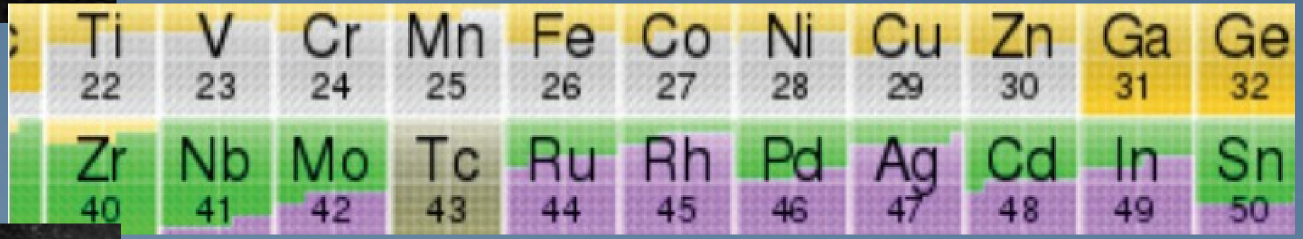
- Nearly 300 pages!
- Over 100 active contributors

- Builds upon original MSE Detailed Science Case (2016)

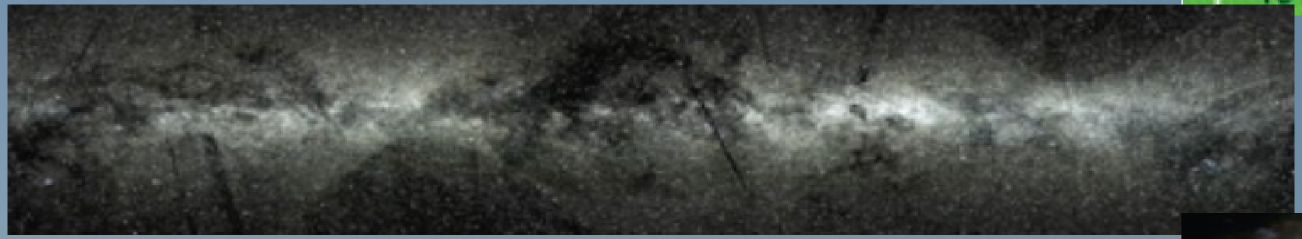
Maunakea Spectroscopic Explorer

Science Working Groups

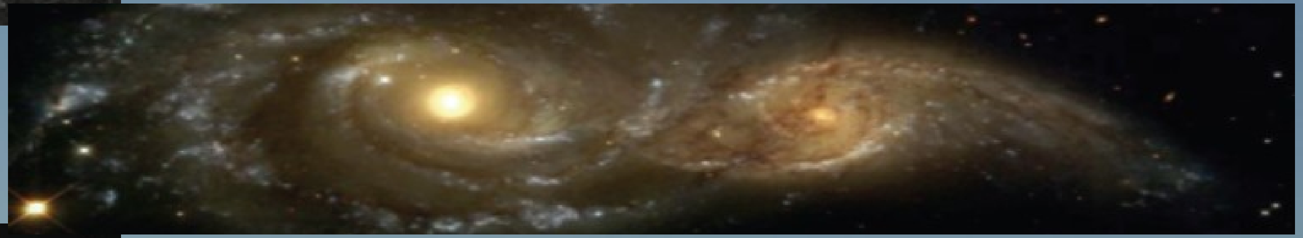
Exoplanets and stellar astrophysics
Maria Bergemann & Daniel Huber



Chemical nucleosynthesis
Sivarani Thirupathi & David Yong



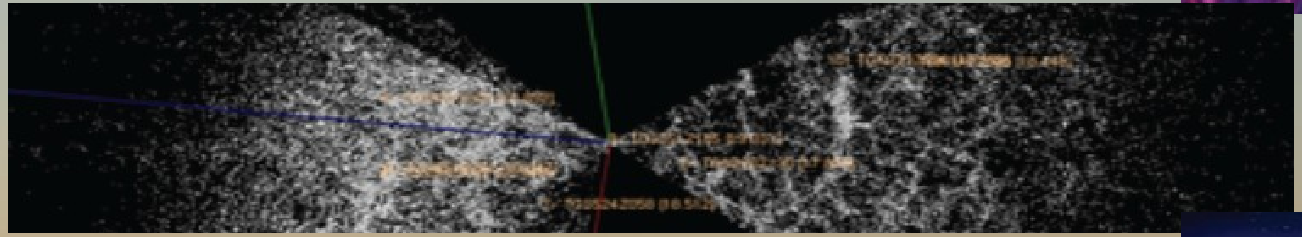
Milky Way and resolved stellar pops
Carine Babusiaux & Sarah Martell



Galaxy Formation and evolution
Kim-Vy Tran & Aaron Robotham

AGN and supermassive black holes
Yue Shen & Sara Ellison

Astrophysical tests of dark matter
Ting Li & Manoj Kaplinghat



Cosmology
Will Percival & Christophe Yeche

Time domain astronomy and transients
Adam Burgasser & Daryl Haggard

Maunakea Spectroscopic Explorer

Massively multiplexed spectroscopy with MSE: Science, Project and Vision

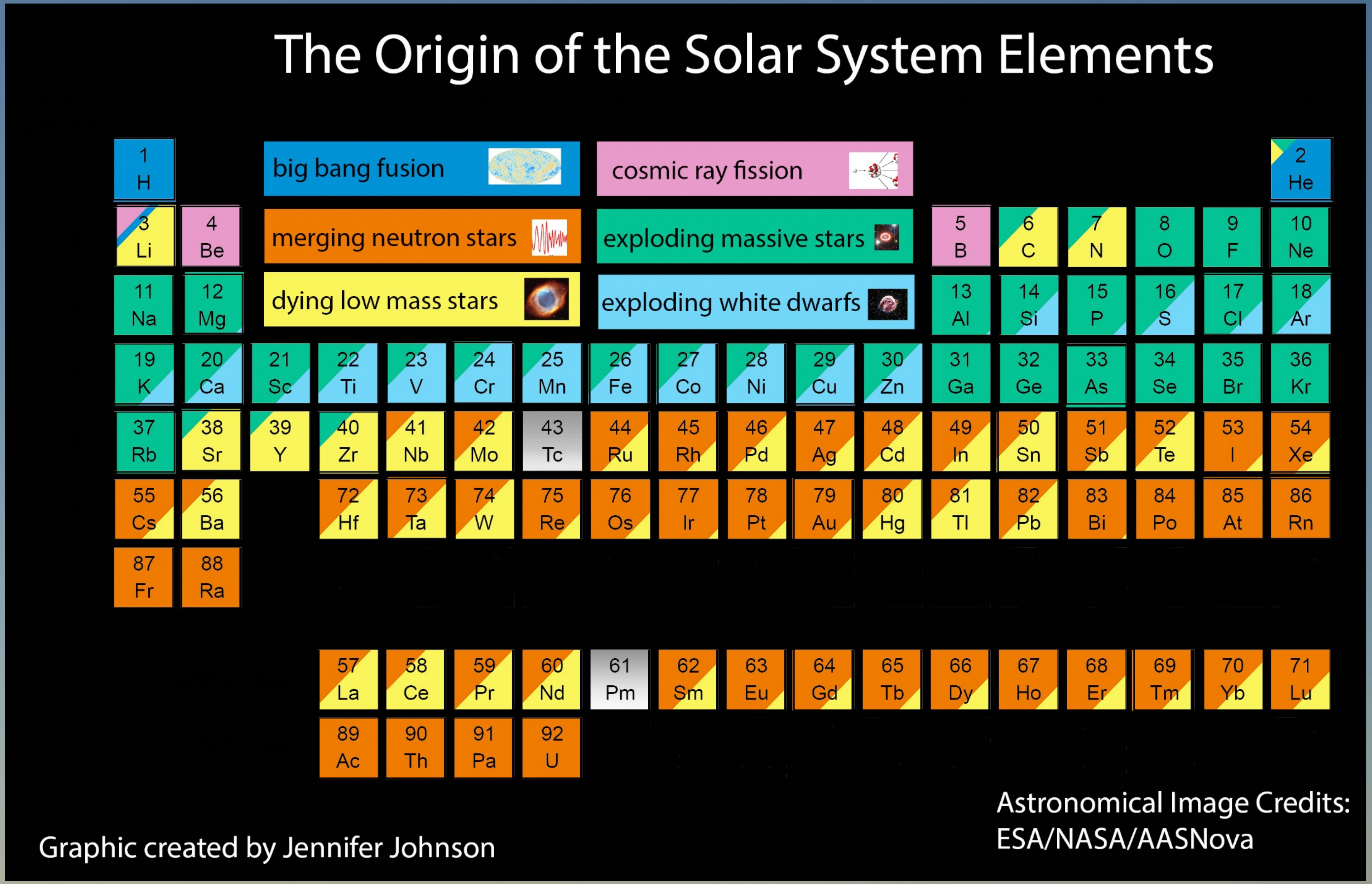
NOAO/Tucson, 26-28 February 2019

Maunakea Spectroscopic Explorer

MSE science highlights

Origins of the elements

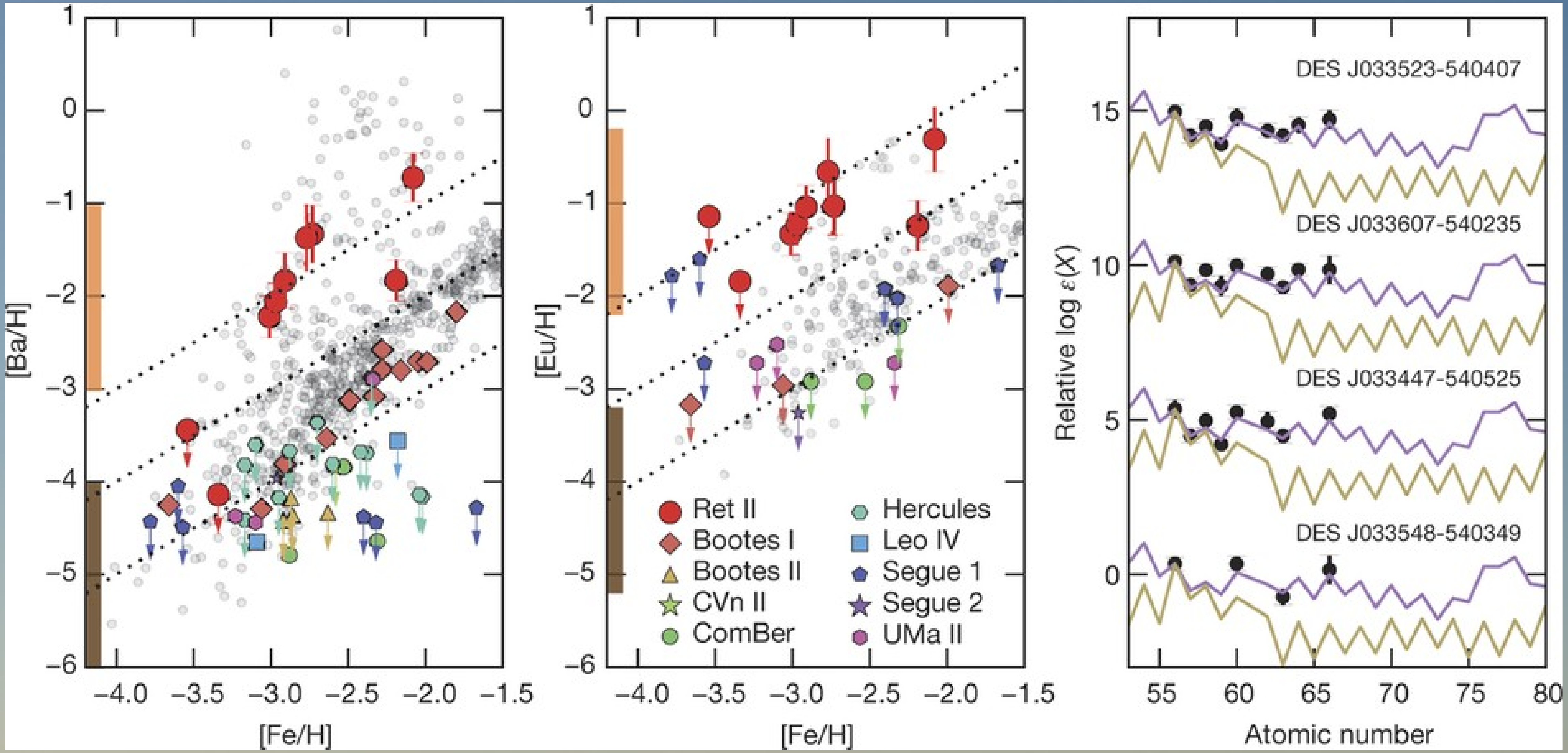
- MSE’s high resolution spectrographs will be able to measure *r*-process element abundances in an unprecedented number of stars, providing the final piece of direct observational evidence of the origins of every element on the Periodic Table



MSE Detailed Science Case 2019

The first *r*-process enhanced galaxy: Reticulum II

- Detailed chemical abundance patterns of stars in Ret II show high levels of rapid neutron-capture element enhancement (*r*-II)

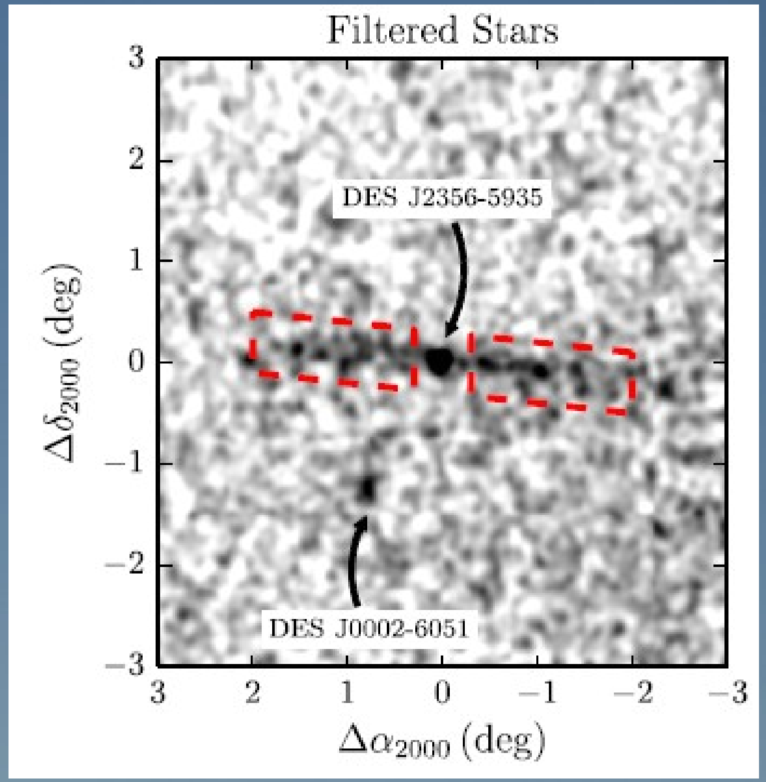


Ji+2016; scaled solar *r*-process (purple) and *s*-process (yellow) patterns are shown

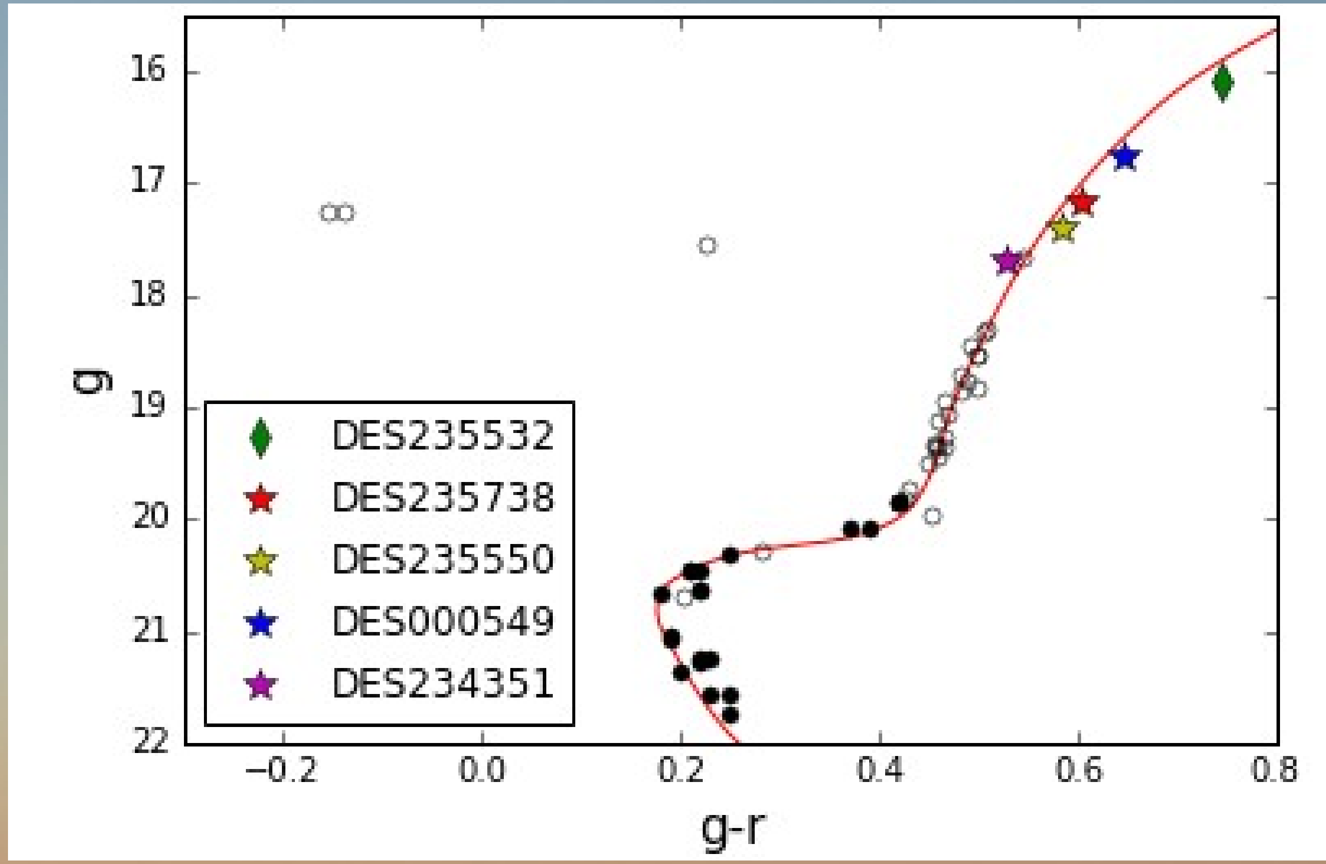
- Suggested explanation is a binary neutron star merger early in this small galaxy polluted the entire population of stars

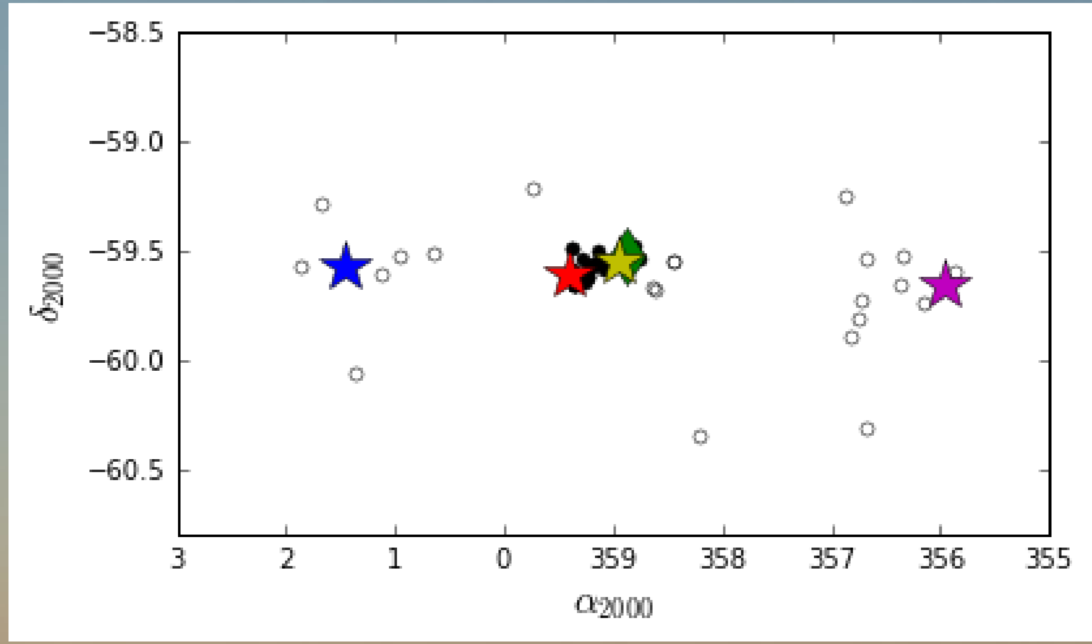
The second *r*-process enhanced galaxy: Tucana III

- Evidence of tidal tails suggest disruption as Tuc III merged with Milky Way
- Provide constraints on Galactic potential, LMC mass/influence (Li+2018, Erkal+2018)



Drlica-Wagner+2015

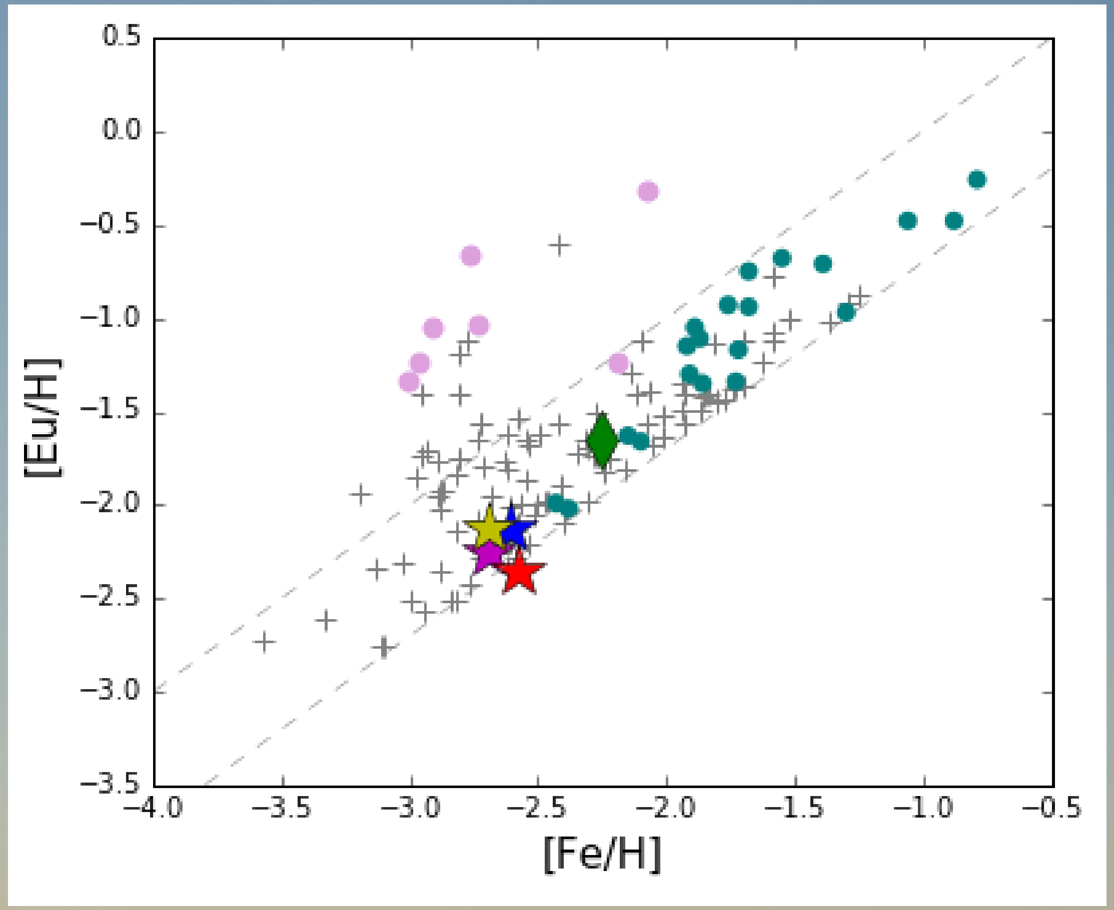




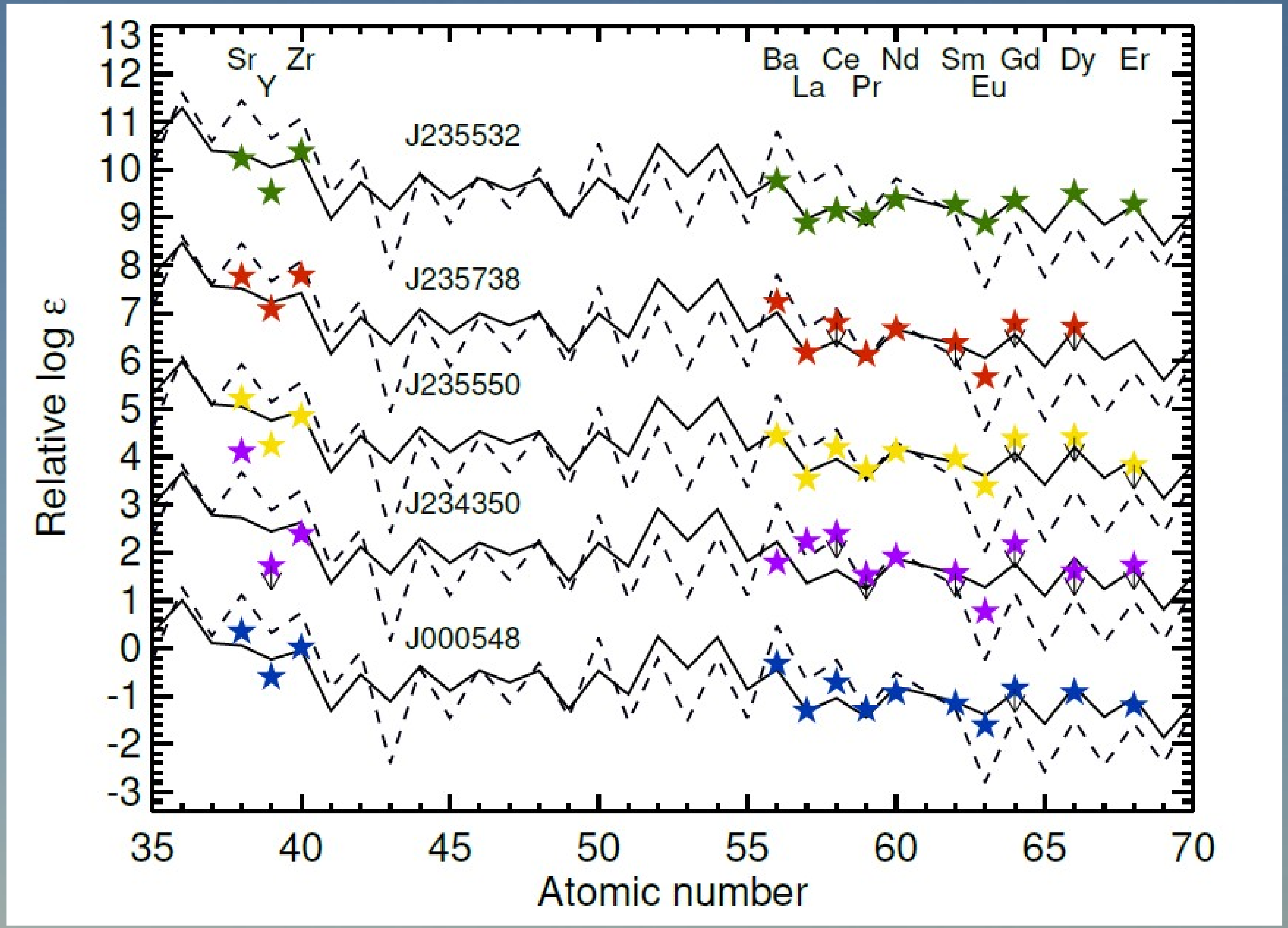
Marshall, Hansen+*submitted*

The second *r*-process enhanced galaxy: Tucana III

- All five Tuc III members are *r*-I stars
  - One star has some *s*-process as well



Grey lines define *r*-I stars; purple circles are Ret II stars; blue points are stars



Solid: scaled solar *r*-process; dashed: scaled solar *s*-process

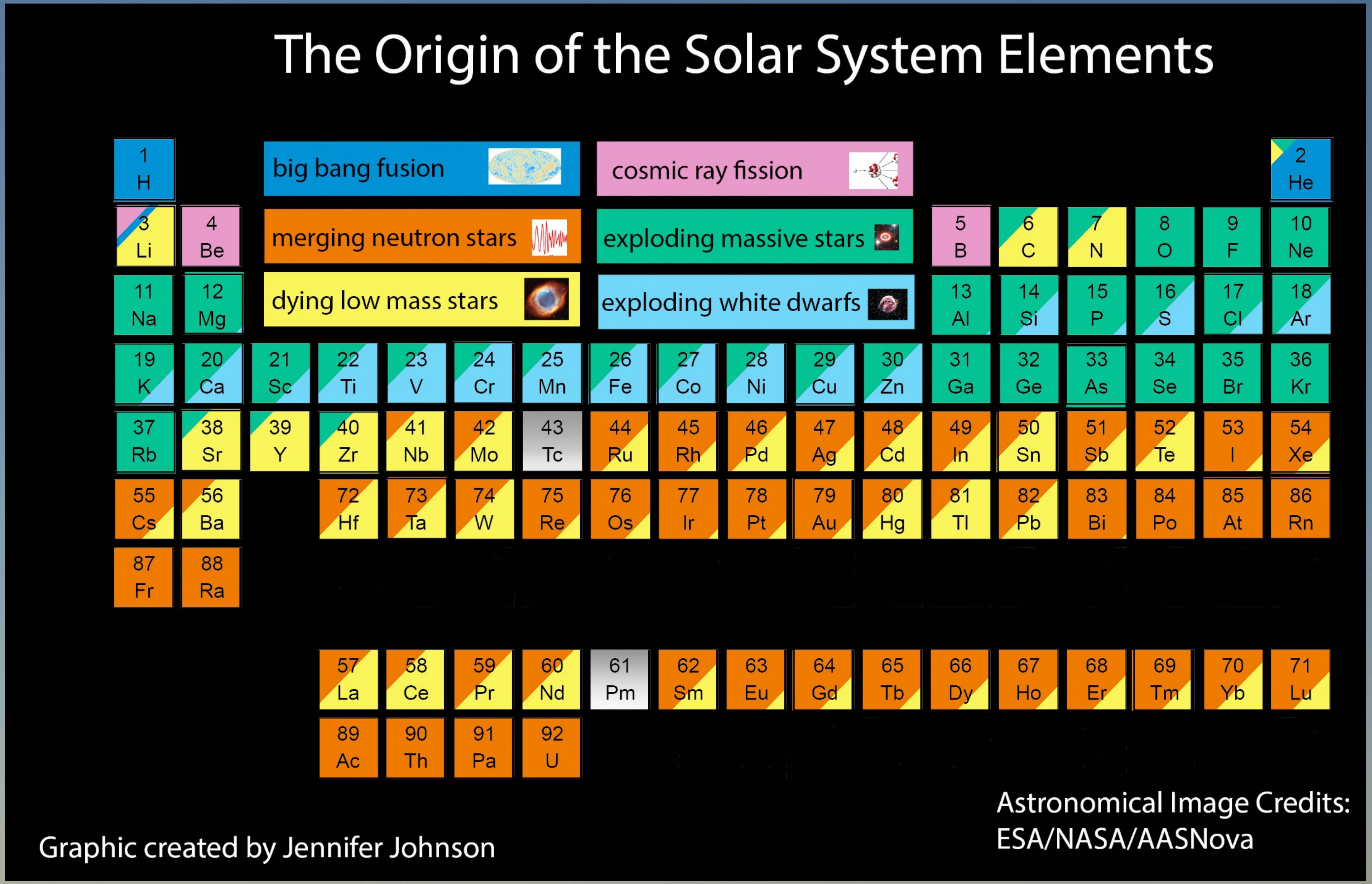
Hansen+2017; Marshall, Hansen+*submitted*

MSE science highlights

Maunakea Spectroscopic Explorer

Origins of the elements

- MSE’s high resolution spectrographs will be able to measure *r*-process element abundances in an unprecedented number of stars, providing the final piece of direct observational evidence of the origins of every element on the Periodic Table



MSE Detailed Science Case 2019

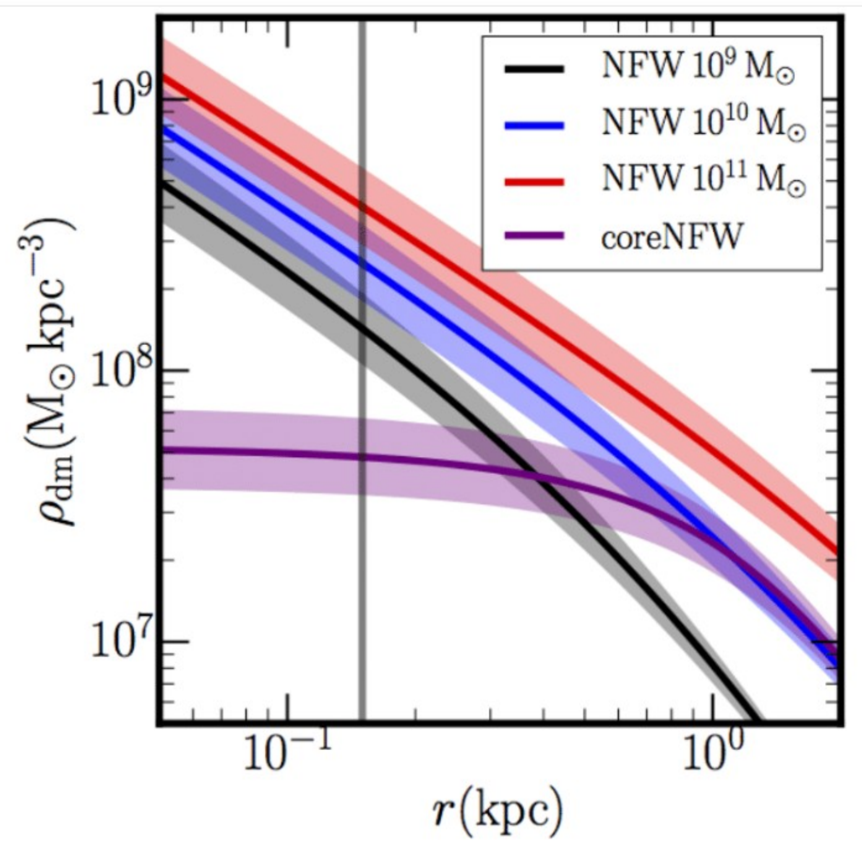
MSE science highlights

Maunakea Spectroscopic Explorer

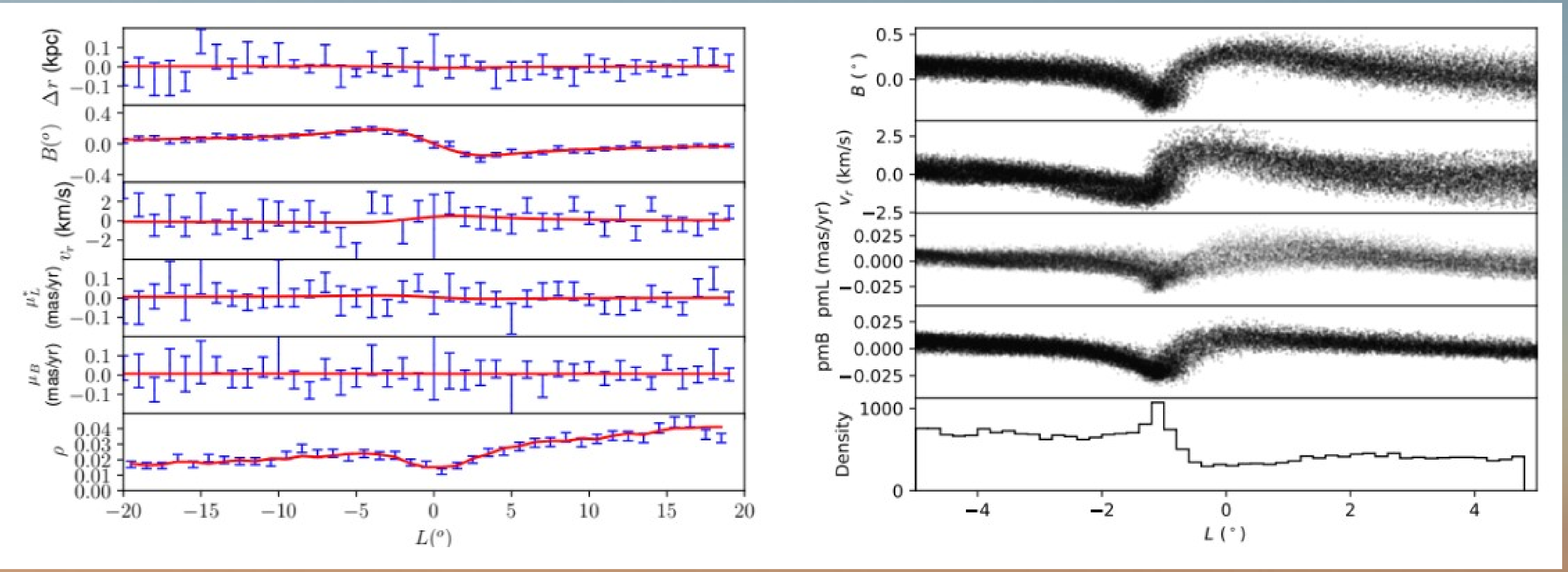
Probing the particle nature of dark matter

- By measuring kinematics of stars in the Milky Way and dwarf galaxies, MSE will be able discriminate between different dark matter particles

MSE Detailed Science Case 2019



Density profiles for dark matter halos having virial masses in the range expected for dwarf galaxies. Figure from Read et al. 2018

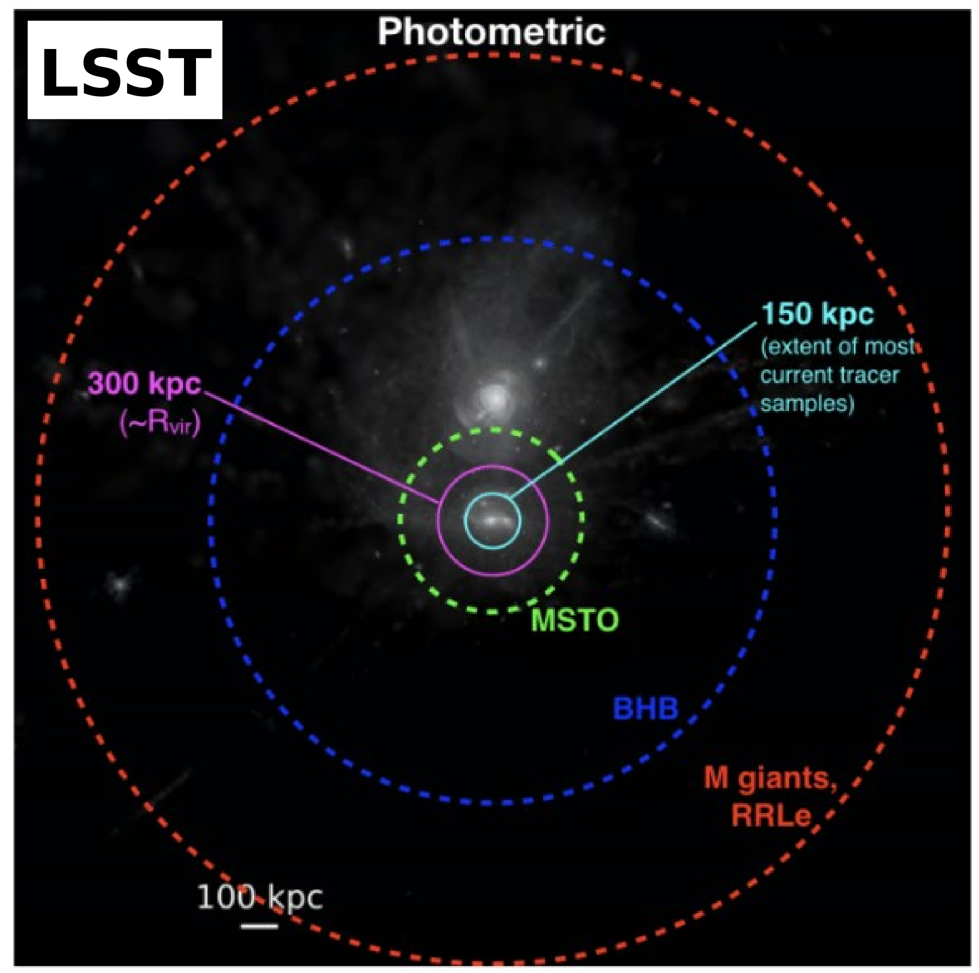


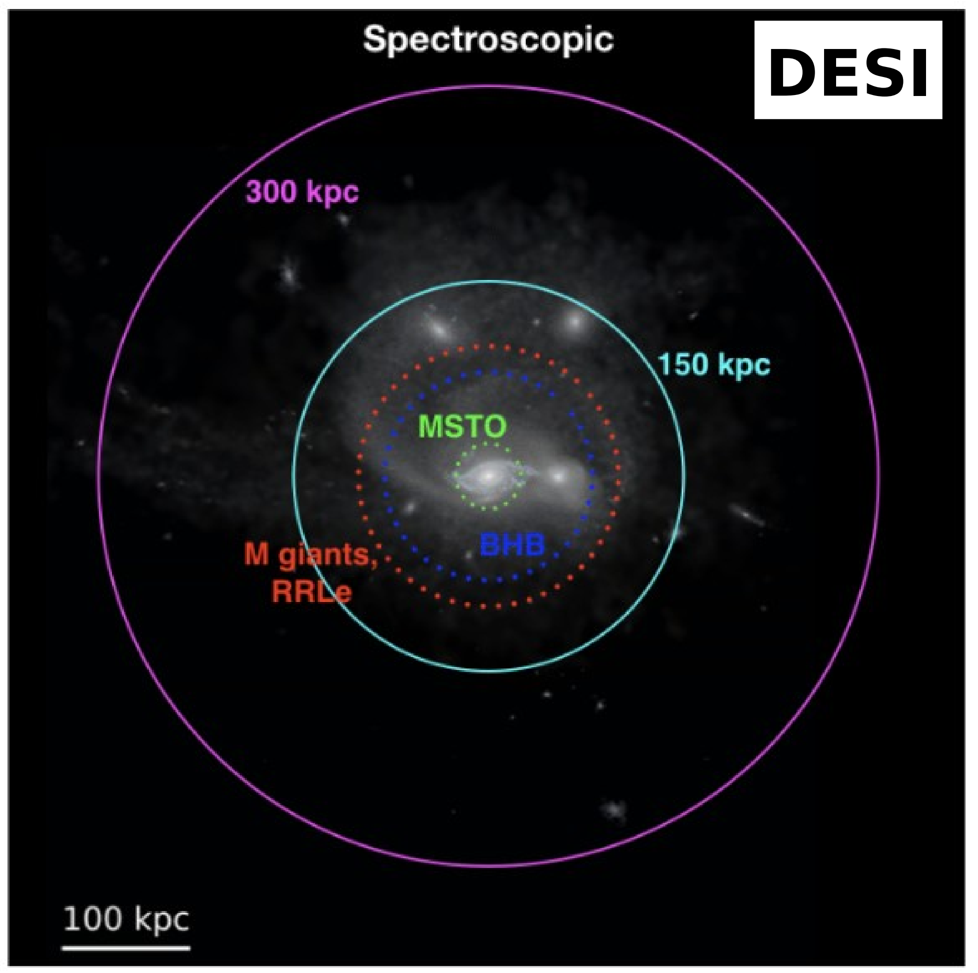
Left: Simulated observations of a 10^7M_o subhalo impact adapted from Erkal & Belokurov 2015. Right: Gap in a simulated GD-1-like stream from a 10^6M_o subhalo. Both are readily detectable by MSE

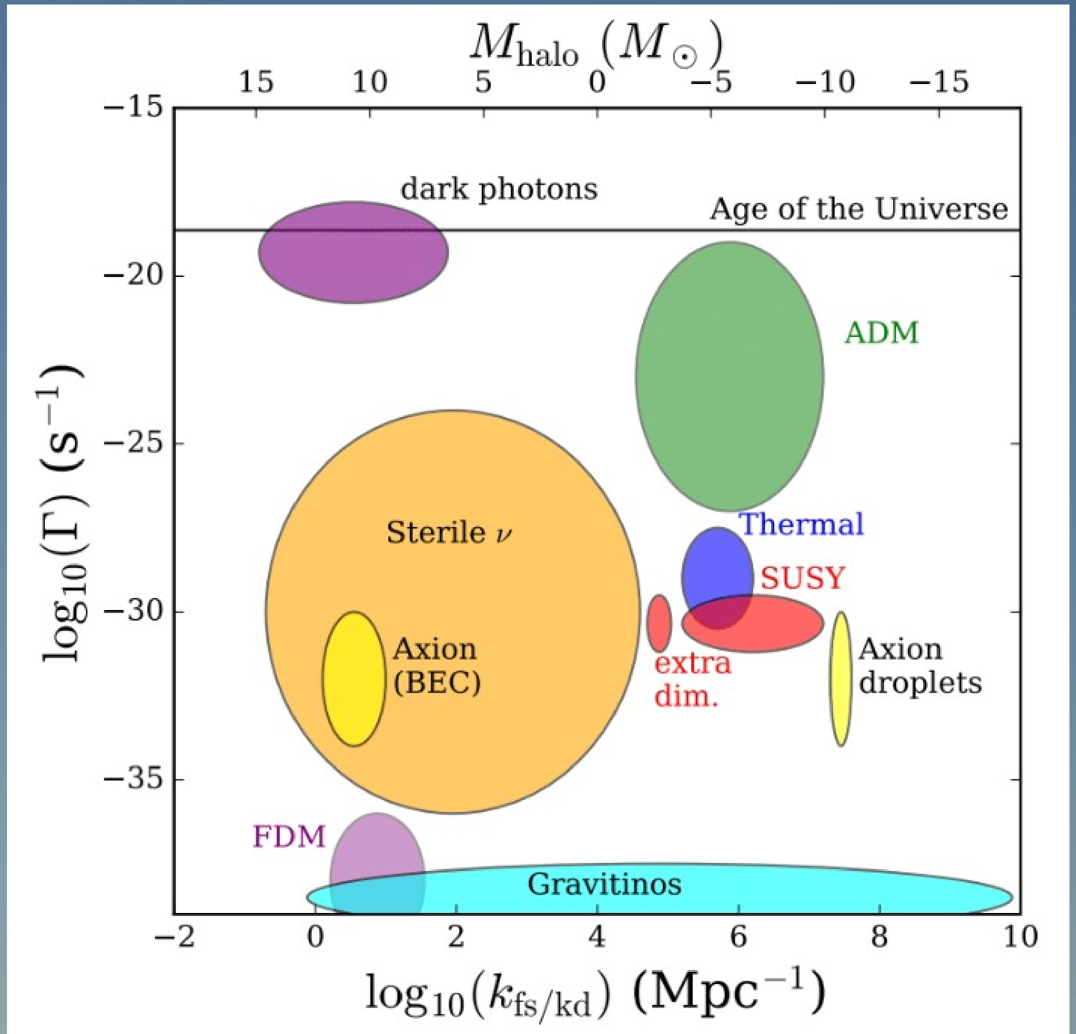
MSE science highlights

Probing the particle nature of dark matter

- By measuring kinematics of stars in the Milky Way and dwarf galaxies, MSE will be able discriminate between different dark matter particles







MSE is the only planned spectroscopic survey that will be able to study the faintest objects discovered by LSST at high and low resolution

MSE Detailed Science Case 2019

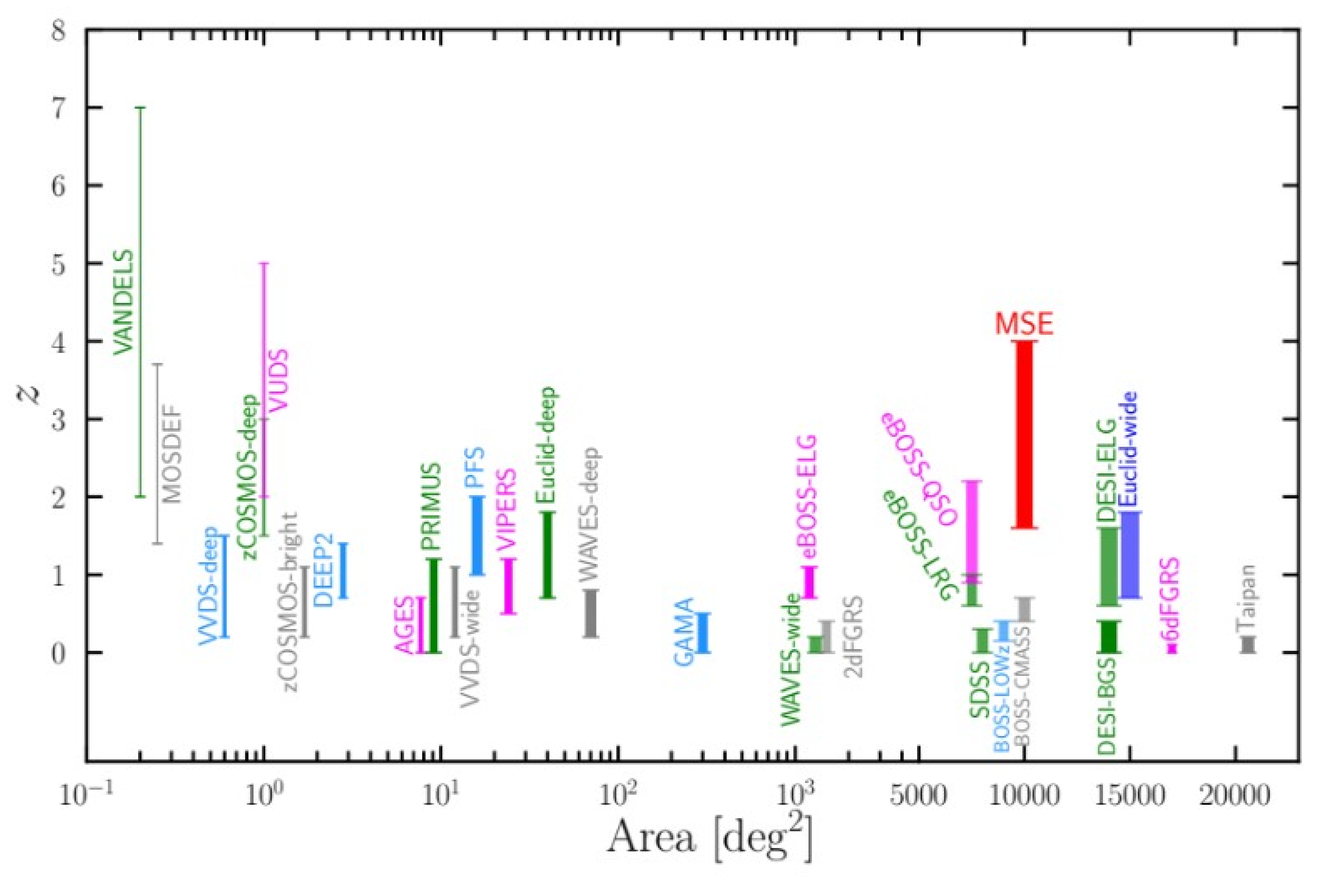
Maunakea Spectroscopic Explorer

MSE science highlights

- MSE will enable one of the largest and highest redshift galaxy surveys possible, by number and by volume

Recent galaxy redshift surveys as a function of their area and redshift range,
compared with the proposed MSE survey. The thickness of each bar is proportional to the total number of galaxies. Note the transition from logarithmic to linear scale on the x-axis at 5000 sq. deg.

MSE Detailed Science Case 2019



MSE science highlights

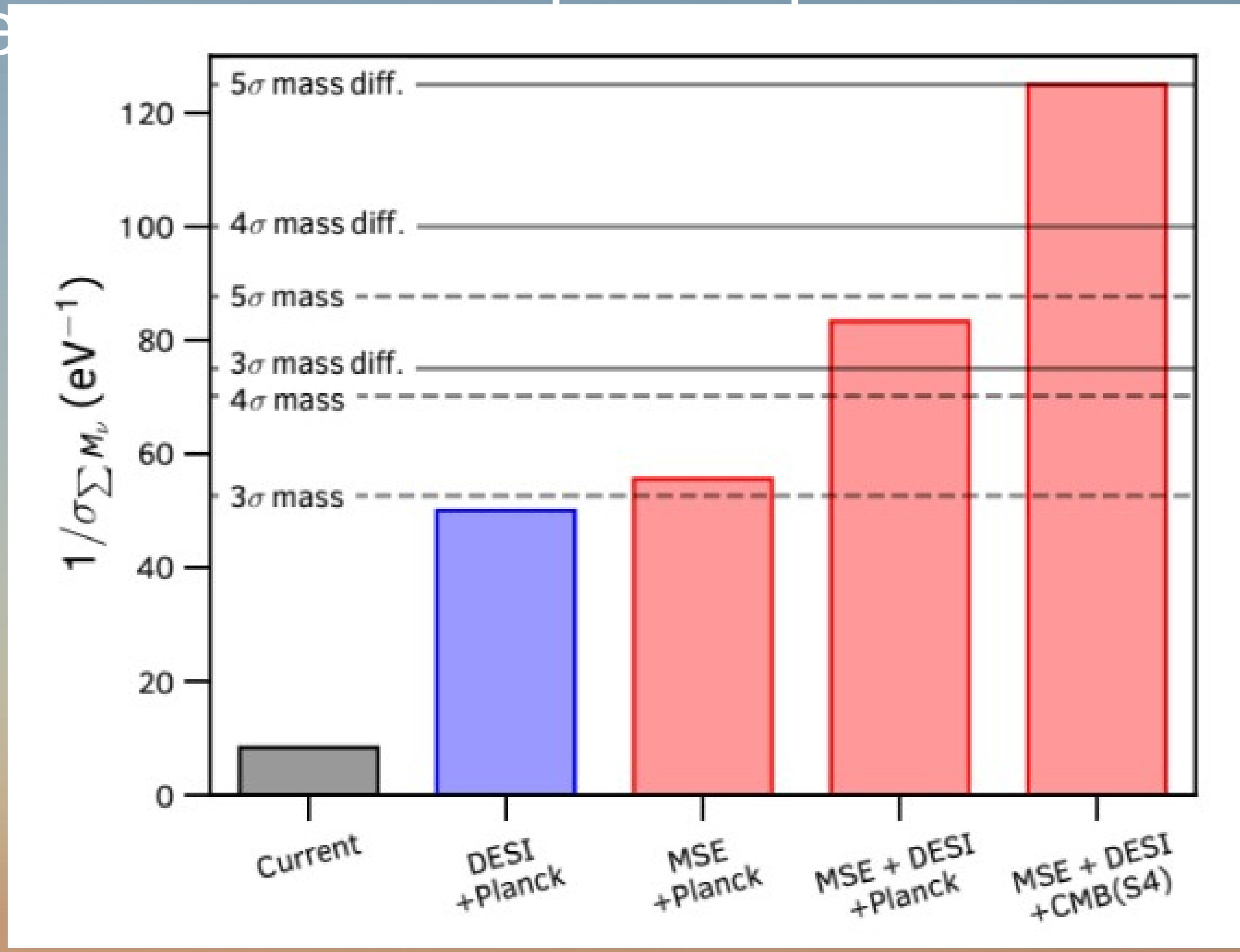
Maunakea Spectroscopic Explorer

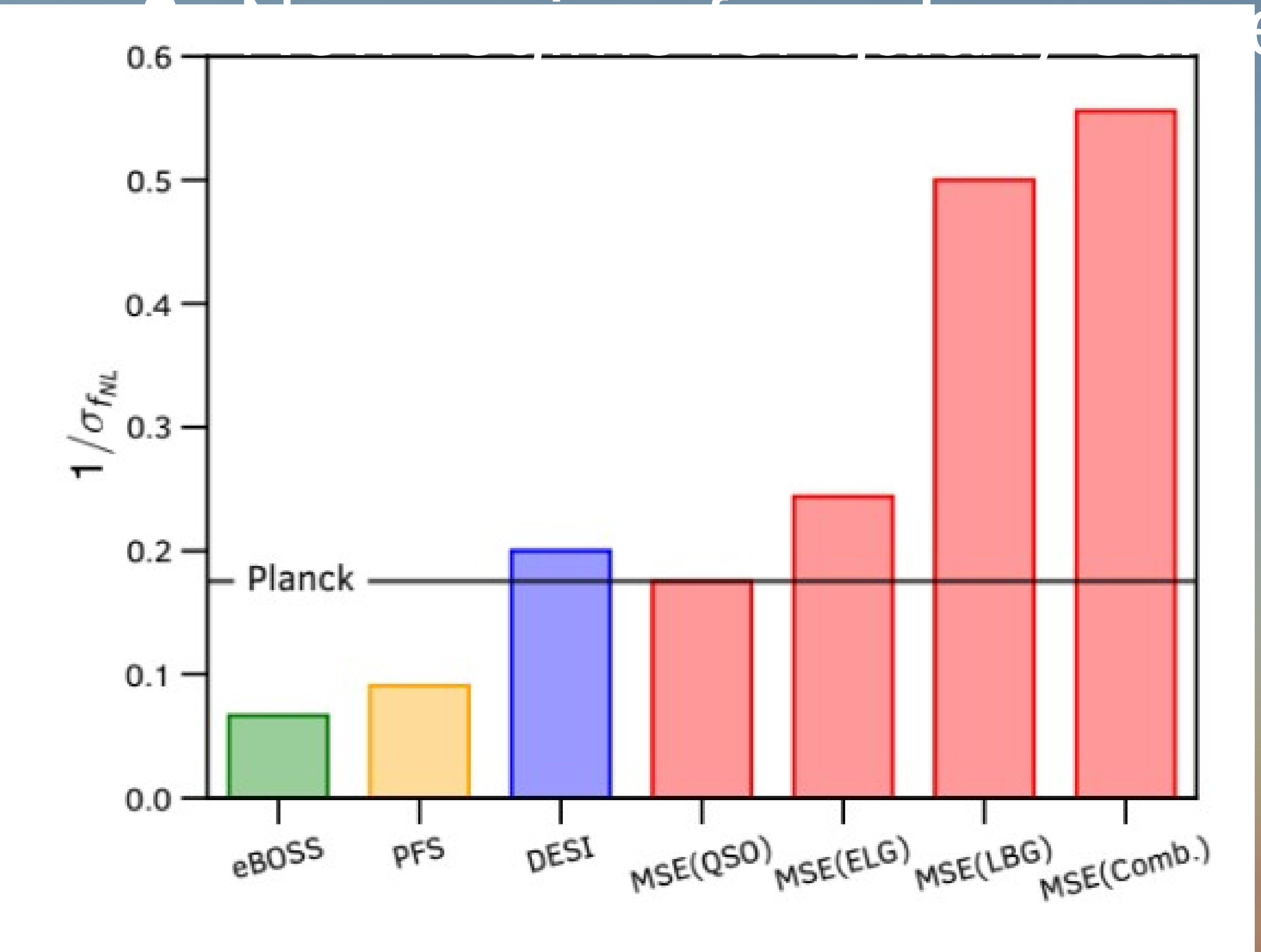
Neutrino mass

- The proposed MSE cosmological large-volume survey of high-redshift galaxies can measure the combined mass of the neutrino better than any other project
- When combined with DESI+CMB(S4), a 5-σ me

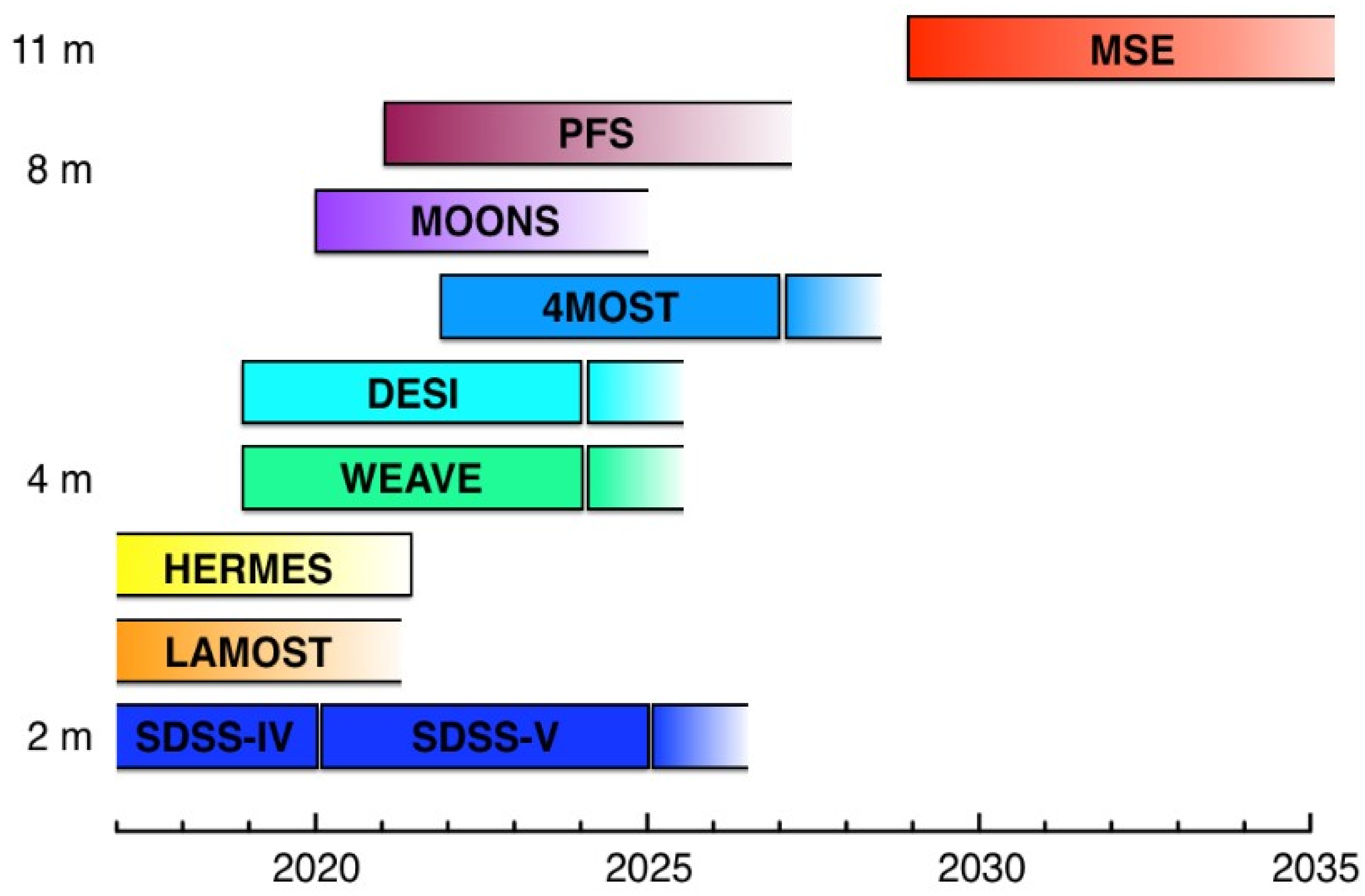
Primordial non-Gaussianity

- Probe physics of inflation
- Survey covers 10,000 square degrees; enormous volume of 280 Gpc^3 out to z~4
- Countless more science applications
- eys

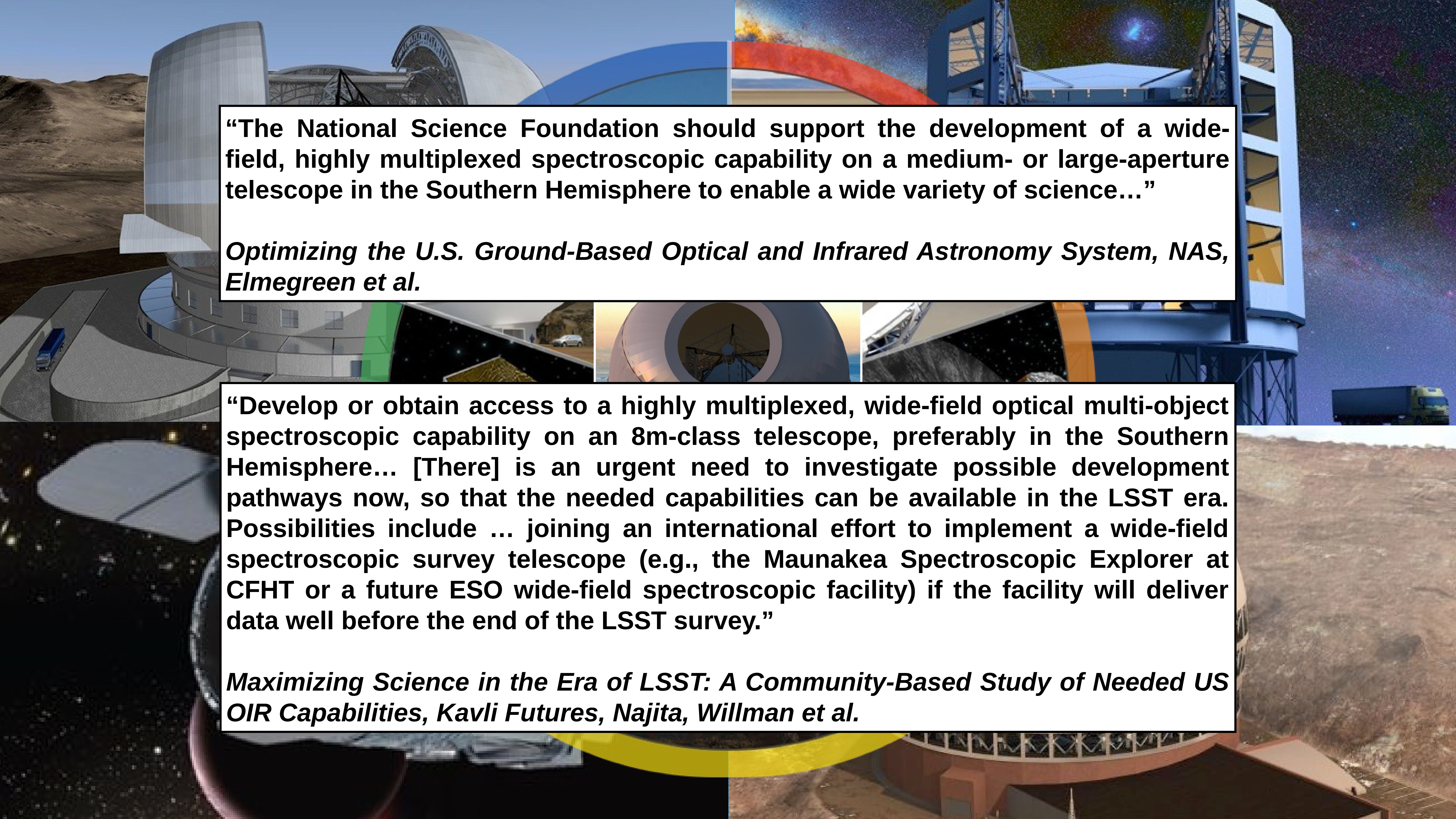




MSE Detailed Science Case 2019



MSE Book 2018



"The National Science Foundation should support the development of a wide-field, highly multiplexed spectroscopic capability on a medium- or large-aperture telescope in the Southern Hemisphere to enable a wide variety of science…"

Optimizing the U.S. Ground-Based Optical and Infrared Astronomy System, NAS, Elmegreen et al.

"Develop or obtain access to a highly multiplexed, wide-field optical multi-object spectroscopic capability on an 8m-class telescope, preferably in the Southern Hemisphere… [There] is an urgent need to investigate possible development pathways now, so that the needed capabilities can be available in the LSST era. Possibilities include … joining an international effort to implement a wide-field spectroscopic survey telescope (e.g., the Maunakea Spectroscopic Explorer at CFHT or a future ESO wide-field spectroscopic facility) if the facility will deliver data well before the end of the LSST survey."

Maximizing Science in the Era of LSST: A Community-Based Study of Needed US OIR Capabilities, Kavli Futures, Najita, Willman et al.

Maunakea Spectroscopic Explorer

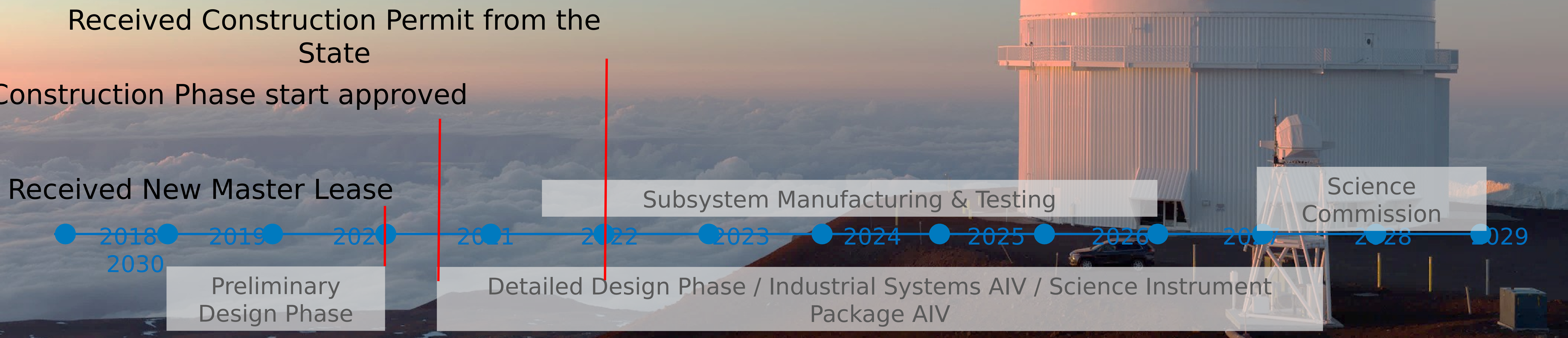
Timeline to Science Operations

Science Commissioning will begin in 2029

- Based on a technically paced schedule with no constraints on resources and cash flow

The project timeline is organized in four major overlapping phases with three milestones:

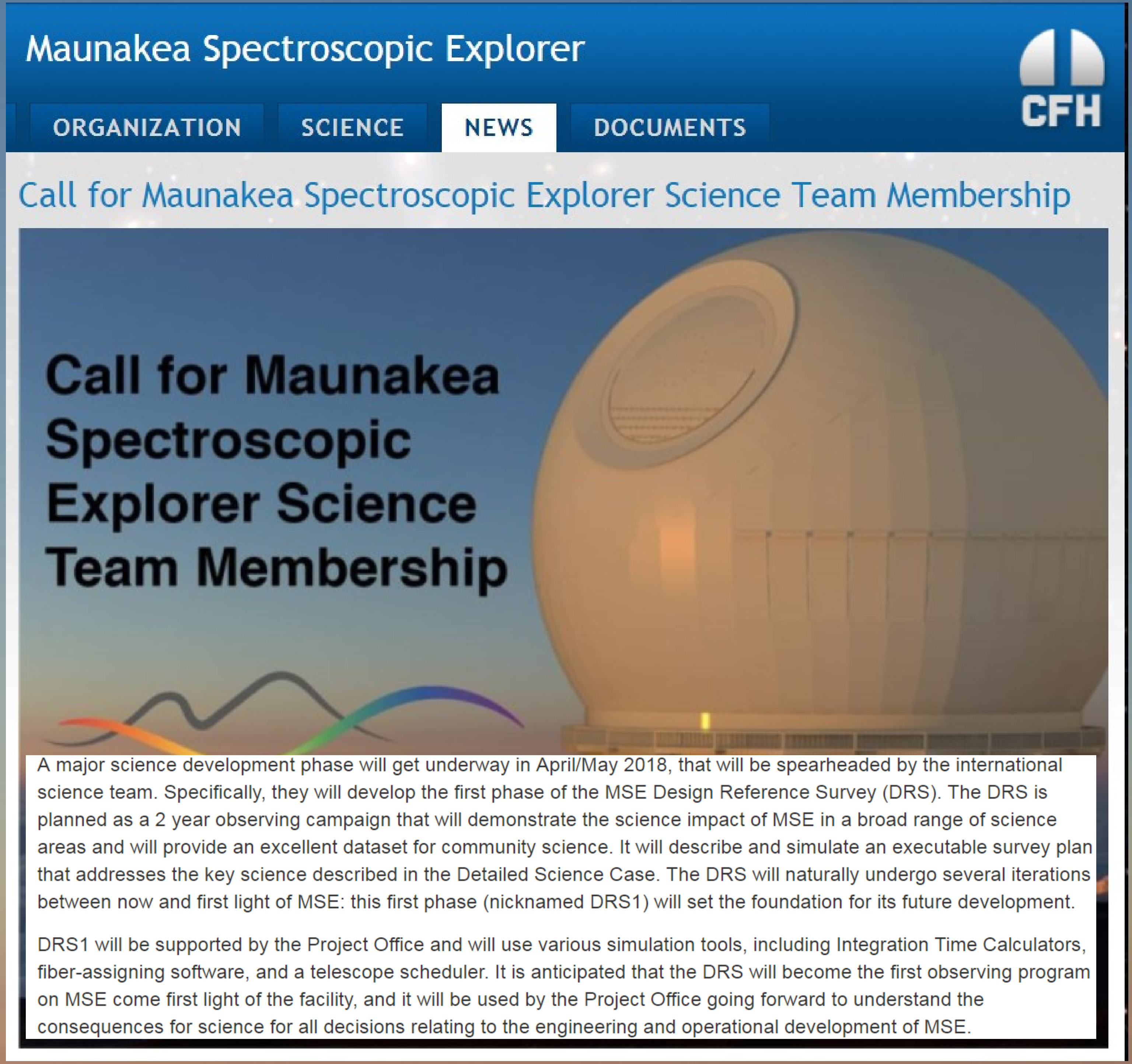
- Preliminary Design Phase - 2 yrs
- Construction Phase - 6.5 yrs duration
  - System-Level Assembly, Integration and Verification (AIV) Phase - 5.5 yrs
  - Science Commissioning - 2 yrs



Maunakea Spectroscopic Explorer

Join the Science Team!

- Send an email to mseinfo@mse.cfht.hawaii.edu or marshall@mse.cfht.hawaii.edu



Maunakea Spectroscopic Explorer

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Call for Maunakea Spectroscopic Explorer Science Team Membership

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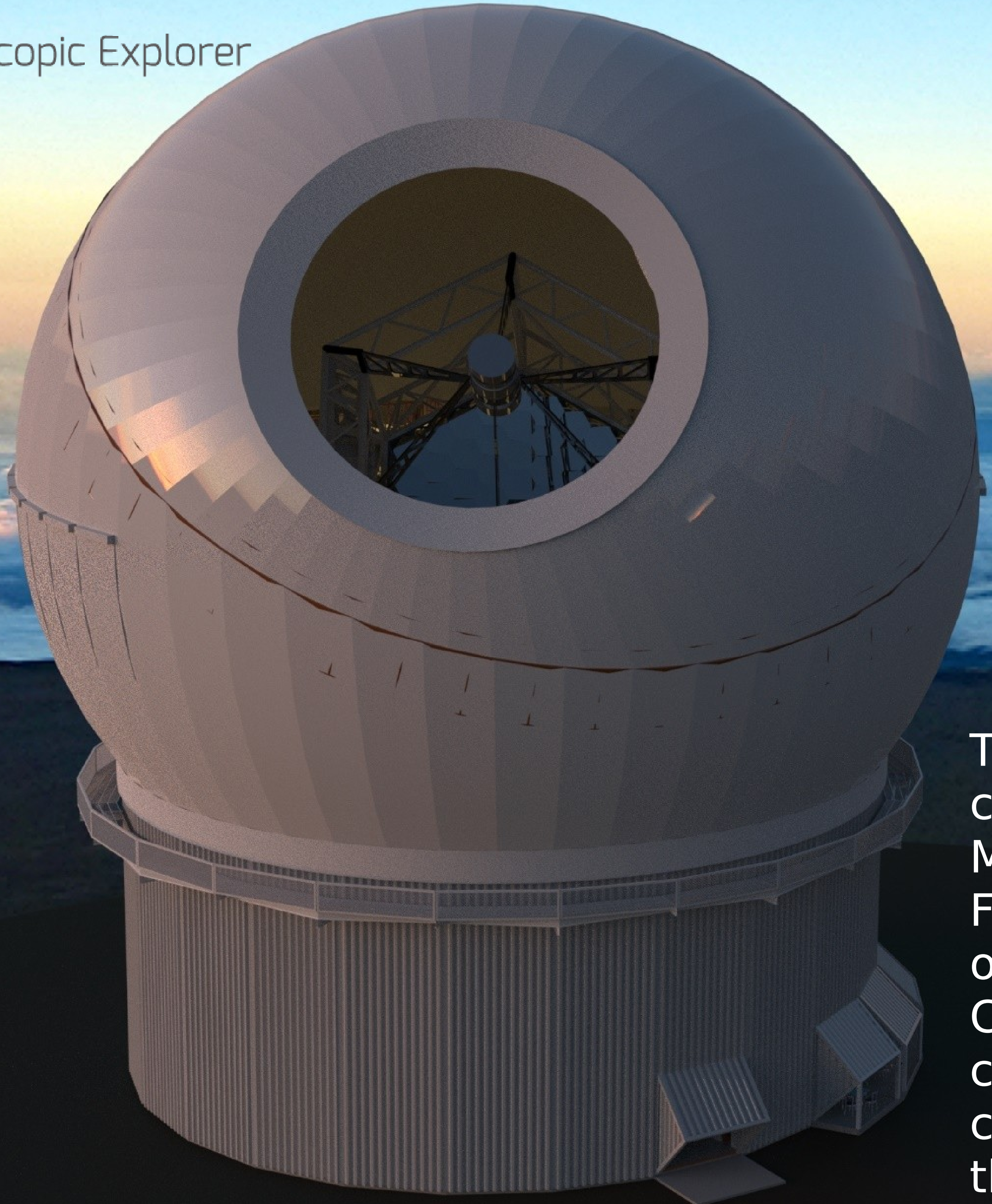
A major science development phase will get underway in April/May 2018, that will be spearheaded by the international science team. Specifically, they will develop the first phase of the MSE Design Reference Survey (DRS). The DRS is planned as a 2 year observing campaign that will demonstrate the science impact of MSE in a broad range of science areas and will provide an excellent dataset for community science. It will describe and simulate an executable survey plan that addresses the key science described in the Detailed Science Case. The DRS will naturally undergo several iterations between now and first light of MSE: this first phase (nicknamed DRS1) will set the foundation for its future development.

DRS1 will be supported by the Project Office and will use various simulation tools, including Integration Time Calculators, fiber-assigning software, and a telescope scheduler. It is anticipated that the DRS will become the first observing program on MSE come first light of the facility, and it will be used by the Project Office going forward to understand the consequences for science for all decisions relating to the engineering and operational development of MSE.

Maunakea Spectroscopic Explorer

Thank you!



The Maunakea Spectroscopic Explorer (MSE) conceptual design phase was conducted by the MSE Project Office, which is hosted by the Canada-France-Hawaii Telescope (CFHT). MSE partner organizations in Canada, France, Hawaii, Australia, China, India, and Spain all contributed to the conceptual design. The authors and the MSE collaboration recognize the cultural importance of the summit of Maunakea to a broad cross section of the Native Hawaiian community.