Maunakea Spectroscopic Explorer

Revealing the faint Universe millions of spectra at a time

The Maunakea Spectroscopic Explorer after Conceptual Design

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The Maunakea Spectroscopic Explorer (MSE) is a project to transform CFHT into …

Maunakea Spectroscopic Explorer

The Maunakea Spectroscopic Explorer (MSE) is a project to transform CFHT into an **11.25m, wide-field, optical and near-infrared** facility **completely dedicated** to **multi-object spectroscopy** of samples that comprise **thousands to millions** of astrophysical objects.

Maunakea Spectroscopic Explorer

The Maunakea Spectroscopic Explorer (MSE) will be the observatory (**facility** + **science platform**) of the next decades, helping astronomers answer some of the **most exciting questions** of modern astronomy!

Maunakea Spectroscopic Explorer

Outline

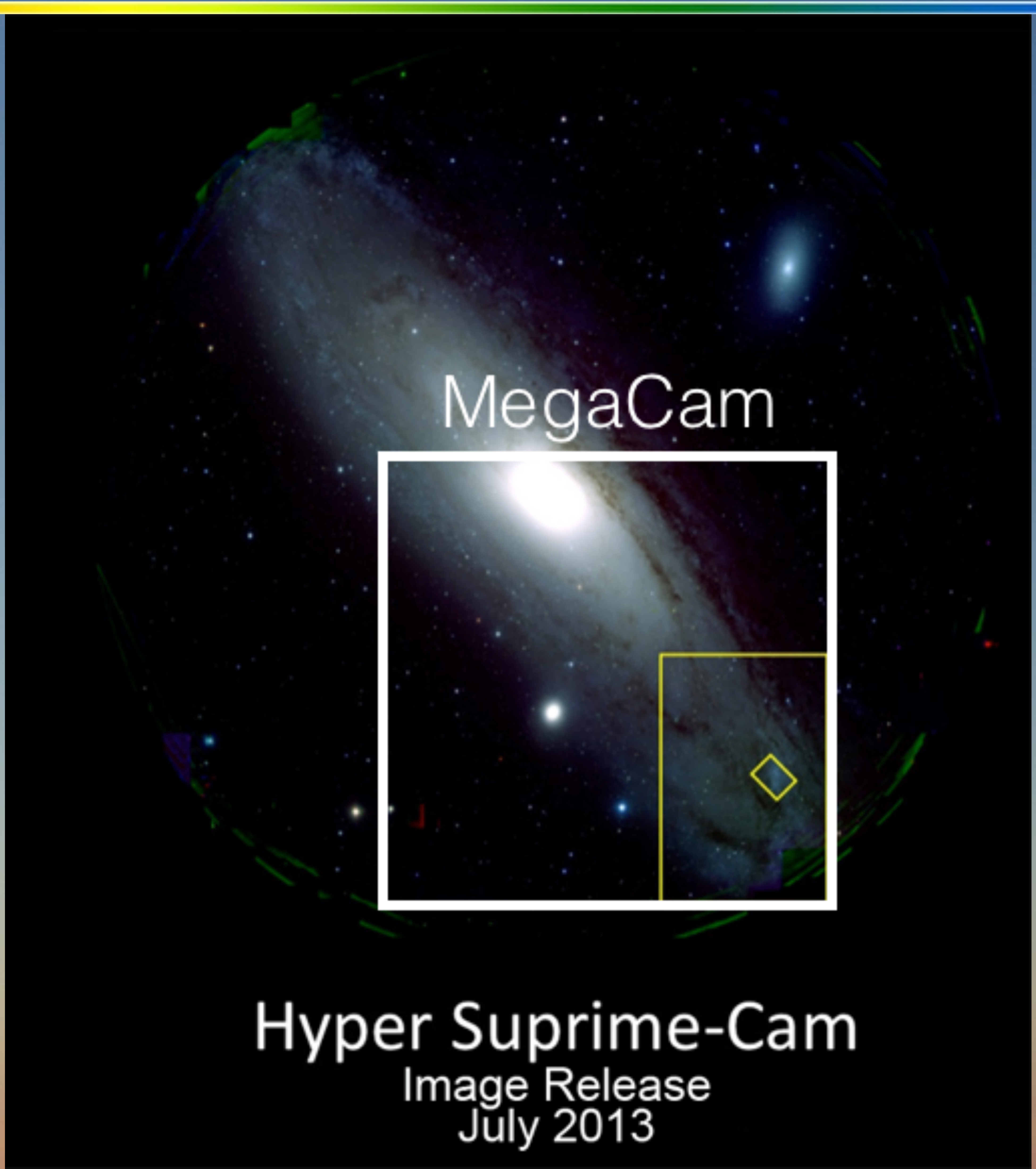
- Context
- Science
- Architecture
- Performance
- Operations
- Partnership, Cost, and Schedule

CONTEXT

CFHT Today

A 40-year old, 3.6-meter telescope

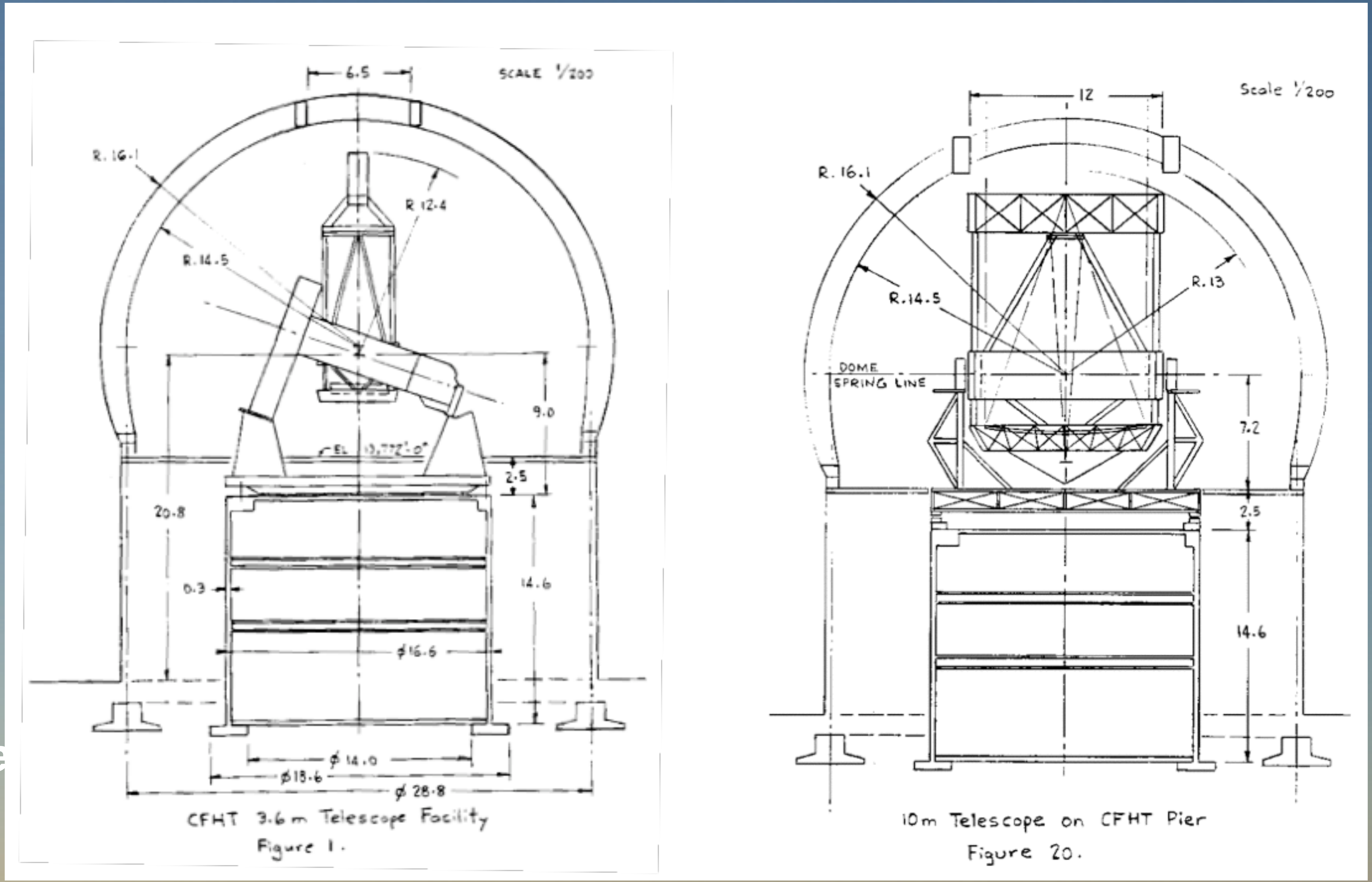
The Competition



Redevelopment of CFHT

Maunakea Spectroscopic Explorer

- "ngCFHT" concept initiated in Canada as part of LRP2010. Feasibility study ran from 2012-2014
- Subsequently received "Priority 0" recommendation in French 5-year Prospective (2014).
- ***CFHT Board set up a Project Office in 2014 to lead the "Design Phase" of ngCFHT → MSE, to run until end of 2017***
- ***Imperative to stay within 10% of the current sky-line envelope.***



2018: "SAC endorses MSE as the scientific future of CFHT. SAC supports proceeding to the Preliminary Design Phase.

Maunakea Spectroscopic Explorer

Wide-field, massively multi-object spectrographs

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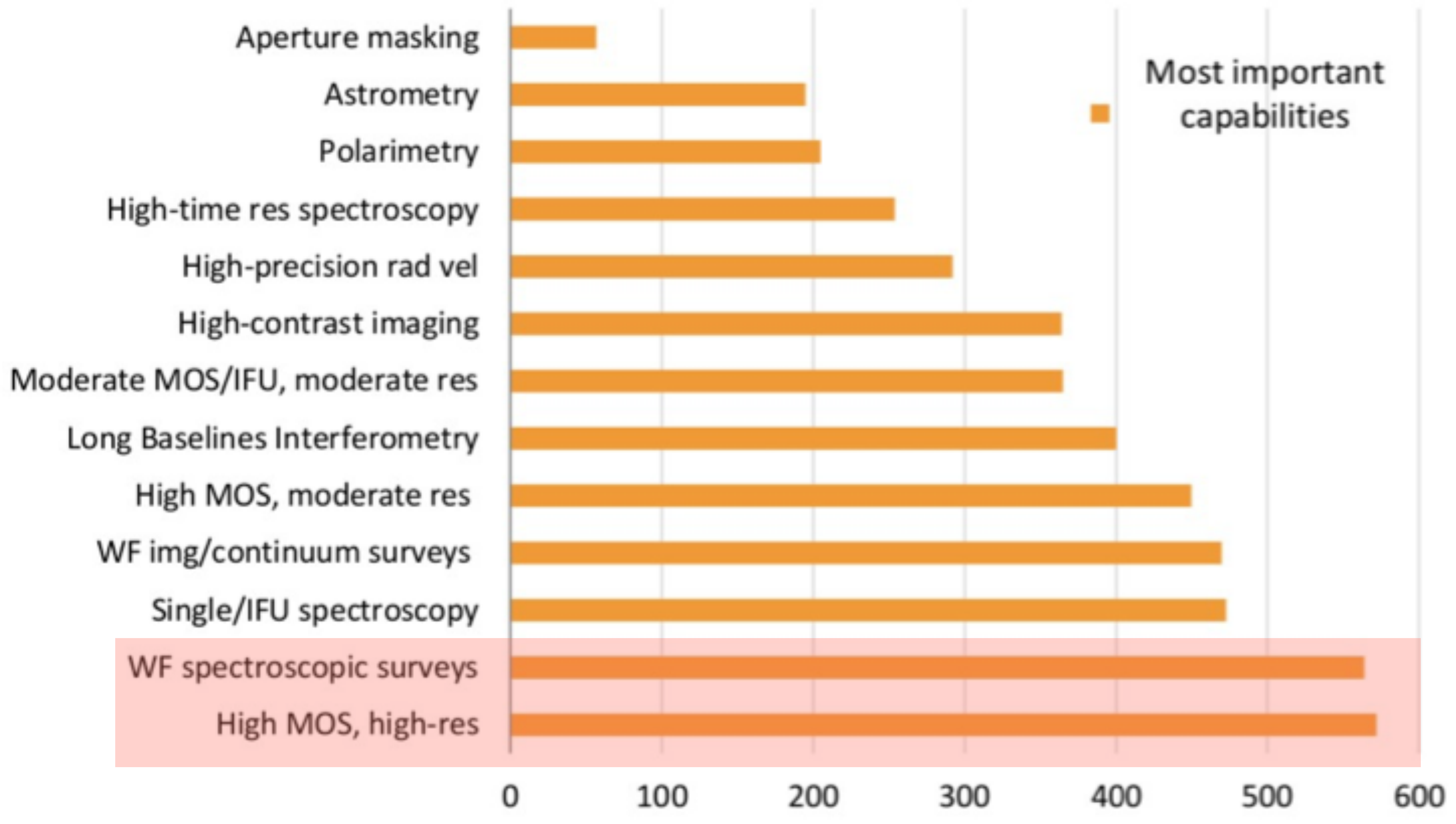


Figure 2. Users were asked to select the most important capabilities for their own research in the 2020–2030 timeframe. Responses are shown in absolute number of preferences expressed for each option. A total of 4,661 responses were received.

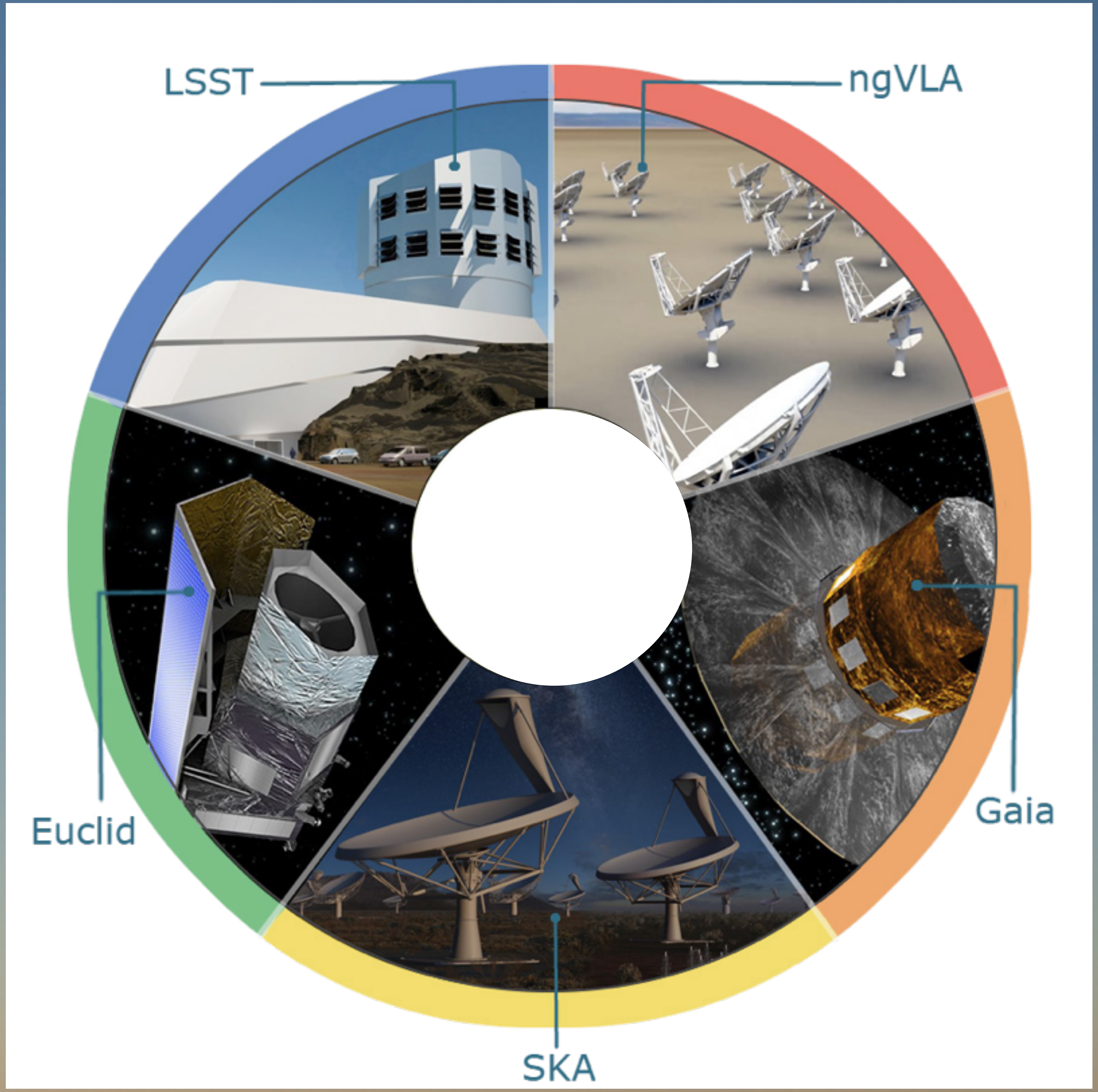
Maunakea Spectroscopic Explorer

Wide-field, massively multi-object spectrographs

- An 8–10-meter class telescope with a heavily multiplexed, wide-field spectrograph is *the facility everyone wants but no one has*:
  - The Australian decadal plan recognizes the importance of a large-aperture, wide-field MOS
  - The Canadian Long Range Plan 2010 notes that a 10m class telescope equipped with an extremely multiplexed spectrograph would “…have a transformative impact in a wide range of fields…"
  - The US Astro 2010 Decadal Review notes that "Massively multiplexed spectrographs in intermediate-class and large-aperture ground-based telescopes would also play an important role" in dark energy studies
  - ESO…

Context

- Era of big facilities, billions of dollars invested, large international teams
  - ***Imaging surveys:***
    PanSTARRS, Subaru/HSC, CFHT/Megacam, Gaia, LSST, Euclid, WFIRST, ...
  - ***Radio surveys:***
    ALMA, SKA, LOFAR, ngVLA
  - ***Small & mid-aperture spectroscopic surveys:***
    VISTA/4MOST, WHT/WEAVE, AAT/HERMES, Subaru/PFS, VLT/MOONS
  - ***Giant telescopes:***
    ELT, GMT, TMT



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MSE will:

- obtain efficiently very large numbers ($>10^6$) of low- (R ~ 2 000), moderate- (R ~ 6 500) and high-resolution (R > 20 000) spectra
- for faint (20 < g < 24) science targets
- over large areas of the sky (10^3 – 10^4 sq.deg)
- spanning blue/optical to near-IR wavelengths, 0.37 –> NIR
- At the highest resolutions, it should have a velocity accuracy of <<1 km/s
- At low resolution, complete wavelength coverage should be possible in a single observation

SCIENCE

Maunakea Spectroscopic Explorer

Detailed Science Case

- About to release an updated version of the MSE Detailed Science Case

The Detailed Science Case of the Maunakea Spectroscopic Explorer

The MSE Science Team

February 22, 2019

- Nearly 300 pages!
- Over 100 authors
- Builds upon original MSE Detailed Science Case (2016)

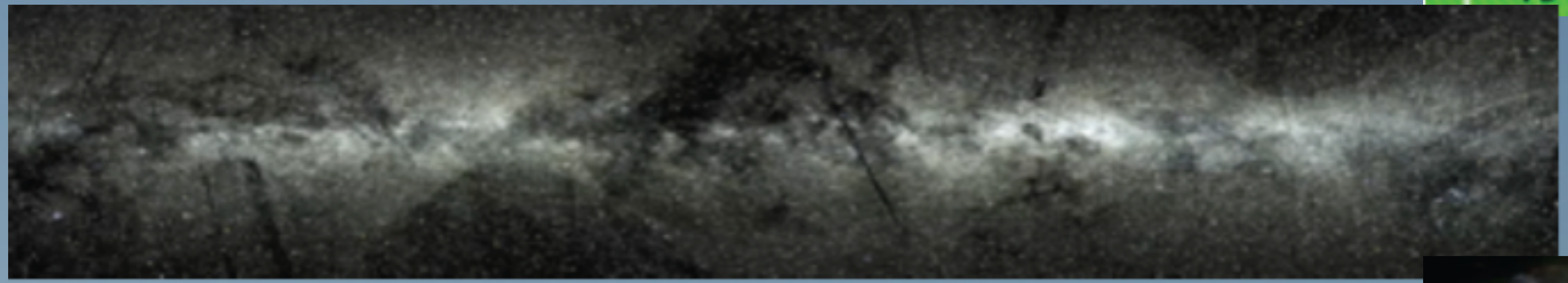
http://arxiv.org/abs/1606.00060 http://arxiv.org/abs/1606.00043

Maunakea Spectroscopic Explorer

Science Working Groups

Exoplanets and stellar astrophysics
Maria Bergemann & Daniel Huber

Chemical nucleosynthesis
Sivarani Thirupathi & David Yong

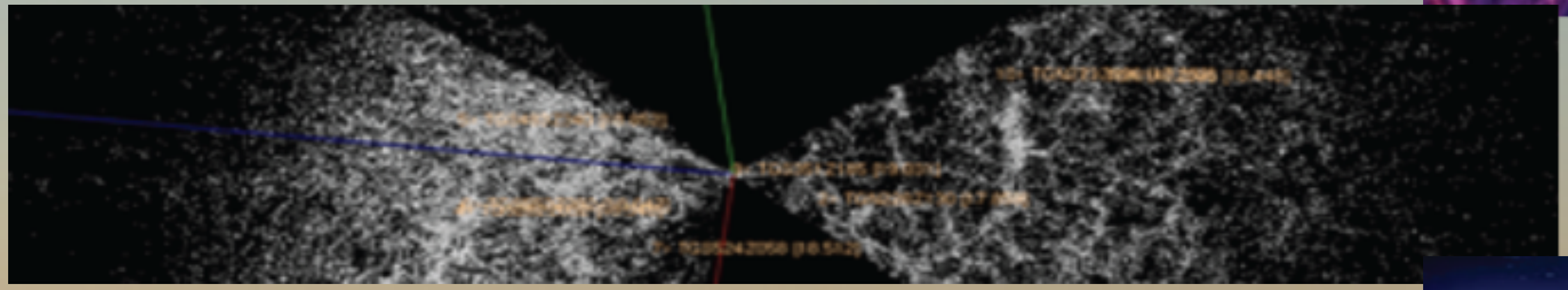


Milky Way and resolved stellar pops
Carine Babusiaux & Sarah Martell

Galaxy Formation and evolution
Kim-Vy Tran & Aaron Robotham

AGN and supermassive black holes
Yue Shen & Sara Ellison

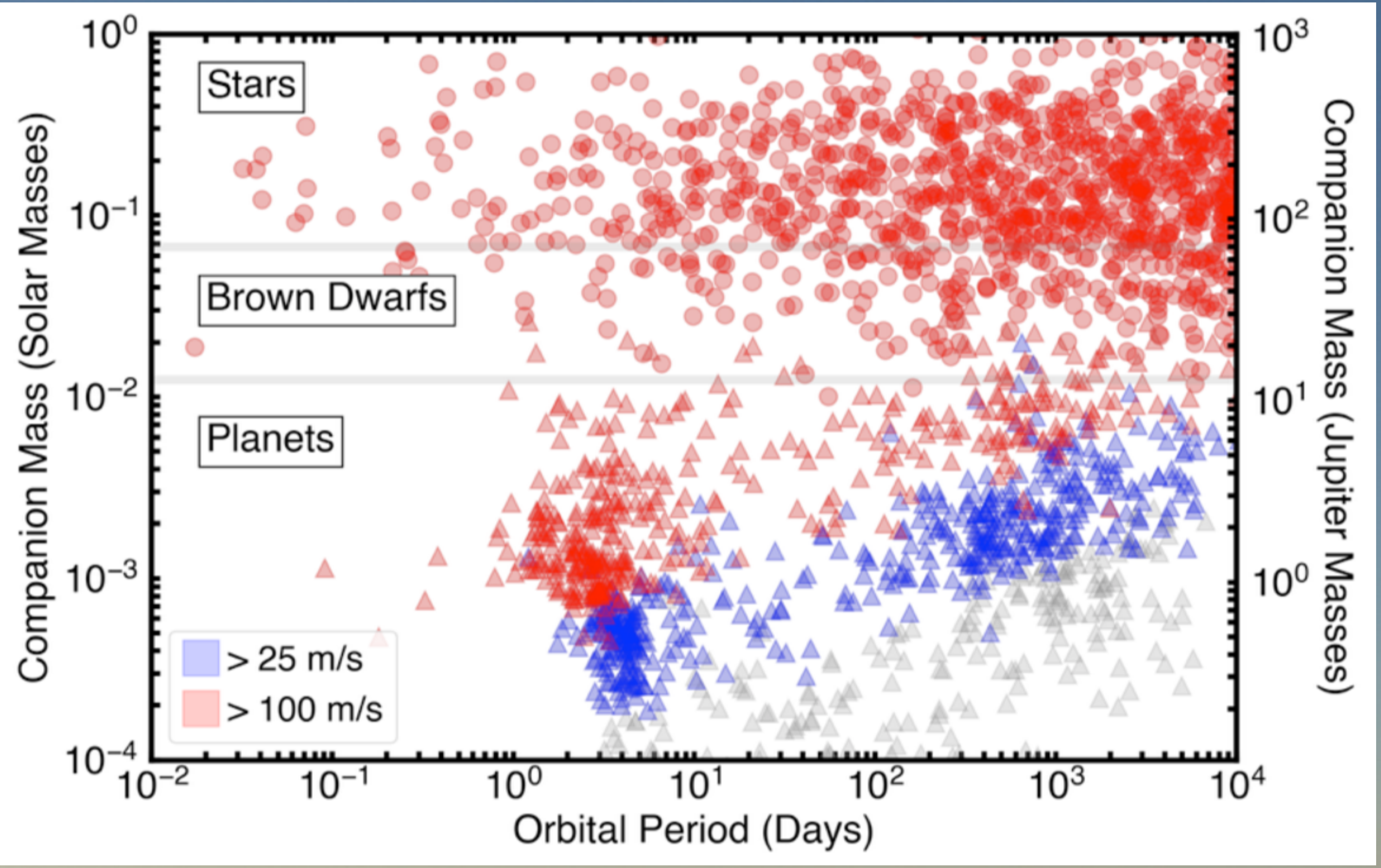
Astrophysical tests of dark matter
Ting Li & Manoj Kaplinghat



Cosmology
Will Percival & **Christophe Yeche**

Time domain astronomy and transients
Adam Burgasser & Daryl Haggard

Radial velocities of planets and brown dwarfs



- A huge amount of parameter space accessible with basic specs.
- Tied to temporal spectroscopy

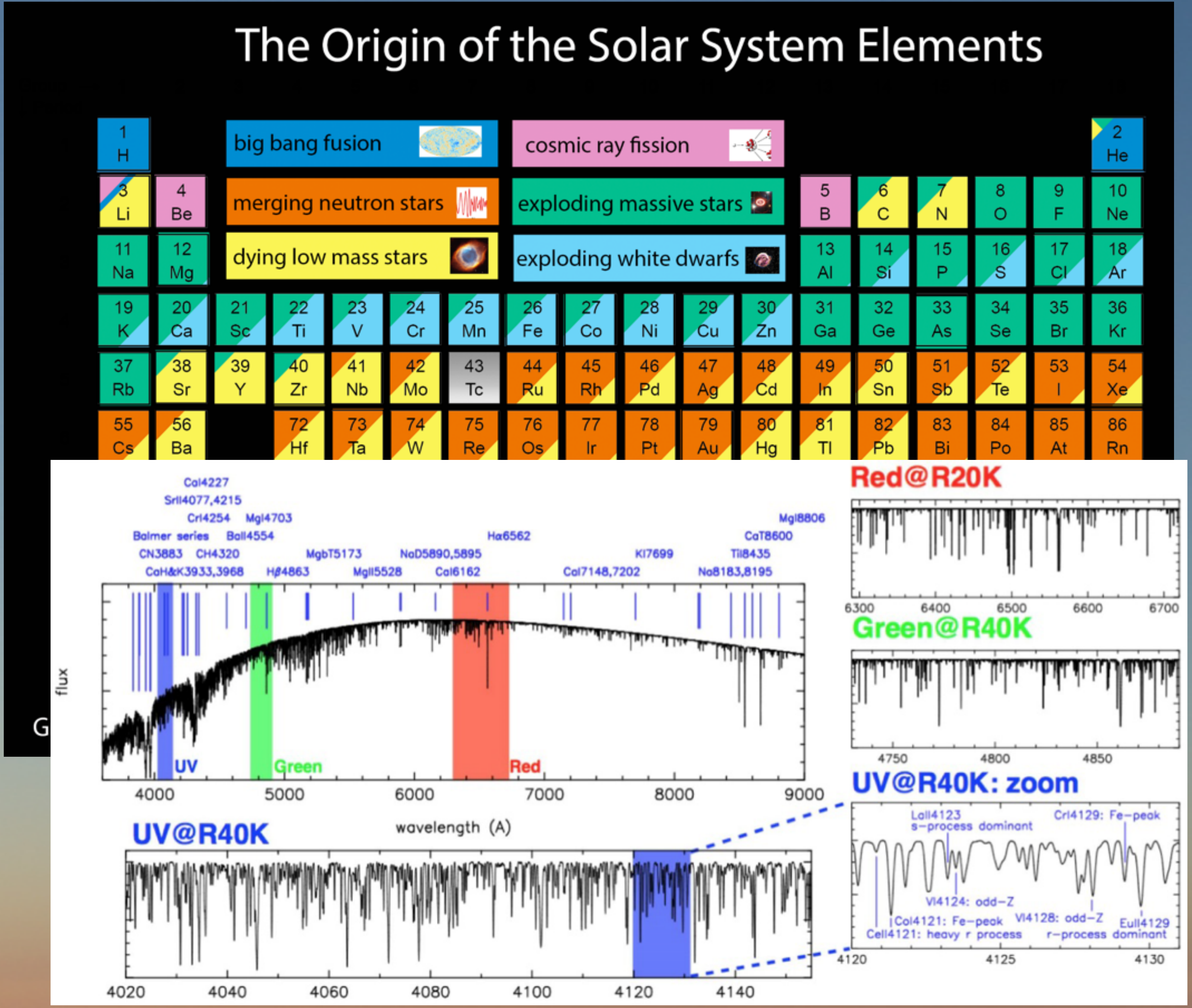
Maunakea Spectroscopic Explorer

Science highlights

Origins of the elements

- From H, He, Li to C, N, O, Ca, Fe …
- Better understanding of nuclear processes, astrophysical locations and details
- Formation sites act as chronometer, allowing to study system formation

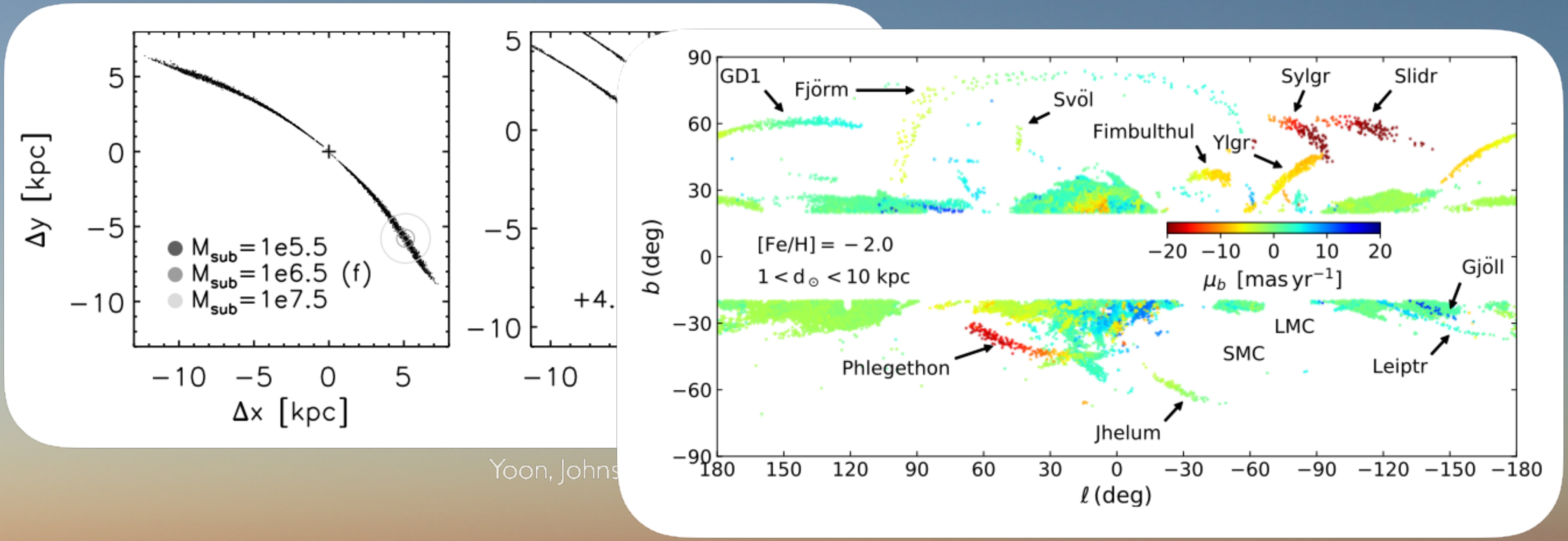
- MSE will measure elemental abundances in an unprecedented number of stars, providing the final piece of direct observational evidence of the origins of every element on the Periodic Table



Science highlights

Probing the particle nature of dark matter

- Using stellar streams as seismograph, MSE will be able to find (and constrain) the population of dark matter sub-halos around the Milky Way

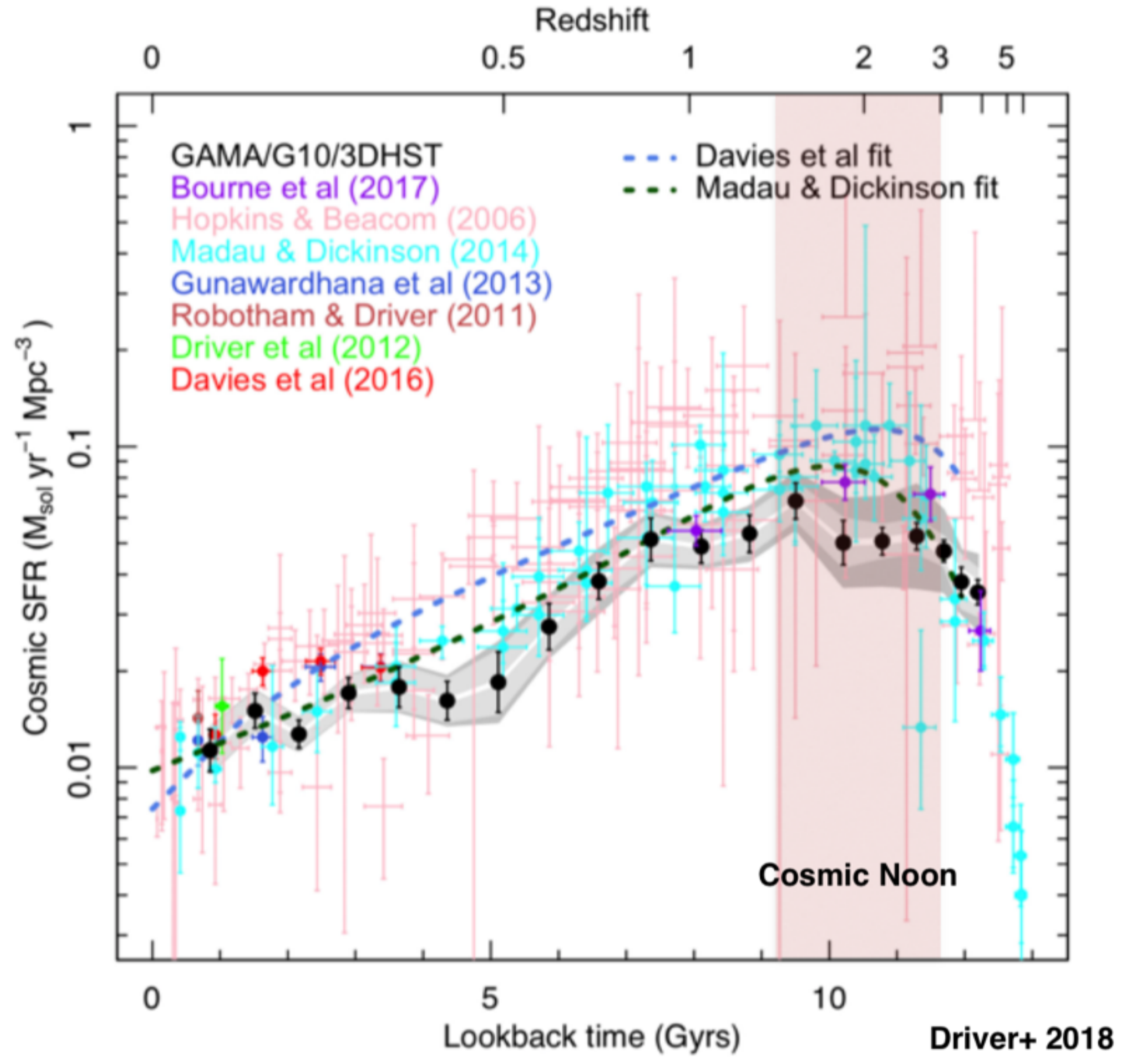


Yoon, Johns…

Ibata, Mahlan & Martin (2019)

Cosmic Star Formation History

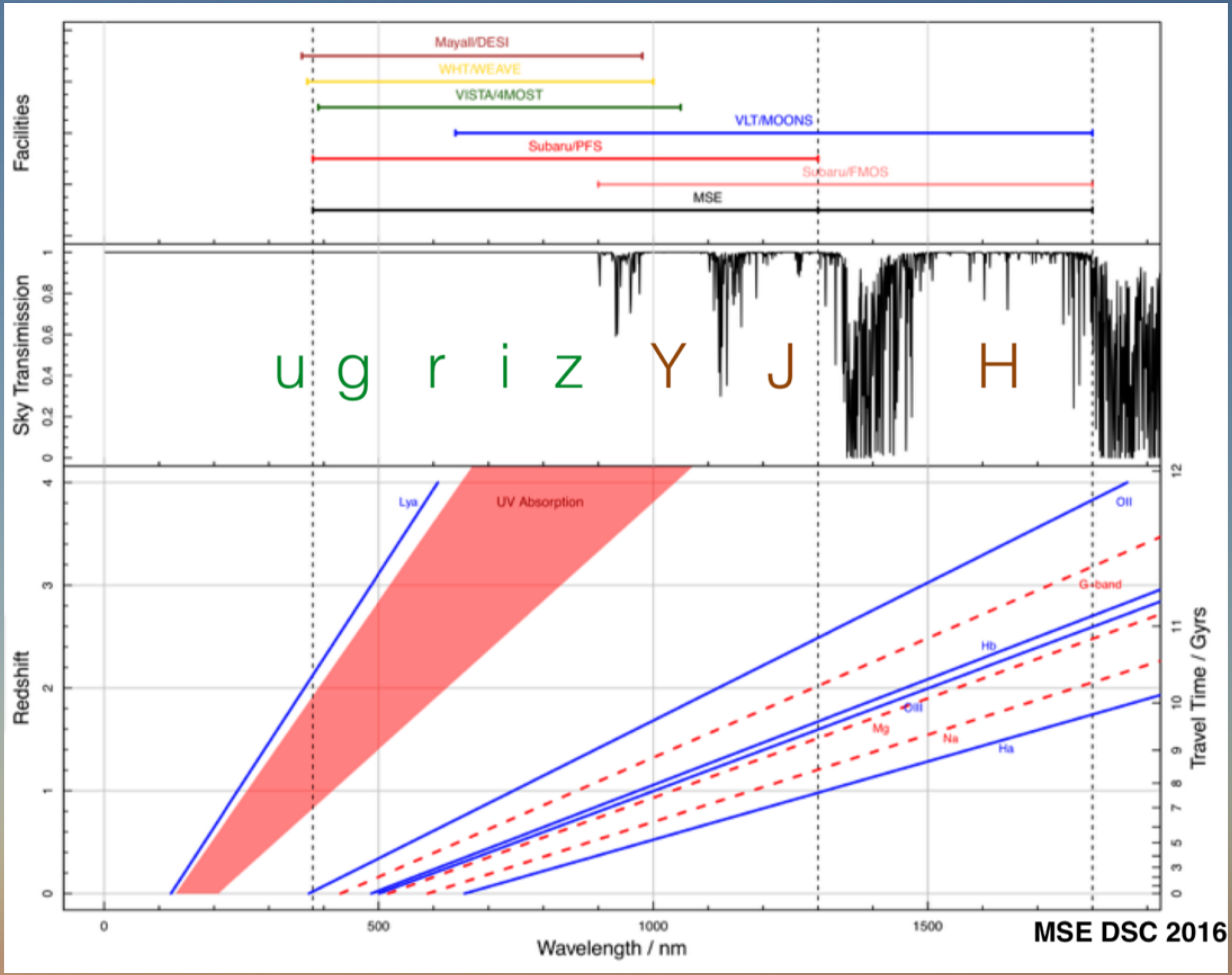
- SDSS has opened up the parameter space for low redshift galaxies by orders of magnitudes.
- A similar survey but at the peak of star formation (AKA cosmic noon) will open up a similar magnitude of science opportunities.
- Key issue is to probe representative volumes.
- These need to be of order Gpc^3.



Cosmic Star Formation History

Maunakea Spectroscopic Explorer

- Key new parameter space for extra-galactic science is H-band.
- This allows us to observe over the z~2 redshift desert in survey mode for the first time (caveat VLT/MOONS, with fewer fiber hours available).
- Also very low z<0.2 survey probing low mass halos and dwarf galaxies.



Science Working Groups

About Venue Registration Agenda Participants

Meeting Agenda

Zoom Link:

Join from PC, Mac, iOS or Android: https://cfht.zoom.us/j/6827754649

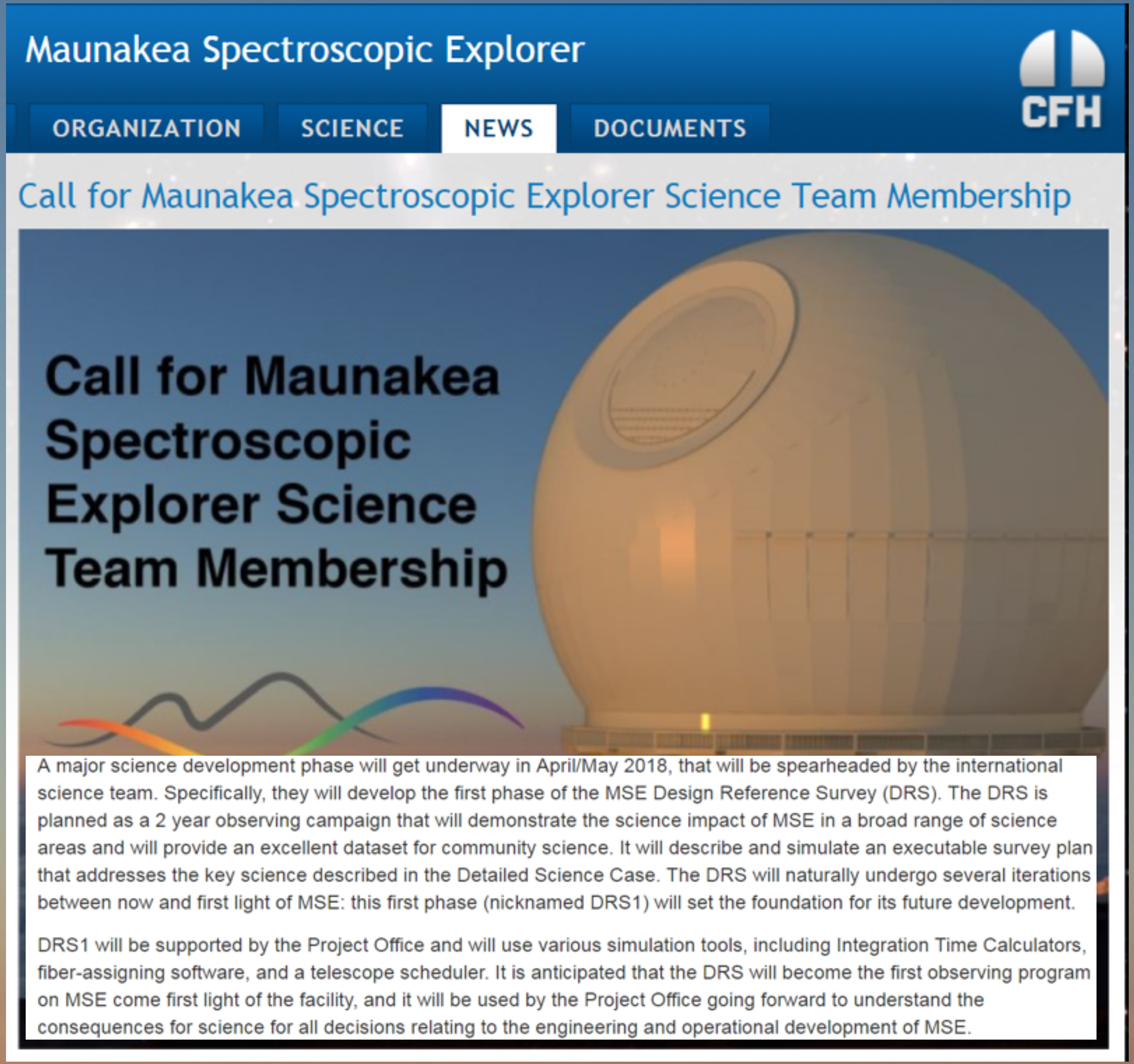
Tuesday 26 February 2019

8:00 Registration & Coffee

Growth of Science Team

- Huge response to the 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*
    - *Other – 130*

  * Current MSE participants



- SF2A Workshop, May 14 (Nice)
- Join mseinfo@mse.cfht.hawaii.edu
  or ping marshall@mse.cfht.hawaii.edu

Maunakea Spectroscopic Explorer

Science requirements

Accessible sky	30000 square degrees (airmass<1.55)						
Aperture (M1 in m)	11.25m						
Field of view (square degrees)	1.5						
Etendue = FoV x π (M1 / 2)²	149						
Modes	**Low**		**Moderate**	**High**			**IFU**
Wavelength range	0.36 - 1.8 μm		0.36 - 0.95 μm	0.36 - 0.95 μm ♯			IFU capable; anticipated second generation capability
	0.36 - 0.95 μm	J, H bands		0.36 - 0.45 μm	0.45 - 0.60 μm	0.60 - 0.95 μm	
Spectral resolutions	2500 *(3000)*	3000 *(5000)*	6000	40000	40000	20000	
Multiplexing	>3200		>3200	>1000			
Spectral windows	Full		≈Half	$\lambda_c/30$	$\lambda_c/30$	$\lambda_c/15$	
Sensitivity	m=24 *		m=23.5 *	m=20.0 ♮			
Velocity precision	20 km/s ♪		9 km/s ♪	< 100 m/s ★			
Spectrophotometic accuracy	< 3 % relative		< 3 % relative	N/A			

♯ Dichroic positions are approximate

* SNR/resolution element = 2

♪ SNR/resolution element = 5

♮ SNR/resolution element = 10

★ SNR/resolution element = 30

Maunakea Spectroscopic Explorer

Science requirements

	8 - 12 m class facilities						
	VLT / MOONS		**Subaru / PFS**		**MSE**		
Dedicated facility	No		No		Yes		
Aperture (M1 in m)	8.2		8.2		11.25		
Field of View (sq. deg)	0.14		1.25		1.52		
Etendue	7.4		66		151		
Multiplexing	1000		2394		4329		
Etendue x Multiplexing	7400 *(= 0.01)*		158004 *(= 0.24)*		653679 *(= 1.00)*		
Observing fraction	< 1 ?		0.2 (first 5 years) 0.2 - 0.5 afterwards ?		1		
Spectral resolution (approx)	4000	18000	3000	5000	3000	6500	40000
Wavelength coverage (um)	0.65 - 1.80	windows	0.38 - 1.26	0.71 - 0.89	0.36 - 1.8	0.36 - 0.95 50%	windows
IFU	No		No		Second generation		

MSE is ***100% dedicated*** to surveys, covers the ***full range*** from ***near-UV*** to the ***H band***, and includes a (very) ***high spectral resolution*** mode for stellar astronomy

Maunakea Spectroscopic Explorer

ARCHITECTURE

Maunakea Spectroscopic Explorer

Architecture

- MSE aims to transform CFHT into a 10m class spectroscopic survey facility
  - *Only dedicated large aperture wide-field MOS facility under development in the world*
  - *MSE development is starting Preliminary Design Phase.*

- Our engineering approach is to maximize utilization of existing designs in order to minimize development of new technologies
  - *Minimize project exposure to technical and programmatic risks*
  - *Ensure project schedule and budget are attainable*

- 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%*

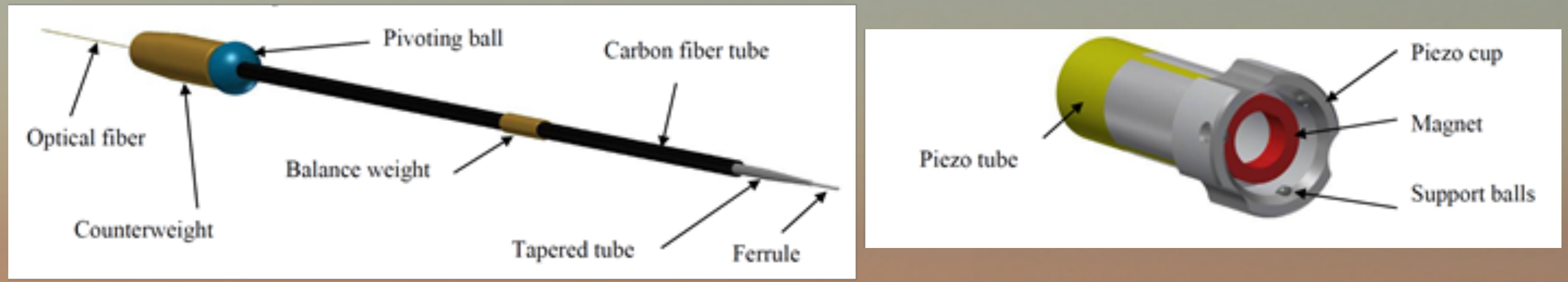
Architecture

- Examples of existing designs and technologies are being utilized
  - Segmented mirror system technologies from giant telescope projects - TMT and ESO ELT
  - Tilting spine fiber positioner and metrology technologies – FMOS and 4MOST
  - Spectrograph designs – Hector and HERMES
  - Commercial off-the-shelf high numerical aperture optical fiber
    - –No micro-lens optics
    - –No connectors to maximize system throughput, stability and repeatability

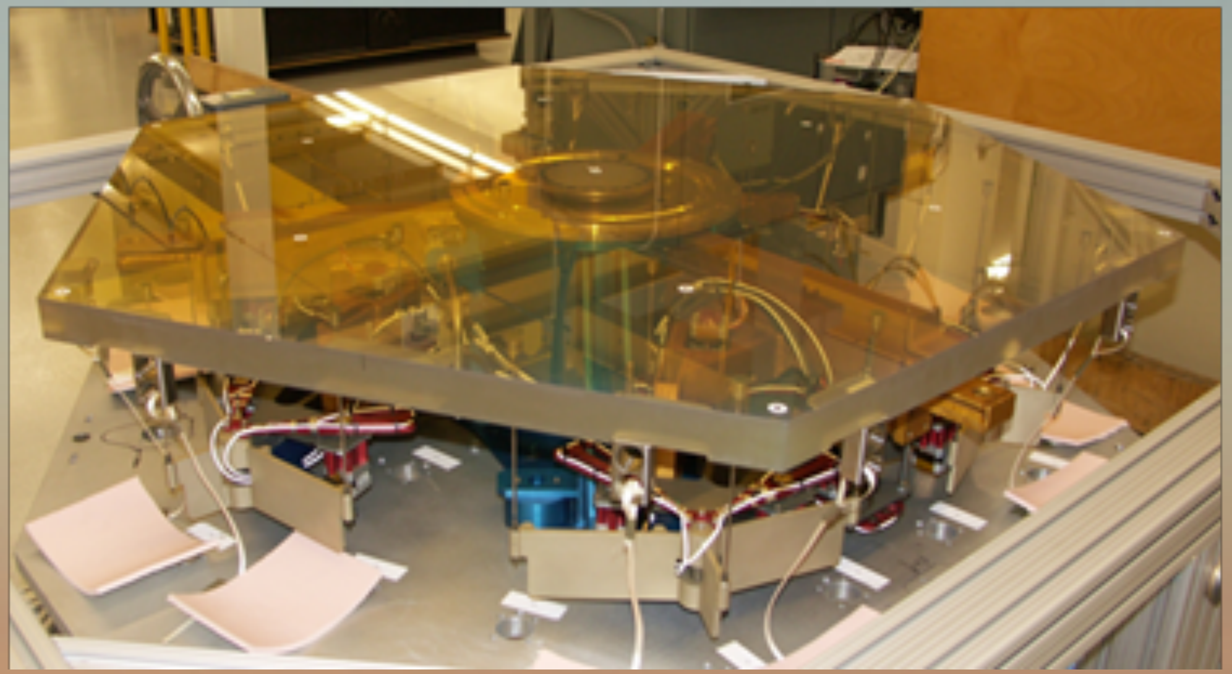
- Redevelopment of CFHT site and Waimea HQ
  - Proven site with exquisite IQ with well established infrastructure
  - <u>Access to over 40 years of experience and knowledge on Maunakea!</u>


CFHT summit facility

Echidna/Sphinx fiber positioner



TMT segment and support assembly



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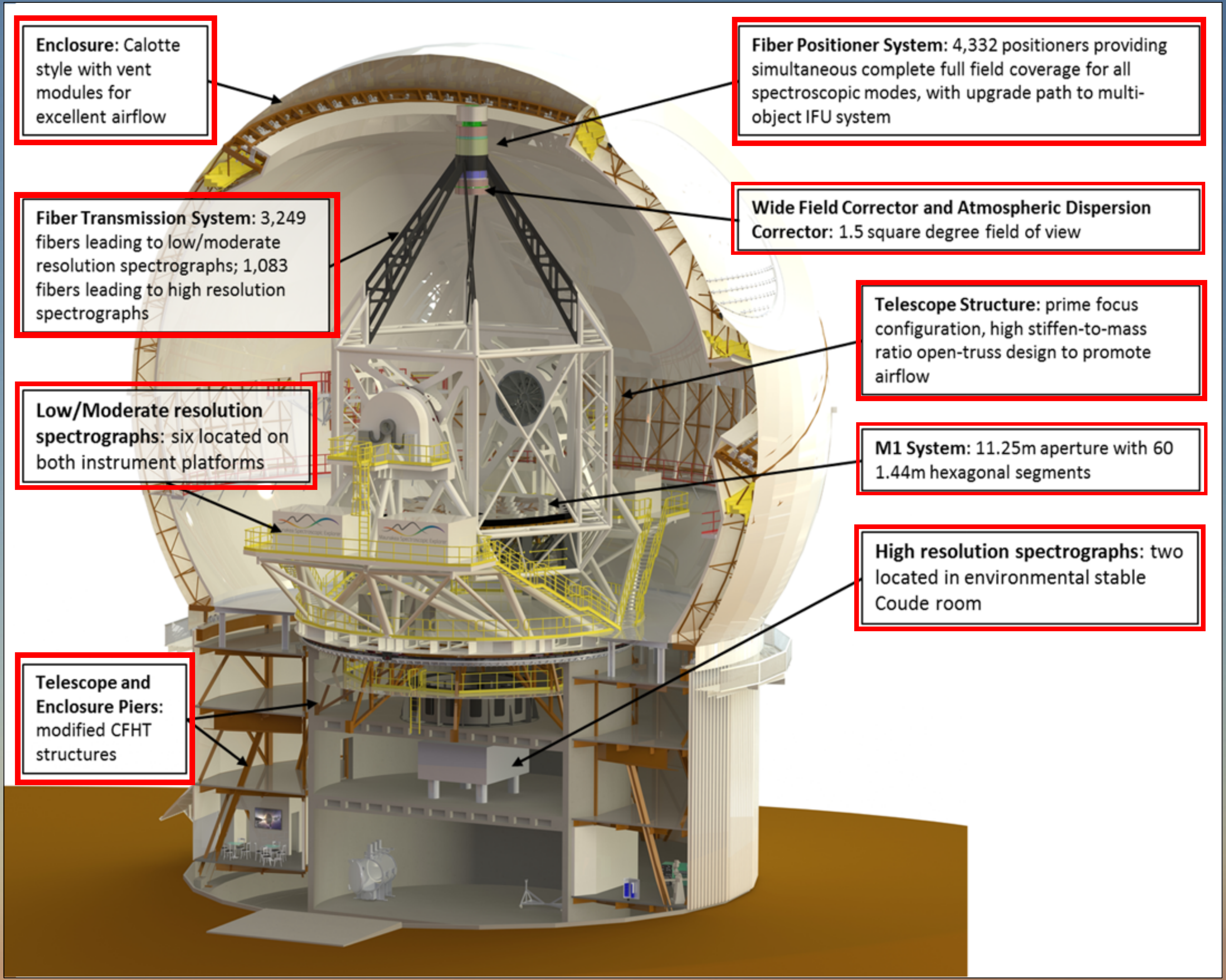
Science Driven Design



Design Choice – OBF & ENCL

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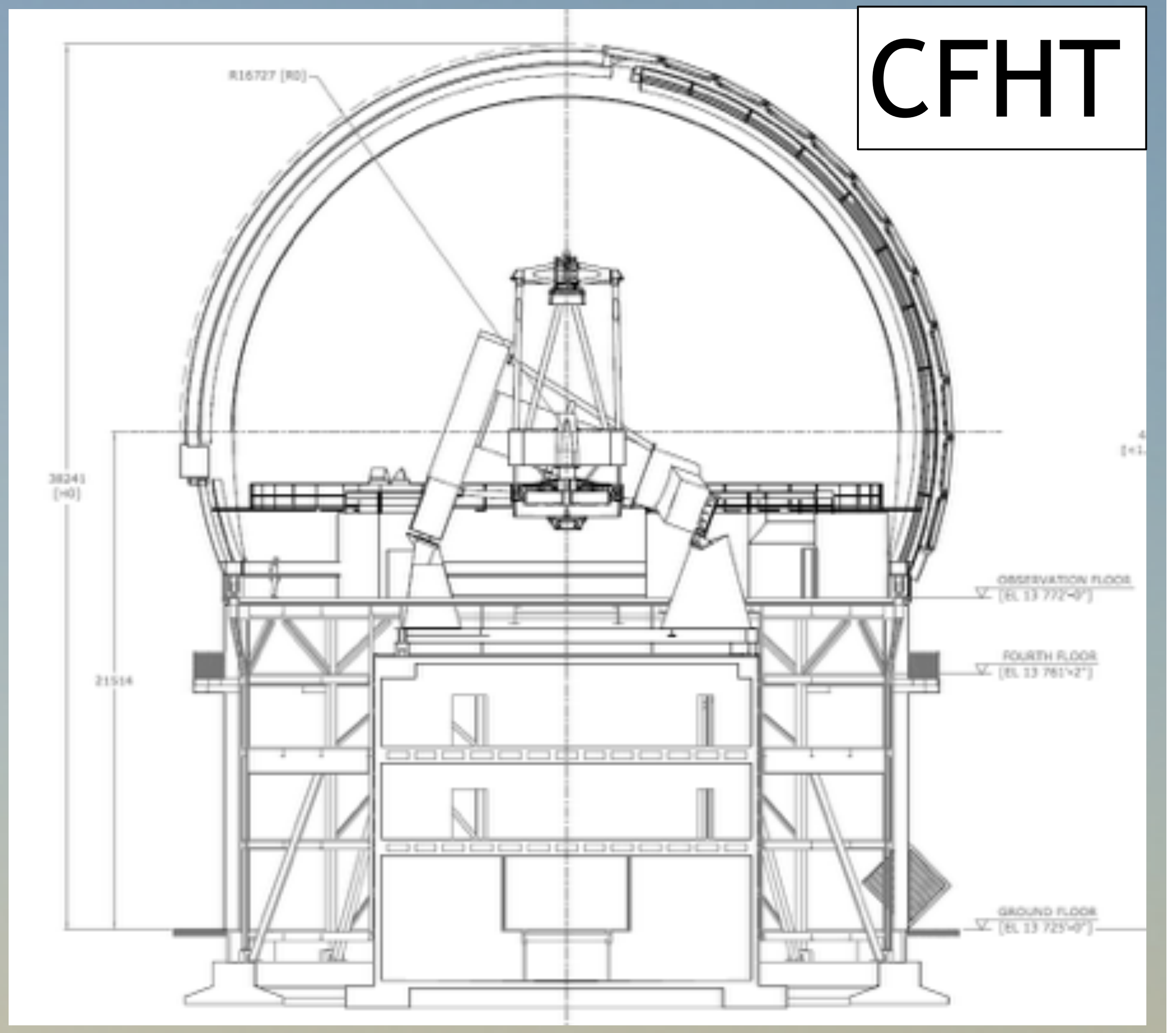
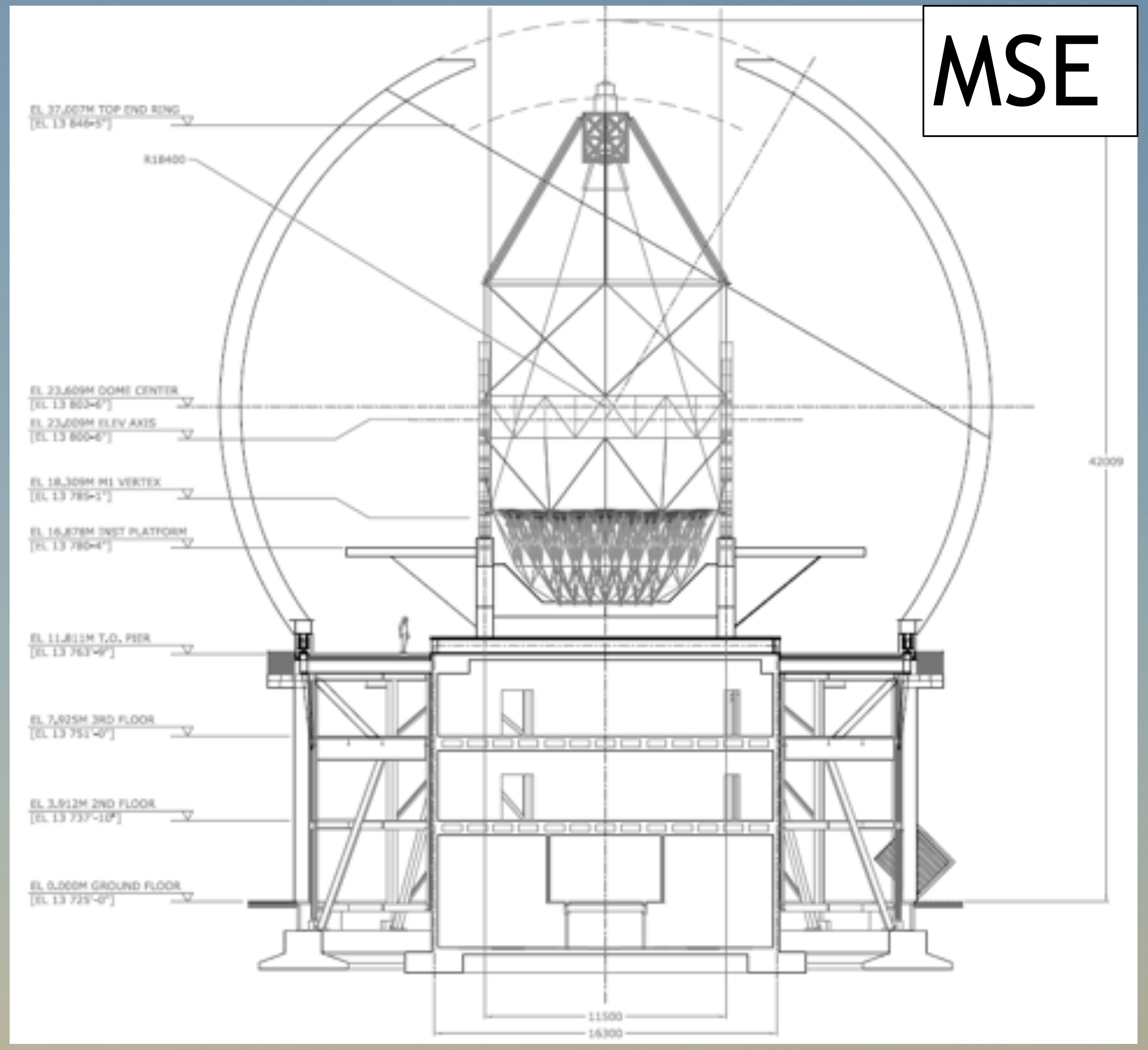
Reusing CFHT Observatory Building Facilities

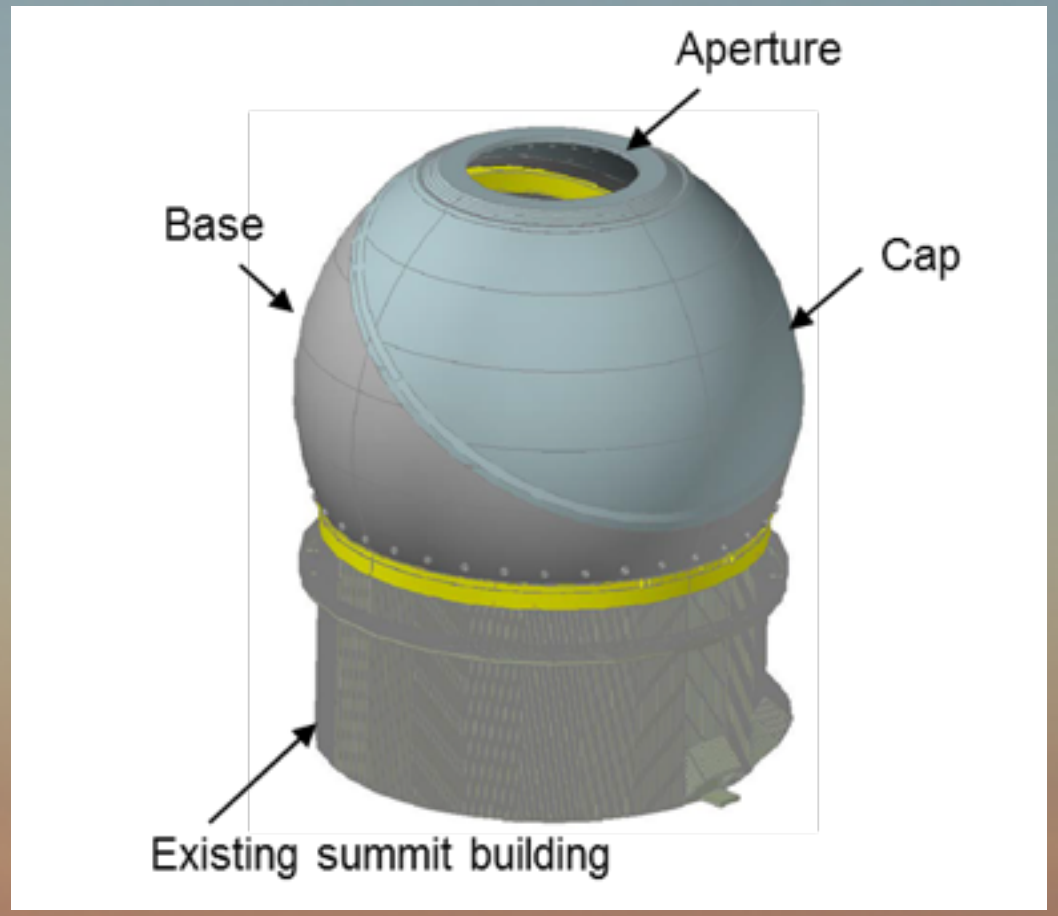
- After seismic upgrade
- Reconfigure building layout to optimize workflow





Calotte style enclosure selected after reviewing the trade study findings from TMT

- Mass & geometry compatible with existing pier
- Lighter enclosure, lower construction & ops costs
- CFHT's style vent modules to facilitate ventilation



Design Choice – TEL

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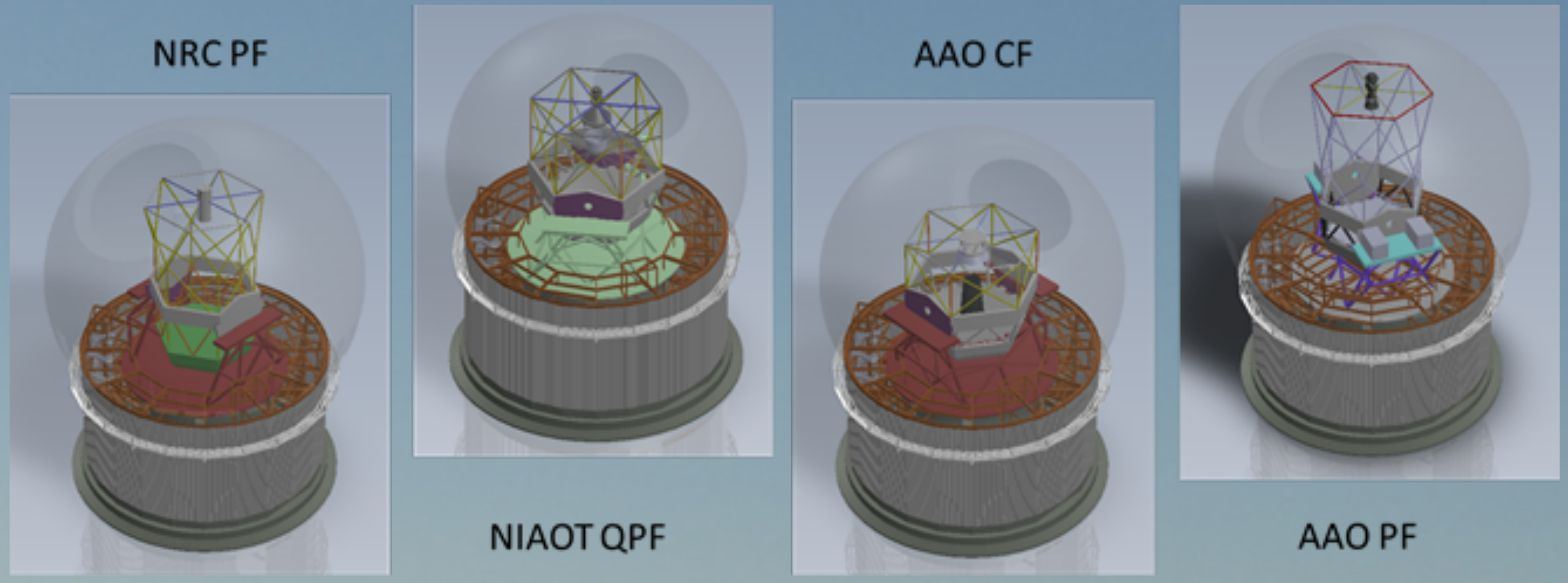
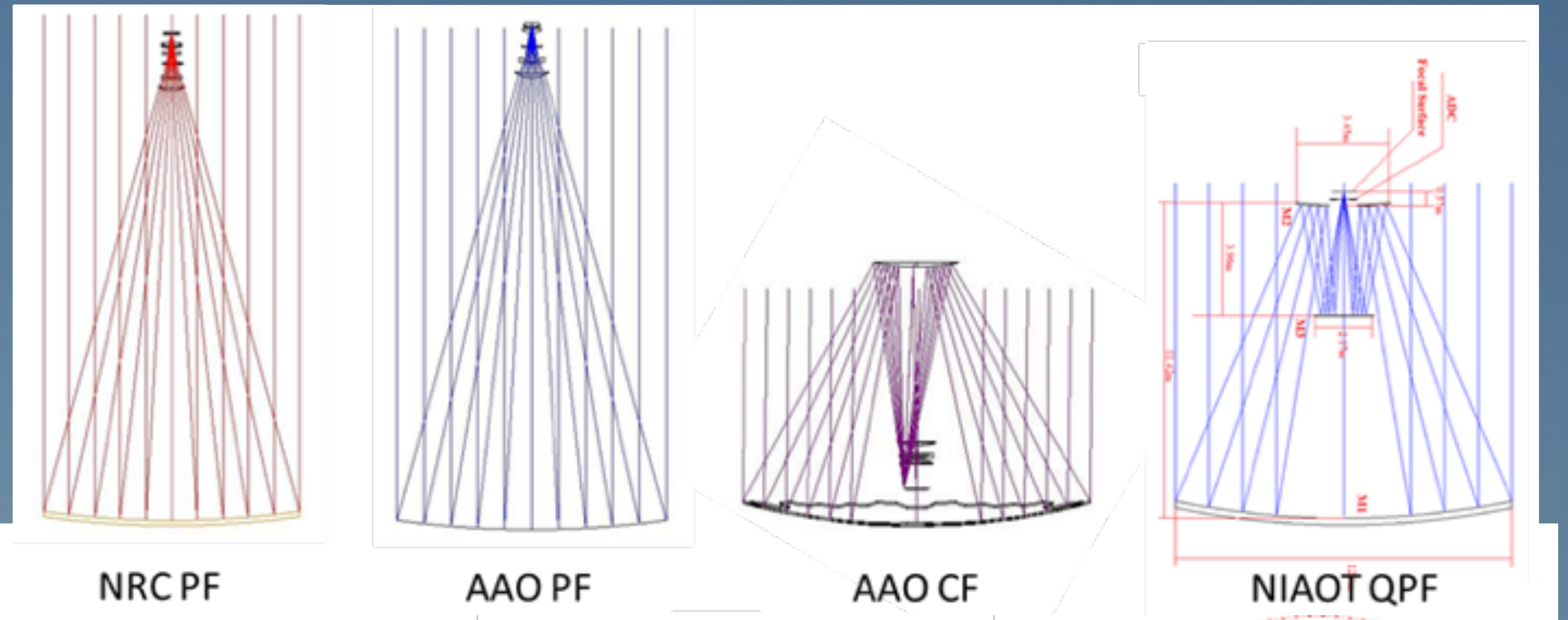
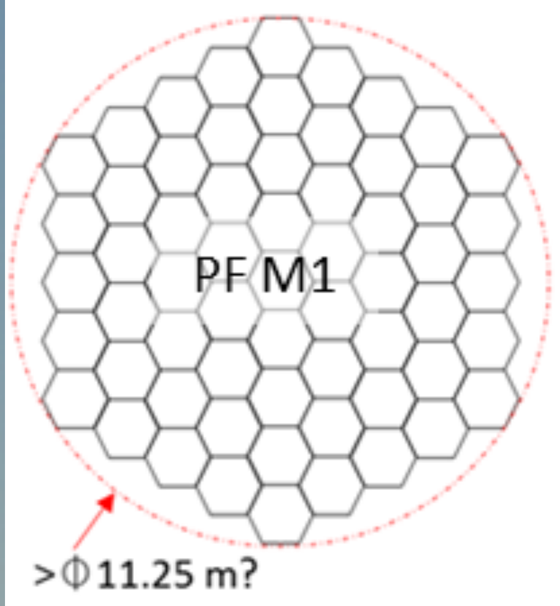
Telescope optical design is driven by key SRD requirements such as sensitivities and field of view.

- Four representative optical configurations, including WFC and ADC, developed for comparative study.
  - Detailed system level comparison of optical & non-optical performance

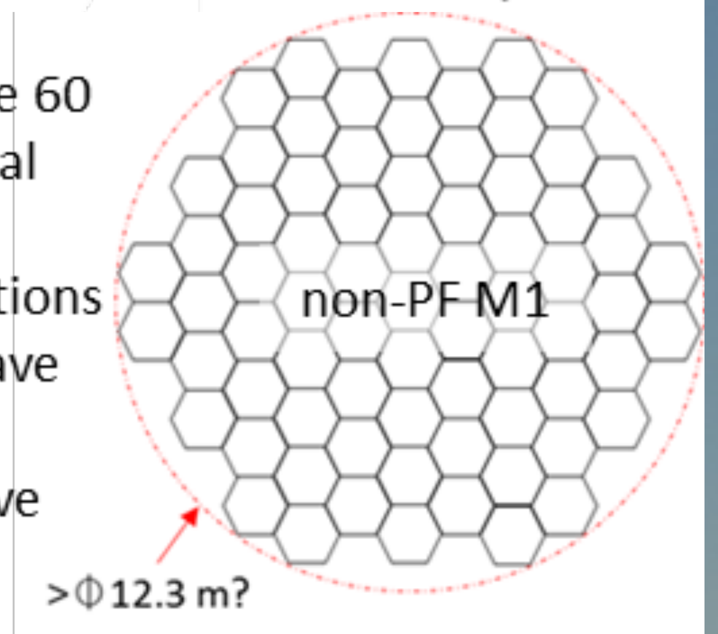


- By comparison, the non-PF designs incur higher cost due extra mirror segments, additional M2 & M3, with little gain in sensitivity.





- PF configurations (left) have 60 segment M1 and small central obscuration
- Although non-PF configurations (right) have larger M1 but have significantly higher central obscuration resulting effective collecting area similar to PF configuration.



	NRC PF	AAO PF	AAO CF	NIAOT QPF
Effective Diameter	Φ10.0 m	Φ10.1 m	Φ10.4 m	Φ10.3 m

After analysis of the four optical configurations Φ11.25 m prime-focus telescope configuration was adopted.

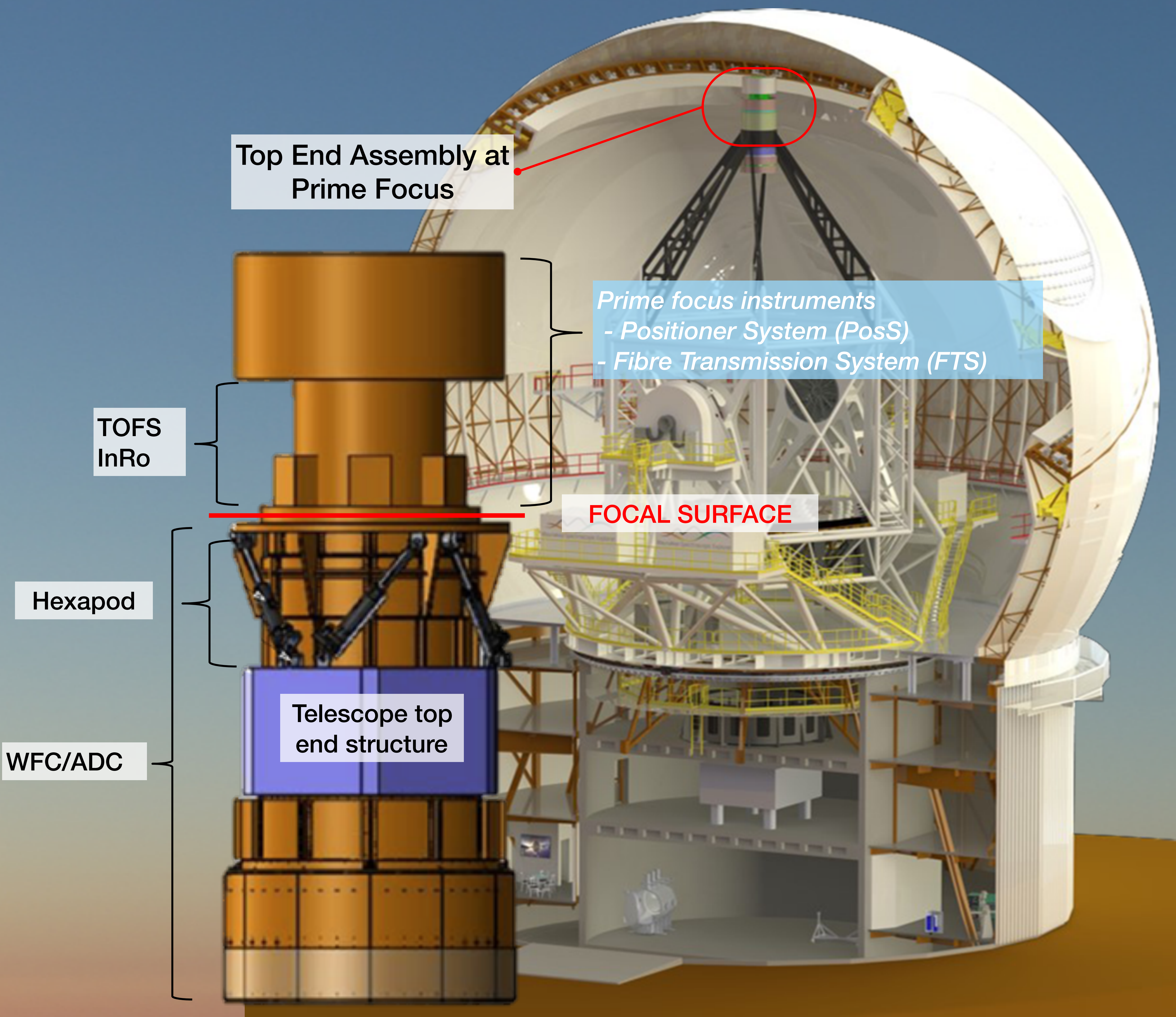
- It represents the optimal design solution in terms of cost and optical feasibility.

The adopted telescope optical design was reviewed and endorsed by external review panel in Feb

Design Choice – Top End Assembly

- TEA was a contribution of GEPI with DT/INSU. It contains the prime focus components and is considered part of the telescope subsystem:
  - Hexapod
  - Wide Field Corrector with integrated atmospheric dispersion correction
    - Novel lateral shift ADC design
  - Telescope Optics Feedback System (TOFS)
    - Acquisition and Guide Cameras
    - Phasing and Alignment Camera
  - Instrument Rotator (InRo) carries TOFS, *PosS* & *FTS*

- TEA functions during observation
  - During observation, the hexapod moves its payload to maintain optimal focus w.r.t. to the primary mirror.
    - Flexure and temperate compensates
  - Instrument Rotator de-rotates the positioners on the focal surface to maintain science targets to fiber inputs alignment

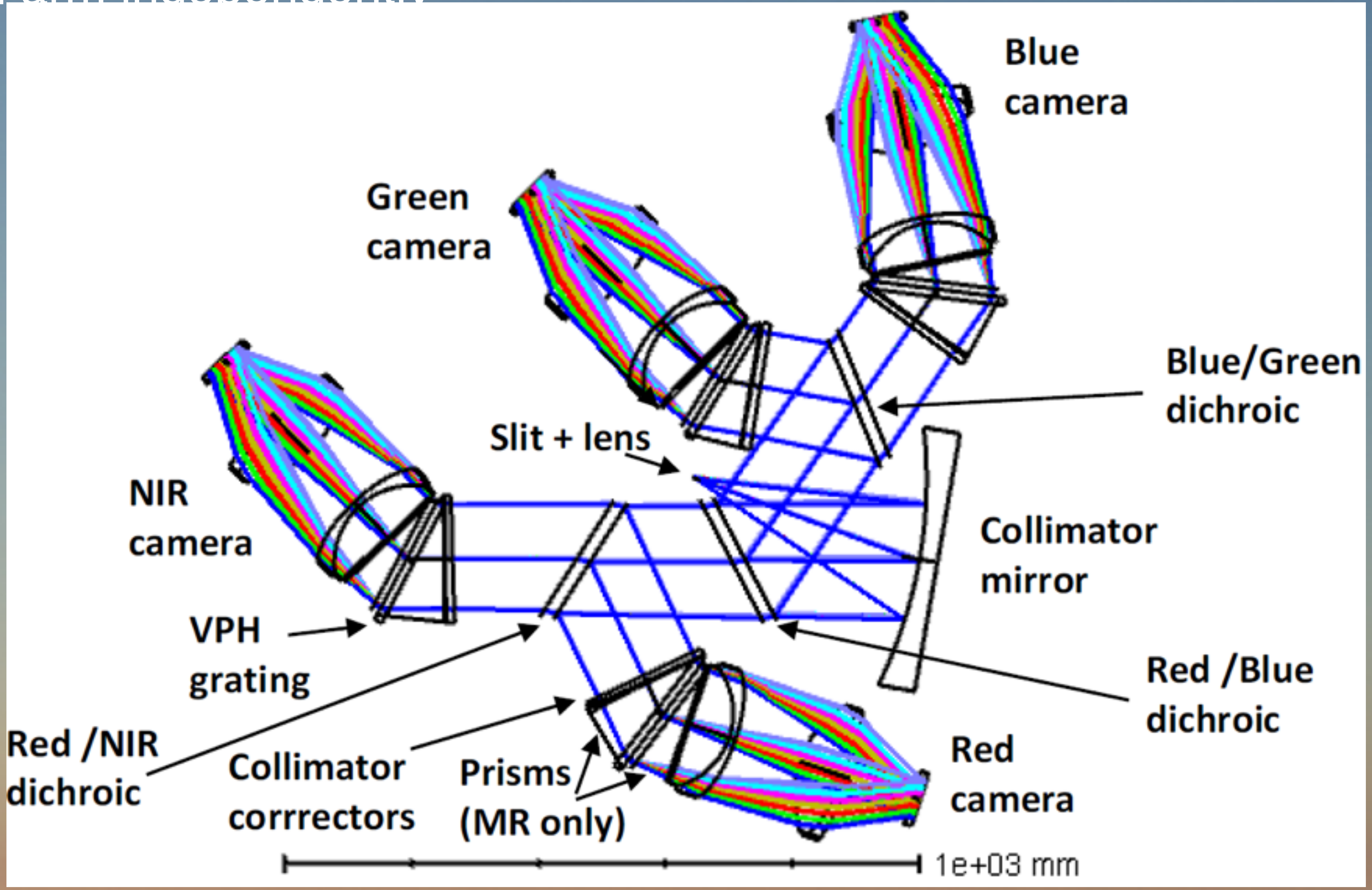


Design Status – LMR Spectrograph

LMR spectrograph conceptual design (LR R3000/MR R6000, Φ1.0”) provided by Centre de Recherche Astrophysique de Lyon (CRAL)

- Four-arm optical design
  - Off-axis Schmidt f/2 collimator
  - Resolution change by switching dispersive elements in each arm independently
    - VPH grating for optical-band LR + J-band
    - VPH grating + prisms for optical-band MR + H-band
- Status: design team to implement the review panel’s CoDR recommendation to pursue alternate optical designs for risk reduction considerations.

	LR				MR			
	Blue	Green	Red	NIR	Blue	Green	Red	NIR
λ_{min}	360nm	540nm	715nm	960nm	391nm	576nm	737nm	1457nm
λ_{max}	560nm	740nm	985nm	1320nm	510nm	700nm	900nm	1780nm
Resolution (Å)	1.78Å	1.75Å	2.36Å	3.15Å	1.02Å	1.02Å	1.35Å	2.68Å
R_{min}	2000	3100	3000	3000	3800	5600	5500	5400
R_{max}	3100	4200	4200	4200	5000	6800	6700	6600



Design Status – HR Spectrograph

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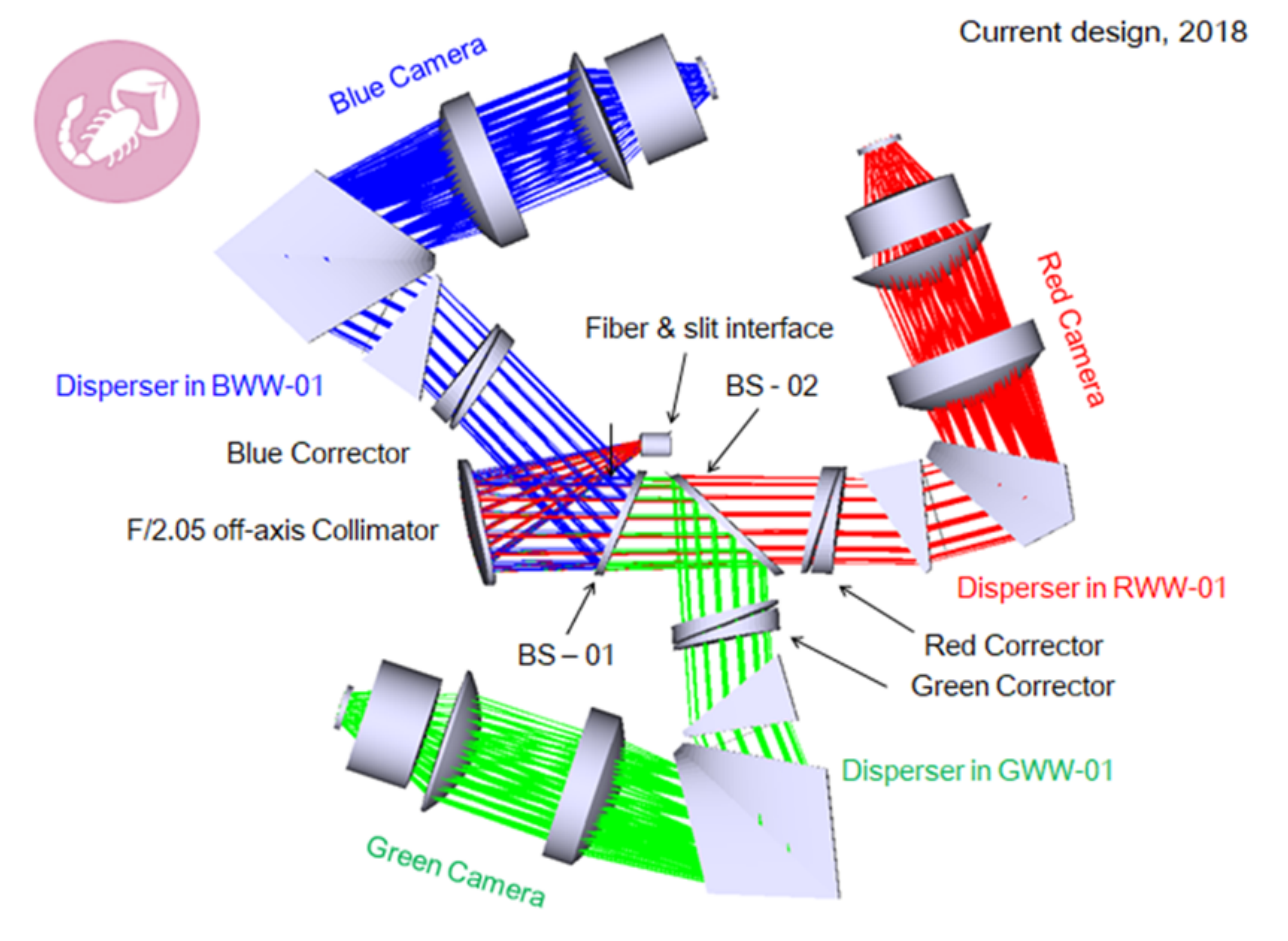
HR spectrograph light-Preliminary Design (R=40K/20K, ⌽0.75”) provided by Nanjing institute of Astronomical optics & Technology (NIAOT)

- Three-arm optical design with three (blue, green and red) wavelength windows
  - Off-axis f/2.05 collimator
  - Each wavelength window has a narrower working window
    - λ_{Blue}/30 of λ_{Blue} at R40K
    - λ_{Green}/30 of λ_{Green} at R40K
    - λ_{Red}/15 of λ_{Red} at R20K

- Status: design team implemented the review panel’s CoDR recommendations in the light-Preliminary Design that is in progress.
  - Currently investigating optics fabrication feasibility with vendors on the dispersers, correctors and cameras

	Blue	Green	Red
λ min	360 nm	440 nm	600 nm
λ max	460 nm	620 nm	900 nm
Working Window	401 - 415 nm	472 - 488.5 nm	626.5 - 672 nm
R	40000	40000	20000



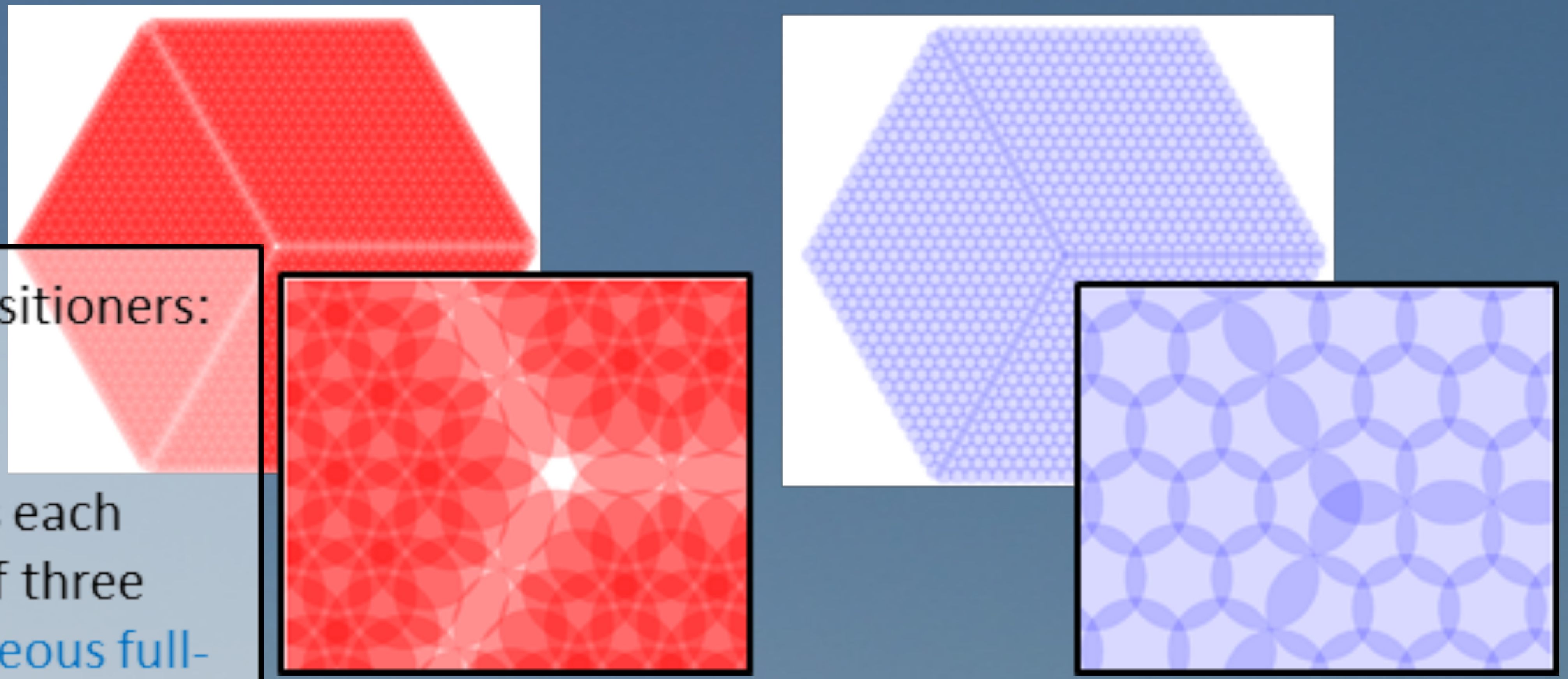
PosS Down-Select

Three competing designs from AAO (Australia), USTC (China) and UAM (Spain) were evaluated.

Patrol radius 90.3 arcsec

Two fibers: closest approach 7 arcsec

Three fibers: cluster within 9.9 arcsec circle



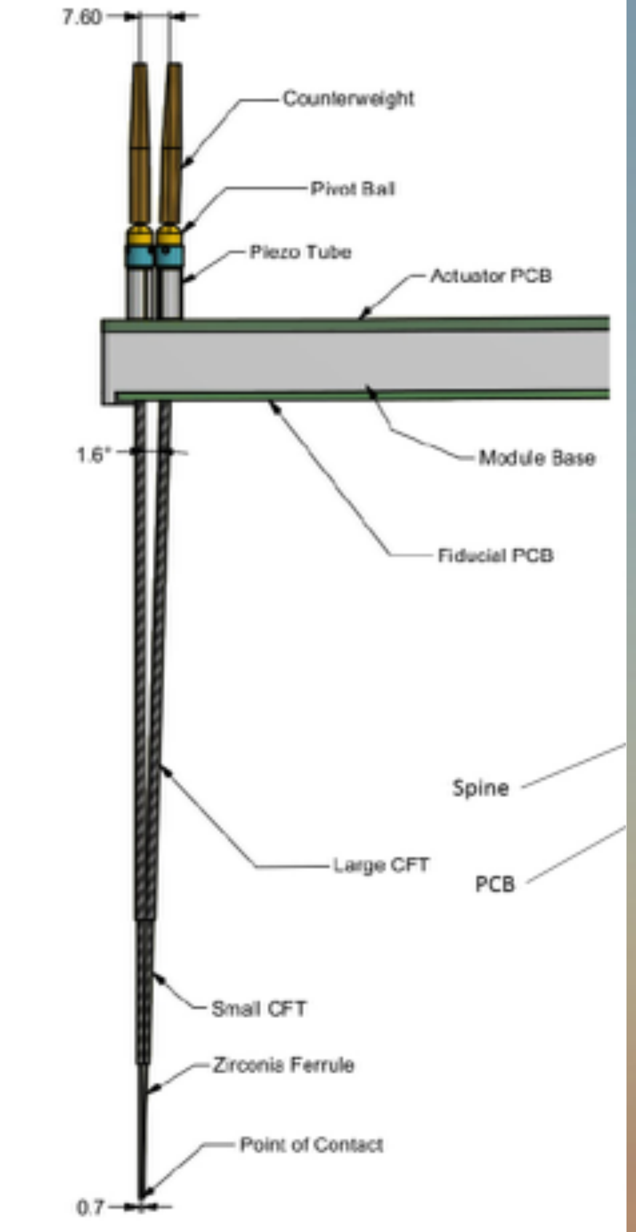
Focal surface layout of 4332 positioners:
- 3249 LMR (red)
- 1083 HR (blue)

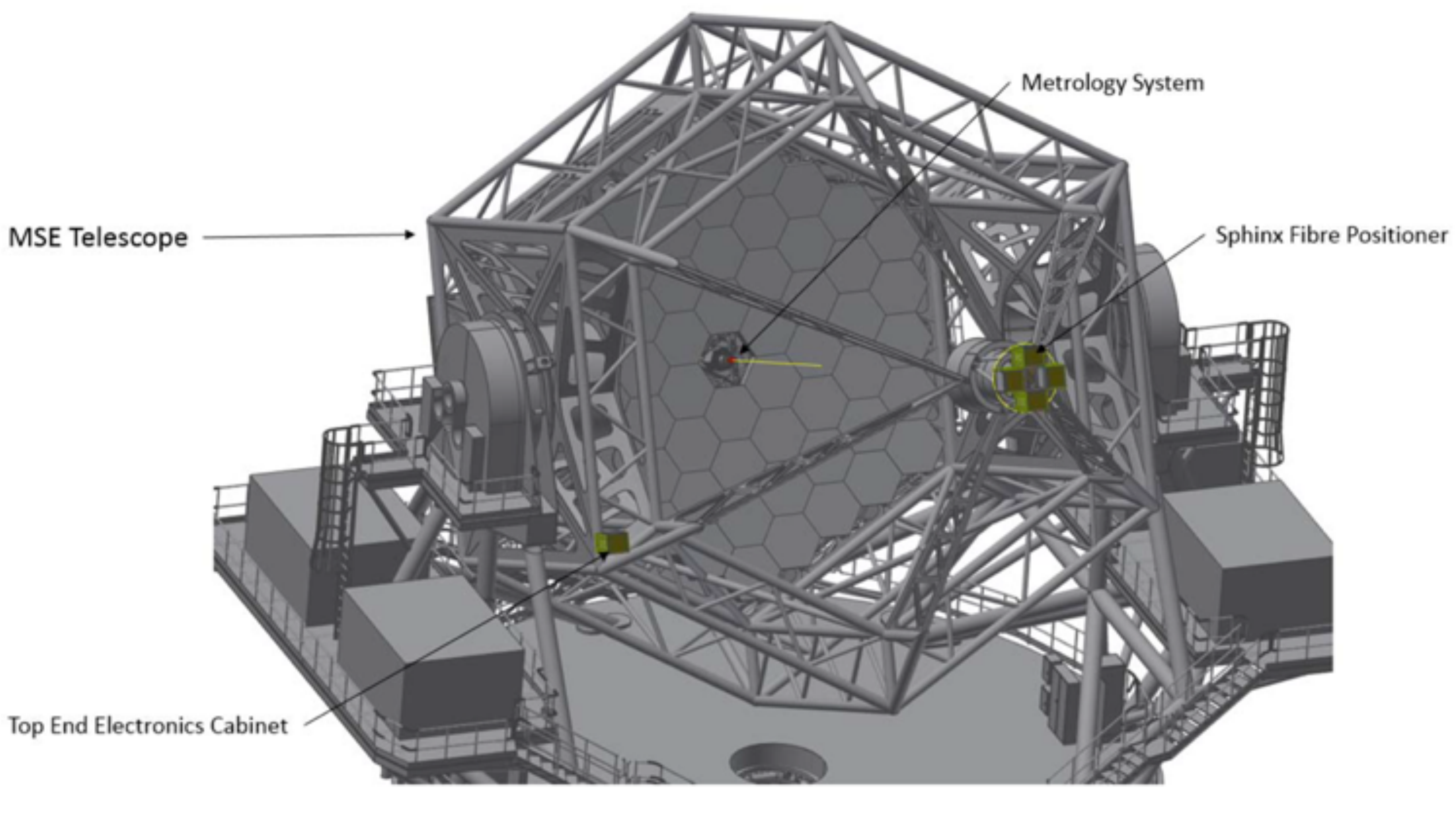
57 modules with 76 positioners each layout in a "triskele" pattern (of three rhombuses) providing simultaneous full-field coverage of LMR (red) and HR (blue) targets.

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

The AAO Sphinx system was selected.

- High target allocation efficiency
- High observing efficiency: simultaneous observation of both LMR and HR targets
- System configuration time in <2 minutes for 4000+ positioners
- System accuracy of 6 um RMS
- AAO test demonstrated FRD variations due to tilt <2%
- PO verified injection efficiency loss due to fiber tilt are insignificant in context of overall system sensitivity





Sphinx comprises a Fiber Positioner (at prime focus) with support electronics (on top-end ring) and a metrology system (near the vertex of M1)

Maunakea Spectroscopic Explorer

PERFORMANCE

Maunakea Spectroscopic Explorer

SRD Compliance Summary

Color code illustrates the compliance of the SRD requirements as fulfilled by the Level 1 Documents:

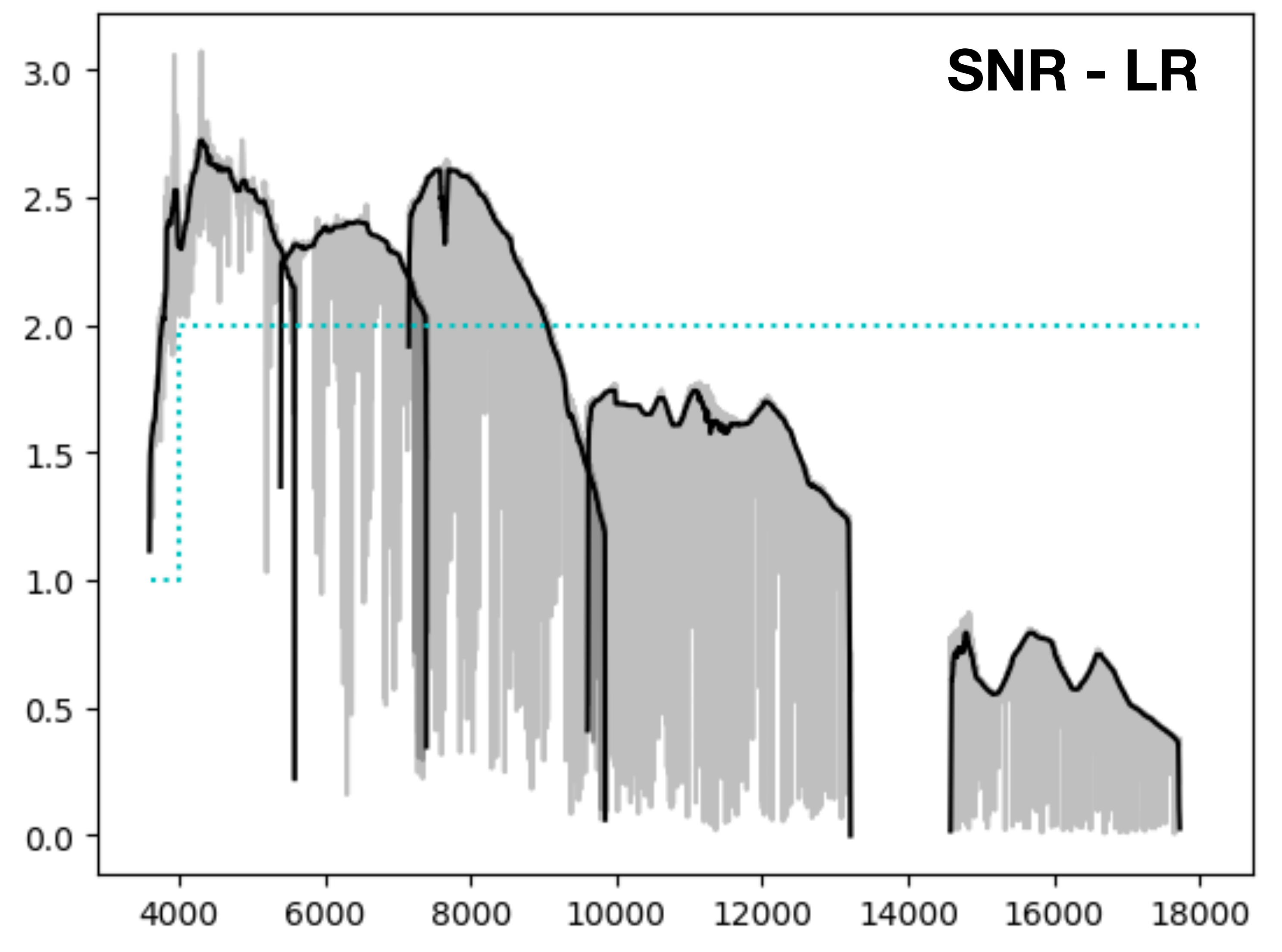
- 1. Spectral resolution
- 2. Focal plane input
- 3. Sensitivity
  - 3a. Spectral coverage
  - 3b. Sensitivity
- 4. Calibration
- 5. Lifetime operations

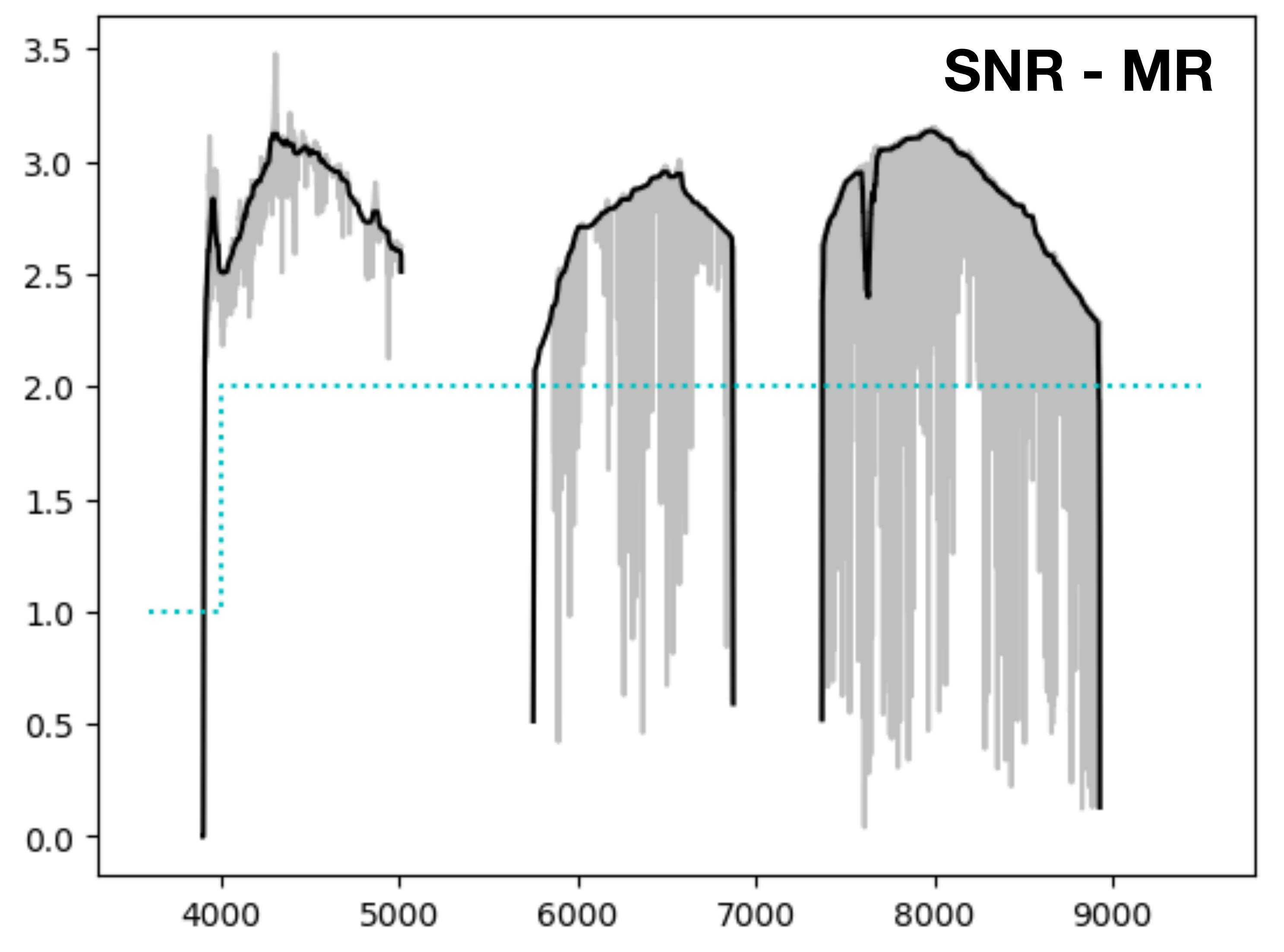
Compliant assessment (Y/N/Partial/TBD)

- Y means fully meet requirement
- TBC means by design or analysis the requirement is already met but we plan to do more work in the Preliminary Design Phase before declaring compliance.
- Partial (yellow) means formal declaration needed from the Project Office to claim compliance.
- Partial (red) means a portion of a multiple-part requirement is met.

Group	Requirement	Description	Compliance [Y/N/Partial]
	Requirements relating to Spectral Resolution:		
1	REQ-SRD-011	Low spectral resolution	Partial
1	REQ-SRD-012	Moderate spectral resolution	Partial
1	REQ-SRD-013	High spectral resolution	Y
	Requirements relating to the Focal Plane Input:		
2	REQ-SRD-021	Science field of view	Y
2	REQ-SRD-022	Multiplexing at low resolution	Partial
2	REQ-SRD-023	Multiplexing at moderate resolution	Partial
2	REQ-SRD-024	Multiplexing at high resolution	Y
2	REQ-SRD-025	Spatially resolved spectra	Y
	Requirements relating to Sensitivity		
3a	REQ-SRD-031	Spectral coverage at low resolution	Y
3a	REQ-SRD-032	Spectral coverage at moderate resolution	Y
3a	REQ-SRD-033	Spectral coverage at high resolution	Y
3b	REQ-SRD-034	Sensitivity at low resolution	Partial
3b	REQ-SRD-035	Sensitivity at moderate resolution	Y
3b	REQ-SRD-036	Sensitivity at high resolution	Partial
	Requirements relating to Calibration		
4	REQ-SRD-041	Velocities at low resolution	TBC
4	REQ-SRD-042	Velocities at moderate resolution	TBC
4	REQ-SRD-043	Velocities at high resolution	TBC
4	REQ-SRD-044	Relative spectrophotometry	Y
4	REQ-SRD-045	Sky subtraction, continuum	Y
4	REQ-SRD-046	Sky subtraction, emission lines	TBC
	Requirements relating to Lifetime Operations		
5	REQ-SRD-051	Accessible sky	Y
5	REQ-SRD-052	Observing efficiency	Y
5	REQ-SRD-053	Observatory lifetime	Y

Solutions: science team lead



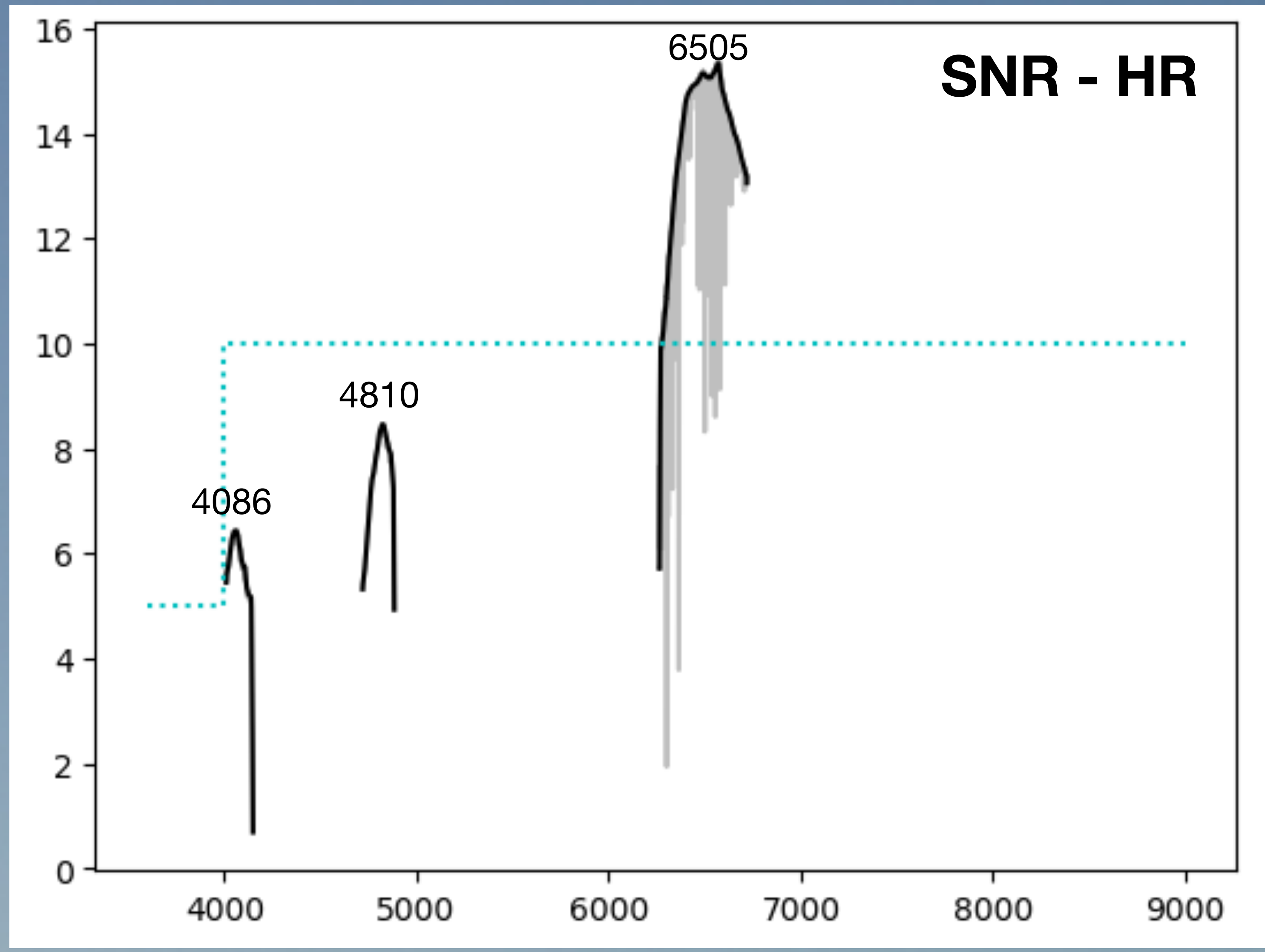


- For LMR science considerations:
  - What are the minimum sensitivities required for J-band and H-band in low resolution?
  - What is the anticipated target density in H-band?
    - 2200/sq. degrees is assumed in the SRD, same as the optical band
    - If the target density is lower, does having standalone H-band spectrograph make sense?
    - Can we do away with H-band LR mode all together?
    - What are the science motivations of the LR and MR resolutions, average and minimum?
    - Can we do away with MR mode all together?

	Wavelength Range	
LR Mode	λ < 950nm	λ > 950nm
Required Average Resolution	2500 ≤ R ≤ 3000	-
Achieved Average Resolution	3396	-
Required Minimum Resolution	R > 2000	R > 3000
Achieved Minimum Resolution	1983	3190

	Wavelength Range
MR Mode	360nm ≤ λ ≤950nm, at each wavelength
Required Average Resolution	5000 ≤ R ≤ 7000
Achieved Average Resolution	$R_{Blue} = 3822$
Achieved Average Resolution	$R_{Green} > 5000$
Achieved Average Resolution	$R_{Red} > 5000$
Required Minimum Resolution	R > 4500
Achieved Minimum Resolution	$R_{Blue} = 3788$
Achieved Minimum Resolution	$R_{Green} > 4500$
Achieved Minimum Resolution	$R_{Red} > 4500$

Solutions?



- For HR science considerations:
  - What is the minimum SNR and resolution for λ<500 nm?
    - For example, is SNR=5 acceptable, instead of 10?
    - For example, is R35K acceptable, instead of R40k, in order to increase SNR?
  - What are the science appropriate central wavelengths for the blue, green and red spectral arms given the λ/30 and λ/15 working windows?

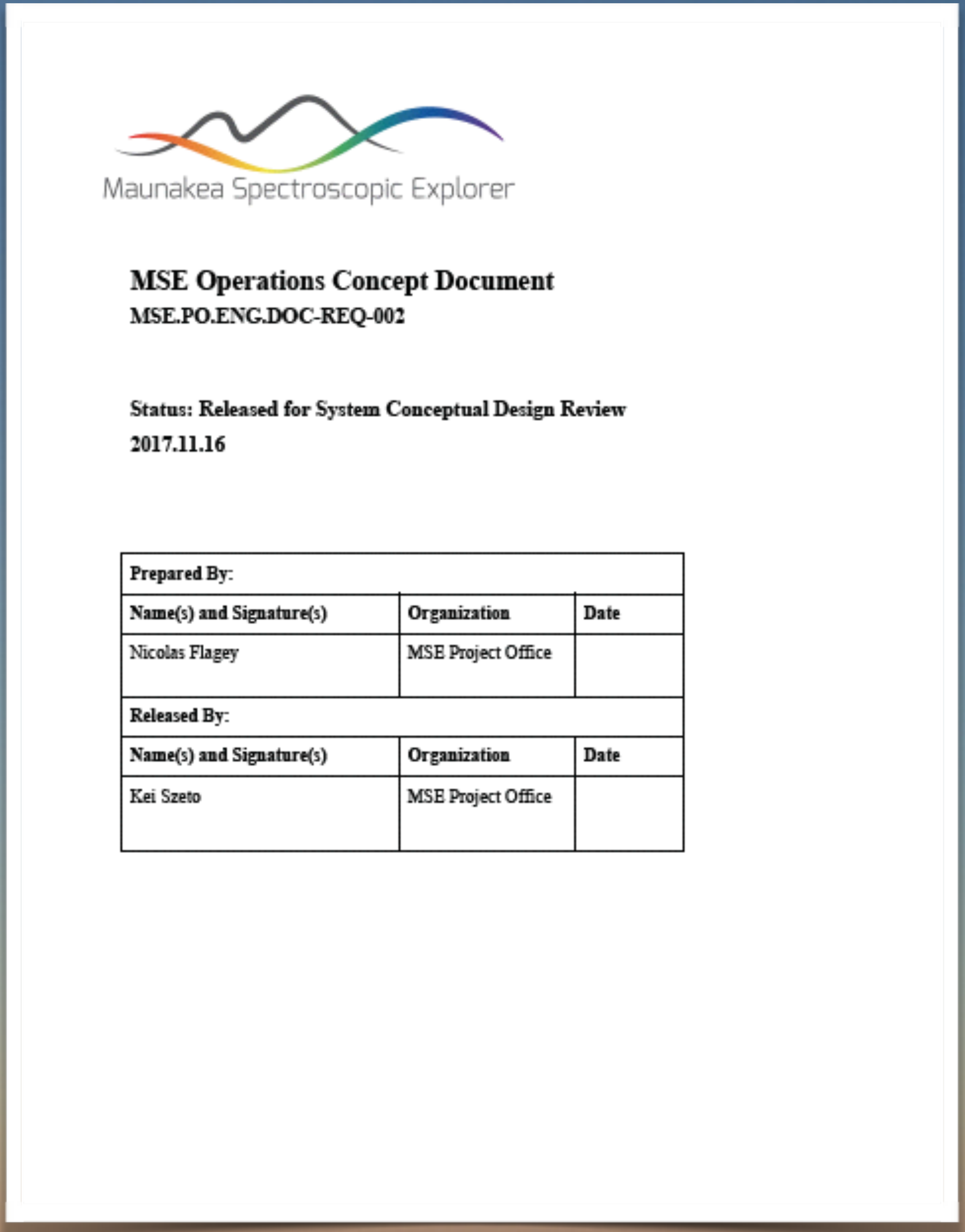
	Wavelength Range	
HR Mode	$\lambda < 500$nm	$\lambda > 500$nm
Required Average Resolution	$38000 \leq R \leq 420000$	$18000 \leq R \leq 22000$
Achieved Average Resolution	$R_{Blue} = 40000$	-
Achieved Average Resolution	$R_{Green} = 40000$	-
Achieved Average Resolution	-	$R_{Red} = 20000$
Required Minimum Resolution	$R > 35000$	$R > 15000$
Achieved Minimum Resolution	$R_{Blue} > 35000$	-
Achieved Minimum Resolution	$R_{Green} > 35000$	-
Achieved Minimum Resolution	-	$R_{Red} > 15000$

OPERATIONS

Operations Concept

- One of the founding documents for the Project Office with the Observatory Architecture and Requirements Documents
  - 79 pages
  - 135 requirements

- Describes how the observatory will be operated to answer the Science Requirements Document, in particular the requirements on:
  - observing efficiency (**quantity** of data):
    - 80% observing efficiency (time spent collecting photons divided by time not lost to weather)
  - calibration (**quality** of data):
    - 0.5% sky subtraction accuracy
    - 3% relative spectrophotometry
    - 100 m/s velocity accuracy at high resolution



Maunakea Spectroscopic Explorer

MSE Operations Concept Document

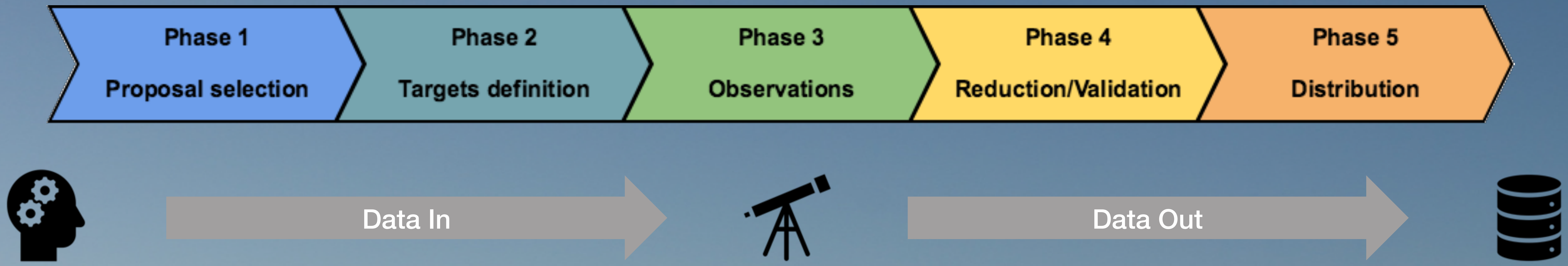
MSE.PO.ENG.DOC-REQ-002

Status: Released for System Conceptual Design Review

2017.11.16

Prepared By:		
Name(s) and Signature(s)	**Organization**	**Date**
Nicolas Flagey	MSE Project Office	
Released By:		
Name(s) and Signature(s)	**Organization**	**Date**
Kei Szeto	MSE Project Office	

Phases of operations



- MSE will follow the typical Phases of an astronomical observatory, following the data flow
- However, the tools will need to be adapted to the large amount of data in & out

Phases of operations – data input

Phase 1

Proposal selection

User interface
website

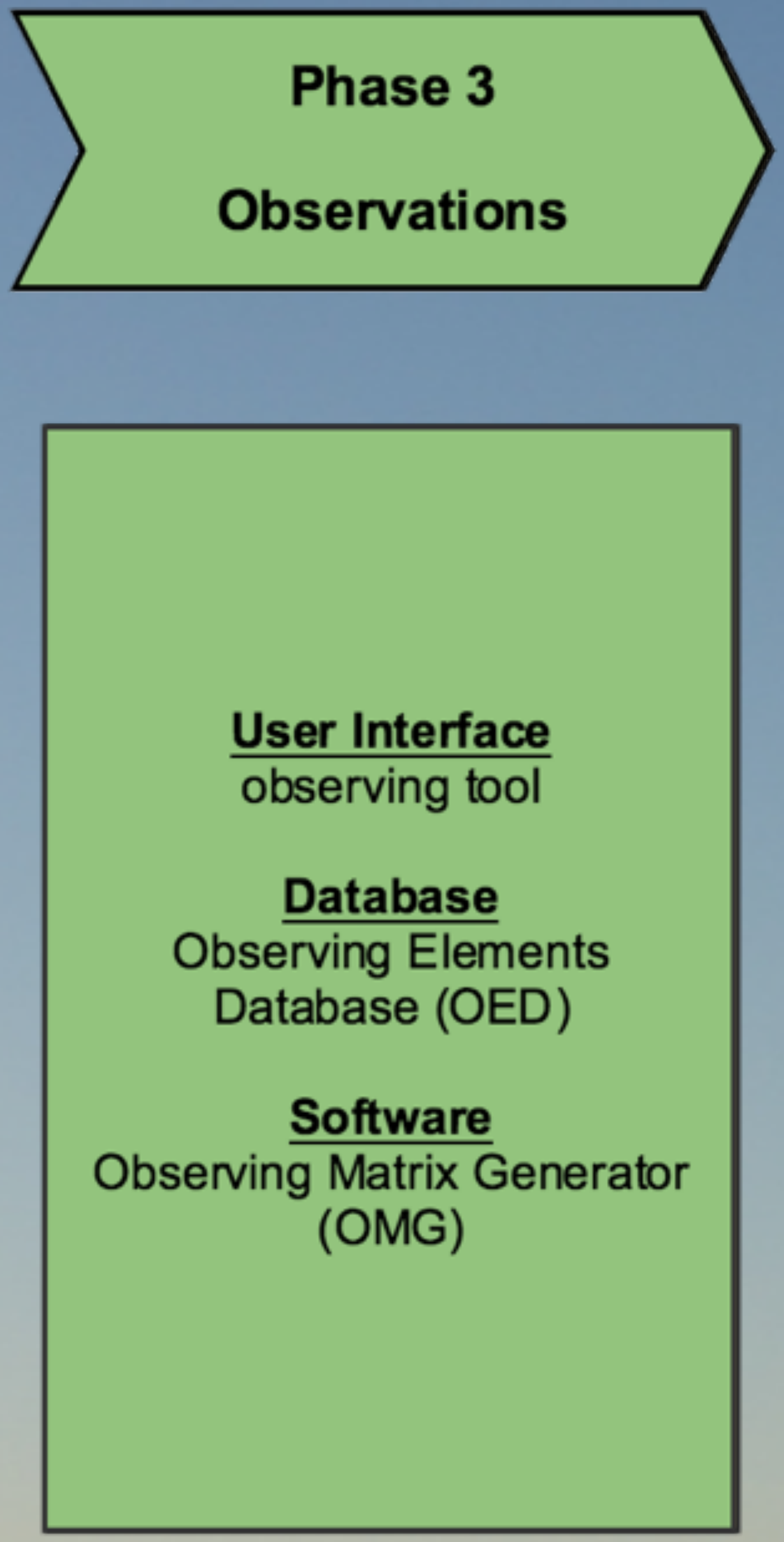
Database
list of proposals, reviews

Software
Exposure Time Calculator (ETC)
Target Allocation Simulator (TAS)

- Phase 1 (proposals):
  - *Large surveys and small programs*
    Long term and short term proposal cycles intertwined
  - *Technical justification will need Exposure Time Calculator (ETC) and Target Allocation Simulator (TAS)*
    ETC - http://etc-dev.cfht.hawaii.edu/mse/
    TAS - http://etc-dev.cfht.hawaii.edu/mse/alloc.html

Maunakea Spectroscopic Explorer

Phases of operations - scheduling



- **Phase 3 (execution)**
  - ***Autonomous software*** *optimizing the sequence of OMs, with possible human supervision*
  - ***Very complex optimization*** *(millions of targets to chose from, 4000+ fibers, two different types of spectrographs) with many constraints (priorities, weather, …)*
- **Phase 4 (validation/reduction)**
  - *Autonomous software reducing spectra and assessing quality of data*
  - ***Real-time feedback*** *to scheduler*

Maunakea Spectroscopic Explorer

Phases of operations – data output

Phase 5

Distribution

User interface
API + website

Database
Science Products Archive (SPA)

- Phase 5 (distribution):
  - *Large amount of data to save (science, environmental, and engineering)*
  - *Data access policy currently being defined by MSE "Board"*

Level 0 – Raw data

Format: 2D
Responsibility: MSE
Content: science data; cal data
Access: MSE (immediate); Survey team (immediate); Other (later)
Multiple release: No

Level 1 – Nighttime release

Format: 2D +1D
Responsibility: MSE
Content: reduced images; nighttime calibrated spectra
Access: MSE (immediate); Survey team (immediate); Other (later)
Multiple release: possible

Level 2 – Daytime release

Format: 2D + 1D
Responsibility: MSE
Content: daytime calibrated spectra; stitched/stacked spectra; basic homogeneous science
Access: MSE (immediate); Survey team (immediate); Other (later)
Multiple release: yes

Level 3 – Survey release

Format: 2D + 1D
Responsibility: Survey teams
Content: spectra; catalog; detailed science; ...
Access: MSE (immediate); Survey team (immediate); Other (later)

Level 4 – Community release

Format: TBD
Responsibility: community
Content: spectra; catalog; detailed science; ...
Access: all (immediate)

Homogeneous, MSE

Amount of Data Produced

- Each observation will produce
  - *3,249 targets x 4 arms = 12,996 spectra at low/moderate resolution*
  - *1,083 targets x 3 arms = 3,249 spectra at high resolution*
  - *16,245 spectra per observation (1 hour typically)*

- Total exposure time per night (average): 6.42 hours (see later how we arrive to that number)
  - *> 100,000 spectra per night*
  - ***> 38,000,000 spectra per year (or > 10,000,000 fiber-hours)***

+ reduced data, added science value, ...

Phases of operations – data output

Phase 5

Distribution

User interface
API + website

Database
Science Products Archive (SPA)

- Phase 5 (distribution):
  - *Ease of access for millions of individual spectra (one per spectrograph arm) and millions of stitched/stacked spectra with added science information*
  - *Allows for cross matching with other catalogs from surveys (LSST, SKA, Euclid, …) and other (TMT, ELT, GMT, …)*
  - *Allows community to interact with the archive and improve it*
  - *NOAO Data Lab: “The goal of the Data Lab is to provide infrastructure and an environment to maximize community use of the high-value survey datasets now being collected with NOAO and other telescopes and instruments.”*

Calibrations & Observing Efficiency

- Calibration (strategy, hardware, software) is a critical topic for a fiber fed spectroscopic facility, but it can be done and we are not alone!
- At this stage, we prepare for the worst and hope for the best
- Combination of daytime, twilight, and nighttime calibration exposures
  - *Lamp calibrations taken before and after every science exposure, with telescope in exact configuration (including environment) as for science exposures*

- Weather losses at CFHT: 10.2 hours night duration – 2.2 hours lost to weather = 8.0 hours available
- Other losses (technical failures, engineering tests, …): 240 hours / years
  → 6.42 hours per night for science photons
- MSE will reach **80% observing efficiency** if typical science observations duration is **44 minutes**

Maunakea Spectroscopic Explorer

PARTNERSHIP, COST, SCHEDULE

Maunakea Spectroscopic Explorer

Preliminary Design Phase

CURRENT MSE PARTICIPANTS

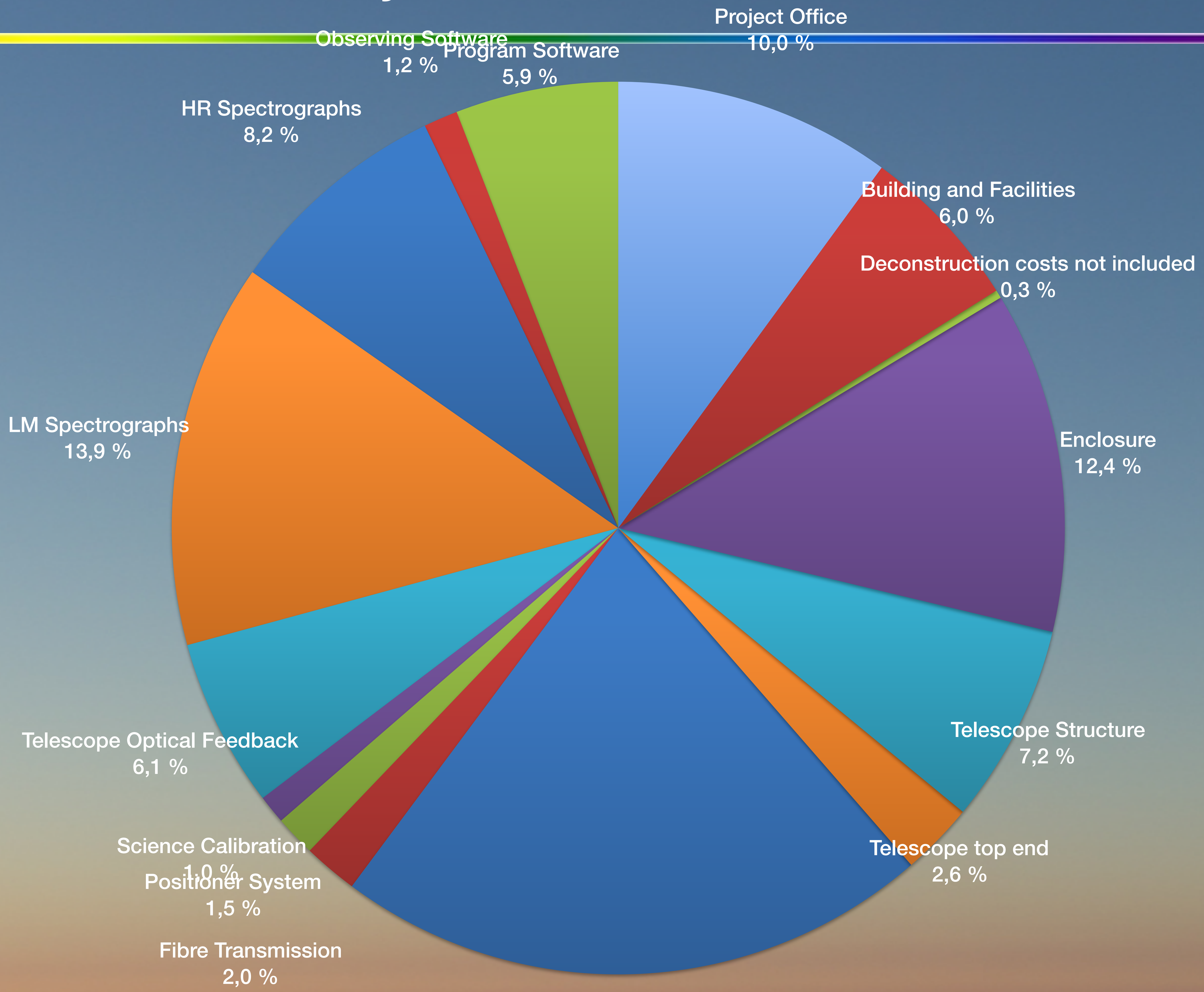
- The PDP starts in 2019 with participants:
  - Australian Astronomical Optics (AAO) Macquarie
  - National Research Council (NRC) of Canada
  - National Astronomical Observatories (NAOC), Chinese Academy of Sciences
  - Centre National de la Recherche Scientifique (CNRS) of France
  - Institute for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

Project Cost Estimate

- Risk Adjusted Construction Cost of $424M
- Base year 2017

- The PDP cost is estimated to be $25M
- $13M of in-kind contributions have been identified.

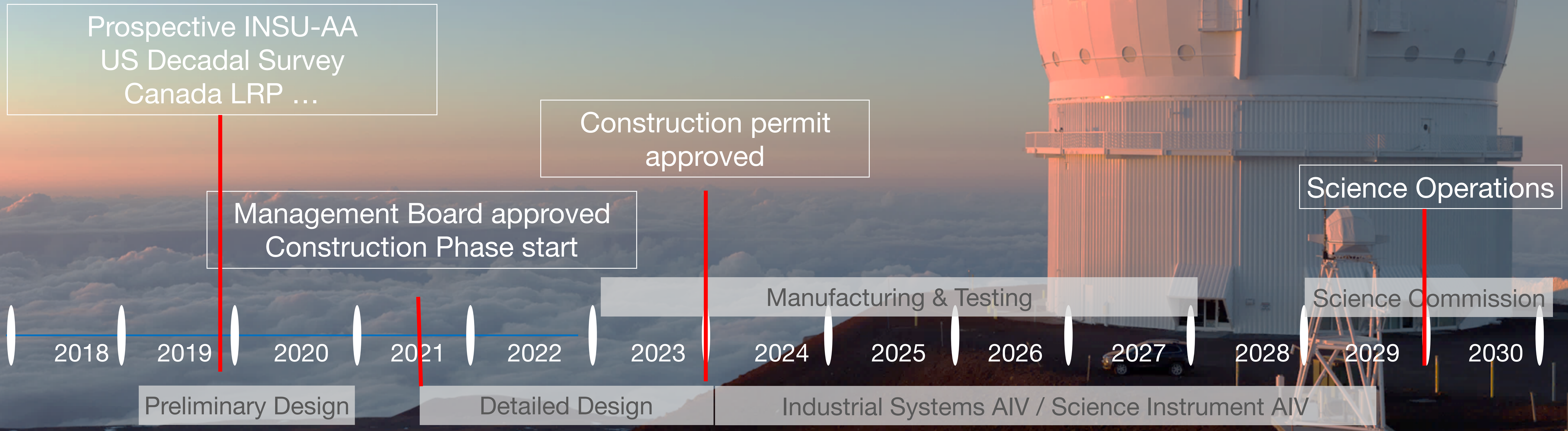
- About $9M invested in CoDP



Project Timeline Estimate

Maunakea Spectroscopic Explorer

Science commission will begin in 2029



Maunakea Spectroscopic Explorer

Summary & Acknowledgement

Accessible sky	30000 square degrees (airmass<1.55)						
Aperture (M1 in m)	11.25m						
Field of view (square degrees)	1.5						
Etendue = FoV x π (M1 / 2)^2	149						
Modes	**Low**		**Moderate**	**High**			**IFU**
Wavelength range	0.36 - 1.8 µm		0.36 - 0.95 µm	0.36 - 0.95 µm #			IFU capable; anticipated second generation capability
	0.36 - 0.95 µm	J, H bands		0.36 - 0.45 µm	0.45 - 0.60 µm	0.60 - 0.95 µm	
Spectral resolutions	2500 *(3000)*	3000 *(5000)*	6000	40000	40000	20000	
Multiplexing	>3200		>3200	>1000			
Spectral windows	Full		≈Half	$\lambda_c/30$	$\lambda_c/30$	$\lambda_c/15$	
Sensitivity	m=24 *		m=23.5 *	m=20.0 ♮			
Velocity precision	20 km/s ♪		9 km/s ♪	< 100 m/s ★			
Spectrophotometic accuracy	< 3 % relative		< 3 % relative	N/A			

♯ Dichroic positions are approximate

* SNR/resolution element = 2

♪ SNR/resolution element = 5

♮ SNR/resolution element = 10

★ SNR/resolution element = 30

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.

SPIROU

Maunakea Spectroscopic Explorer

SPIROU

- Spirou is the most recent instrument commissioned at CFHT
  - *A very precise high spectral resolution near-IR spectro-polarimeter*
  - *The best planet-finder on Earth!*
- Spirou Legacy Survey (SLS) just started after successful instrument acceptance review in January
- SLS and other Spirou programs require 100s of night at CFHT, which is consistent with MSE timeline
- Ideas about reusing Spirou beyond CFHT decommissioning