Conceptual design of the MOBIE spectrograph for TMT

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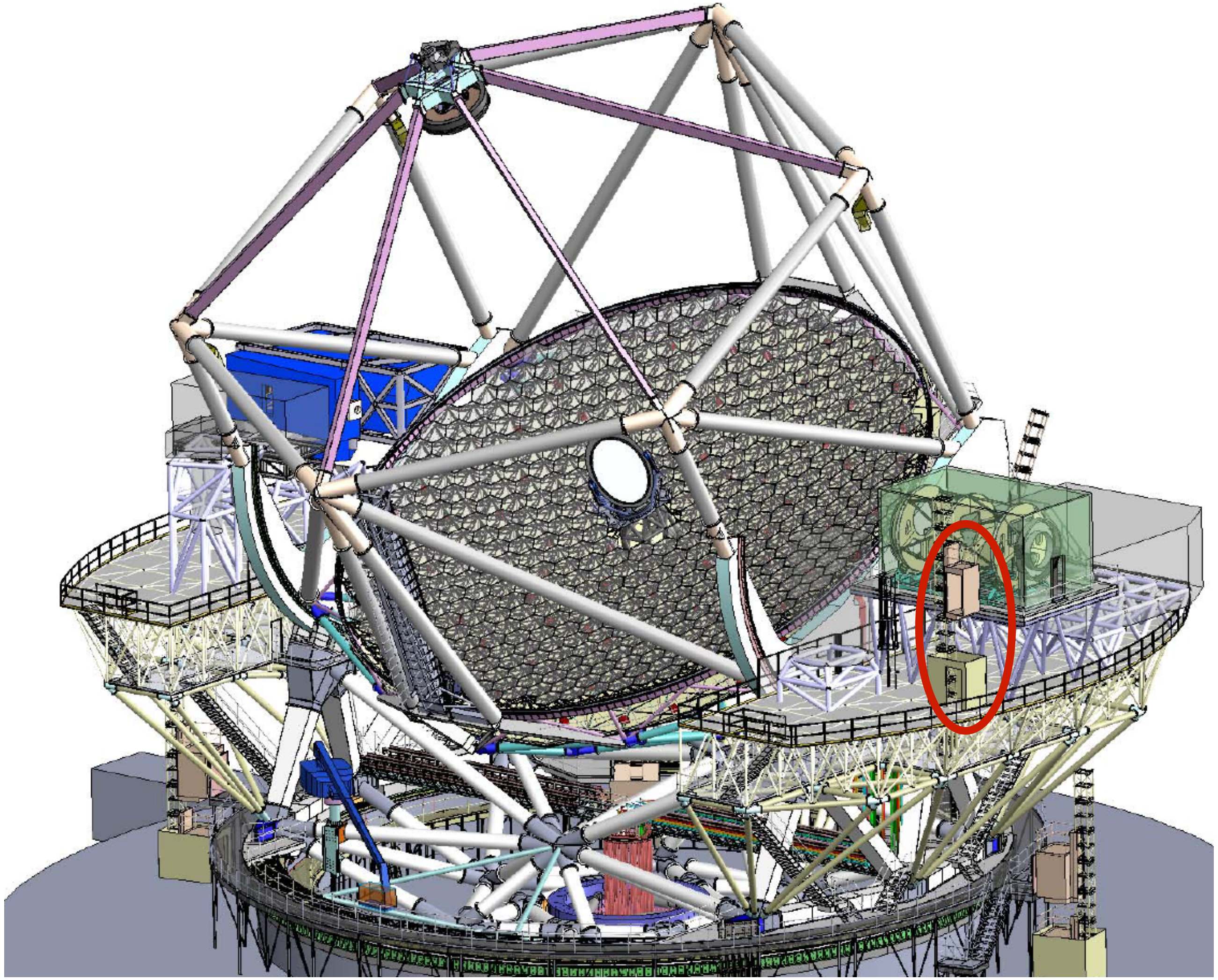
University of California Observatories Santa Cruz

TMT Science Forum
Tucson Az. July 17-19 2014

MOBIE on TMT



Overview of this talk:

- MOBIE Conceptual Design Phase (CDP) science and design teams
- MOBIE project key contributors (consultants and vendors)
- TMT WFOS requirements and MOBIE design parameters
- Project history
- Instrument design goals
- Instrument optical design summary
- Instrument subsystem designs and status
- Conclusions and next steps

MOBIE CoD Team (Today)
MOBIE CoD Team (10/2013)

- Rebecca Bernstein, Principal Investigator and Optical Designer
- Chuck Steidel, Project Scientist/ Interim Principal Investigator
- Bruce Bigelow, Project Manager and Systems Engineering
- Matt Radovan, Instrument Specialist (Jan. 2013),Interim PM & SE
- Nick Konidaris, Optical Designer

- University of California:
  - Terry Mast, UCO, error analysis and budgets
  - Matt Radovan, UCO, mechanics and opto-mechanics
- National Astronomical Observatory of Japan:
  - Satoshi Miyazaki, NAOJ, cameras, filter exchangers, shutters
  - Shinobu Ozaki, NAOJ, cameras, filter exchangers, shutters
- China:
  - Zhongwen Hu, NAIOT, guider/WFS conceptual optical designs
  - Qingfeng Zhu, USTC, guider/WFS detector systems
- University of Hawaii:
  - Peter Onaka, UH-IfA, work package manager, electronic engineering
  - Sidik Isani, UH-IfA, detector control software
  - Hubert Yamada, UH-IfA, instrument control software

MOBIE Science Team (Thru 10/2013)

- Science Team
  - Rebecca Bernstein, UCSC
  - Chuck Steidel, CIT
  - Judy Cohen, CIT
  - Janet Colucci, UCSC
  - Sandy Faber, UCSC
  - Raja Guhathakurta, UCSC
  - Jason X. Prochaska, UCSC
  - Connie Rockosi, UCSC
  - Alice Shapley, UCLA
  - Bob Abraham, U. Toronto
  - Jarle Brinchmann, Leiden
  - Jason Kalirai, STScI
- Science cases and operational concepts described in the MOBIE OCDD
- Functional and performance requirements described in the MOBIE DRD
- Key MOBIE project documents located on the TMT website:
  - http://www.tmt.org/documents

MOBIE CDP Key Contributors

- Consultants:

– Steve Gunnels	Paragon Engineering, Inc. (structures)
– Scott Ellis, Richard Pfisterer	Photon Engineering, Inc. (stray light analyses)
– Mitch Ruda, Tilman Stuhlinger	Ruda Cardinal Inc. (optical engineering)
– Greg Bredthauer	STA Inc. (CCD controller electronics survey)
– Gerry Luppino, Eric Moore	GL Scientific, Inc. (detector systems)
– Eric Smith, Marek Kopolnicki	Lockheed ATC (systems engineering)
– Richard Trissel	Richard Trissel Consulting (SPDT optical test design)

- Vendors:

– ATT, Inc.	Laser tracker metrology design study
– e2v	Detectors and focal plane mosaics
– ITT Excelis, Inc.	Collimator design studies
– L3 – Brashear Inc.	Collimator and camera design studies
– Composite Mirror Applic., Inc.	Collimator design study
– LightWorks, Inc.	Camera design studies
– Saber Engineering, Inc.	Slit mask exchange system design study
– Cox – Ixmation Inc.	“
– Doerfer Engineering, Inc.	“
– Aerotech, Inc., Lintech Inc, THK	Large motion stage design studies
– Optical Solutions Inc.	Single-point diamond turning development (350mm dia.)
– United Lens Company	CaF2 crystal generating

TMT Requirements for a Wide Field Optical Spectrograph (WFOS)

TMT
THIRTY METER TELESCOPE

Extremely ambitious performance goals:

- **None of the 6-10m wide-field spectrographs met these requirements simultaneously.**
  (e.g. LRIS, DEIMOS, IMACS, VMOS, GMOS)
- **Spectrograph field of view & resolution**
  Get harder with telescope diameter!

d=300 mm

$$R = \frac{\lambda}{\delta\lambda} = 2\frac{\tan\delta}{\phi}\frac{d}{D}$$

d/D = spectro beam / primary dia.

δ = blaze angle (grating length)

ϕ = seeing disk = ~1” in the optical

Slit Mask Scale- 2.1mm / arcsec

Description	Requirement
Wavelength	0.31 – 1.0μm
Image quality: Imaging	≤ 0.2 arcsec FWHM in each band
Image quality: Spectroscopy	≤ 0.2 arcsec FWHM at any wavelength
Field of View	40.5 arcmin^2. Multiple fields okay.
Slit Length	≥ 500 arcsec total
Spatial Sampling	< 0.15” per pixel, goal < 0.1”
Spectral Resolution	R = 500-5000 w/ 0.75” slit, (requirement) R = 150-7500 (goal)
Throughput	≥ 30% from 0.31 – 1.0μm, or “similar to best current spectrometers”
Sensitivity	Shot noise limited for > 60s exposures. Background subtraction errors < shot noise 100,000s. Nod and shuffle desirable.
Wavelength Stability	Flexure < 0.15 arcsec at detector

TMT-WFOS Key Requirements Vs. Current MOBIE Design

TMT-WFOS requirements/goals	Realized in MOBIE design
Wavelength range: 0.31 –1.0μm	0.30 – 1.1μm
Field of view: >40 arcmin^2	25 arcmin^2 (~8.3 x 3 arcmin)
Total slit length ≥ 500″	500″ (~8.3 arcmin)
Image quality:	
– fwhm ≤ 0.2″ (imaging), 0.1μm band	< 0.2″
– fwhm <0.2″ (spectro) any λ, no re-focus	< 0.2″ (preserves resolution)
Spectral resolution:	
– 1000< R<5000 for 0.75″ slit	R = ~1000, ~5000, ~8000
– Complete λ-coverage at R~1000	complete or select orders
Throughput ≥ 30% (all λ)	> Est. ~40% down to 0.30μm

FOV Notes:
R~5000 ~6.9 x 3 arcmin (red and blue)
R~8000 ~3 x 3 arcmin (red) & 4.5 x 3 (blue)

MOBIE Project History

- **Feasibility Study:**
  - May 2008 – Dec 2008 (8 mo.) – Optical design and fabrication study (reviewers recommend proceeding immediately to conceptual design)
- **Conceptual Design Phase (CDP)**
  - **CDP Stage 1:**
    - Jun 2009 – Dec 2010 (18 mo.) – Initial conceptual designs, cost estimates for TMT 2011 cost review
  - **CDP Value Engineering Studies:**
    - Jan 2011 – Jul 2011 (7 mo.) - Requirements vs. cost trades
    - Aug 2011 – Feb 2012 (7 mo.) - De-scope options and recommendations ("optimal" MOBIE with 25 square arcmin field area, 500 arcsec slit)
  - **CDP Stage 2:**
    - Mar 2012 – Sep 2013 (16 mo.) - Continue conceptual designs, integrate MOBIE project with TMT project management control system (PMCS) and integrated project schedule (IPS)
  - **CDP Stage 2 Workshop:**
    - October 2013 – MOBIE project design and documentation hand-off to TMT. MOBIE Conceptual design not complete at this time.

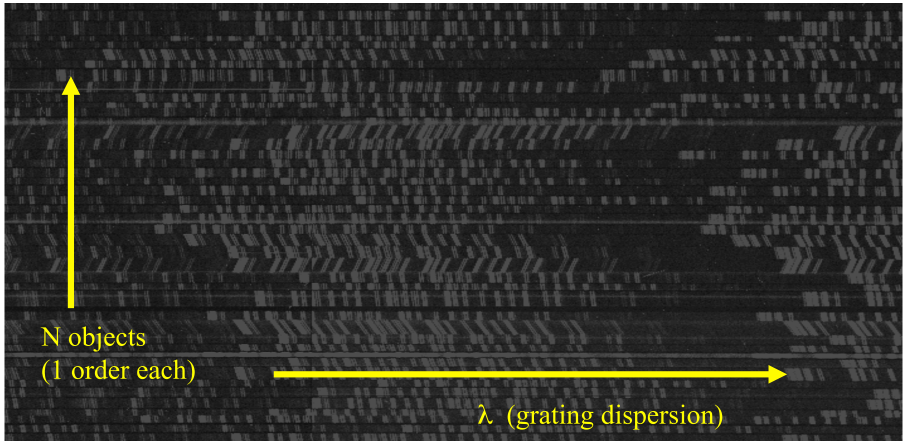
The MOBIE Design Concept: A Hybrid Solution

"Discovery" science

- Examples: surveys
  - IGM structure and composition at 2<z<6
  - stellar populations (chem. & kinematics z>1.5)
- Design priorities:
  - Resolution (λ/Δλ): 1,000 – 5,000
  - Multiplexing: 100's

- Single order spectra

Wide Field Multi-Object spectrographs:
DEIMOS (Keck), VMOS (VLT), IMACS (Magellan)

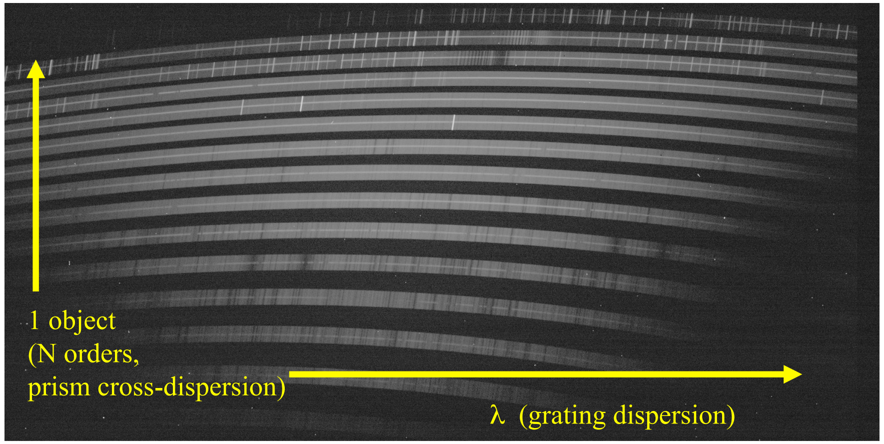


"Diagnostic" science

- Examples: targeted studies
  - Abundances & Kinematics of stars w/in 20 Mpc
  - Galactic and Local Group substructure
- Design priorities:
  - Resolution (λ/Δλ): 8,000 – 16,000
  - Multiplexing: 10's

- Multi-order Spectra (No Moving parts!)

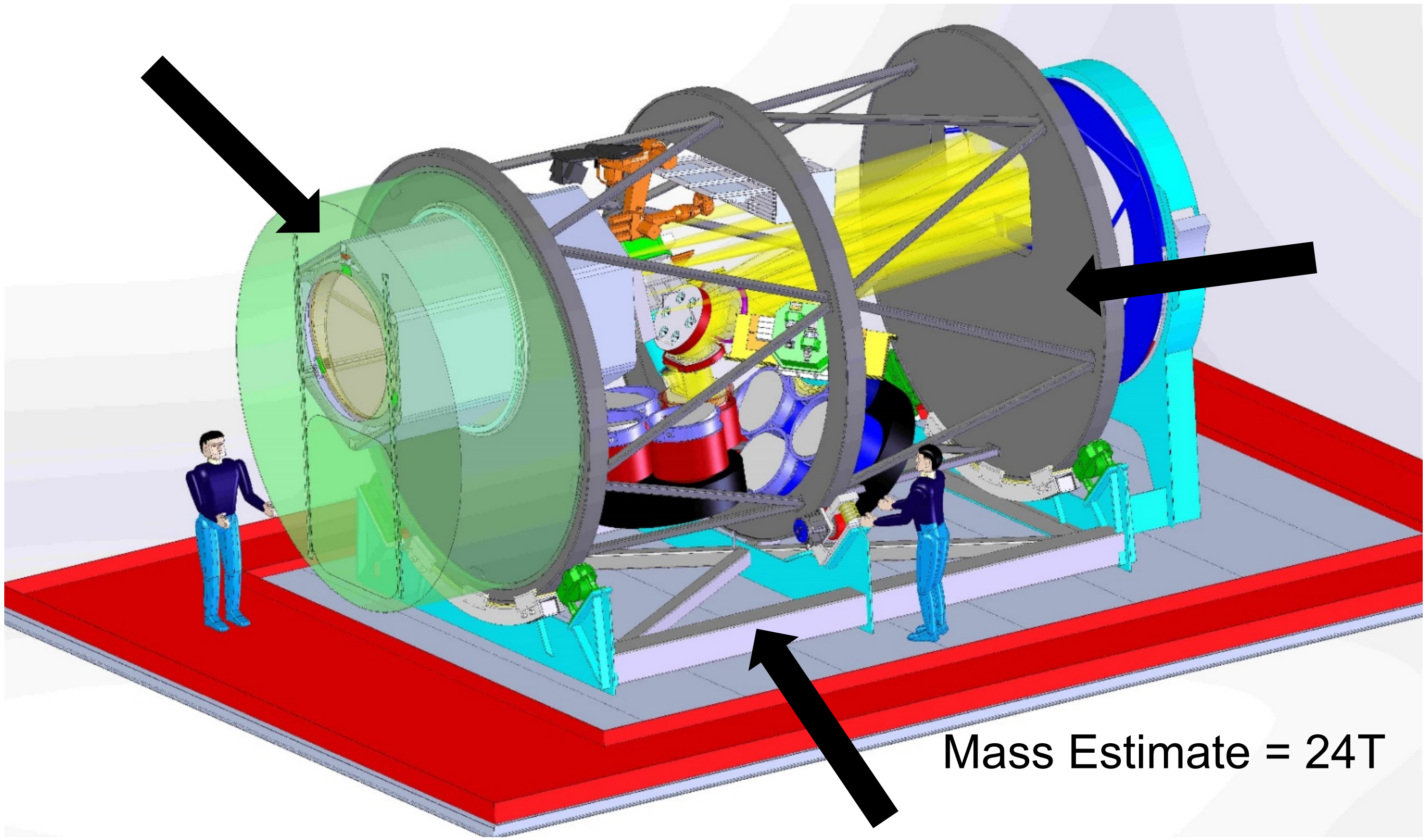
Echellette spectrographs:
ESI (Keck), MagE (Magellan), XShooter (VLT)



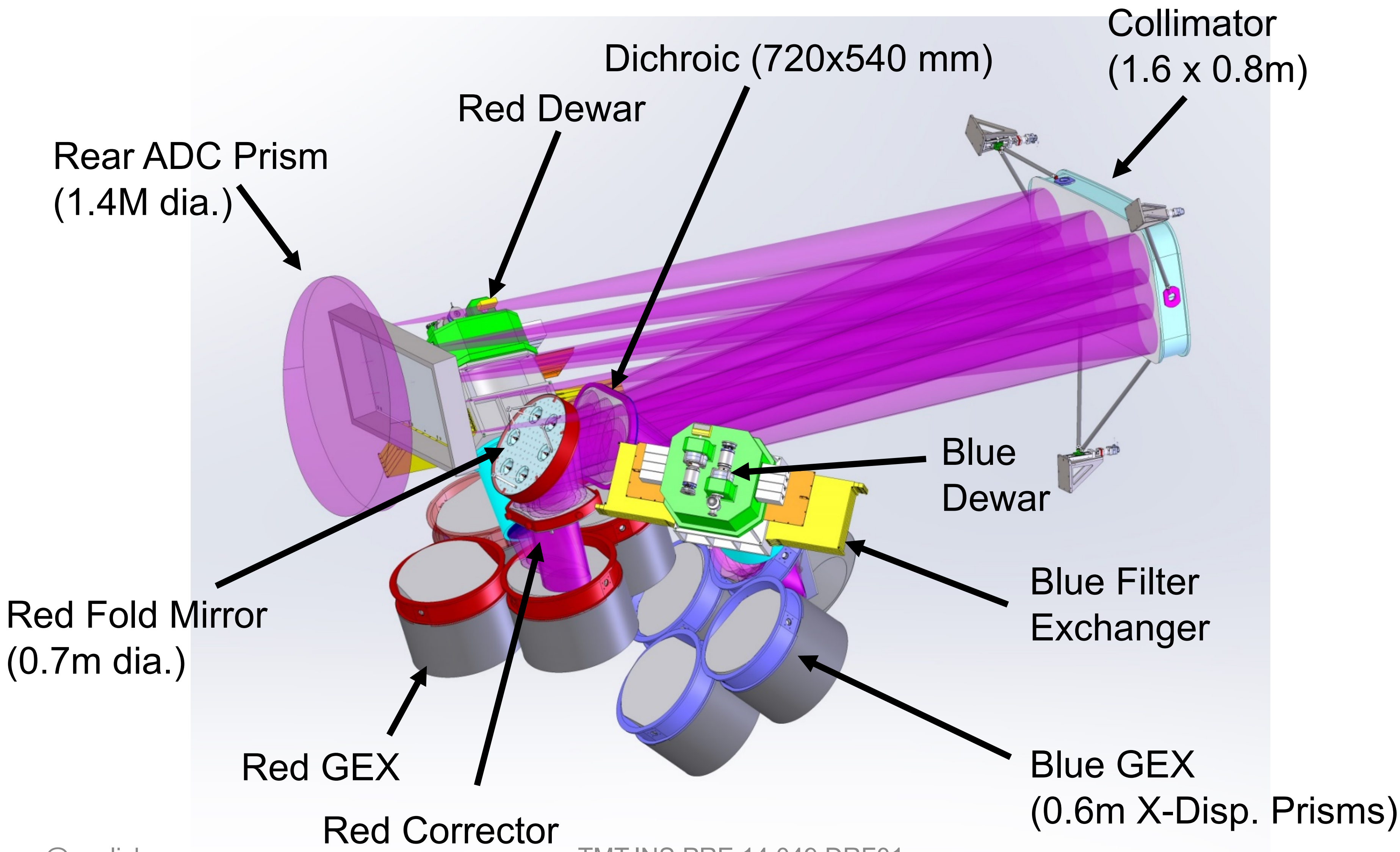
The MOBIE Design Concept: A Hybrid Solution

The hybrid is a **M**ulti-**O**bject, **B**roadband, **I**maging **E**chellette**:**

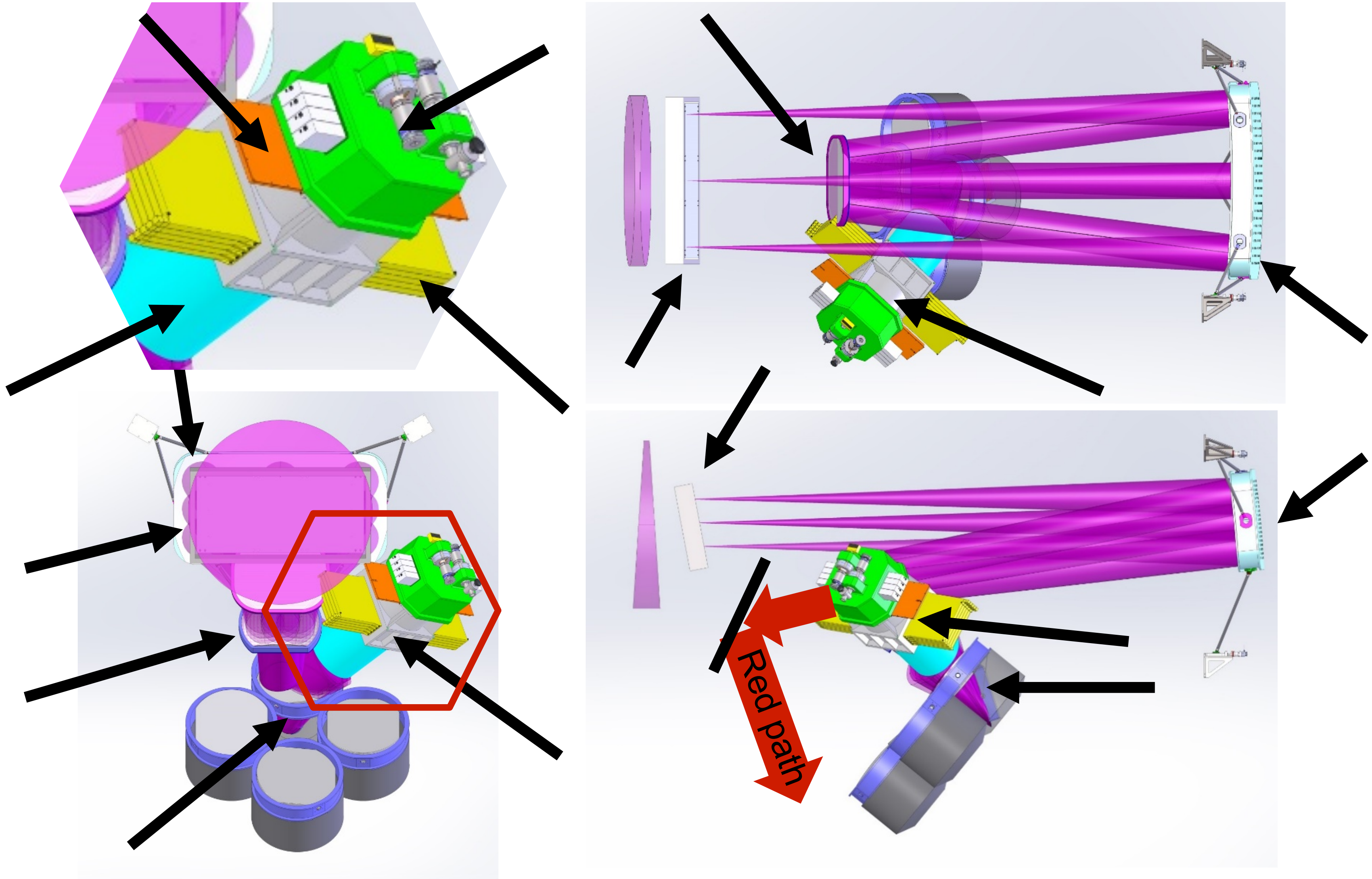
- Two color channels, plane reflection gratings, double-pass prism cross-dispersion
- Full wavelength coverage (0.3-1.0μm) in all spectroscopic modes
- Observers can trade field size, resolution, and wavelength coverage according to science needs



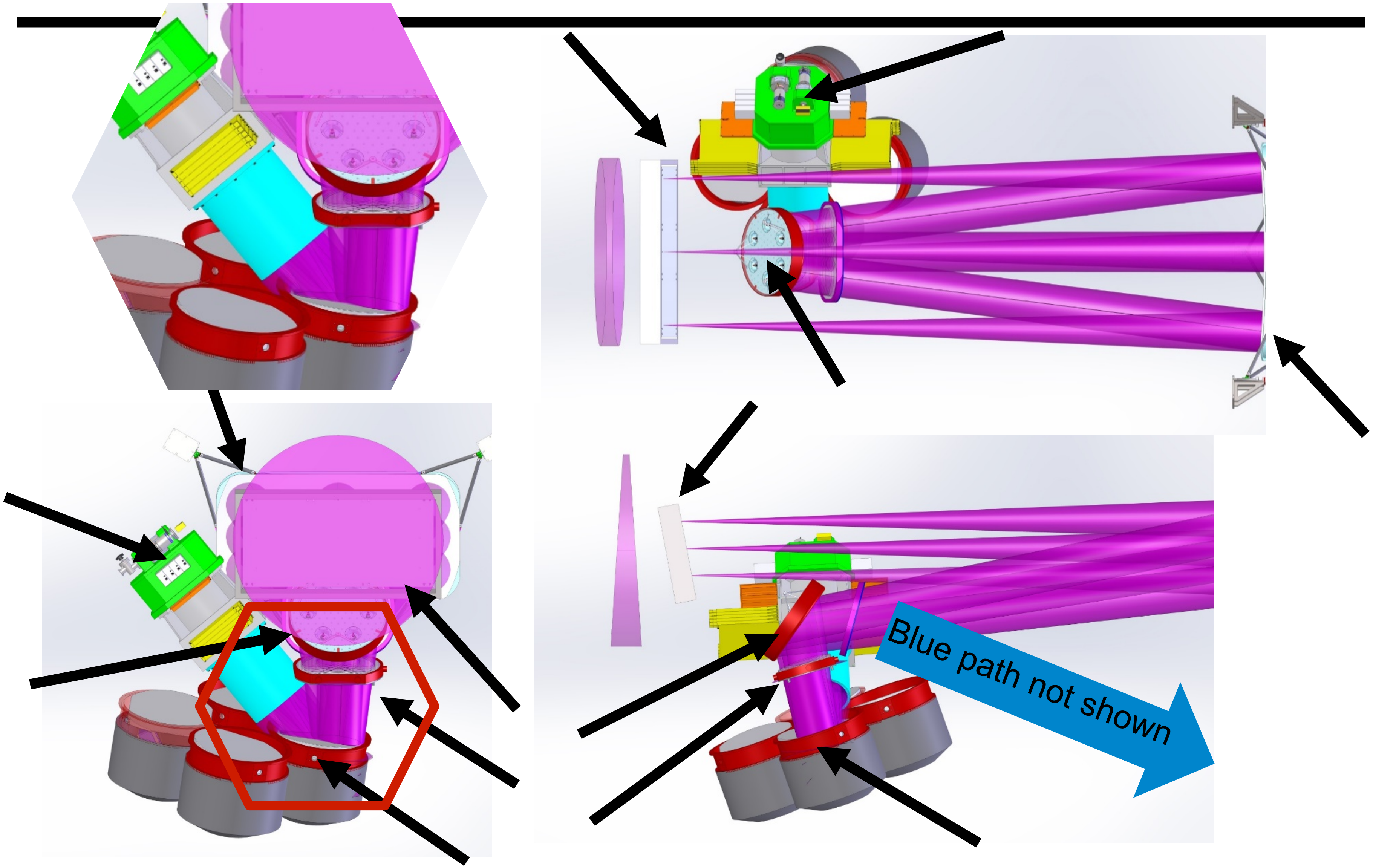
ADC, Mainframe, and Carriage Removed



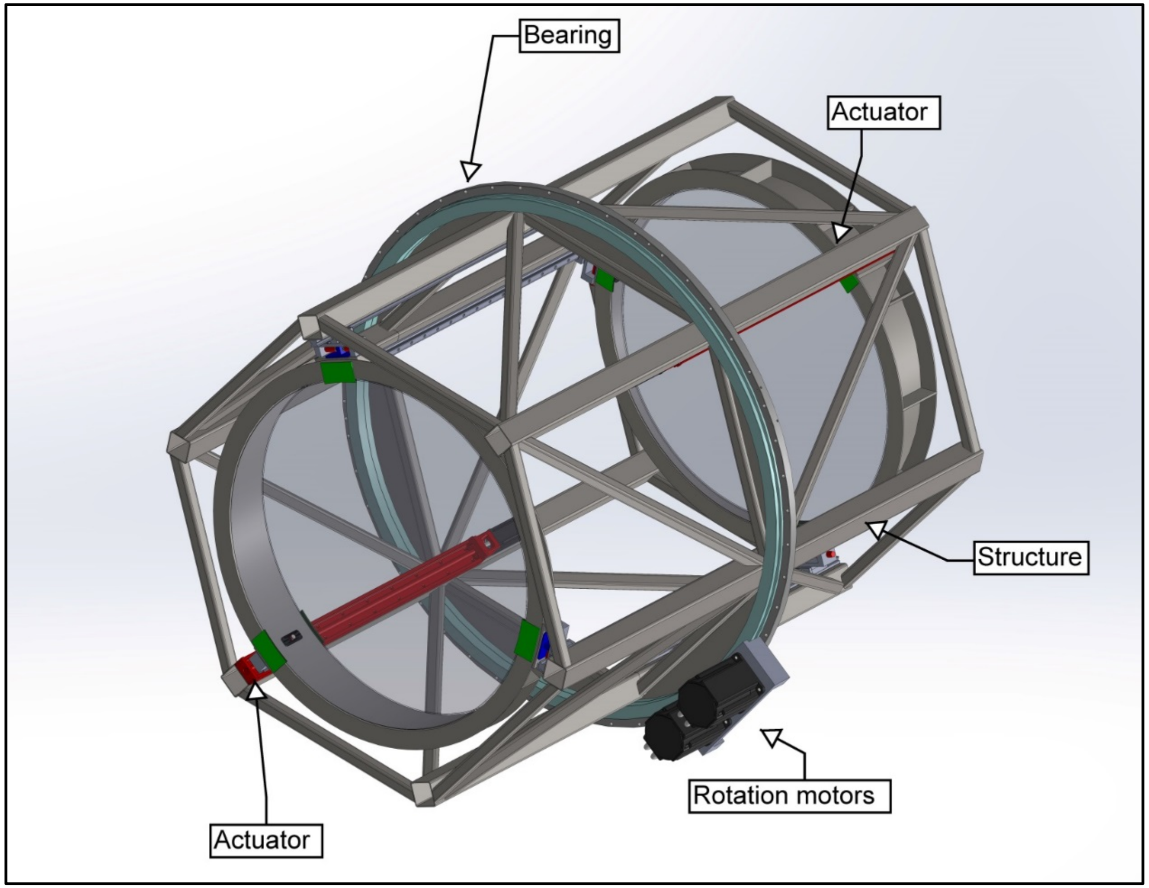
Blue Side

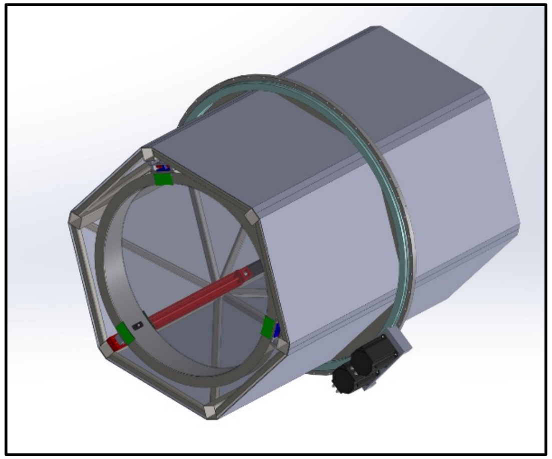


Red Side



ADC – Atm. Dispersion Corrector

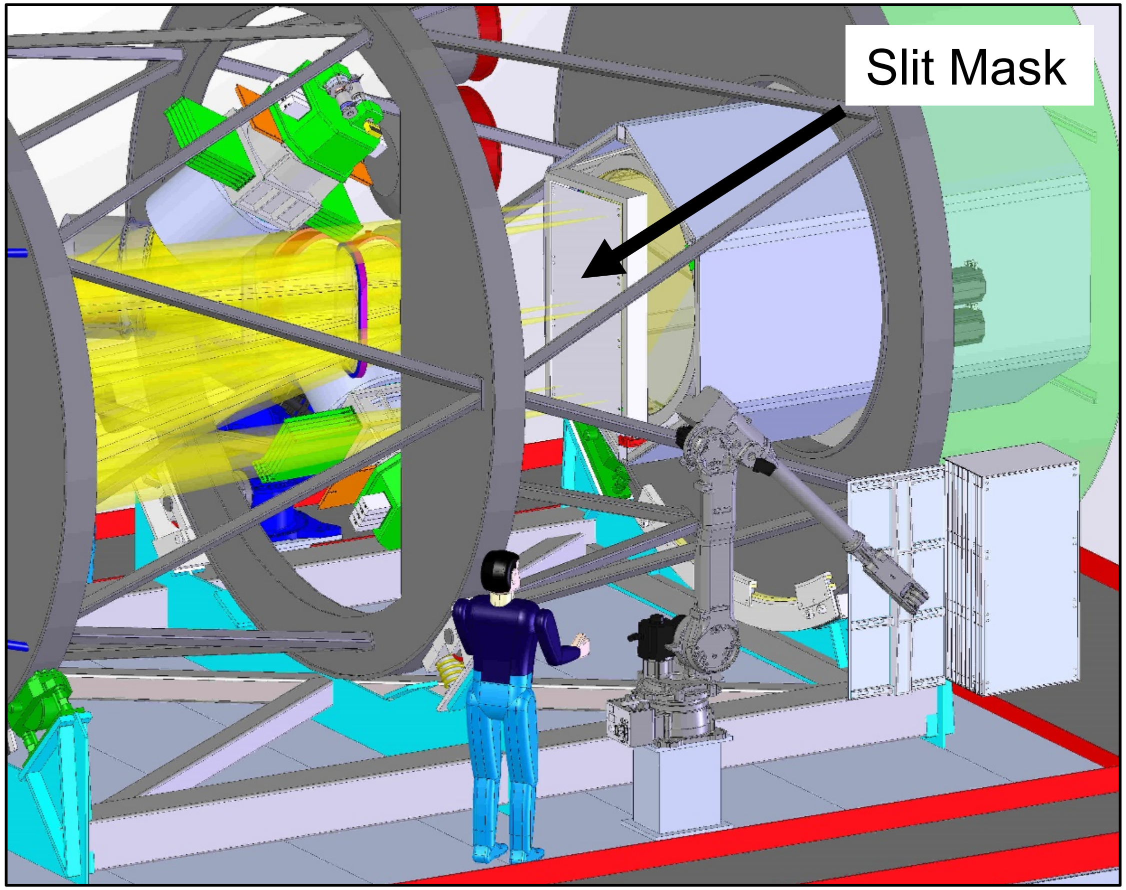


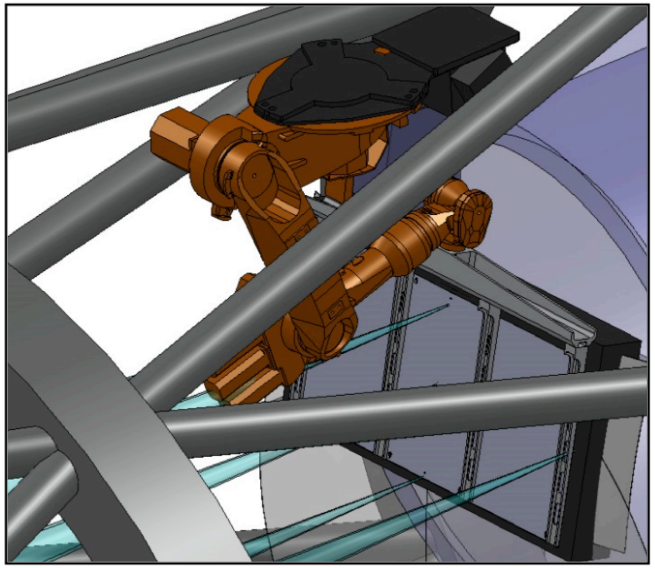


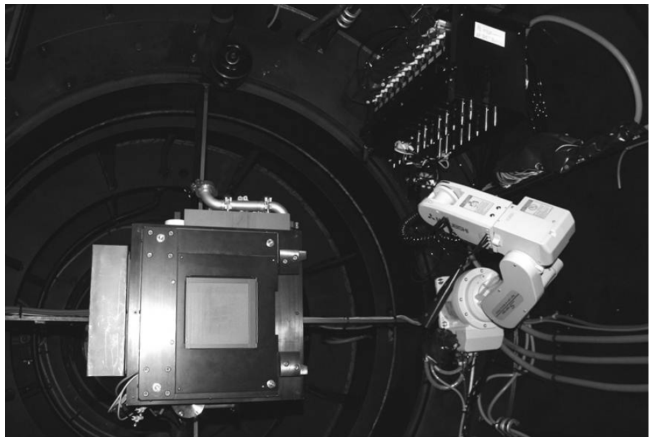
ADC:

- Fused silica prisms, 1.4m in diameter, sol-gel coatings
- Linear ADC heritage from Keck L-ADC
- ADC System must rotate independently of instrument to follow telescope elevation angle

MEX – Mask Exchange System



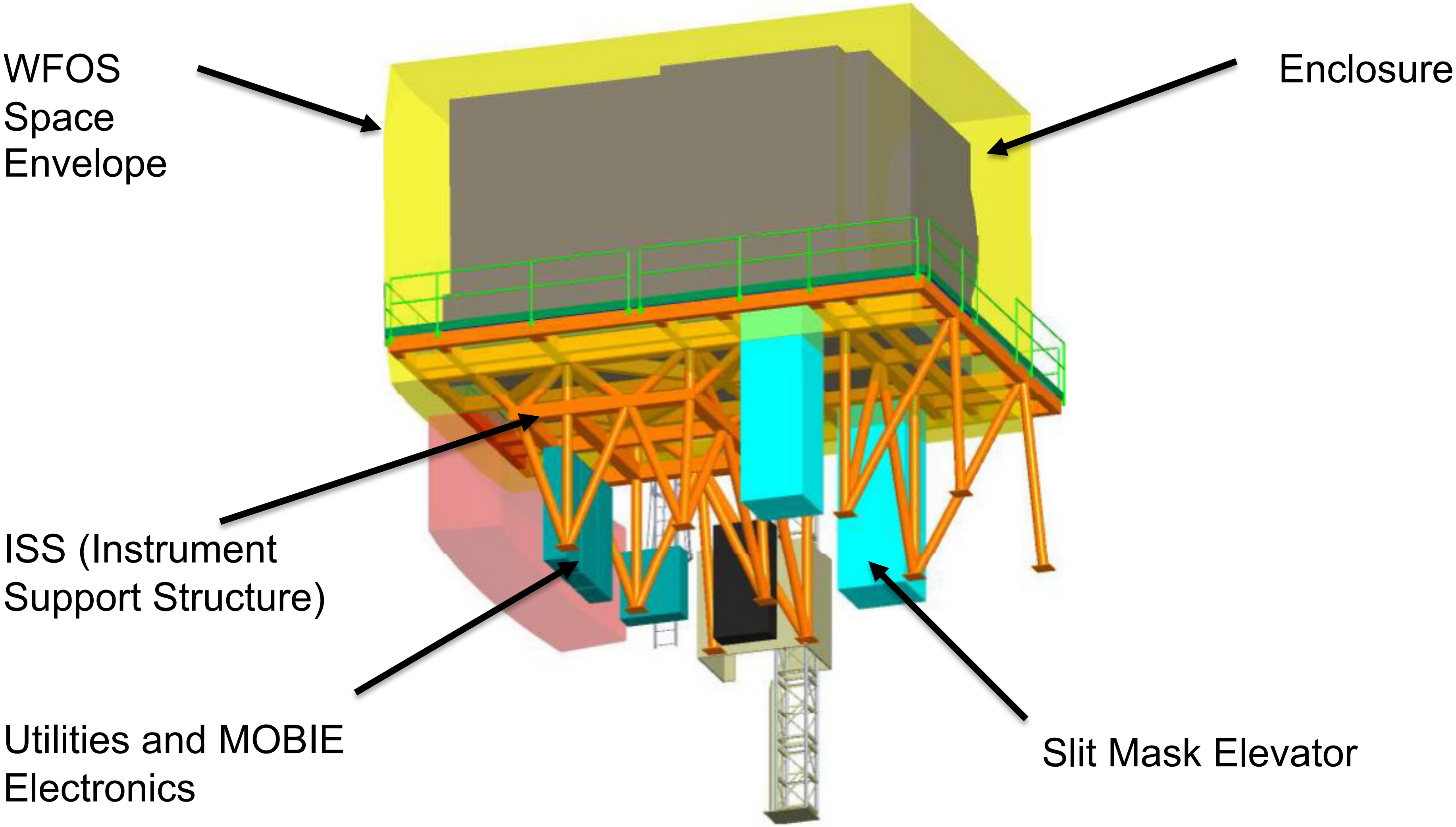




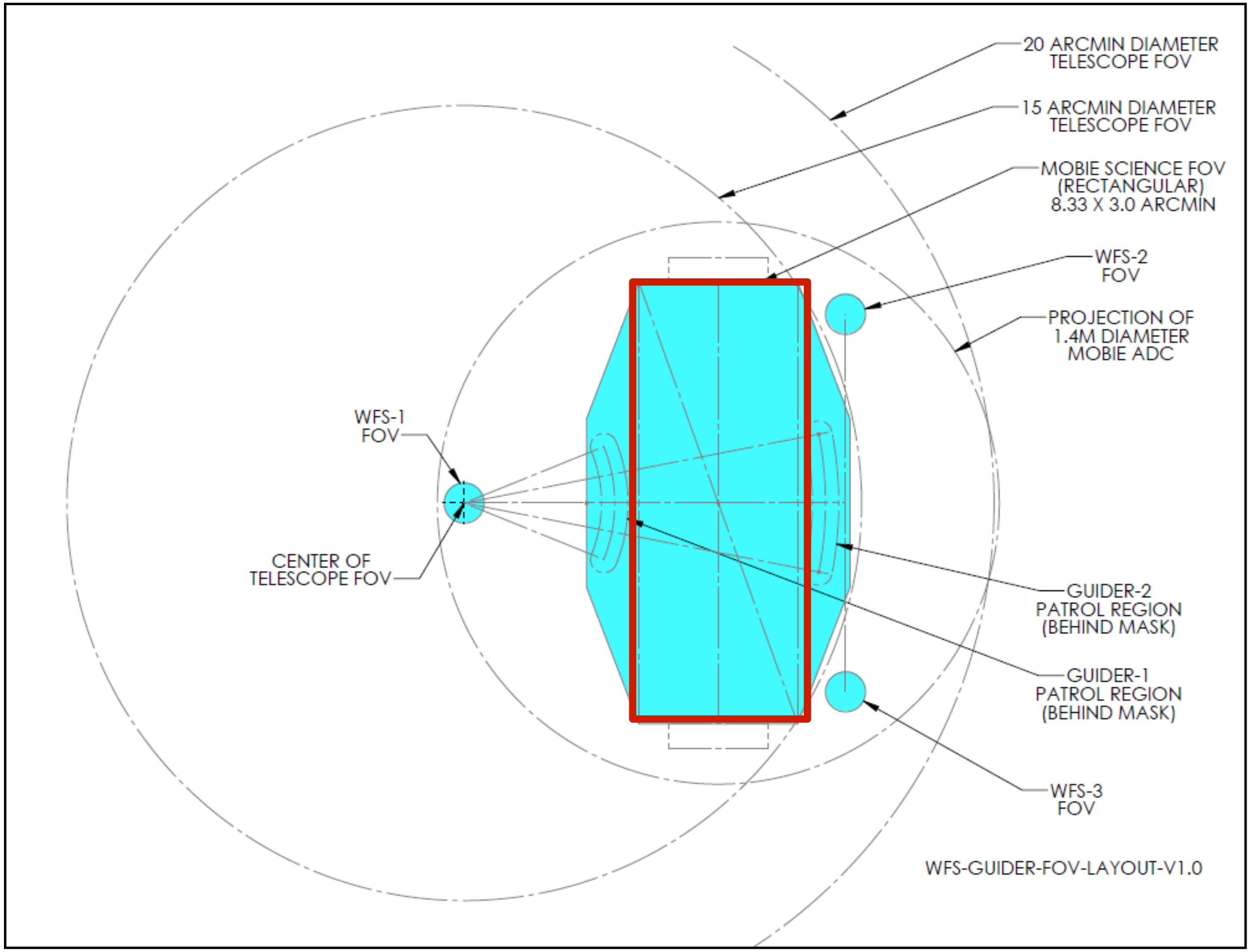
MEX:

- 1090mm x 400mm slit masks, capacity of 10 per night ?
- Heritage from NAOJ Kiso robot filter exchanger
- Review options for on-board and out-board mounting of robot

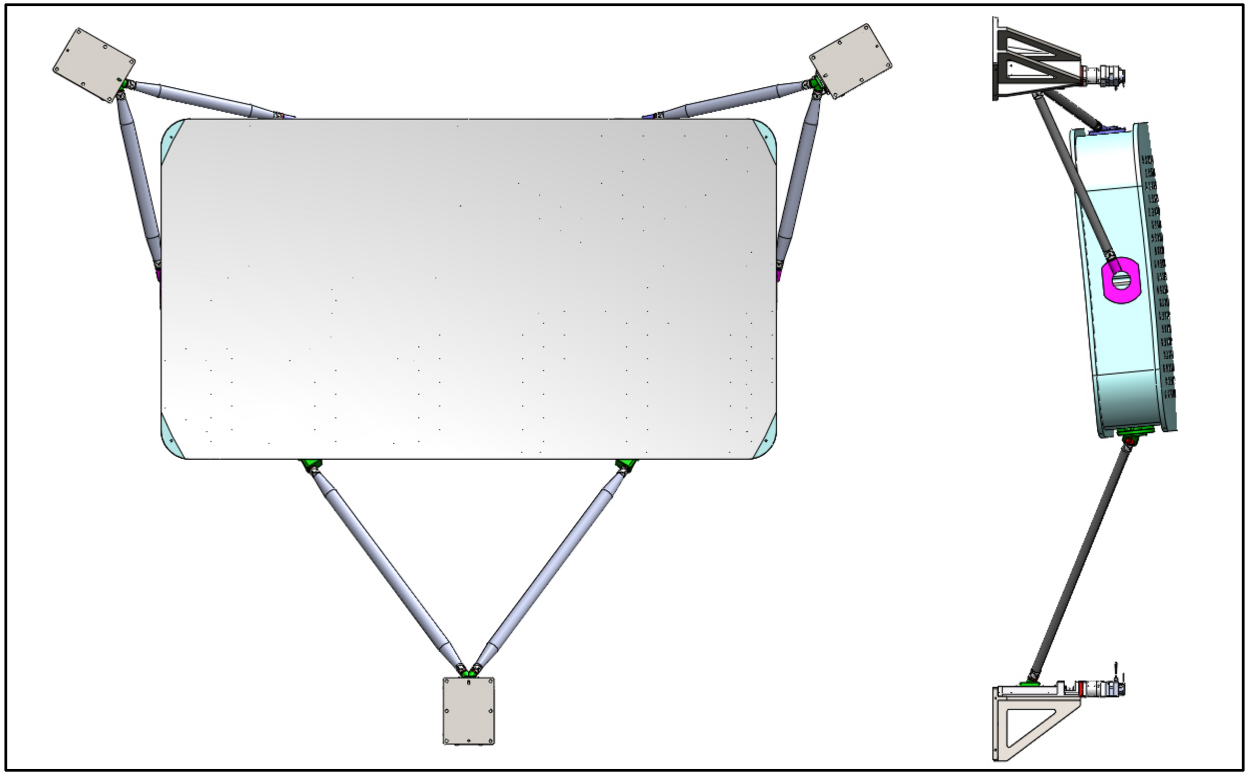
ISS and MEX Elevator

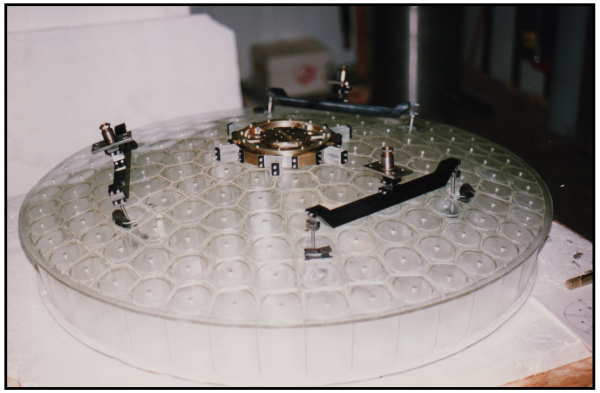


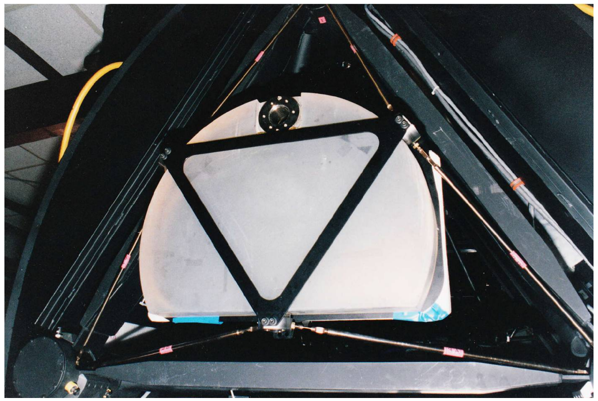
MOBIE Guiders and WFS



COL – Collimator System



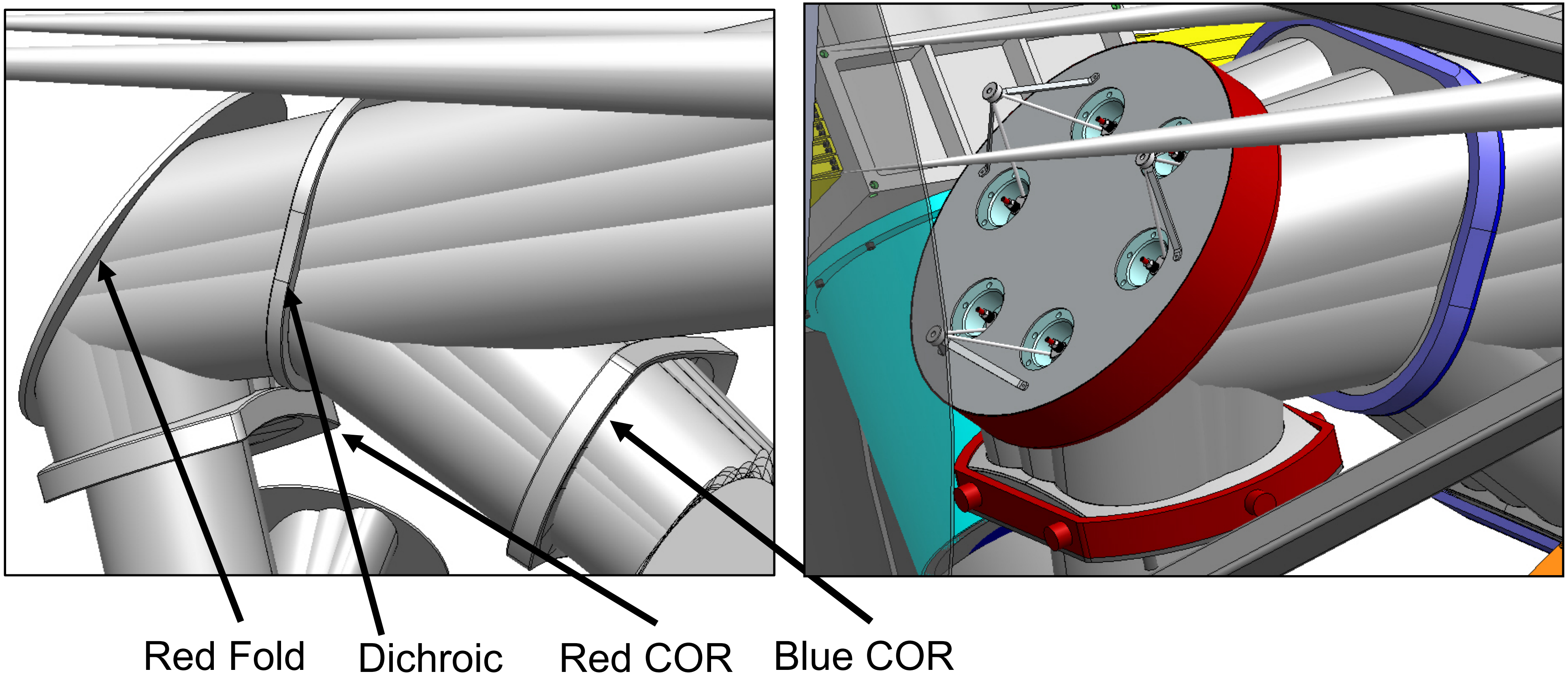




COL:

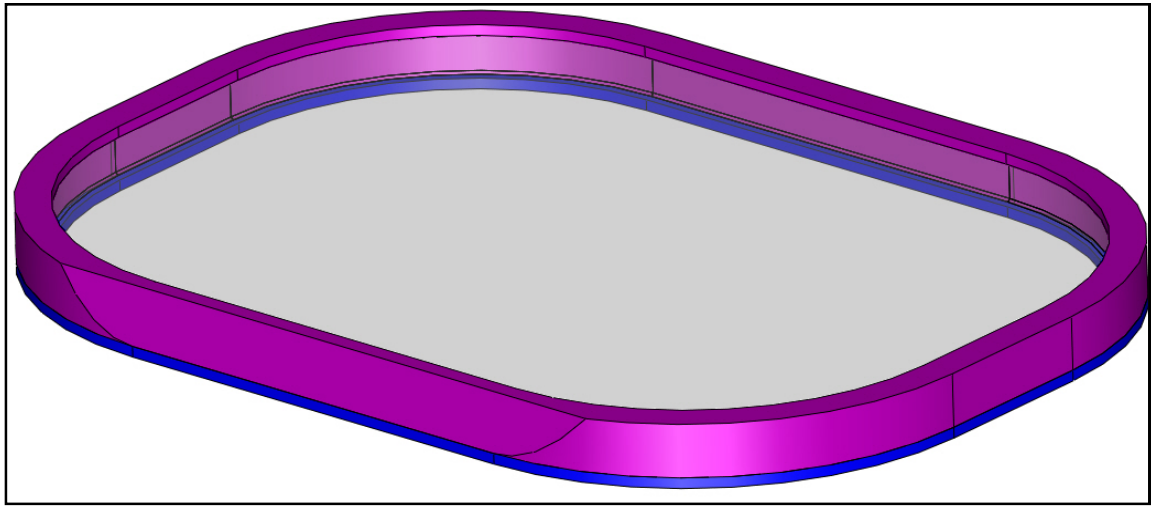
- ~1600 mm x ~800 mm, Rc=~9m off-axis paraboloid. Lightweight glass-ceramic or Hextek borosilicate sub-straight.
- Kinematic opto-mechanical interfaces, based on Keck HIRES ~1m camera mirrors
- Three linear actuators, 6 flexured support struts, similar to Keck ESI 0.6m dia. collimator, provide focus, tip, and tilt control to stabilize the collimator focus on the telescope focal surface

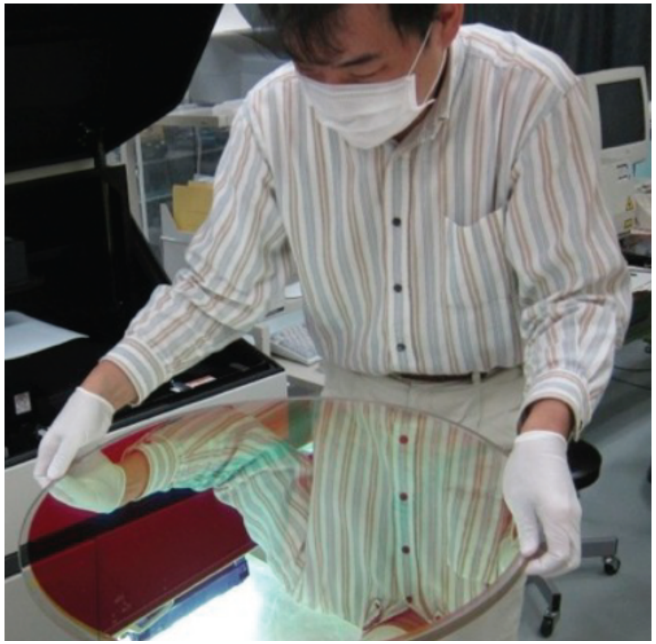
FOS – Folding Optical Systems



FOS:
- Includes dichroic, red fold mirror, and corrector optics
- Optics are tightly packed, with minimal clearance to optical beams
- Optics are shaped (trimmed) to avoid vignetting and minimize mass/volume

FOS – Dichroic

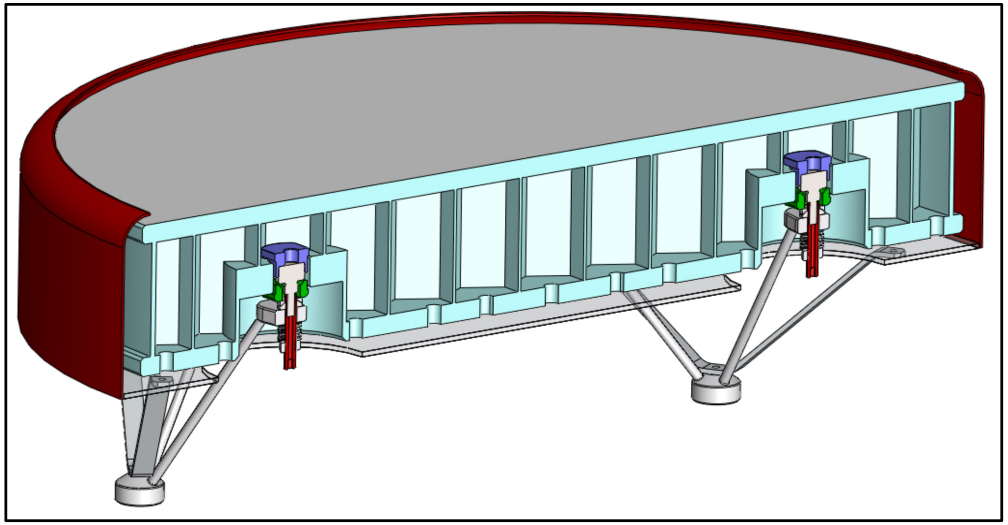


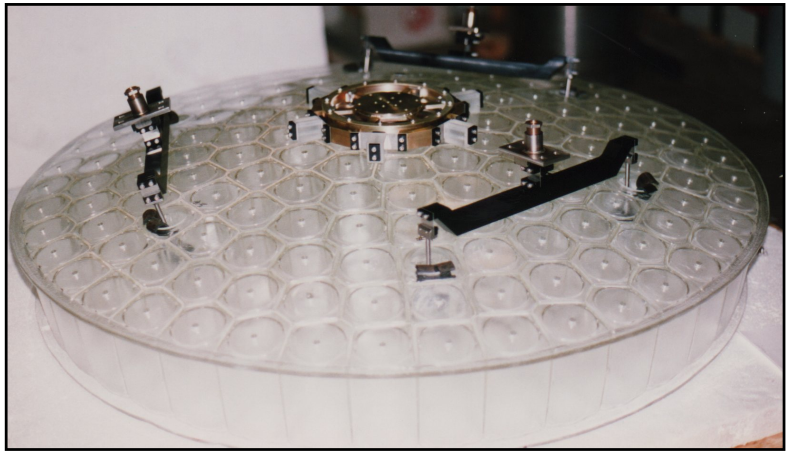


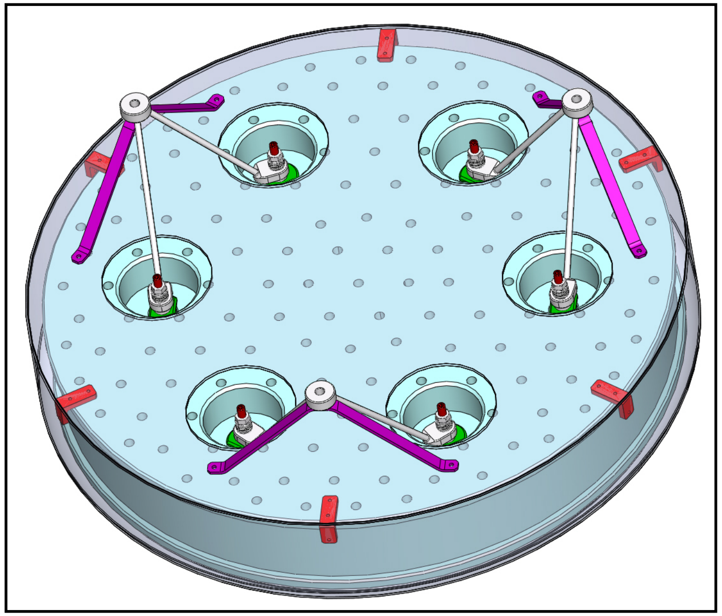
DCR:

- Dichroic is ~720 mm x 540 mm x 30 mm thick
- Comparable in size and difficulty to large filters (e.g. PanSTARRS, ODI, HSC, DECam)
- Kinematic mounting concept using discrete defining and preloading points

FOS – Red Fold Mirror



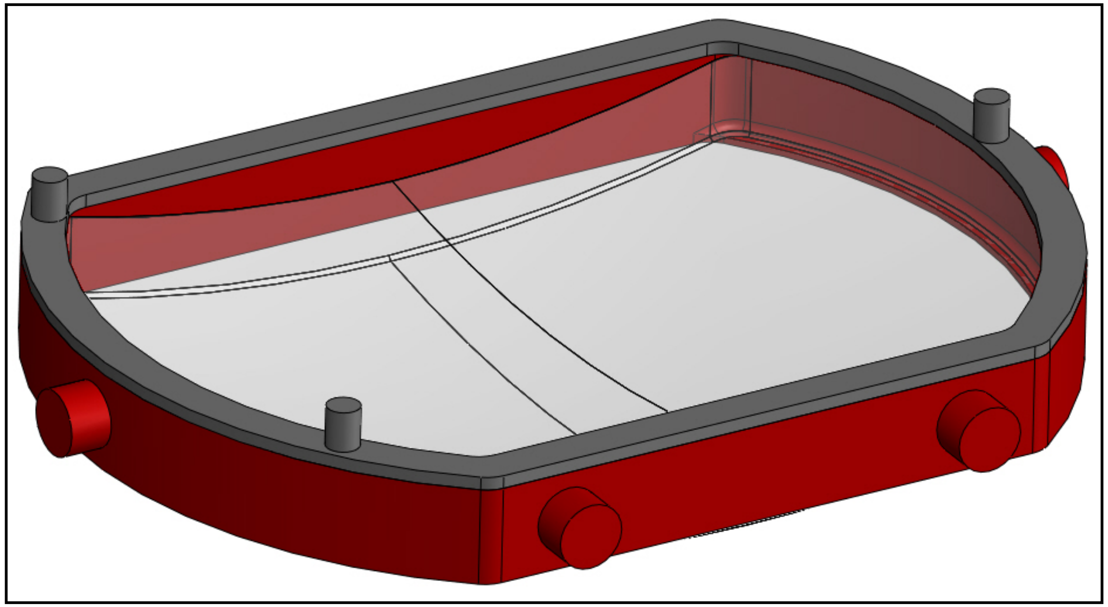


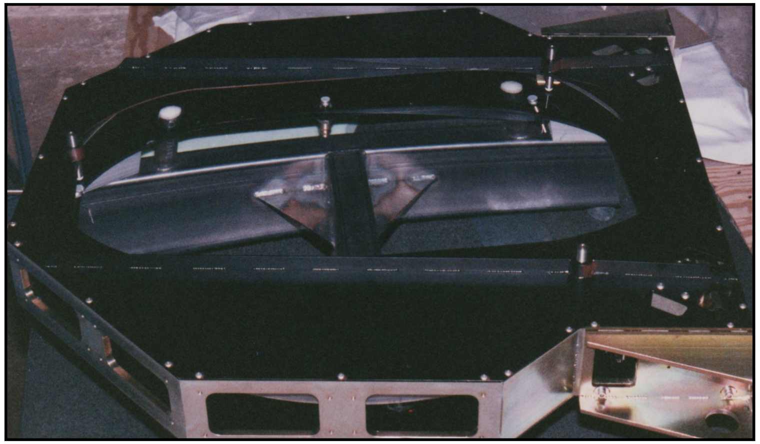


MOBIE RFM design:

- 0.7m light weighted low CTE glass-ceramic or Hextek substrate comparable in size to HIRES and LBT M3 mirrors (1m-class)
- HIRES heritage for kinematic mounting via polymer clamps, ball joints, and bipods
- Keck M1 mirror problems are a strong reason to develop mechanical clamping rather than bonding attachments

FOS – Corrector Lenses

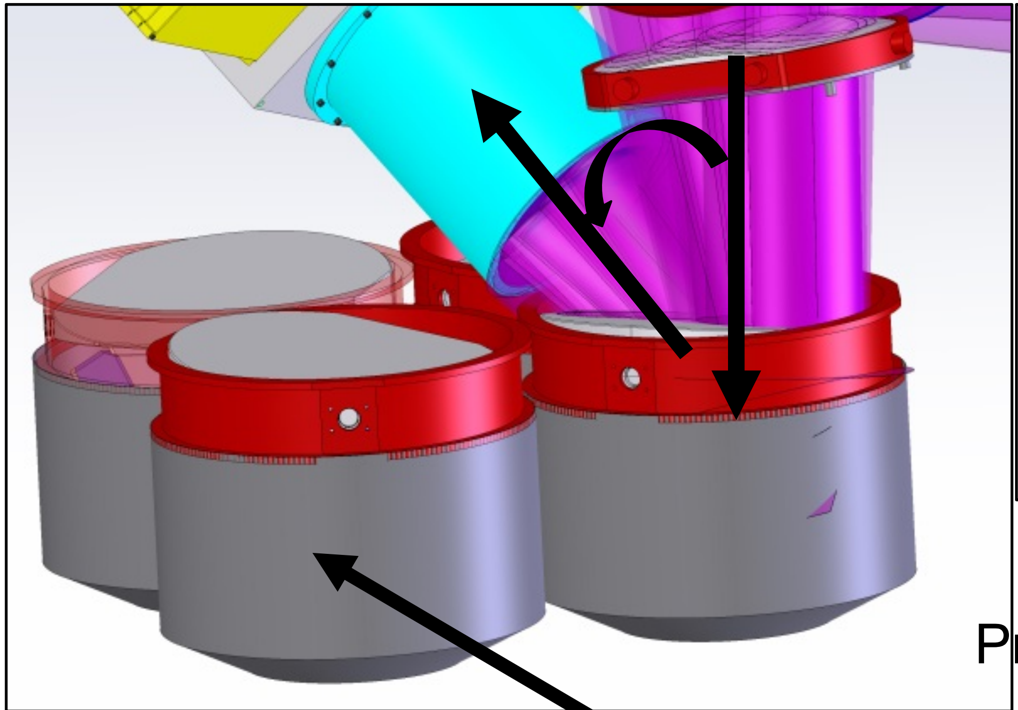


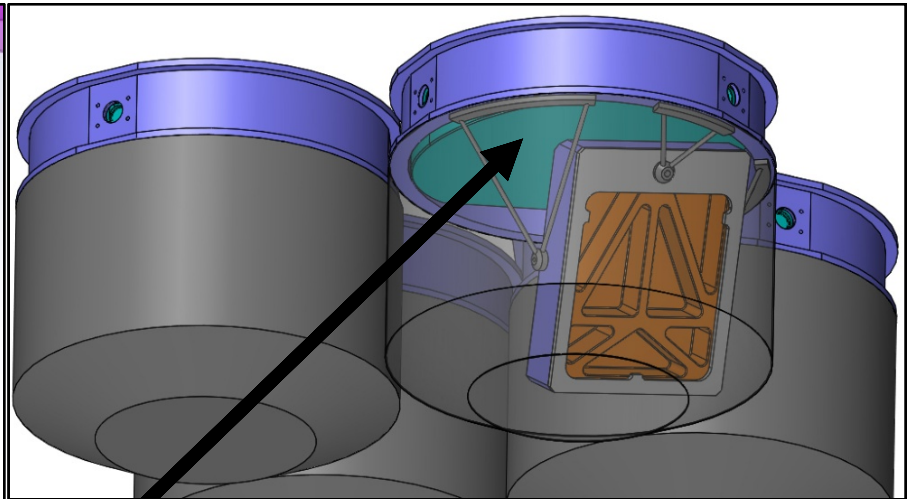


COR:

- Corrector lenses are ~600 mm in diameter, sides removed to prevent vignetting
- Lens size/difficulty smaller/easier than optics for MMT f/5, PanSTARRS, HSC, DECam, etc.
- Heritage from HIRES for kinematic optical mounts using discrete defining and preload points

GEX – Grating Exchange Systems





Prism

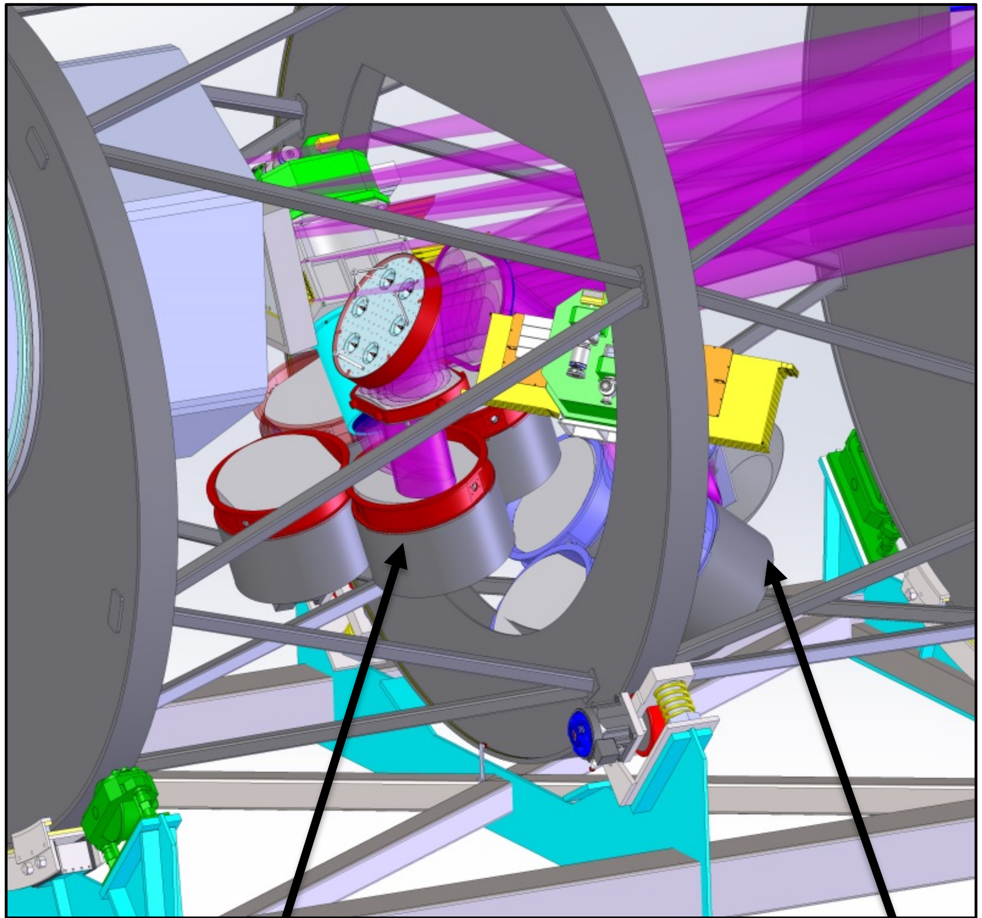
150 kg ea. est.

IMACS MOE optics unit

GEX:

- Includes optic modules for spectro. + direct imaging
- Kinematic mountings for 300mm x 500mm gratings, ~0.6m diameter prisms and imaging mirrors
- Heritage from IMACS-MOE, mounts using discrete defining and preload points, rotary selection

GEX – Grating Exchange Systems



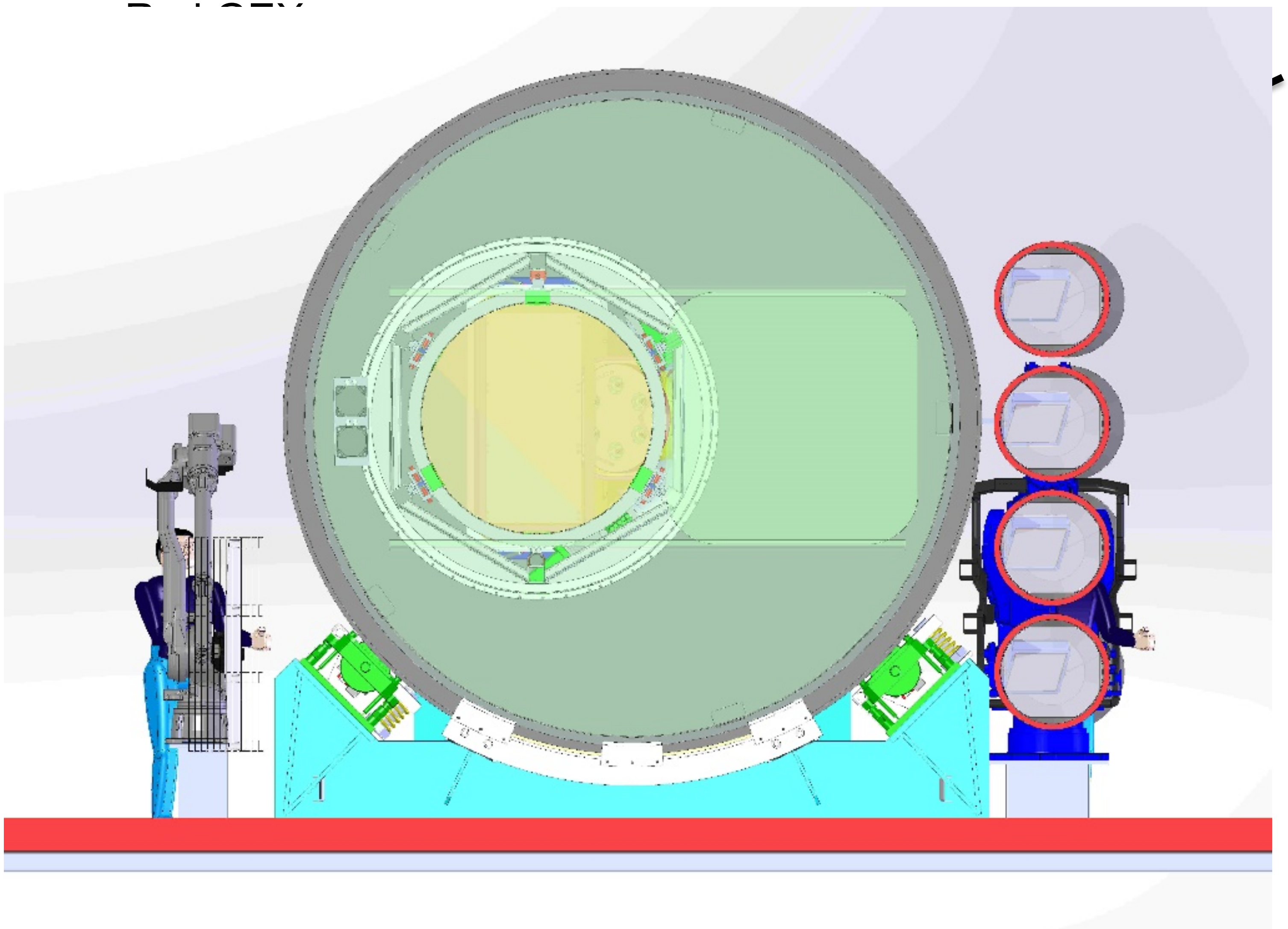
Red GEX

Blue GEX

IMACS grating exchanger

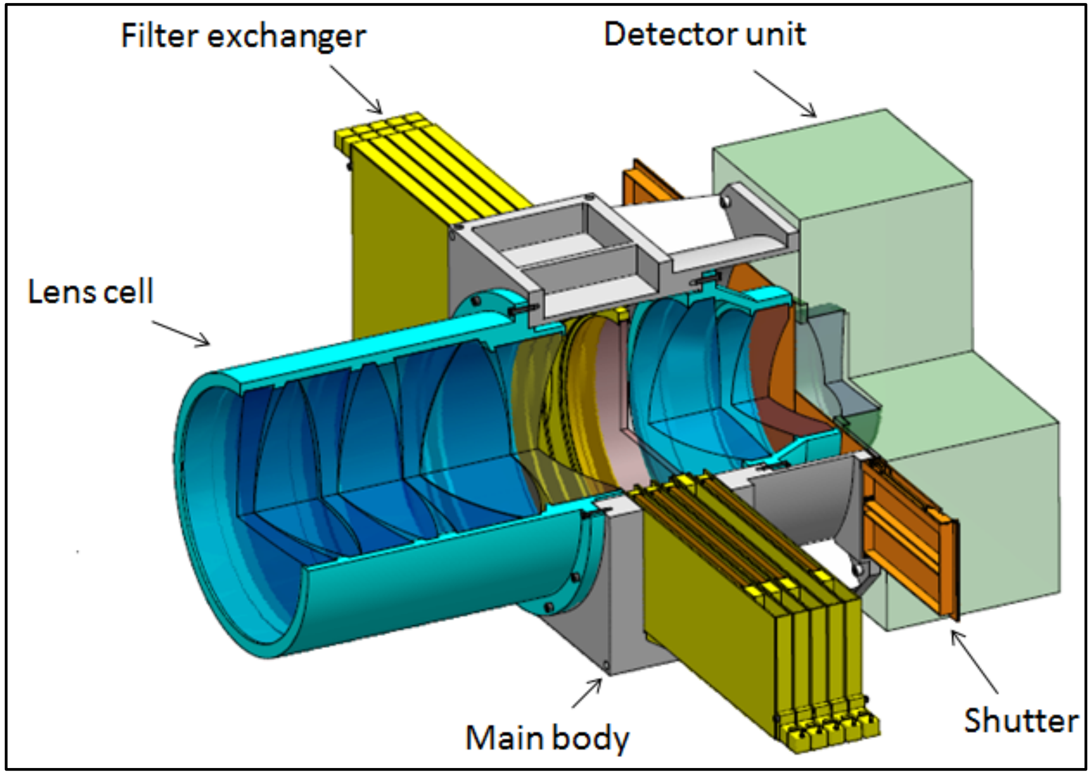
- GEX rotatory stage required size and precision will be challenging. COTs may not be an option.
- Stage and structure not shown.

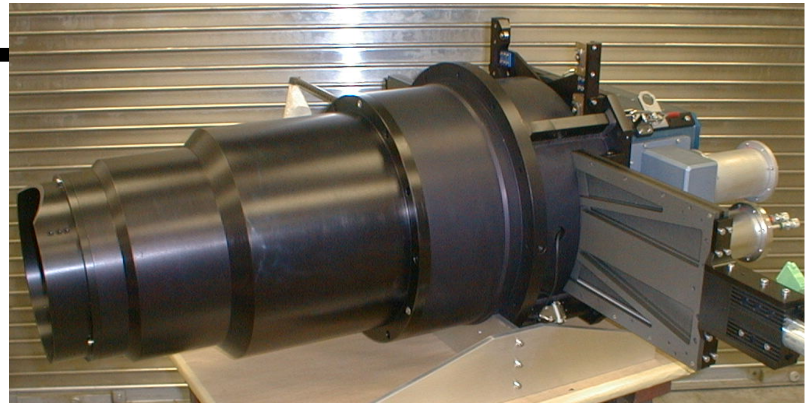
GEX – Grating Exchange Systems
Robot Option

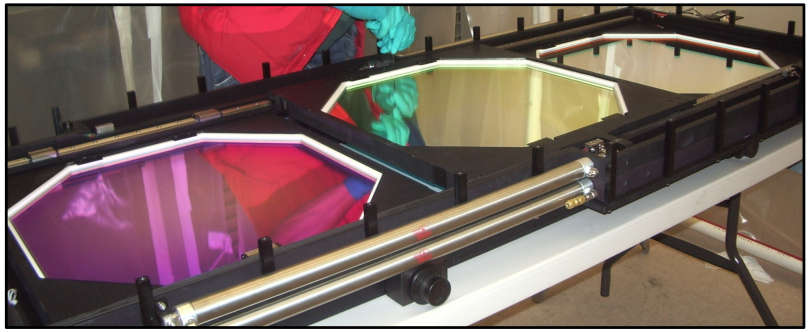


Blue GEX

CAM – Camera Systems





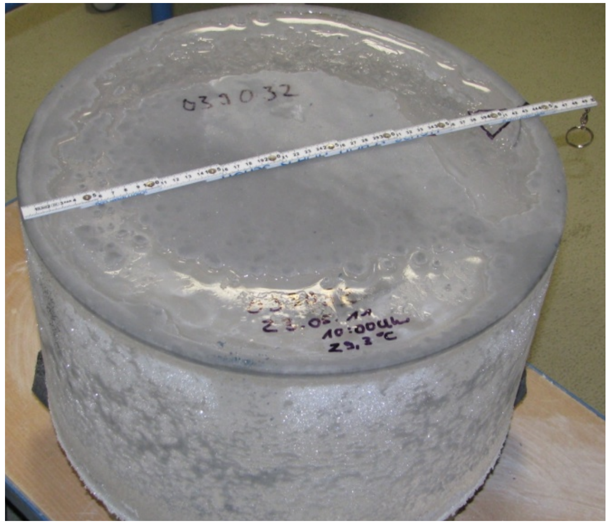


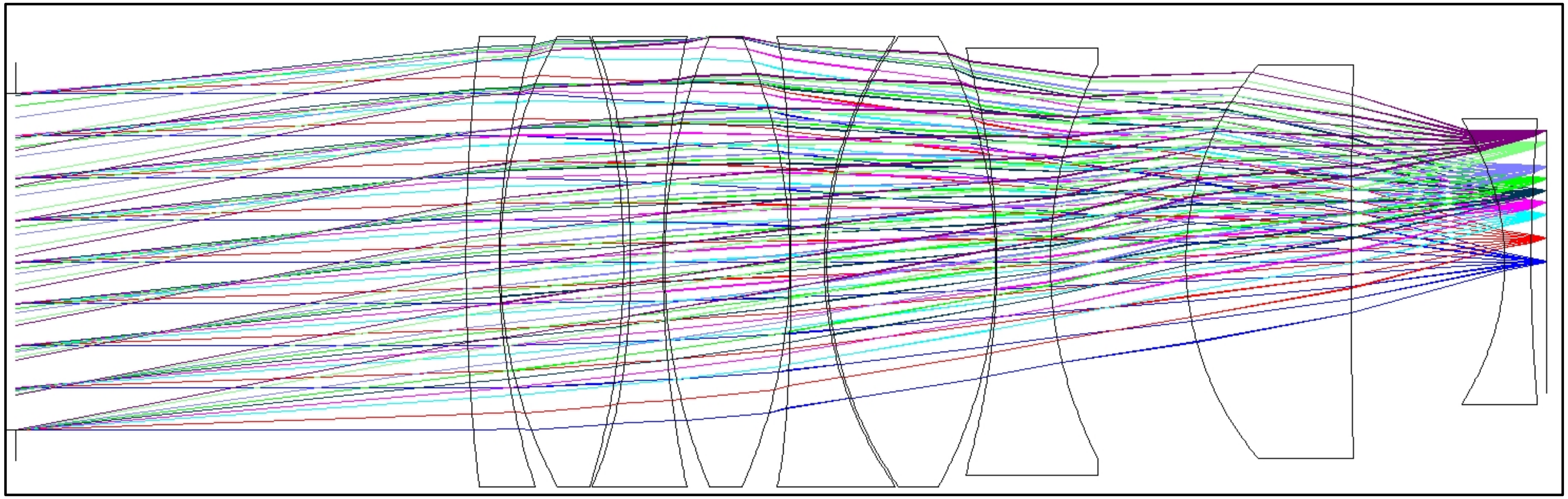
CAM:

- Includes blue and red channel cameras, shutters, filter exchangers
- Subsystem/vendor heritage from PanSTARRS, HSC, IMACS, etc.

CAM – Blue Camera

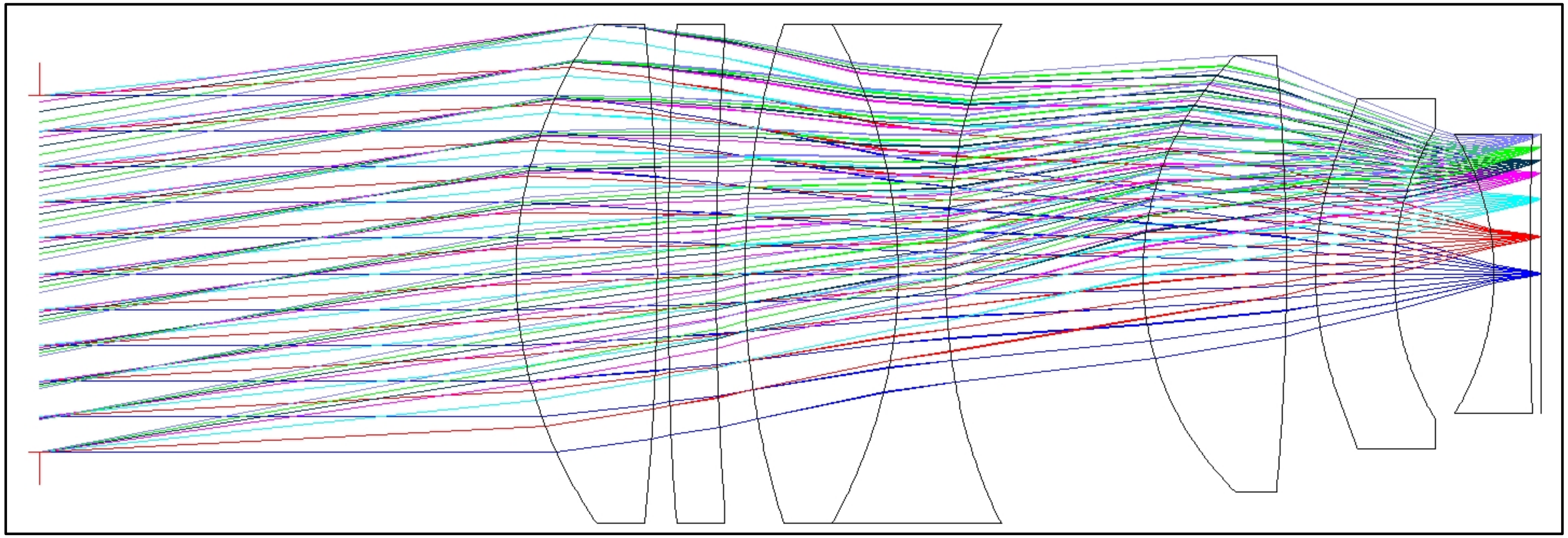
- Camera designs explored
  - F/# = 1.5 – 2.0 → 2.0 baseline
  - FOV acceptance angle = 20 – 24 → 22˚ baseline
- Currently vignetting >20% at outer field positions
- Current CaF2 lens diameters limited to 440mm
- Glasses: Fused silica and CaF2 (Hellma, Nikon)
- Groups: All air-spaced singlets
- Aspheres: 4-5 needed, can be placed on CaF2 or FS, based on cost and risk



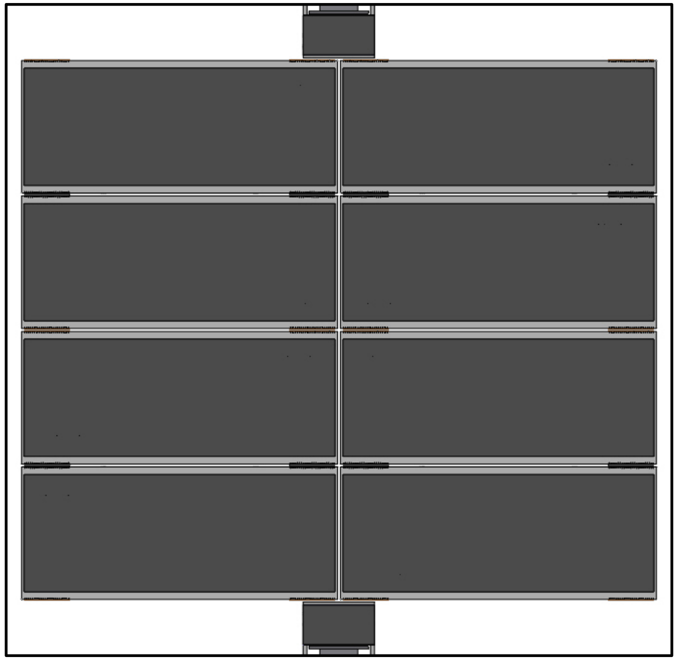


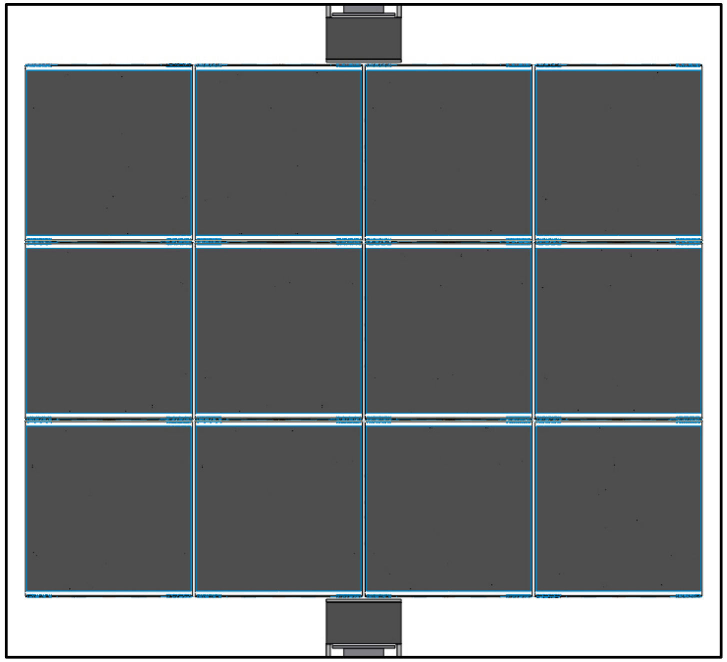
CAM – Red Camera

- Camera designs explored
  - F/# = 1.5 – 2.0 → 2.0 baseline
  - FOV acceptance angle = 20 – 24 → 22˚ baseline
- Currently vignetting >20% at outer field positions
- Current CaF2 lens diameters limited to 440mm (can possibly increase)
- Glasses: CaF2, S-TIM22, S-BAH10, FS
- Aspheres: Four or Five need, can be placed on various surfaces, based on risk and cost
- Groups: One bonded doublet at present (air-spacing also possible).



DET – Focal Plane Mosaics

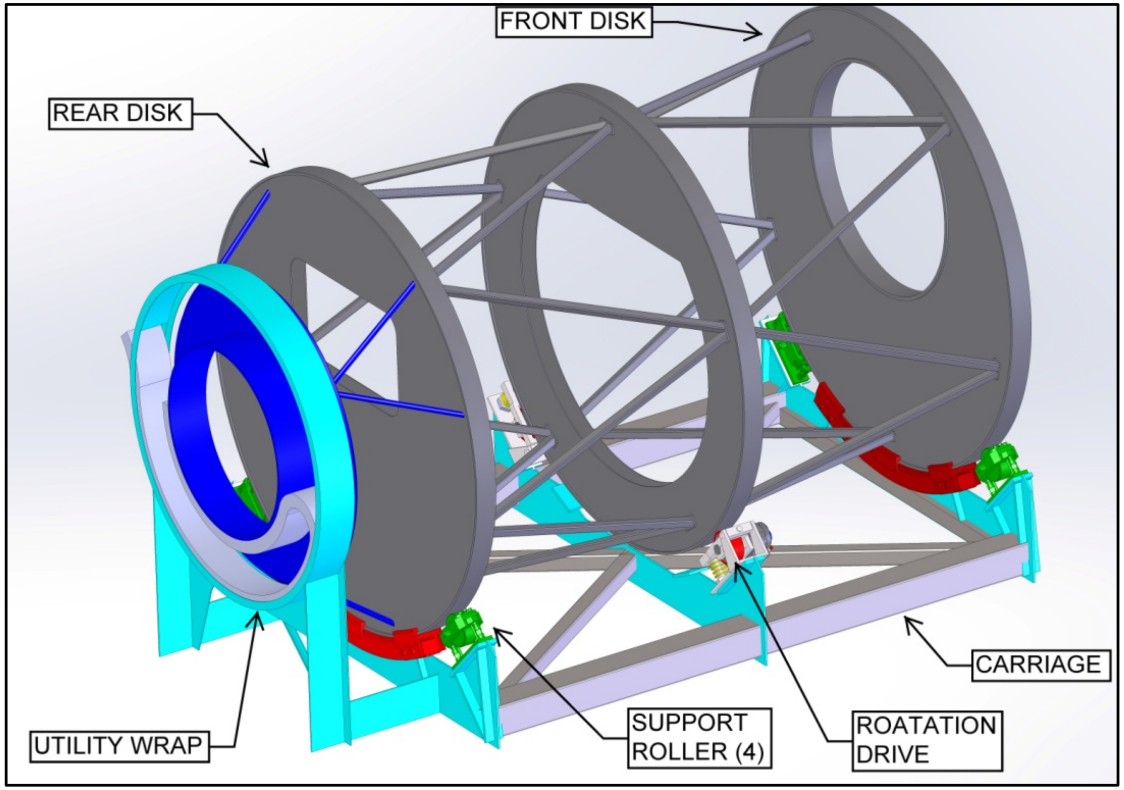


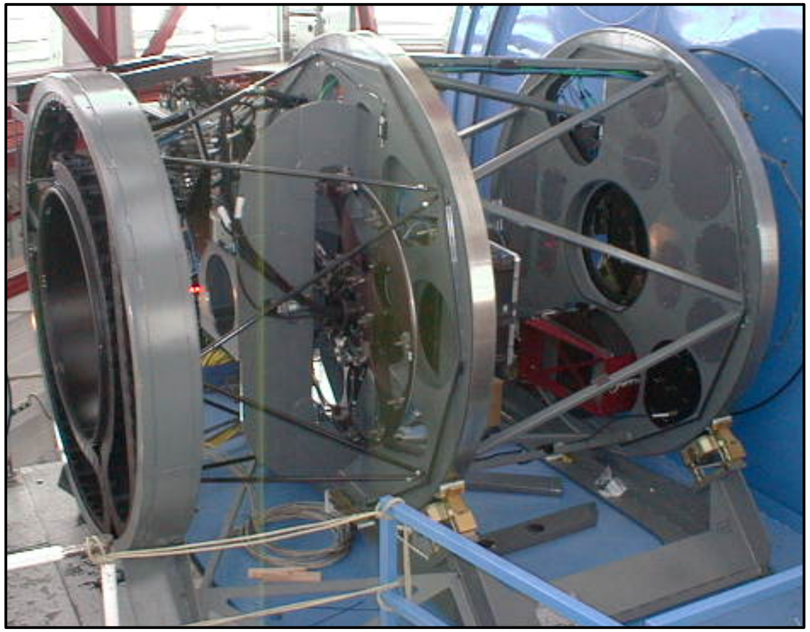


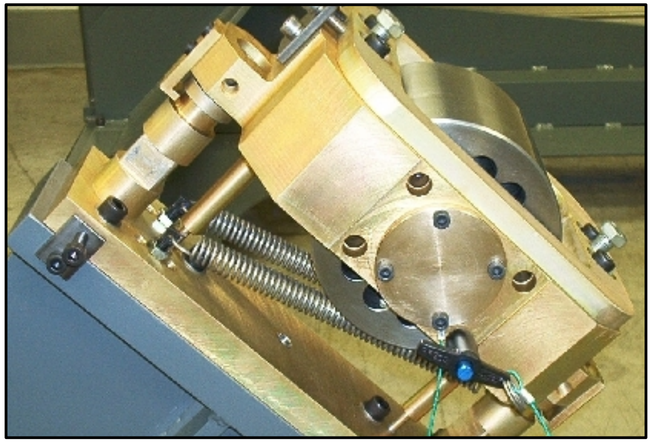
DET:

- 1 arcsec sky = 275 microns at the focal plane
- Required focal plane area is ~180mm x ~270mm
- Two currently preferred mosaic options using 15 micron pixels:
  - 12K x 16K via 2 x 4 mosaic of 3K x 8K devices, 16 readout channels
  - 12K x 16K via 3 x 4 mosaic of 4K x 4K devices, 48 readout channels
- **Flexure compensation done with hexapod mosaic support**

STR – Carriage and Mainframe



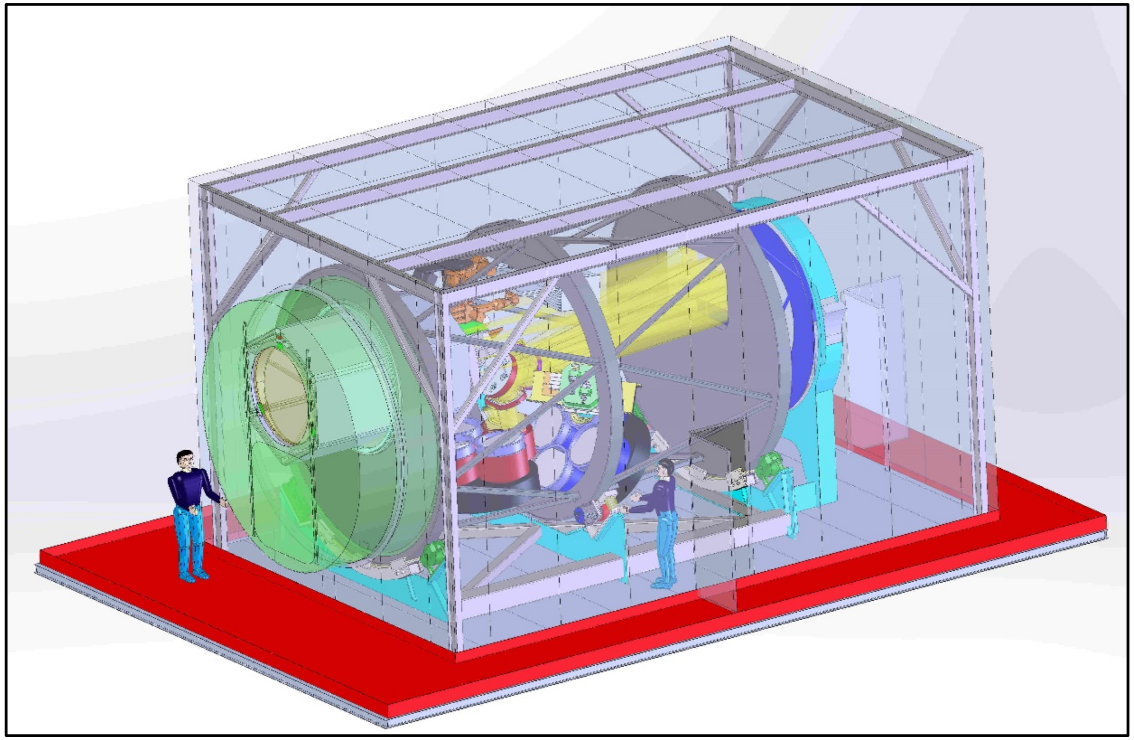


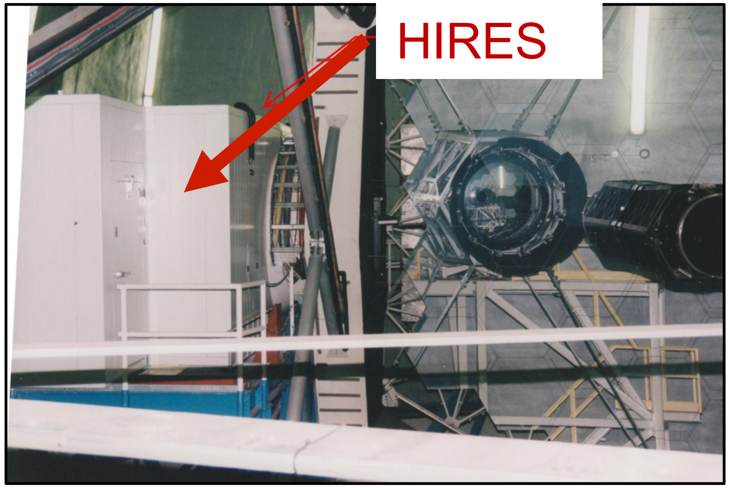


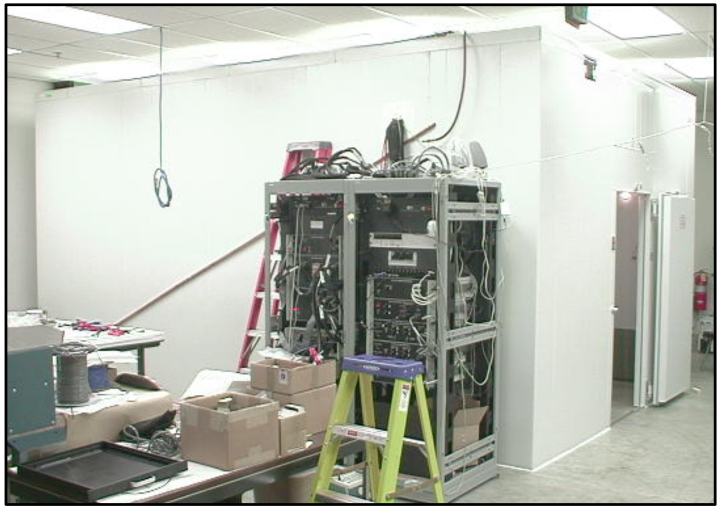
STR:

- Includes carriage, mainframe, rotation drives, seismic restraints. 2.5g (200y. earthquake) & 4.0g (1000y.)
- Heritage from IMACS carriage, structure, and support rollers (4m disks in MOBIE vs. 2m disks in IMACS)

ENC – Instrument Enclosures

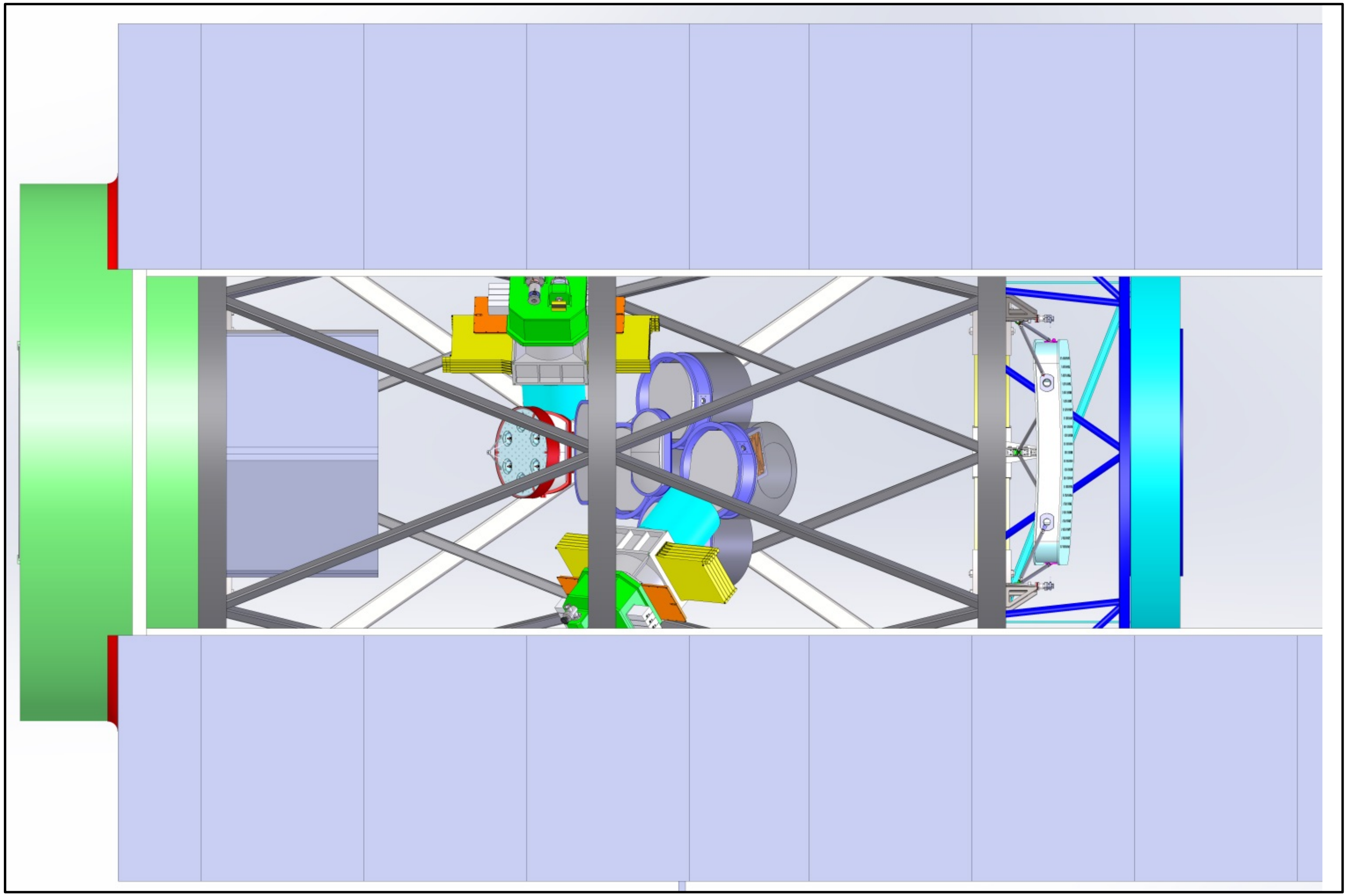






- Standard BMIL Bally enclosure with custom moment frame
- 15T mass (enclosure and moment frame)
- 7.2m x 6m x 9.1m (WxHxL)

ENC – Instrument Enclosures



Removable center panels in roof provide crane access for service.

Conclusions and Next Steps

- There are well-defined designs for all of the MOBIE subsystems, with some caveats:
  - Although heritage exists;
    - The CAM optical designs require updating and optimization
    - The MEX system requires a decision on location of the robot
    - The GEX system requires completion of the rotary stage designs or a 1-2 robot solution
    - Structure concept incomplete
    - Focal plane needs optimization (size and # of guiders and wave front sensors)
- The MOBIE subsystem conceptual designs are viable and most have heritage from instruments on the 6-10m telescopes
- Next steps for the MOBIE project conceptual design phase:
  - Assemble new team
  - MOBIE Mini-studies (May 2014-Dec. 2014)
  - Complete outstanding CDP work and hold the conceptual design review (Jan. 2015-Dec. 2015)
  - Start PDR phase (April 2016)

MOBIE Mini-Studies Team

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