Maunakea Spectroscopic Explorer

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LORCA workshop
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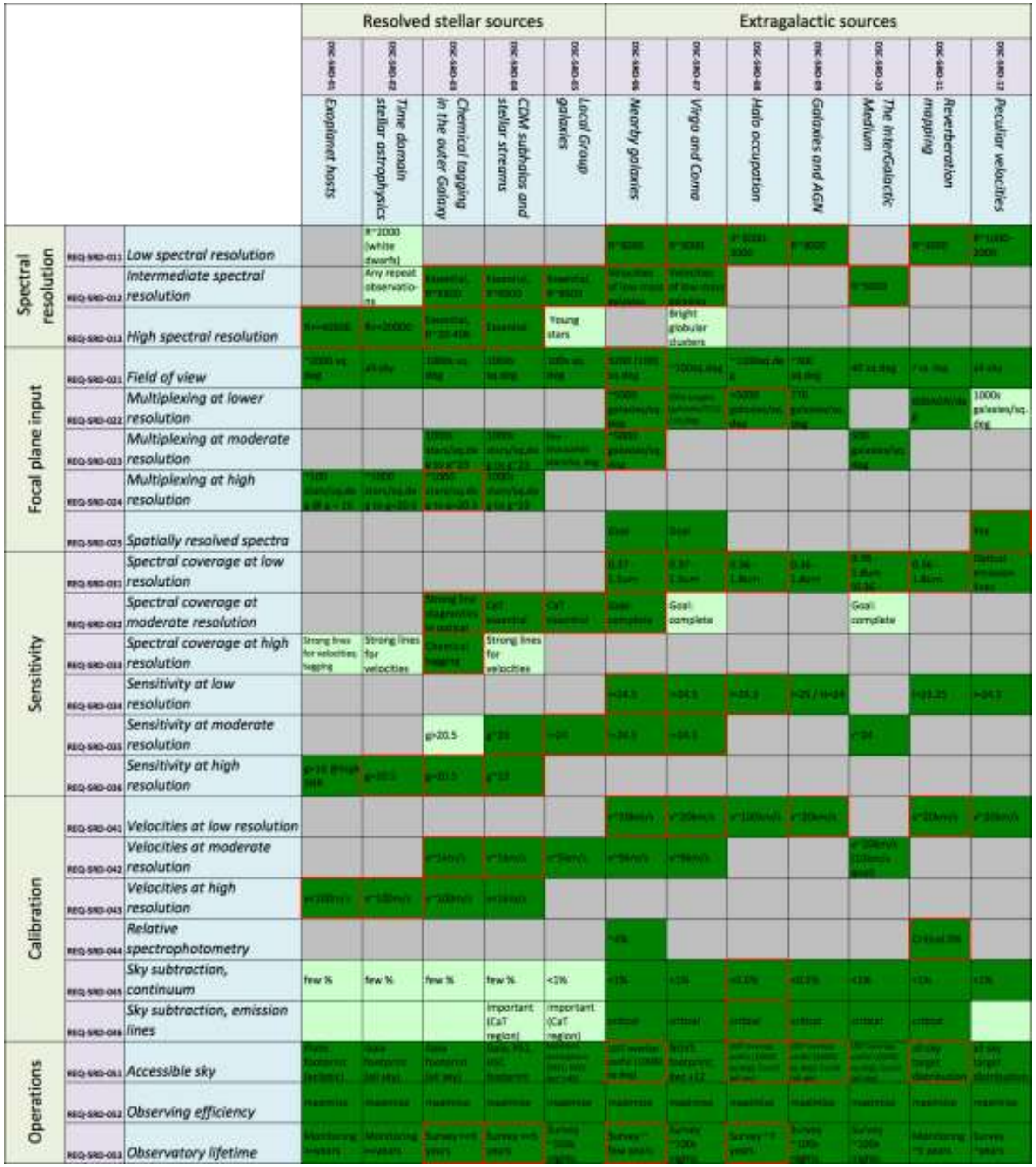
Science matrix

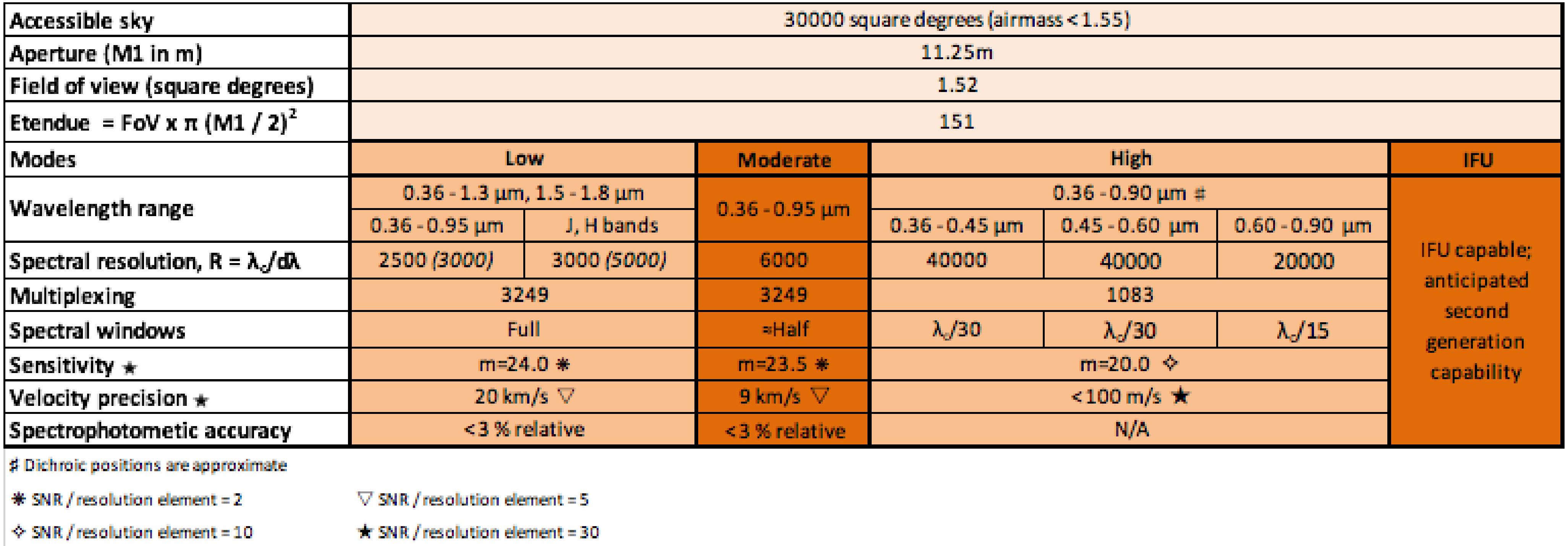
- PlaTO follow-up: host star characterisation
- Gaia follow-up: high resolution observations for all stars
- Dark matter: radial velocities of numerous faint targets
- Galaxy formation and evolution up to high z
- Transient follow-up over long durations
- Reverberation mapping



			Resolved stellar sources					Extragalactic sources						
			DSC-SRD-01	DSC-SRD-02	DSC-SRD-03	DSC-SRD-04	DSC-SRD-05	DSC-SRD-06	DSC-SRD-07	DSC-SRD-08	DSC-SRD-09	DSC-SRD-10	DSC-SRD-11	DSC-SRD-12
			Exoplanet hosts	Time domain stellar astrophysics	Chemical tagging in the outer Galaxy	CDM subhalos and stellar streams	Local Group galaxies	Nearby galaxies	Virgo and Coma	Halo occupation	Galaxies and AGN	The InterGalactic Medium	Reverberation mapping	Peculiar velocities
Spectral resolution	REQ-SRD-011	Low spectral resolution		R~2000 (white dwarfs)				[illegible]	[illegible]	[illegible]	[illegible]		[illegible]	[illegible]
	REQ-SRD-012	Intermediate spectral resolution		Any repeat observatio-ns	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]			[illegible]		
	REQ-SRD-013	High spectral resolution	[illegible]	[illegible]	[illegible]	[illegible]	Young stars		Bright globular clusters					
Focal plane input	REQ-SRD-021	Field of view	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
	REQ-SRD-022	Multiplexing at lower resolution						[illegible]	[illegible]	[illegible]	[illegible]		[illegible]	1000s galaxies/sq. deg
	REQ-SRD-023	Multiplexing at moderate resolution			[illegible]	[illegible]	[illegible]	[illegible]				[illegible]		
	REQ-SRD-024	Multiplexing at high resolution	[illegible]	[illegible]	[illegible]	[illegible]								
	REQ-SRD-025	Spatially resolved spectra						[illegible]	[illegible]					[illegible]
Sensitivity	REQ-SRD-031	Spectral coverage at low resolution						[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
	REQ-SRD-032	Spectral coverage at moderate resolution			[illegible]	[illegible]	[illegible]	[illegible]	Goal: complete			Goal: complete		
	REQ-SRD-033	Spectral coverage at high resolution	Strong lines for velocities, tagging	Strong lines for velocities	[illegible]	Strong lines for velocities								
	REQ-SRD-034	Sensitivity at low resolution						[illegible]	[illegible]	[illegible]	[illegible]		[illegible]	[illegible]
	REQ-SRD-035	Sensitivity at moderate resolution			g>20.5	[illegible]	[illegible]	[illegible]	[illegible]			[illegible]		
	REQ-SRD-036	Sensitivity at high resolution	[illegible]	[illegible]	[illegible]	[illegible]								
Calibration	REQ-SRD-041	Velocities at low resolution						[illegible]	[illegible]	[illegible]	[illegible]		[illegible]	[illegible]
	REQ-SRD-042	Velocities at moderate resolution			[illegible]	[illegible]	[illegible]	[illegible]	[illegible]			[illegible]		
	REQ-SRD-043	Velocities at high resolution	[illegible]	[illegible]	[illegible]	[illegible]								
	REQ-SRD-044	Relative spectrophotometry						[illegible]					[illegible]	
	REQ-SRD-045	Sky subtraction, continuum	few %	few %	few %	few %	<1%	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
	REQ-SRD-046	Sky subtraction, emission lines				important (CaT region)	important (CaT region)	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	
Operations	REQ-SRD-051	Accessible sky	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
	REQ-SRD-052	Observing efficiency	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
	REQ-SRD-053	Observatory lifetime	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

Maunakea Spectroscopic Explorer

MSE Key Capabilities



Accessible sky	30000 square degrees (airmass < 1.55)						
Aperture (M1 in m)	11.25m						
Field of view (square degrees)	1.52						
Etendue = FoV x π (M1 / 2)^2	151						
Modes	Low		Moderate	High			IFU
Wavelength range	0.36 - 1.3 μm, 1.5 - 1.8 μm		0.36 - 0.95 μm	0.36 - 0.90 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 - 0.90 μm	
Spectral resolution, R = $\lambda_c/d\lambda$	2500 *(3000)*	3000 *(5000)*	6000	40000	40000	20000	
Multiplexing	3249		3249	1083			
Spectral windows	Full		≈Half	$\lambda_c/30$	$\lambda_c/30$	$\lambda_c/15$	
Sensitivity ★	m=24.0 ✱		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			

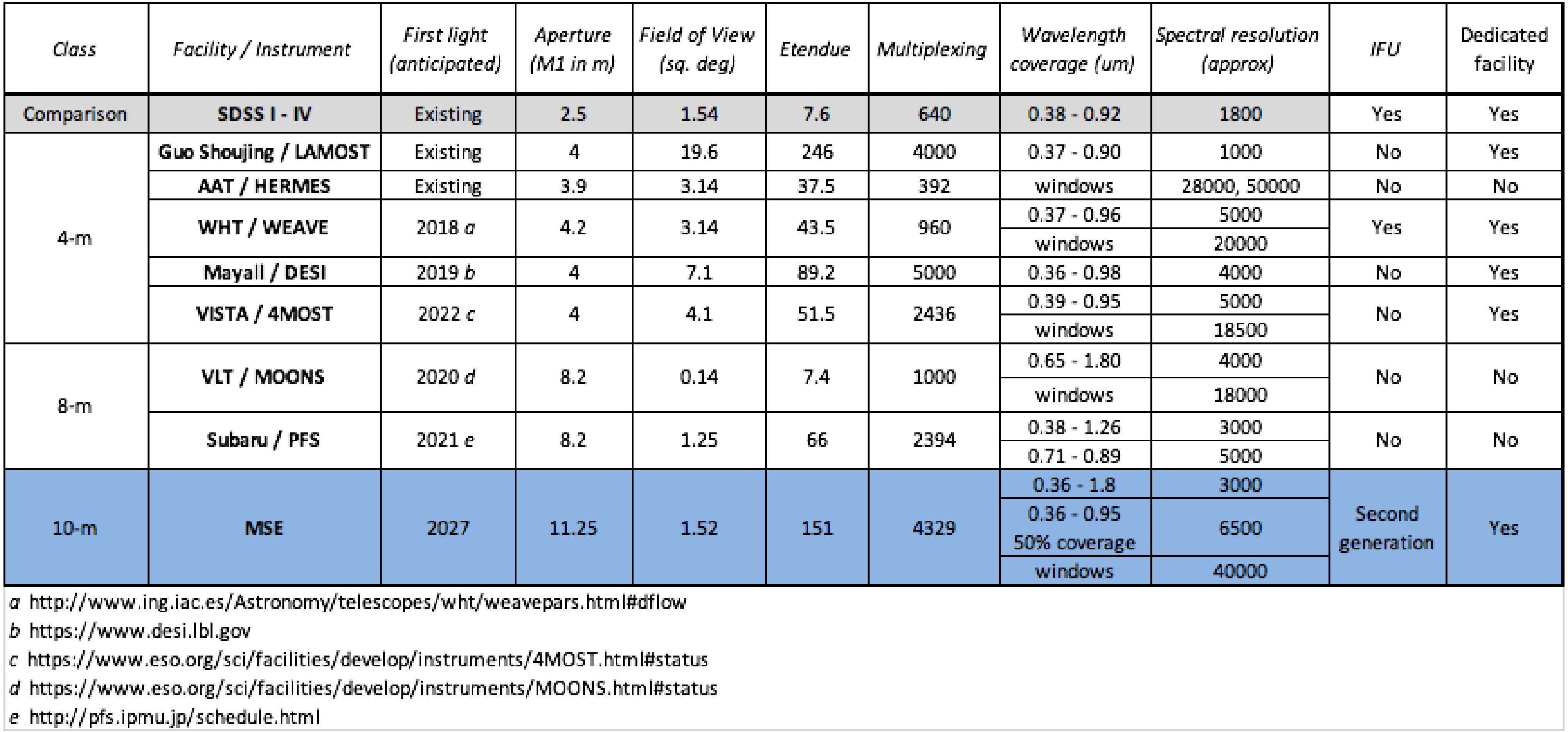
♯ Dichroic positions are approximate

✱ SNR / resolution element = 2 ▽ SNR / resolution element = 5

✧ SNR / resolution element = 10 ★ SNR / resolution element = 30

- Survey speed: 11.25m primary, >4300 fibres, dedicated telescope
- Spectral performance:
  - simultaneous low & high resolution
  - switching low & moderate resolution, switching J & H band
  - dedicated to spectroscopic surveys: stability, homogeneous databases

International WF-MOS

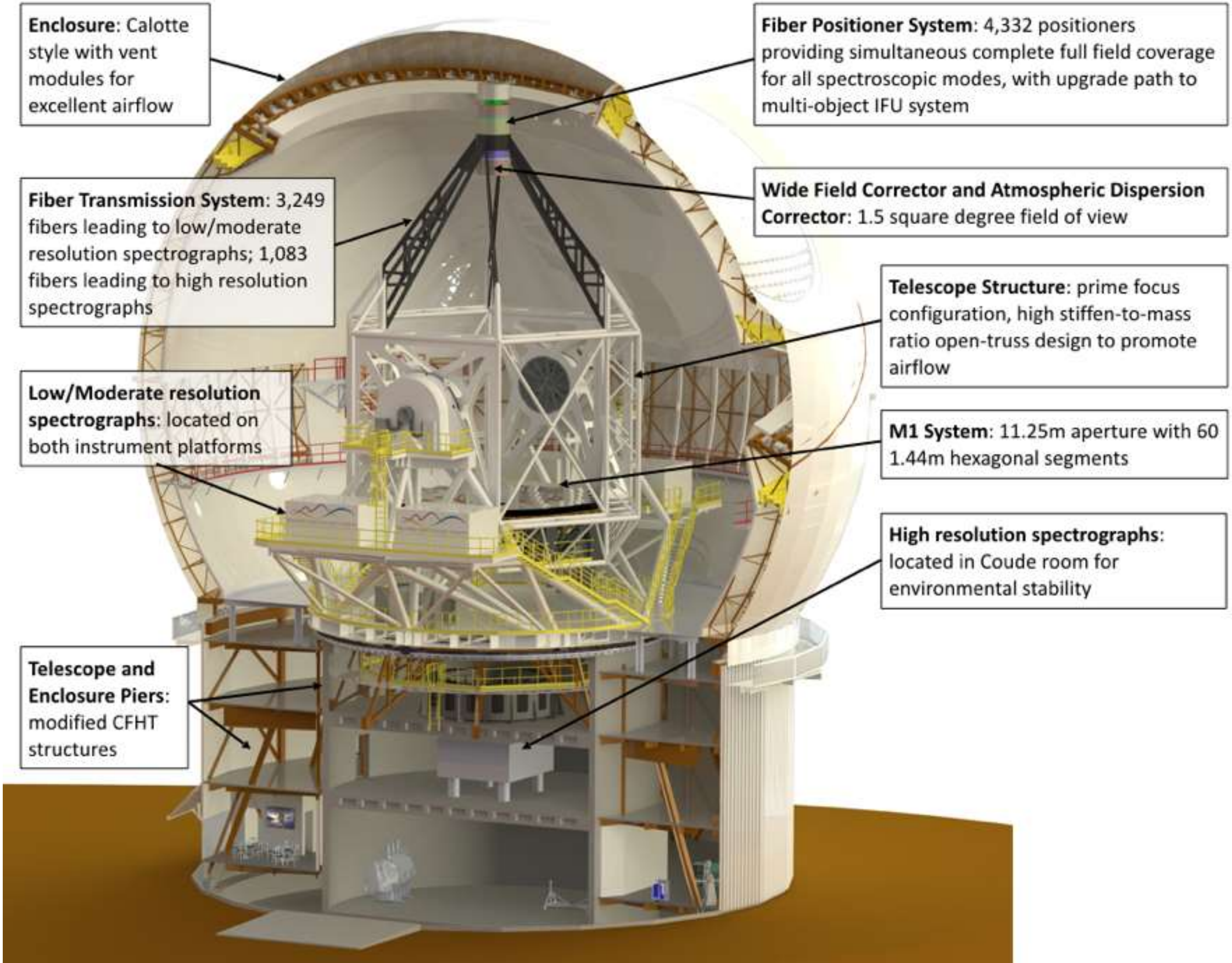


Class	*Facility / Instrument*	*First light (anticipated)*	*Aperture (M1 in m)*	*Field of View (sq. deg)*	*Etendue*	*Multiplexing*	*Wavelength coverage (um)*	*Spectral resolution (approx)*	*IFU*	Dedicated facility
Comparison	**SDSS I - IV**	Existing	2.5	1.54	7.6	640	0.38 - 0.92	1800	Yes	Yes
4-m	**Guo Shoujing / LAMOST**	Existing	4	19.6	246	4000	0.37 - 0.90	1000	No	Yes
	AAT / HERMES	Existing	3.9	3.14	37.5	392	windows	28000, 50000	No	No
	WHT / WEAVE	2018 *a*	4.2	3.14	43.5	960	0.37 - 0.96	5000	Yes	Yes
							windows	20000		
	Mayall / DESI	2019 *b*	4	7.1	89.2	5000	0.36 - 0.98	4000	No	Yes
	VISTA / 4MOST	2022 *c*	4	4.1	51.5	2436	0.39 - 0.95	5000	No	Yes
							windows	18500		
8-m	**VLT / MOONS**	2020 *d*	8.2	0.14	7.4	1000	0.65 - 1.80	4000	No	No
							windows	18000		
	Subaru / PFS	2021 *e*	8.2	1.25	66	2394	0.38 - 1.26	3000	No	No
							0.71 - 0.89	5000		
10-m	**MSE**	2027	11.25	1.52	151	4329	0.36 - 1.8	3000	Second generation	Yes
							0.36 - 0.95 50% coverage	6500		
							windows	40000		

a http://www.ing.iac.es/Astronomy/telescopes/wht/weavepars.html#dflow
b https://www.desi.lbl.gov
c https://www.eso.org/sci/facilities/develop/instruments/4MOST.html#status
d https://www.eso.org/sci/facilities/develop/instruments/MOONS.html#status
e http://pfs.ipmu.jp/schedule.html

Also **ESO SpecTel** concept (Ellis et al. 2017); Working Group report; no detailed requirements or design available for comparison (WG recommends 10-12m class telescope, ~5 square degree field of view, ~5000 fibres, possible deployable IFUs)

Facility transformation



Enclosure: Calotte style with vent modules for excellent airflow

Fiber Positioner System: 4,332 positioners providing simultaneous complete full field coverage for all spectroscopic modes, with upgrade path to multi-object IFU system

Fiber Transmission System: 3,249 fibers leading to low/moderate resolution spectrographs; 1,083 fibers leading to high resolution spectrographs

Wide Field Corrector and Atmospheric Dispersion Corrector: 1.5 square degree field of view

Telescope Structure: prime focus configuration, high stiffen-to-mass ratio open-truss design to promote airflow

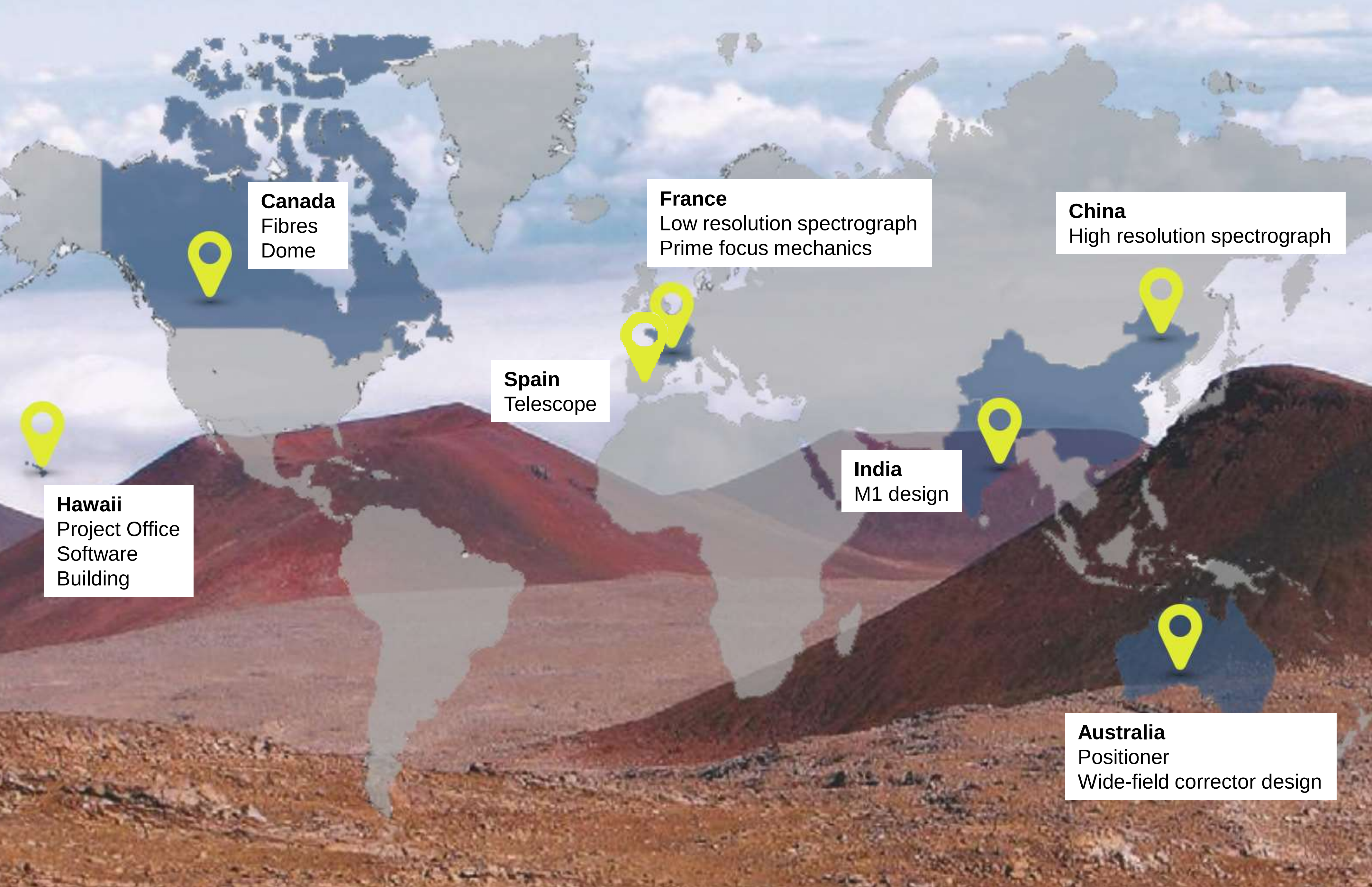
Low/Moderate resolution spectrographs: located on both instrument platforms

M1 System: 11.25m aperture with 60 1.44m hexagonal segments

High resolution spectrographs: located in Coude room for environmental stability

Telescope and Enclosure Piers: modified CFHT structures

The MSE Team



Canada
Fibres
Dome

France
Low resolution spectrograph
Prime focus mechanics

China
High resolution spectrograph

Spain
Telescope

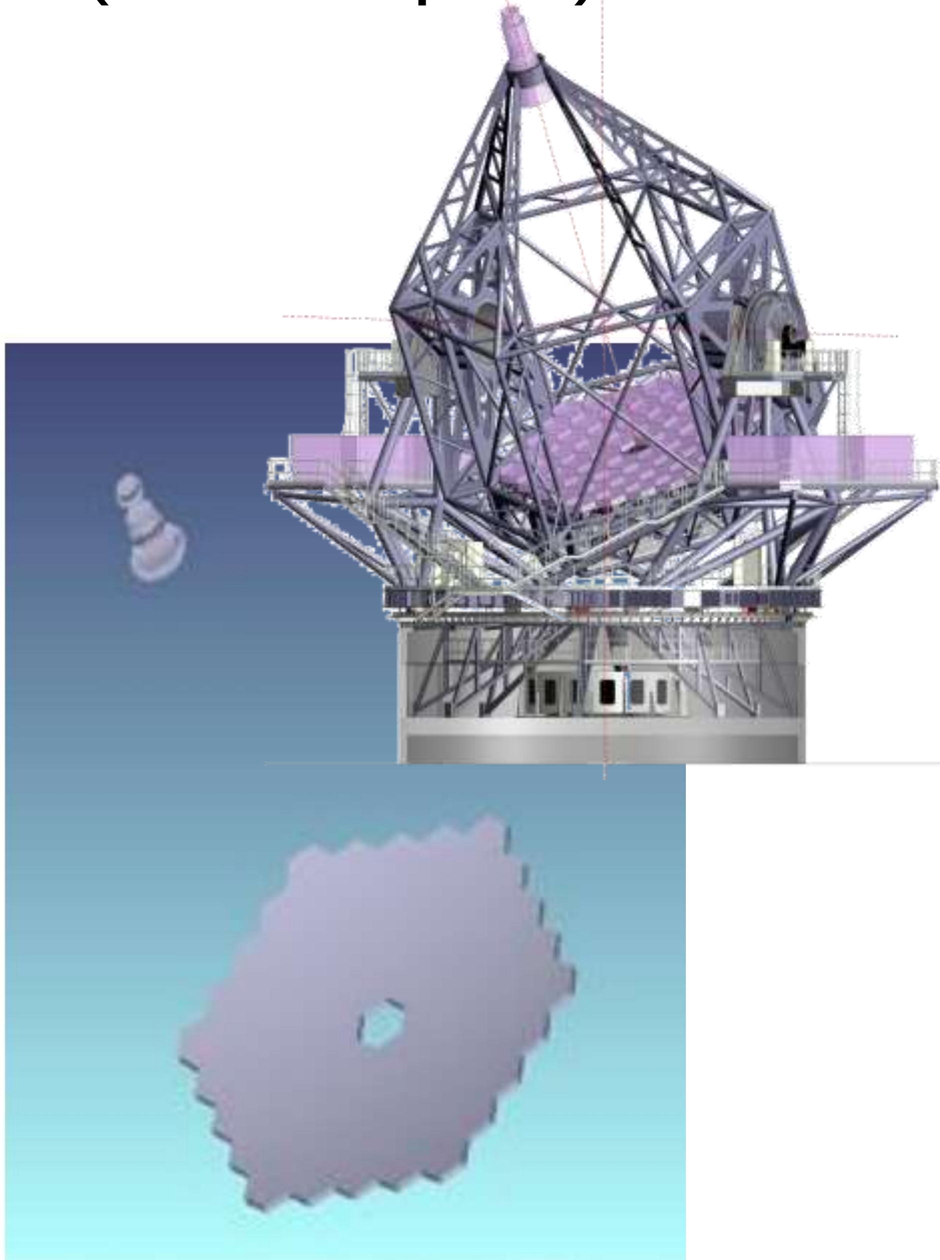
India
M1 design

Hawaii
Project Office
Software
Building

Australia
Positioner
Wide-field corrector design

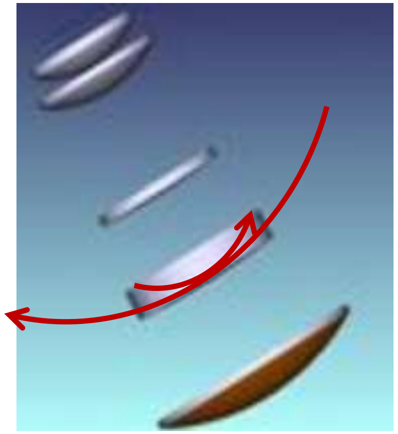
Telescope (IDOM Spain)

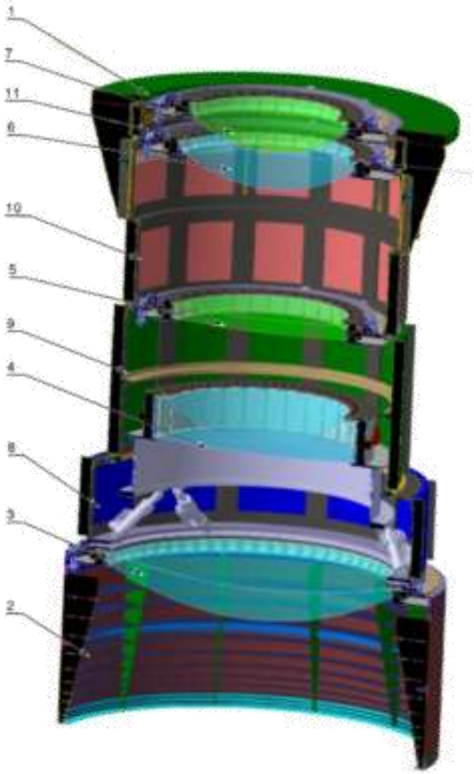
- Segmented primary mirror
  - 60 hexagonal segments
  - 1.44m corner-to-corner (similar to TMT and E-ELT to reuse existing facilities)
  - diameter 11.25m
- Fits inside the upgraded enclosure
  - focal length 18.845m
  - current observing floor removed
  - 10% size increase of the dome
- Prime focus for large field of view
- Instrument platforms due to alt-azimuthal mount
- Yoke concept rather than rocking chair due to stiffness/mass trade-off

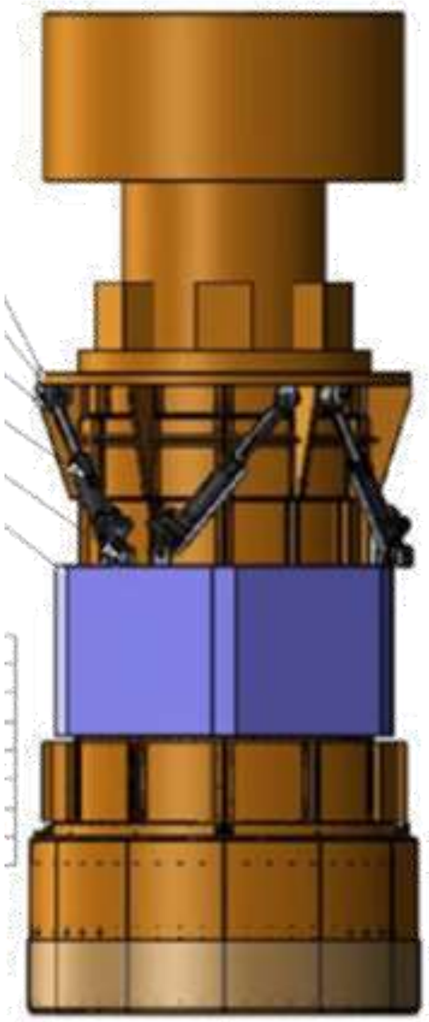


Top end assembly (AAO & DT INSU)

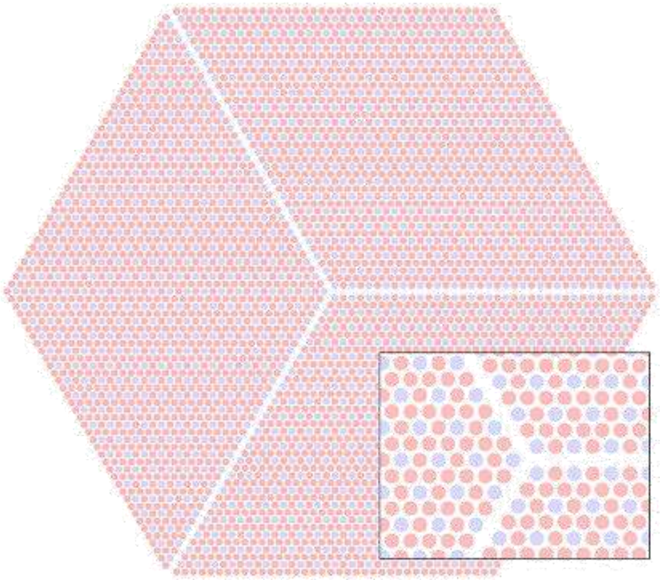
- Includes
  - wide-field corrector optics
  - wide-field corrector positioning
  - fibre positioner and electronics
  - field derotator
- Novel approach to ADC to increase the throughput (reduce the number of optics)
  - shift L2
  - shift all other optics in the other direction
  - translate all the other optics
- Concept design
  - based on spacers to meet the wide range of positions to align optics
  - includes 2 hexapods
    - to move L2
    - to move the whole top end

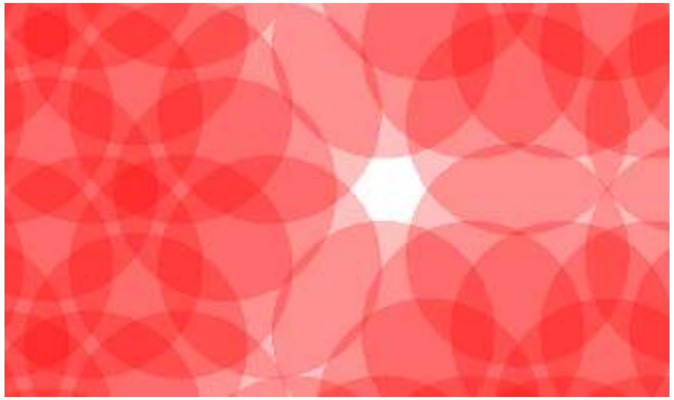


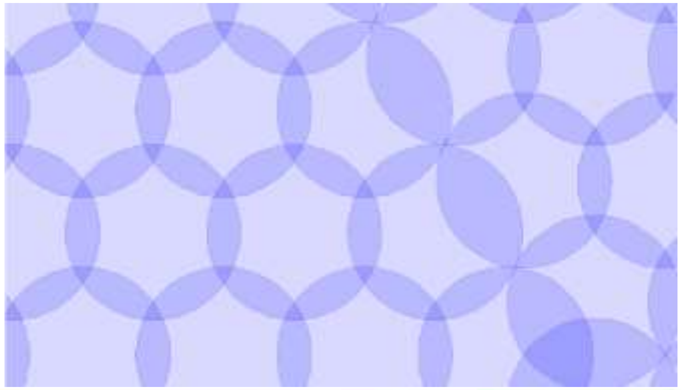




Positioner (AAO)





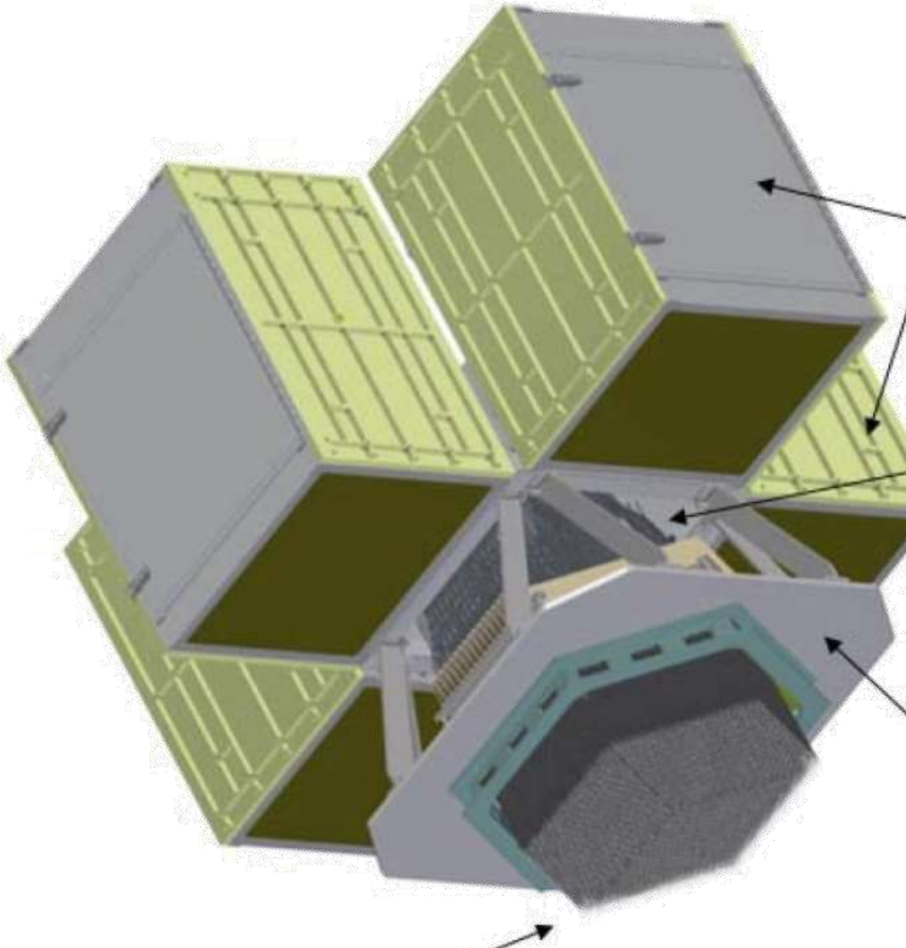


- Sphinx
  - based on Echidna concept
  - longer spines (reduced geometric FRD)
  - reduced thermal emission (lower voltages)
  - 57 modules arranged in hexagonal shape

- Fibre arrangement
  - 2 HR / 5 LMR
  - patrol radius 1.2×pitch
  - coverage HR/LMR is:
    - 1 fibre 100%/100% (complete coverage)
    - 2 fibres 58%/100%
    - 3 fibres: 4%/97%
  - high allocation efficiency

- Works with metrology camera located in the centre of M1
  - residual error: 5µm achieved in 5 moves

Positioner (AAO)

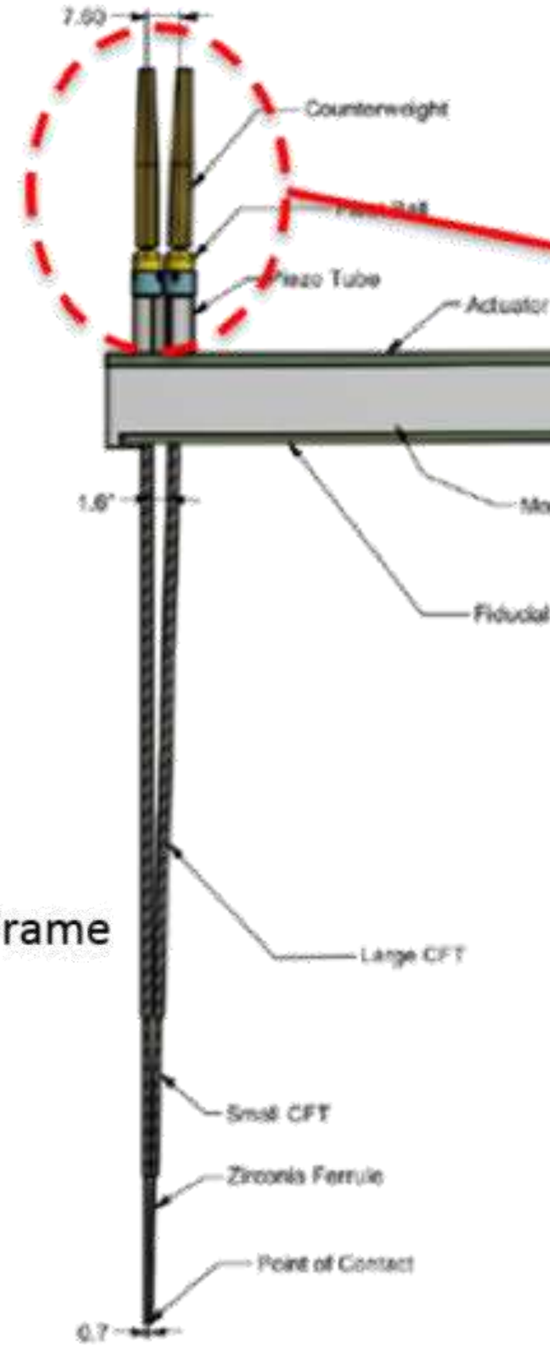


Electronics Cabinets

Electronics Frame

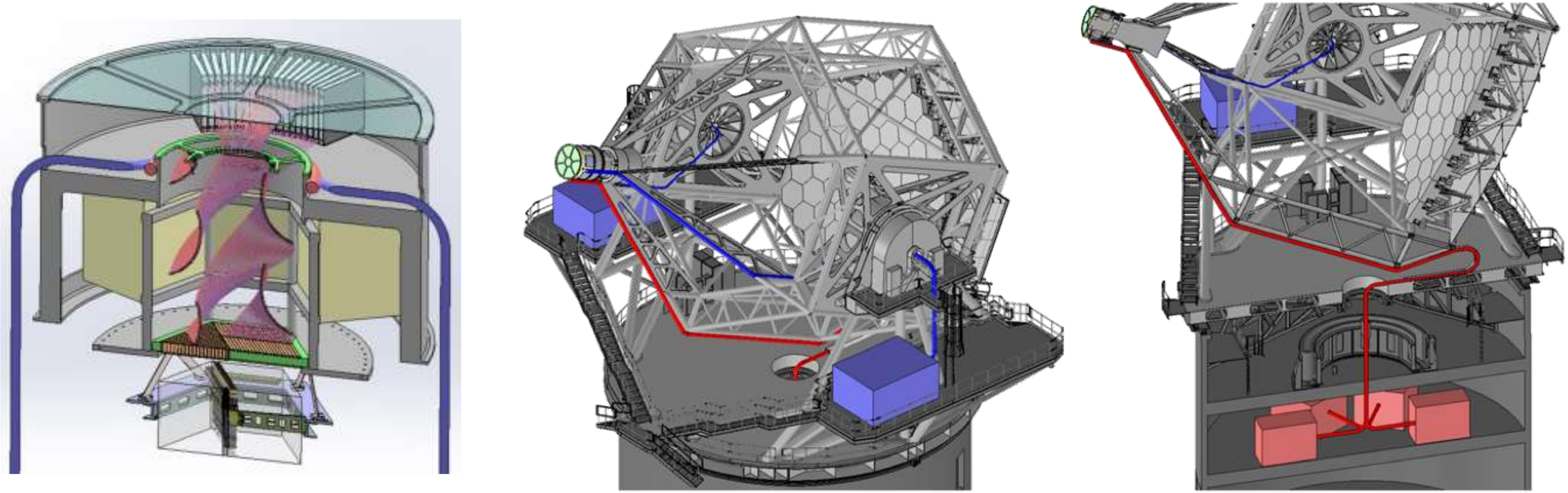
Mount for InRo Interface Frame

Spines



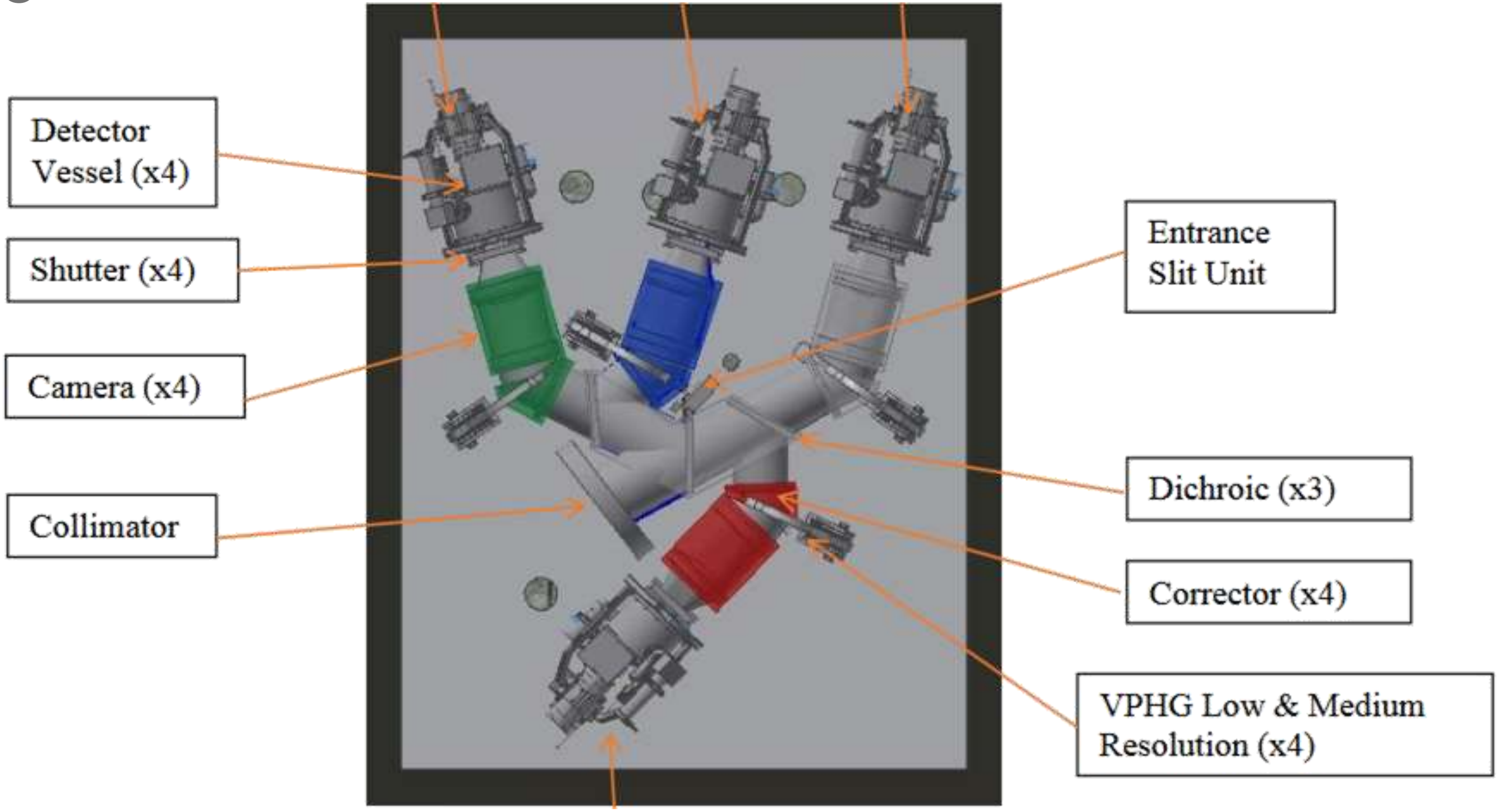
Fibres (NRC & FiberTech Optica)

- Fibres
  - HR: 80µm (0.8”) core, LMR: 100µm (1.0¨) core
  - high NA fibres to avoid f-ratio adaptation: 0.26-0.28 NA to inject at f/2
  - candidate manufacturers: Polymicro, Ceramoptec
- Fibre link geometries
  - no breaks/connectors
  - 57 identical cables (one per Sphinx module) to LR and LMR
  - lengths: 35m to LMR, 50m to HR

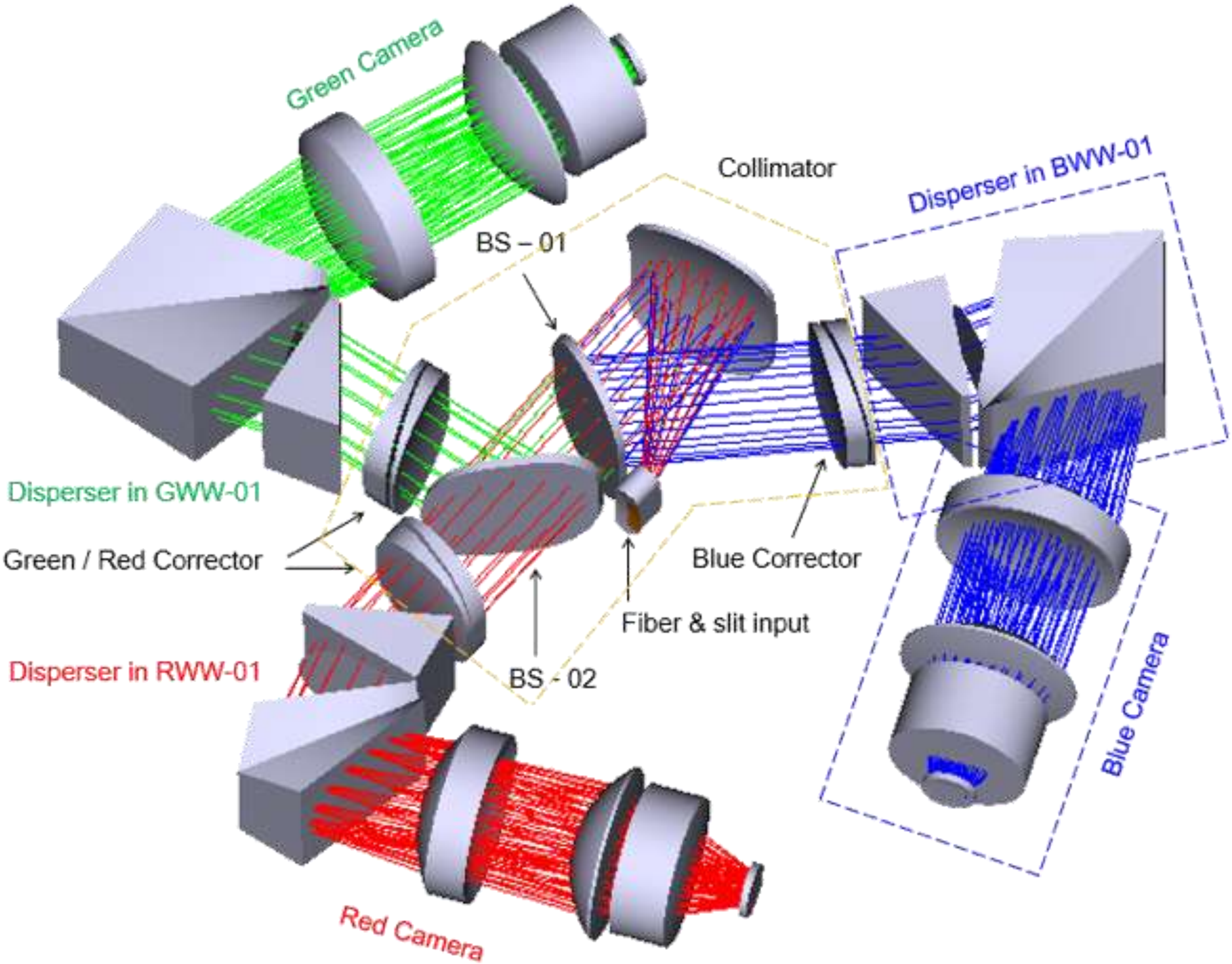


LMR (CRAL & AAO)

- Evolution of the design for Hector (AAO)
- 6 units, 4 arms (3 CCDs, 1 Hawaii4RG)
- Low/moderate switching by exchanging VPHs with grisms
- J/H band switching by exchanging gratings
- Cooled to -63°C



HR (NIAOT)


Green Camera
Collimator
Disperser in BWW-01
BS – 01
Disperser in GWW-01
Green / Red Corrector
Blue Corrector
Fiber & slit input
Disperser in RWW-01
BS - 02
Blue Camera
Red Camera

HR (NIAOT)

- Challenging due to resolution and étendue

- Resolution (3-arm design)

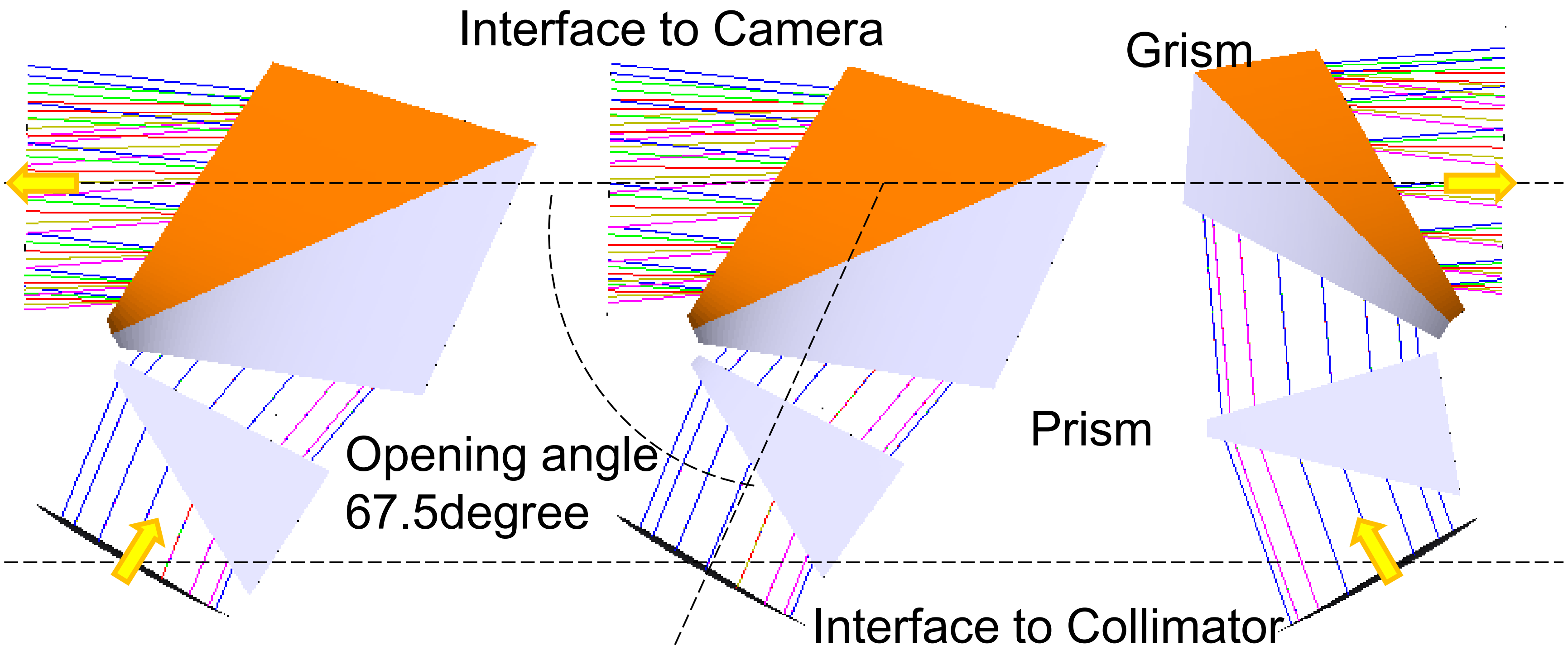
  - 40 000: 401-416nm & 472-490nm
  - 20 000: 626-675nm

- Multiplex: 542 (2 units)

- Optical design
  - driven by feasibility of dispersive elements
  - constrained by injection at f/2 in fibres
  - all channels optimised independently (corrector, disperser, camera)
  - 300mm beams
  - Off-axis f/2.05 collimator
  - f/1.55 transmissive cameras with 3 highly aspheric surfaces
  - 6.2-pixel sampling (10µm pixels)

HR (NIAOT)

- Dispersive element design
  - reduce line density with an immersed grating: grism (design driver)+prism
  - 5700 - 6500 l/mm
  - 300mm beam
  - grating technology: VPH or ion-beam etching



(a) Blue channel (b) Green channel (c) Red channel

Project Status

2010: Launch of ngCFHT study
2014: Creation of MSE Project Office
2015 — 2017: Major subsystem conceptual design studies
2017: 10 subsystem conceptual design reviews
2018: System-level requirement and conceptual design review
Transition to preliminary design phase

- looking for a new project scientist (in Hawaii)
- making the science team and consortium grow
- collecting funds
- open to new collaborators for:
  - LMR
  - M1 design
  - software
  - top-end assembly

ACKNOWLEDGEMENTS

The Maunakea Spectroscopic Explorer (MSE) conceptual design phase was conducted by the MSE Project Office, which is hosted by the Canada-France-Hawaii Telescope. 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.