OST Instruments Status

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OST Instrument Interface Meeting

June 13, 2017

OST F2F Meeting (Slides to be scrubbed – please check for a new version of these charts to be posted soon to confluence)

June 14-15, 2017

Instrument Accommodation Module (IAM) Overview

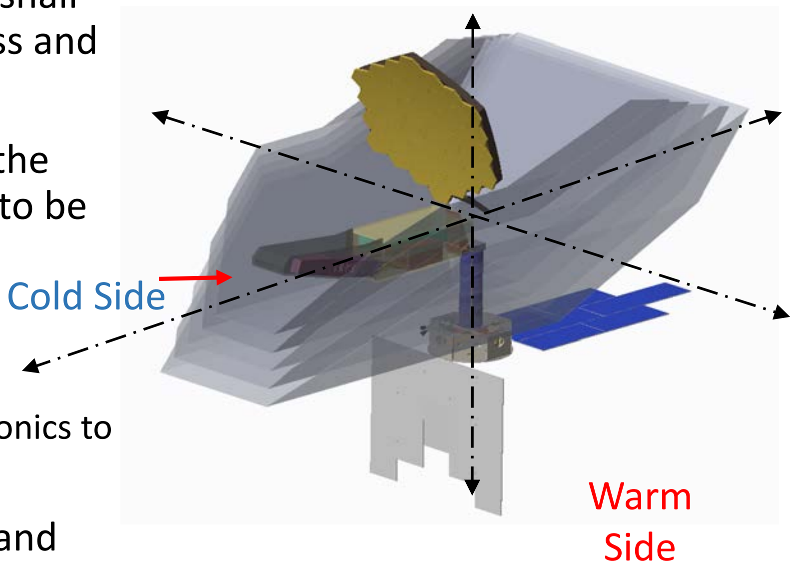
IAM Requirements

IAM Concept and Elements

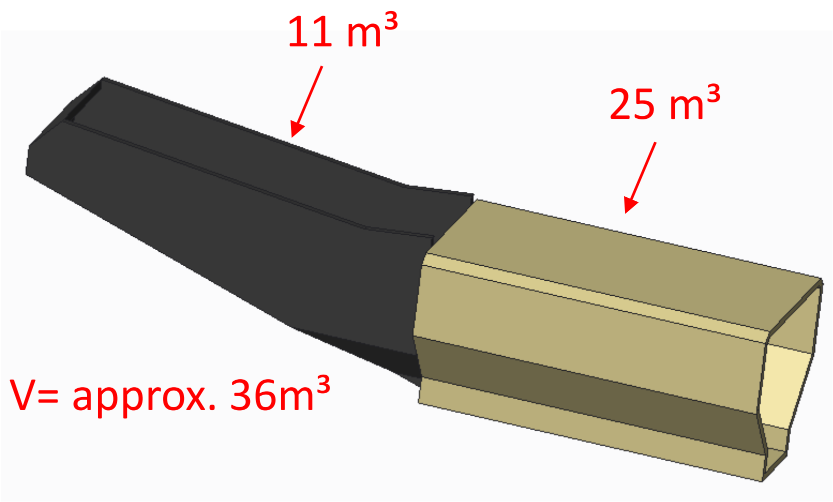
Instrument Resource Status

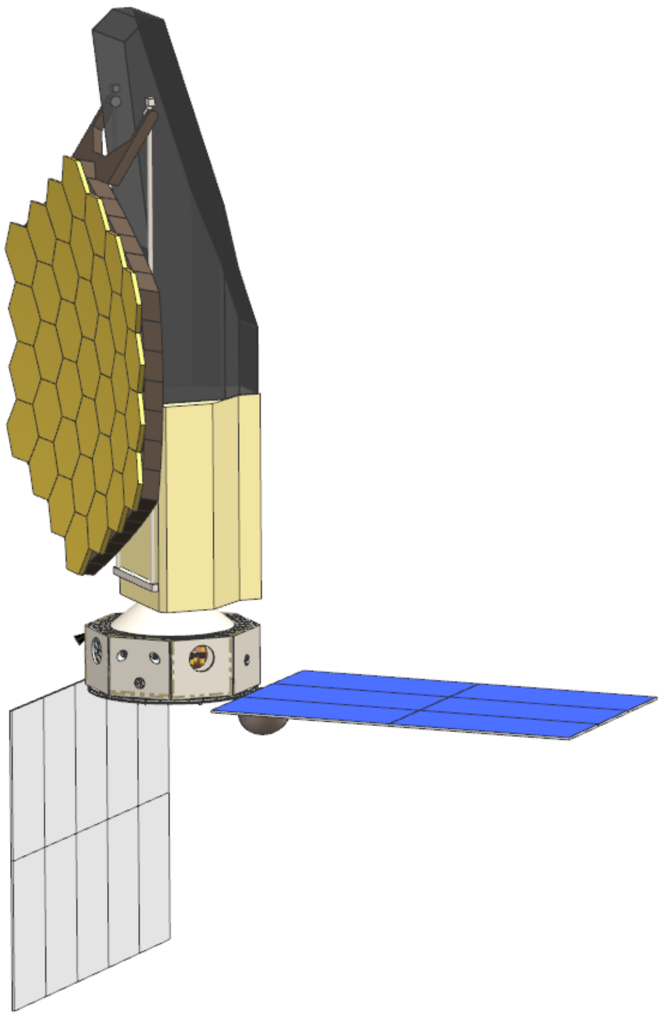
IAM Requirements

- Science instrument cooling to 4 K will be performed by the observatory
- Instrument focal plane cooling to sub K temperatures shall be performed by the instrument within its power, mass and volume allocations.
- Observatory will be provide a 20K region for some of the instrument electronics and hardware which will need to be physically closer to the IAM
- The observatory will provide accommodations on the warm/spacecraft side for instrument electronics.
  - IAM will be located within TBR distance to warm electronics to keep this distance as short as possible.
- The observatory will provide for science data storage and transmission to ground.
  - Detector electronics and data processing will (could) be shared for similar instruments such as HRS, FIP and MRSS.
- Instruments will be positioned within IAM based on their requirements for focal plane access, volume constraints and closer access to warm electronics/optics areas on spacecraft.

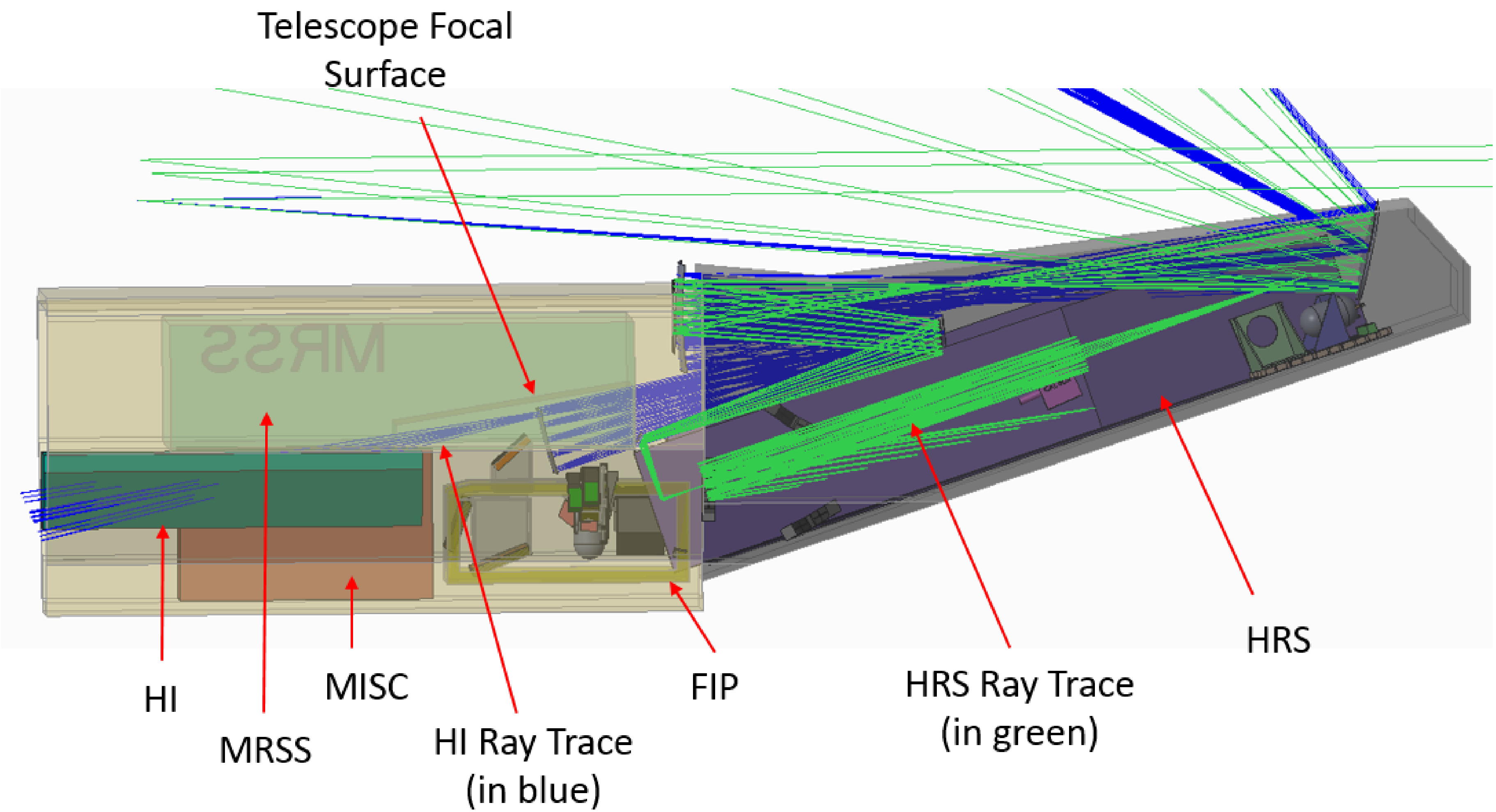


Instrument Volume Estimate

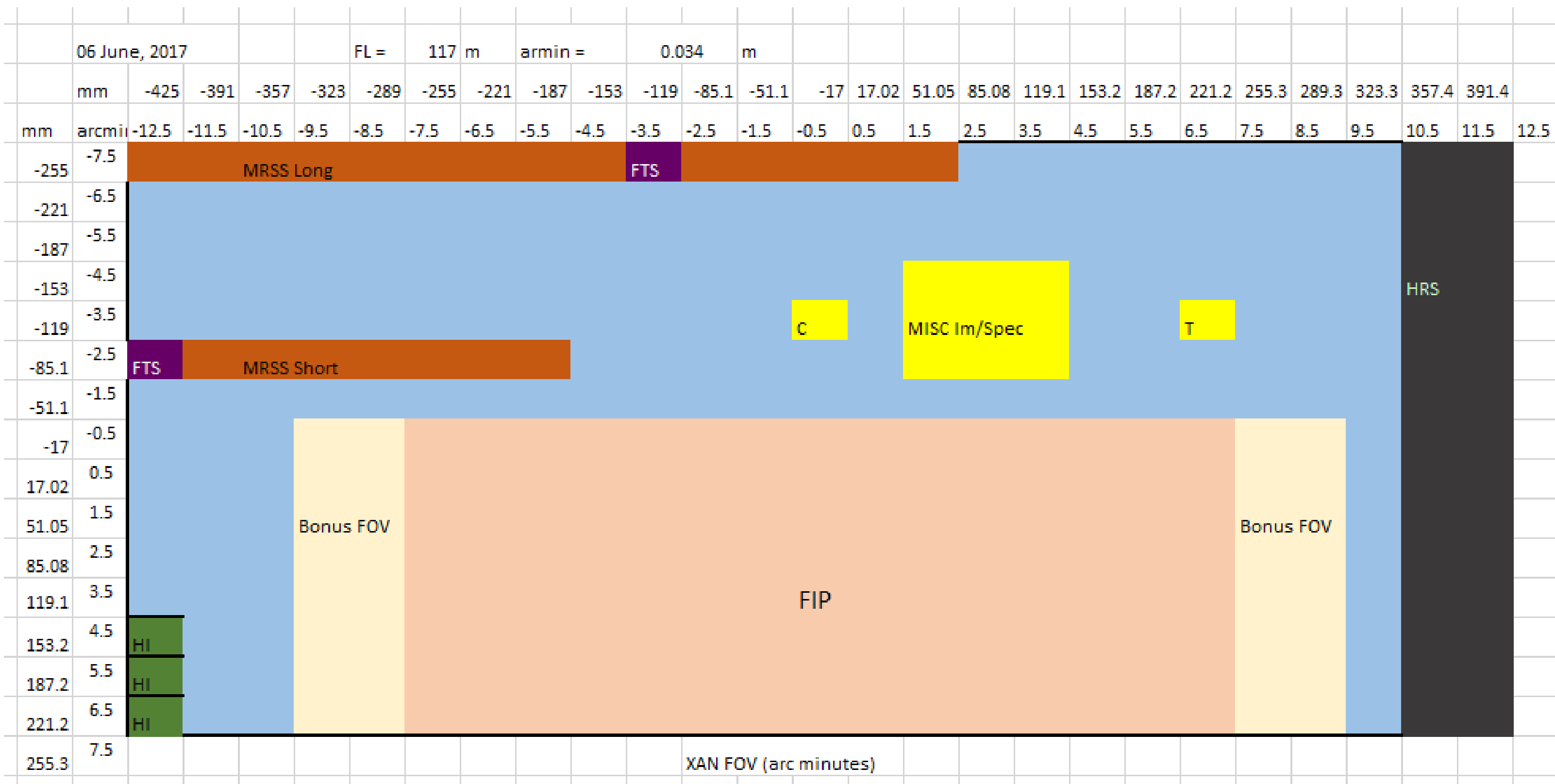


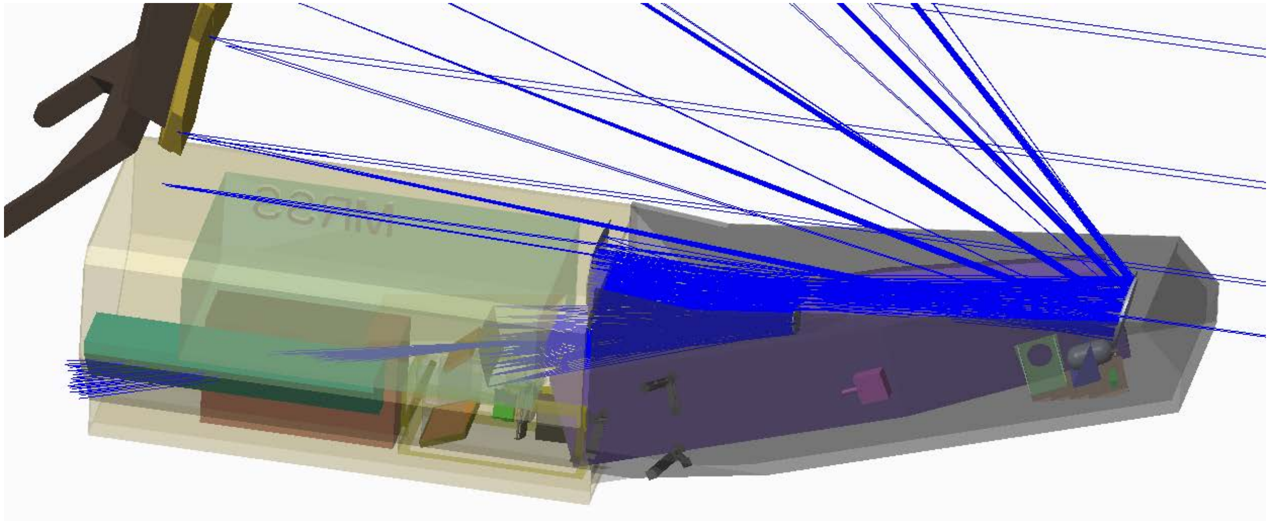


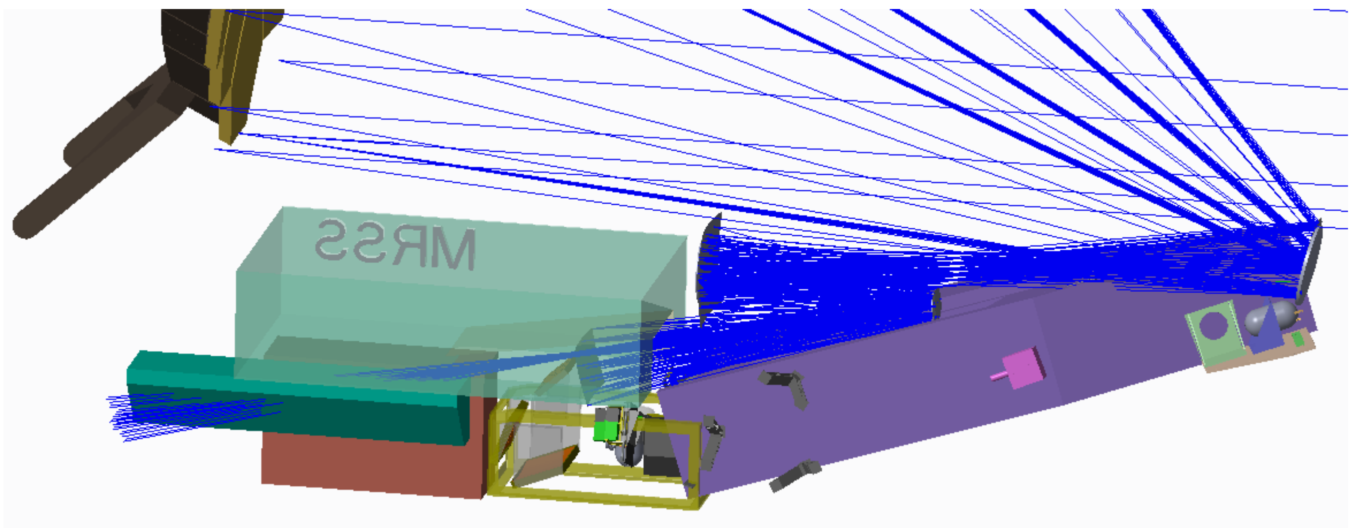
Instrument Accommodation Module (IAM)



Focal Plane Layout



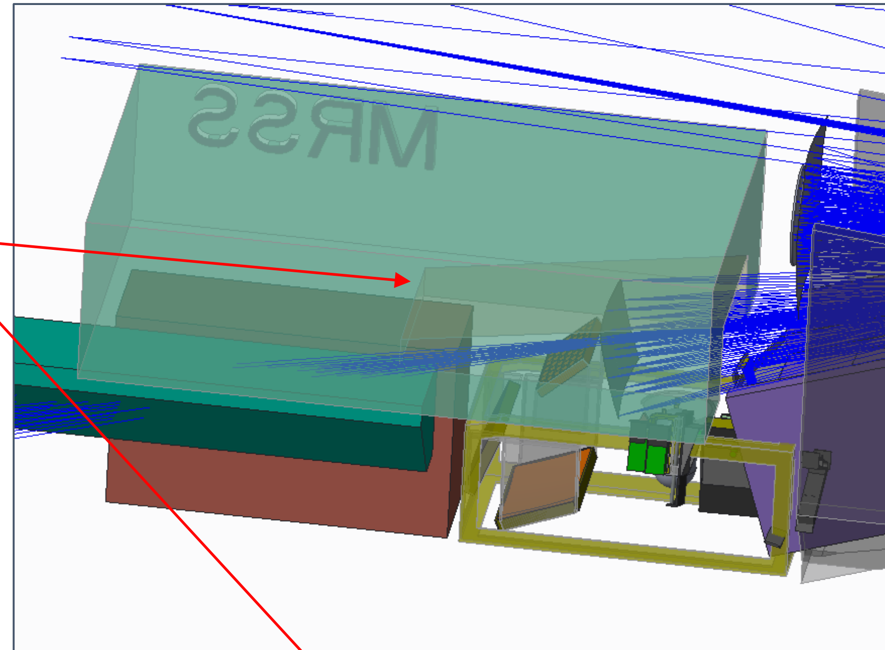

MRSS

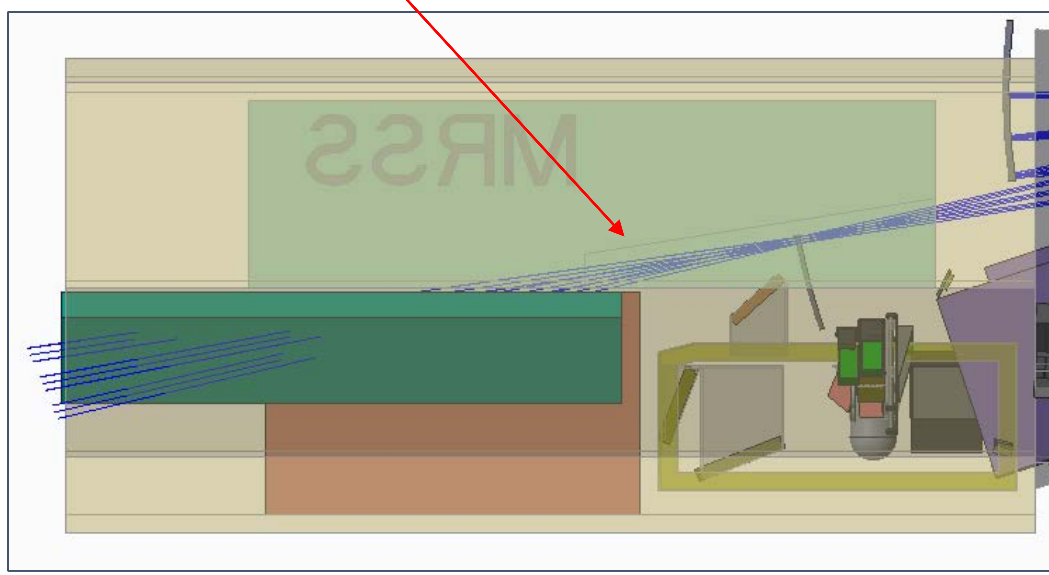

MRSS

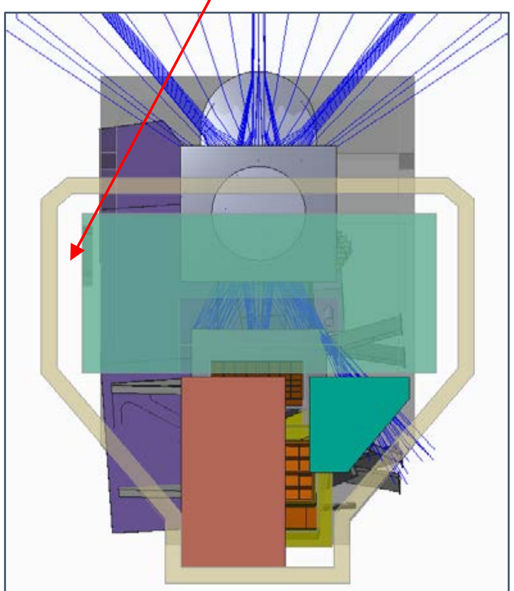
MRSS Instrument

Channel in MRSS for light rays to get to HI and MISC instruments. HI ray trace will be lowered.

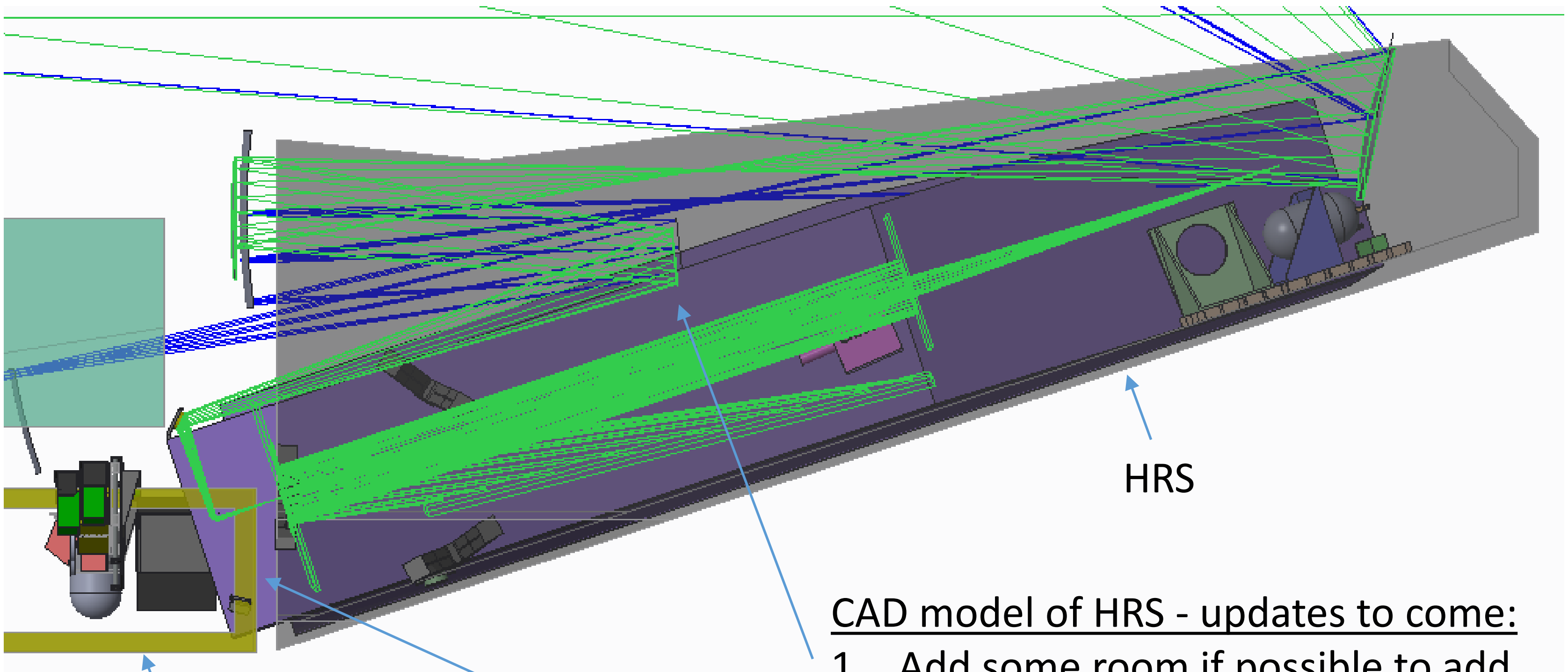
5 to 6 inch gaps to sides and top for mounts and harness.







HRS Instrument

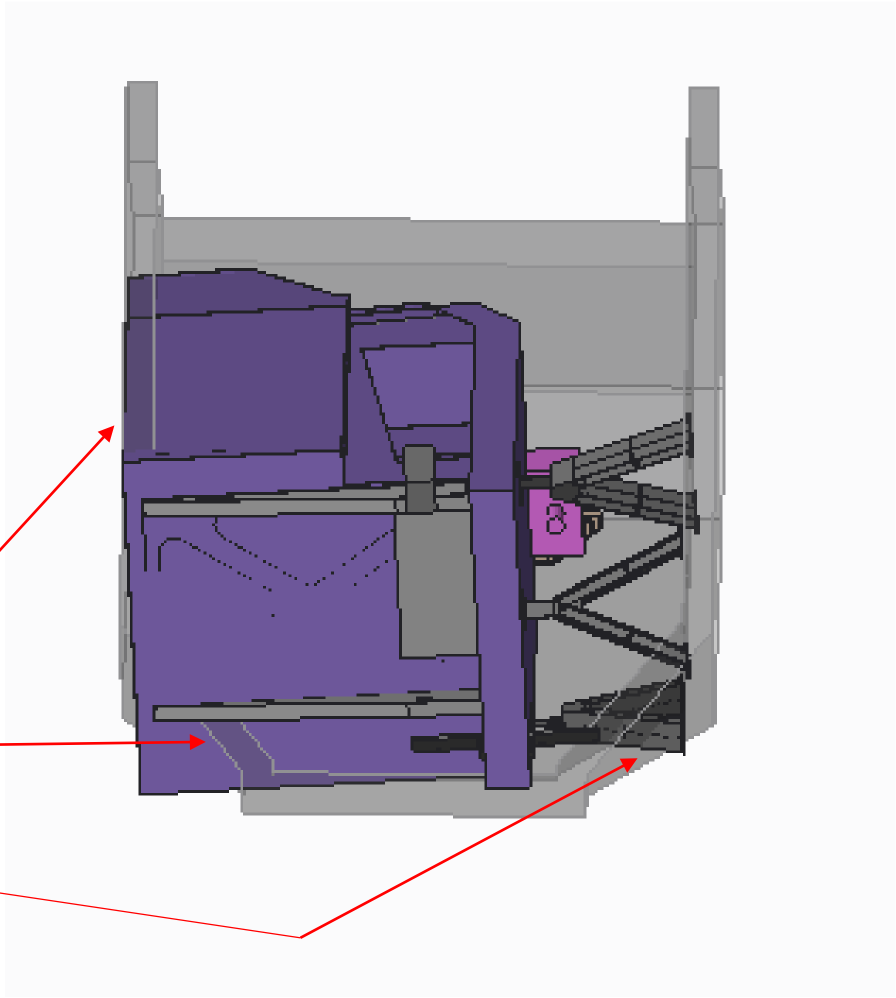


FIP

CAD model of HRS - updates to come:

1. Add some room if possible to add supports for Telescope Secondary Mirror
2. Update layout to eliminate interference with FIP

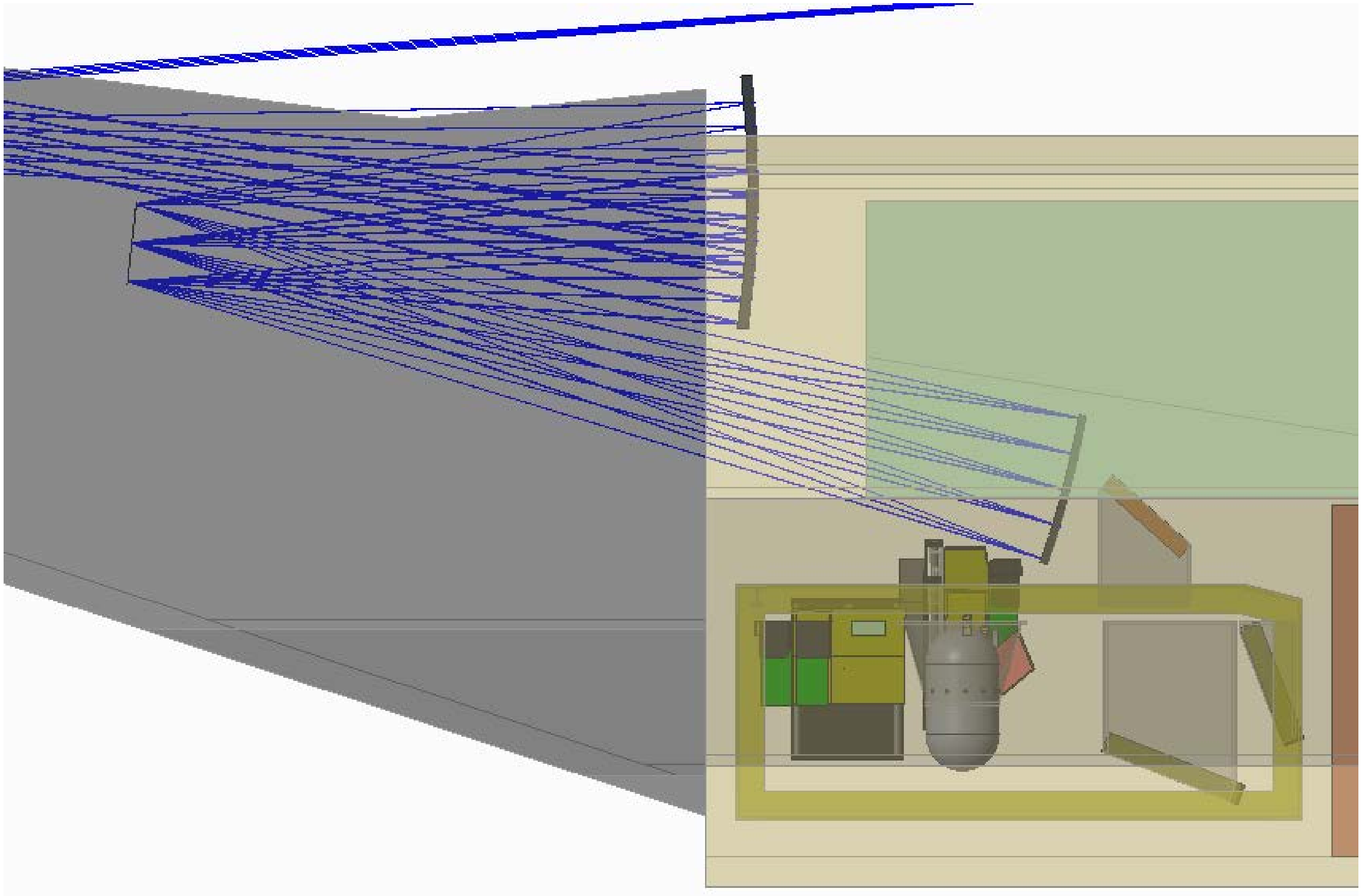
HRS Instrument



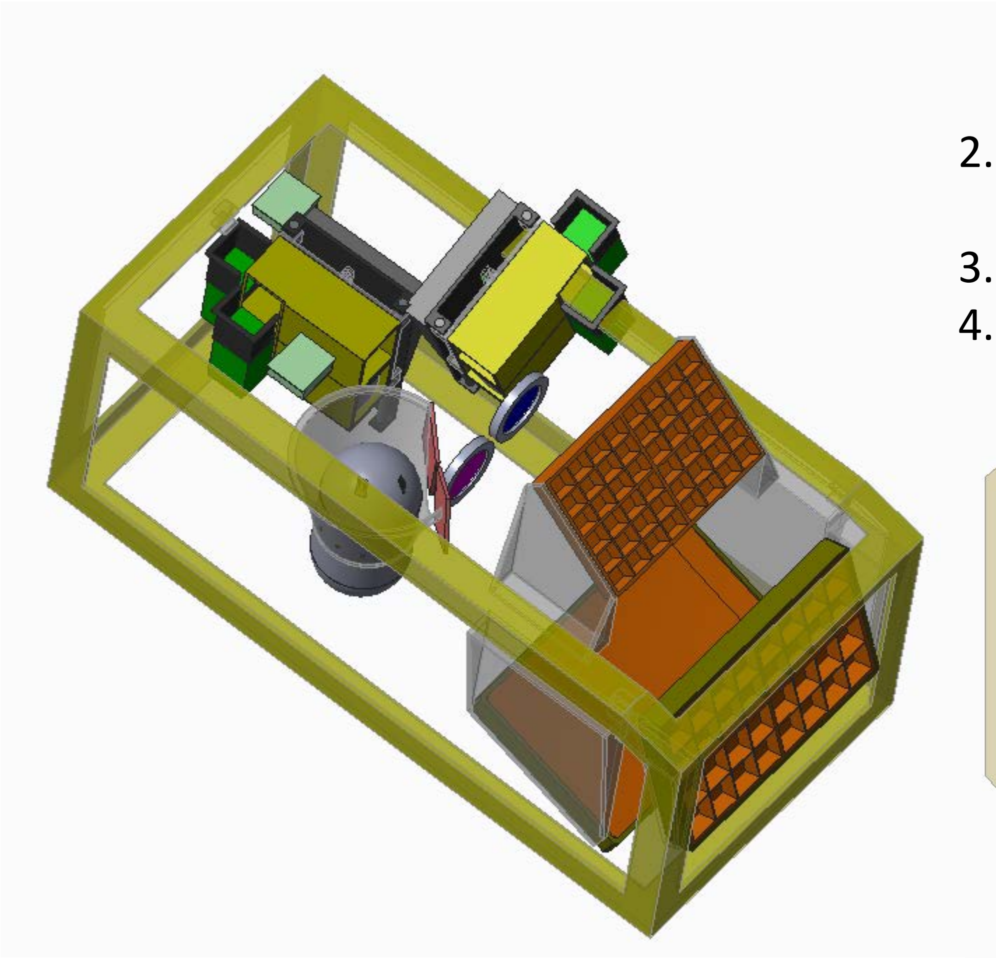
CAD model of HRS - updates to come:

1. HRS interferes with IAM housing in two places shown. Update HRS design.
2. Update strut designs to stay within IAM housing.
3. Fabry Perots being added to instrument.

FIP Instrument

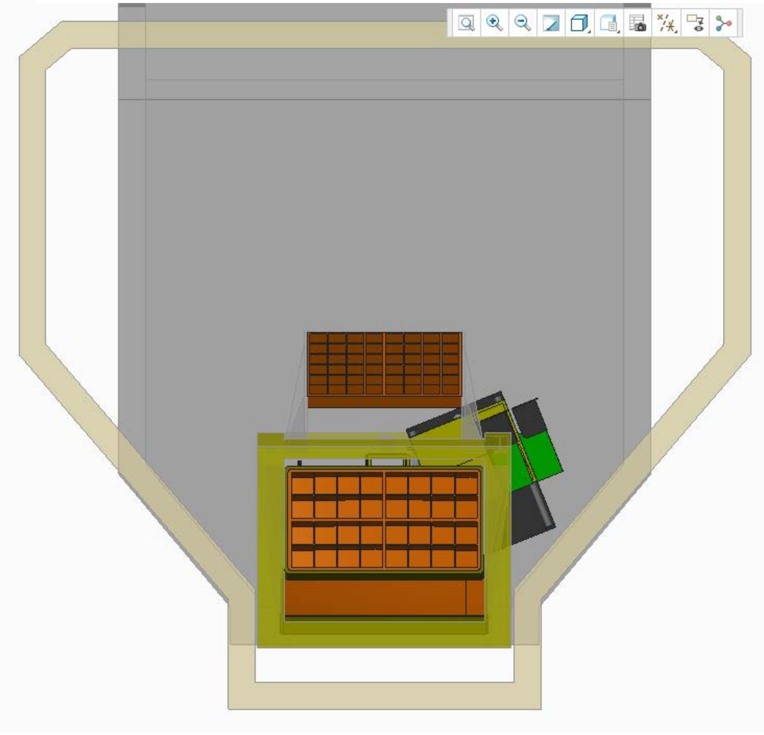


FIP Instrument

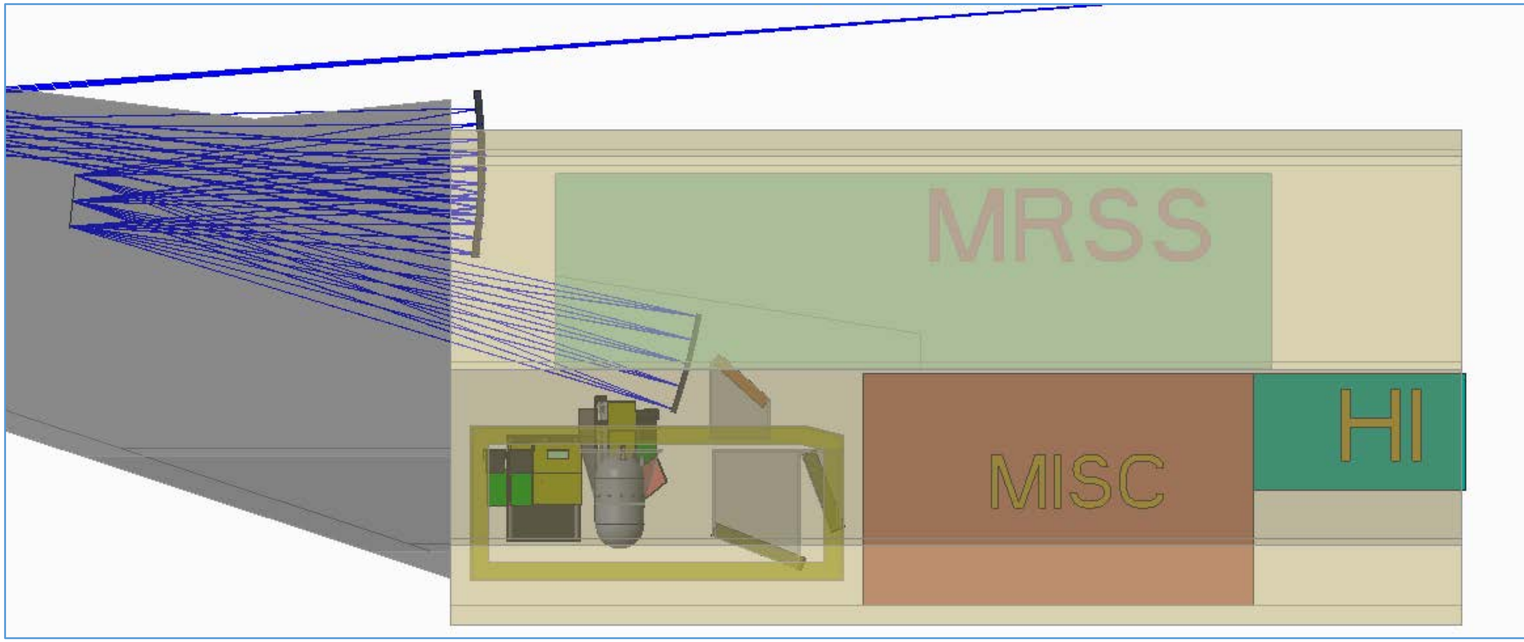


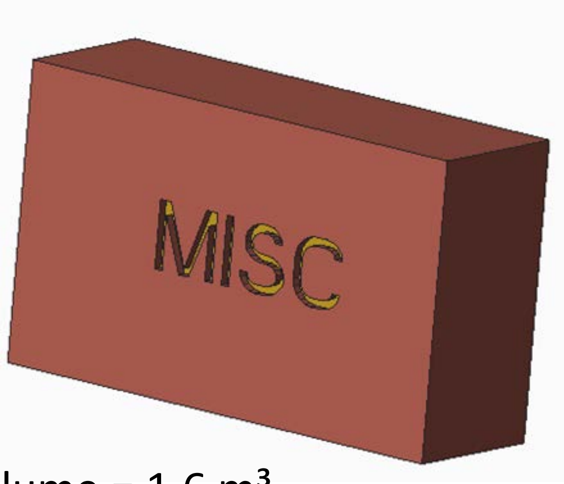
CAD model of FIP - updates to come:

1. Rearrange instrument contents to fit within IAM…on-going process.
2. Add mechanisms for mirrors and lenses.
3. Add in optical bench.
4. Update Frame.



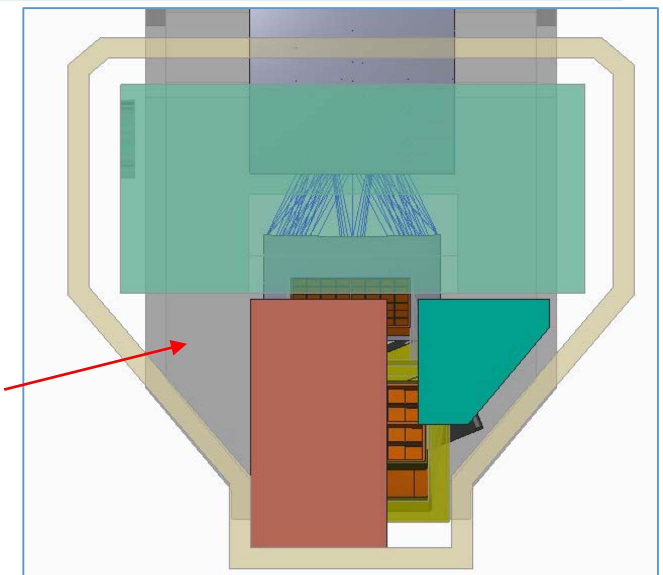
MISC Instrument





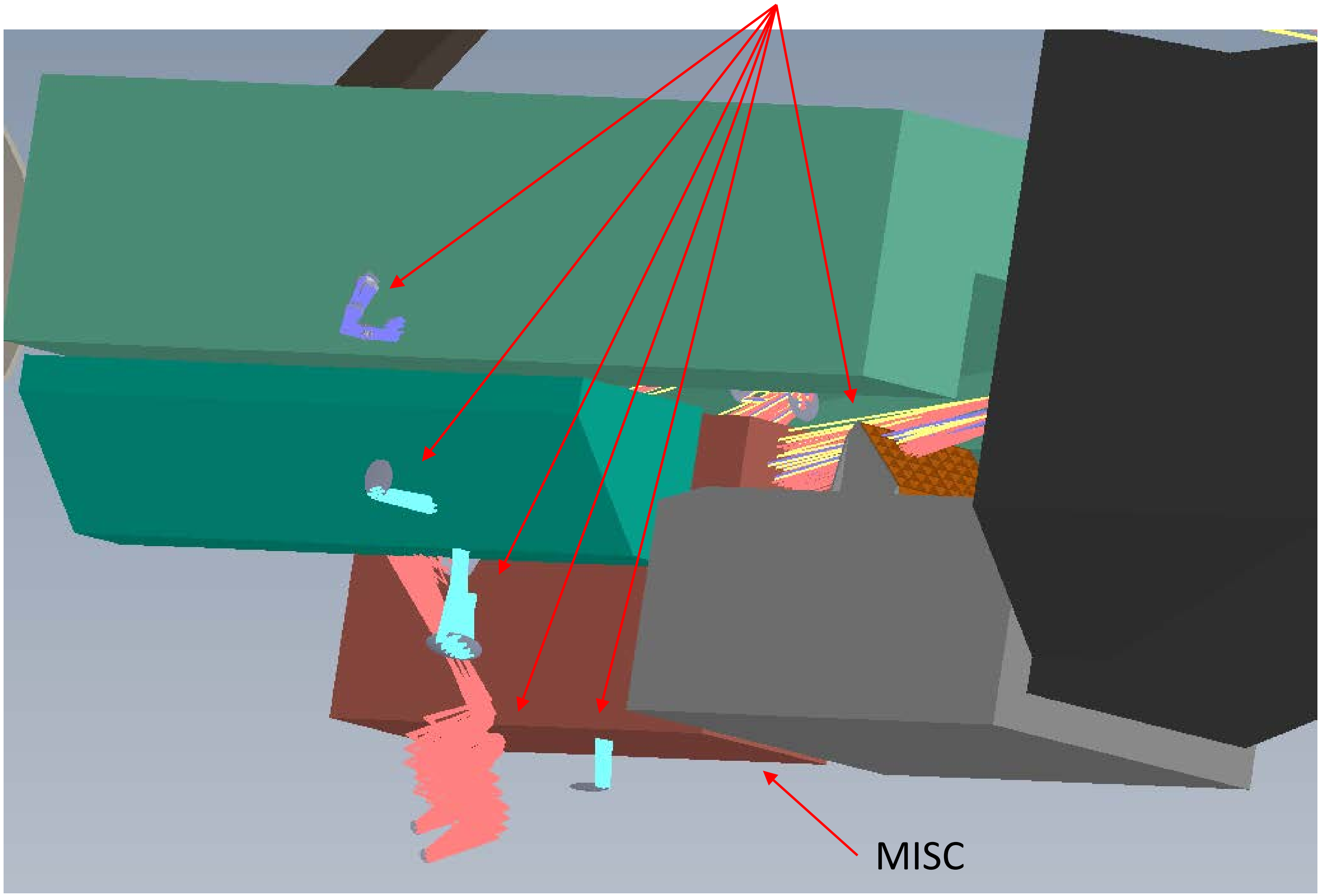
Volume = 1.6 m^3

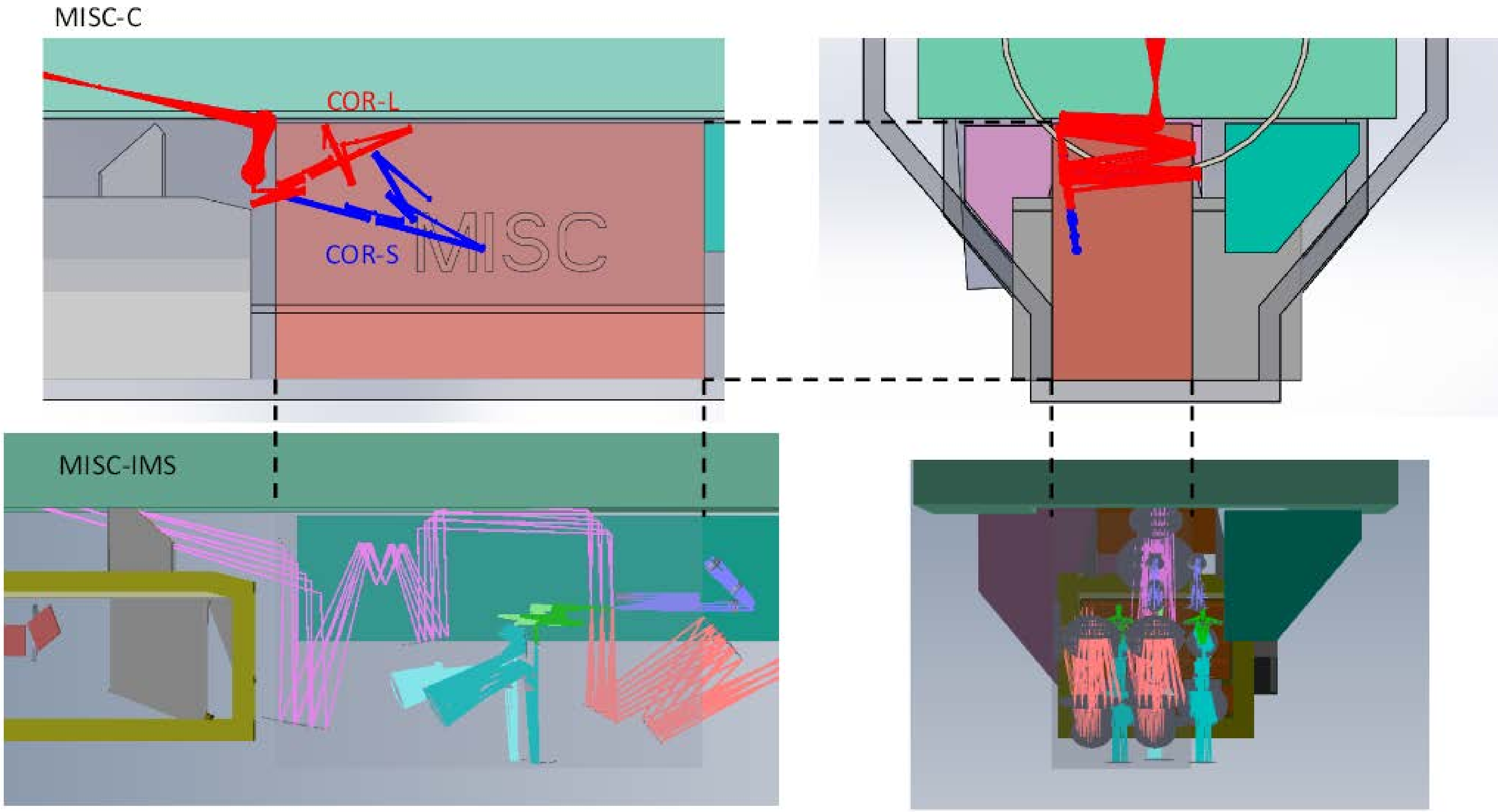
Potentially can use some of this volume if needed



MISC Instrument

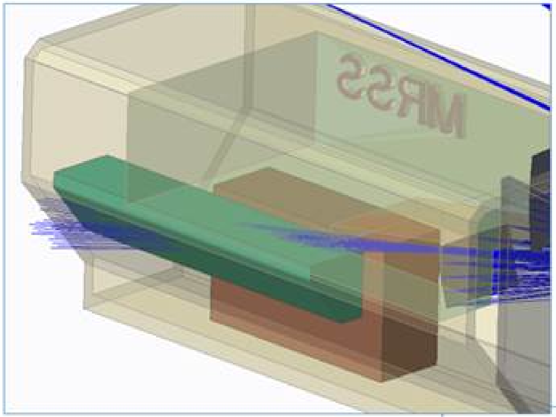
First-cut Ray Trace layout. Need to get optics and ray Traces inside MISC volume

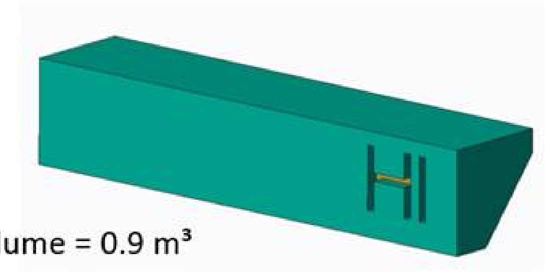




Updated from info on June 13th – Instrument Meeting

HI Instrument



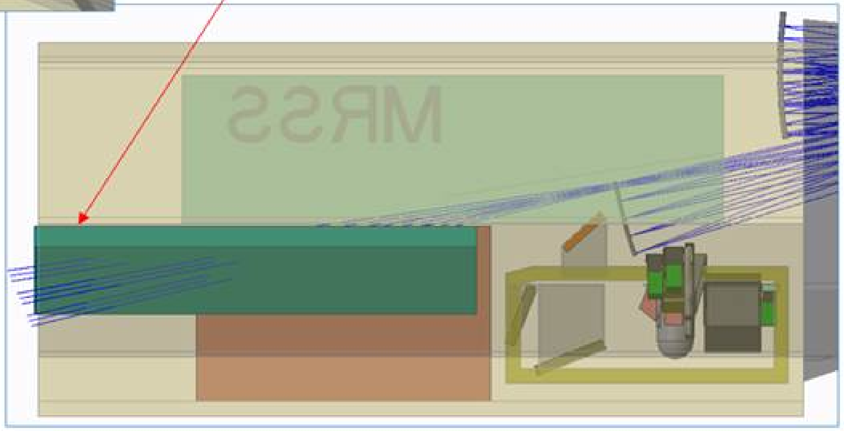


Volume = 0.9 m³

CAD model of HI - update to come:

Drop Ray Trace to lower-left on Telescope Focal Surface, and this will likely require HI to have a Pick-off Mirror at lower-front end to direct rays into instrument.

HI Instrument



Instrument Accommodations

Instrument Accommodation Requirements

Functional and Physical Interfaces

Open Instrument Issues

Traceability Summary

Driving Science Goals

- Tracing the Signatures of Life and the Ingredients of Habitable Worlds
- Unveiling the Growth of Black Holes and Galaxies over Cosmic Time
- Charting the Rise of Metals, Dust, and the First Galaxies
- Characterizing Small Bodies in the Solar System
- See Backup charts….

Required Instrument Specifications

Mid-Res Survey Spectrometer

Bandpass: 30 µm to 800 µm **(30 µm)**
Grating, R = 500; FTS, R=3000

Hi-Res Spectrometer (HRS)

Bandpass: 25 µm to 160 µm **(35µm)**
Resolution: 100,000 at 50 µm

Heterodyne Instrument

Bandpass: **63 µm** to 600 µm (63, 112,122, 157, 205,250-270, 500-600)
Resolution: 1.00E+08

Far-IR Imager/Polarimeter (FIP)

FIR Imaging (**40 µm** – 500µm)

Mid-IR Imager Spectrometer Coronagraph (MISC)

Bandpass: (5) 7 µm to 38 µm **(20 µm)**
Resolution: Various

OST Instrument Design Wavelengths

Telescope Specifications

Telescope:

FOV:
15 x 30 arcmin

Wavelength:
6 µm – 600 µm

Spatial resolution:
Diffraction limited at 20 – 40 µm

Telescope design:
9 meter off-axis (unobstructed view)Three-mirror anastigmat with fine steering mirror, 37 segments, 1.294 m segments

Operating temperature:
4 K

OST Instrument Summary

OST Instrument Inputs Summary

1	Name	Medium Resolution Survey Spectrometer (MRS)	HI-Res Spectrometer (HRS)	Heterodyn Instrument (HI)	FIR Imager / Polarimeter (FIP)	MID-IR Imager Spectrometer Coronagraph (MISC)
a	Study Lead	JPL	GSFC	Europe (France, CNES)	GSFC	JAXA
b	Science Lead	Lee Armus Alex Pope	Edwin Bergin	Maryvonne Gerin Gary Melnick	Joaquin Vieira Margaret Meixner Kate Su	Itsuki Sakon Kimberly Ennico Smith
c	Instrument Lead	Matt Bradford	S. Harvey Moseley	Martina Wiedner	Johannes Staghun	Tom Roellig
2	Optical Design Form	Offner relay	Synthetic Grating	relay	wide field relay	various
3	Bandpass (μm)	30 - 800	25 - 160	500-600, 250-270, 157, 205, 122, 112, 63	40 - 500	7 to 38
4	Design Wavelength (μm)	30	35	63	40	20
5	Spectral Resolution	Grating, R = 500: FTS, R=3000	100,000 at 50 μm	1.00E+08	-	various
6	Telescope Aperture (m)	>6	8	>10	9	11
7	Telescope Shape	circular preferred	circular	circular preferred	circular	circular (Coronagraph strongly prefers a circular aperture without obstruction by a secondary mirror nor support structures).
8	sensitivity or PSF shape?	sensitivity	-	both	-	shape
9	Telescope F/#	any	any	-	4	-
10	On vs Off-axis pupil ?	Off-axis (mild preference)	Neutral	Require small blockage; beware of standing waves	Off-axis pupil preferred; not required	Off-axis pupil preferrred, important for exoplanet observing
11	Full FOV	6 to 8 slits, 1x100 diff limited pixel samples	7 beams (spatial)	1 x 1 arcmin	30 x 30 arcmin	2 x 2 arcmin plus slits
12	Pixel Sampling	lambda/D requested	lambda / D at 50 μm	2 beams	0.9 lam/D	FWHM span 4 pixels in Coronagraph, 2 pixels in imager
13	Detector?	100 x 300 array of 100 micron pixels	10^5 pixels, 0.5 to 1mm pitch, arbitrary format	feed horns	large array of 0.5 mm pixels	1k x 1k array of 18 or 30 micron pix
14	Scanning?	2-3 arcmin scanning at instrument level; drift scanning of telescope over 10 deg	not a design driver	Drift scanning of telescope over degrees	1 square degree	N/A
15	Image quality	Diffraction limited at design wavelength	Diffraction limited at design wavelength	Diffraction limited at design wavelength	Diffraction limited at design wavelength	diff limited at 20 microns
16	Sensitivity	stray light < 4% emissivity of telescope	1/2 in-band background of R = 100,000	-	NEP 10e-19 W/sqrt(Hz)	Yes
17	Stability	modulate at 0.1 to 10 Hz	-	1/10 of one "beam" for pointing		3mas pointing, aided by internal tip/tilt mirror
18	Mechanisms?	FTS stage	-	chopping mirror	Scan mirror desired	DM for coronagraphy
19	Interfaces?	optical	2.5 meter grating	-	-	-
20	Special Considerations?	-	-	Local Oscillator	-	-
21	Detector driven beam steering?*					
	*What is the detector requirement to dithering?					
22	Anything Else?	-	Synthetic Grating is major development	-	-	-

See Details on following charts

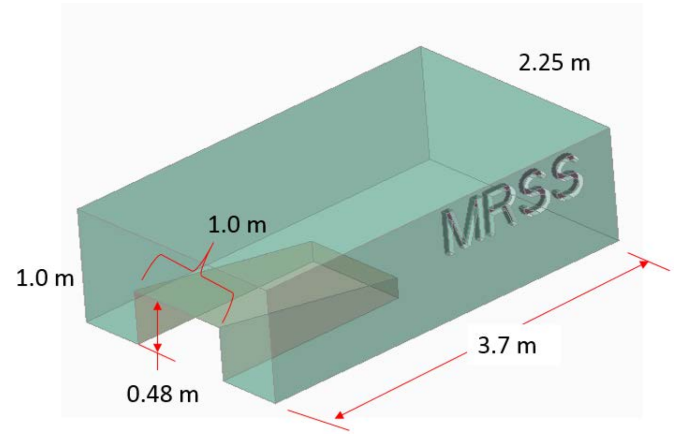
ORIGINS Space Telescope

OST Instrument Resource Allocation Guidelines, Notional Starting Points

Resource	Allocated Total for ALL 5 instruments	Current Total for all 5 Instruments	Basis	Comments
Mass	825 kg	2370 Kg	Mass available based on Vulcan-ACES LV capability to L2	165 kg average per instrument
Power Warm Side	600 W	TBD	Double JWST Inst. Power	Sharing vs. duty cycling TBD
Power Cold Side	100 mW	TBD	Based on initial thermal analyses	Short duration operations exceeding this may be allowed (e. g. mechanism operations)
Volume Warm Side	TBD	TBD		Need more detailed S/C bus layout
Volume Cold Side	11 m^3	TBD	Based on available volume in 5m fairing with 9m off-axis telescope aperture. 50% packing efficiency.	2.2 m^3 average per instrument. Highly dependent on instrument form factors and packaging.
Data Volume	235 Gbit/day	TBD	JWST Instrument Data Volume	
Wave-Front Error	921 nm	TBD	Initial optical error budget	

Medium Resolution Survey Spectrometer (MRSS)

1	Name	**Medium Resolution Survey Spectrometer (MRS)**
a	Study Lead	JPL
b	Science Lead	Lee Armus Alex Pope
c	Instrument Lead	Matt Bradford
2	Optical Design Form	Offner relay
3	Bandpass (µm)	30 - 800
4	Design Wavelength (µm)	30
5	Spectral Resolution	Grating, R = 500: FTS, R=3000
6	Telescope Aperture (m)	>6
7	Telescope Shape	circular preferred
8	sensitivity or PSF shape?	sensitivity
9	Telescope F/#	any
10	On vs Off-axis pupil ?	Off-axis (mild preference)
11	Full FOV	6 to 8 slits, 1x100 diff limited pixel samples
12	Pixel Sampling	lambda/D requested
13	Detector?	100 x 300 array of 100 micron pixels
14	Scanning?	2-3 arcmin scanning at instrument level; drift scanning of telescope over 10 deg
15	Image quality	Diffraction limited at design wavelength
16	Sensitivity	stray light < 4% emissivity of telescope
17	Stability	modulate at 0.1 to 10 Hz
18	Mechanisms?	FTS stage
19	Interfaces?	optical
20	Special Considerations?	-
21	Detector driven beam steering?*	



- Optical Traces being worked now, some initial work shared with optical team – making more compact.
- Focal Plane has gone through some iterations and we are settling on a path forward
- Team X Initial study complete
- Mass: 486-499 Kg (without and with high-res interferometer)
- Volume: 7.9 m^3, but space near focal plane most crucial.
- Power: 2400W
- Data Rate: 0.5 Gbits/s average

MRSS Configuration

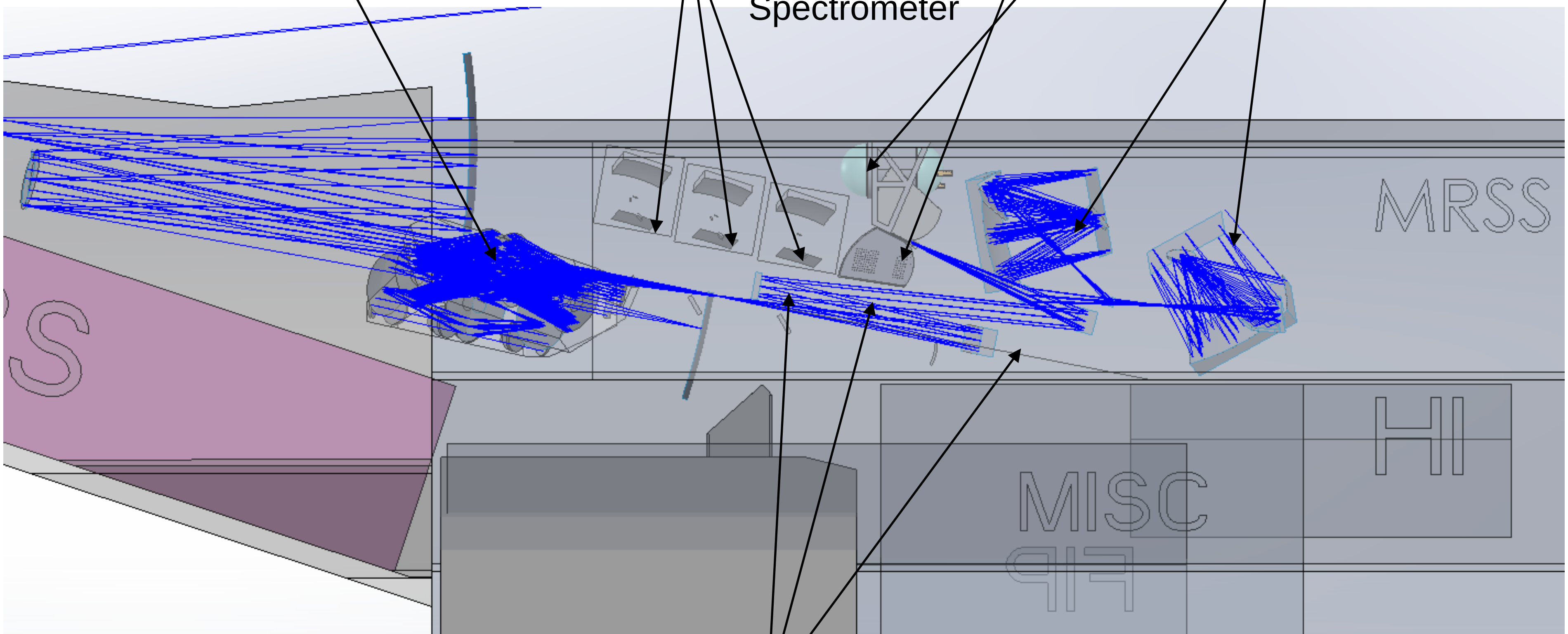
Long Wave & Short Wave Interferometers

Band 1, 2, 3 Spectrometers

Band 6 Waveguide Grating Spectrometer

ADR Cooler

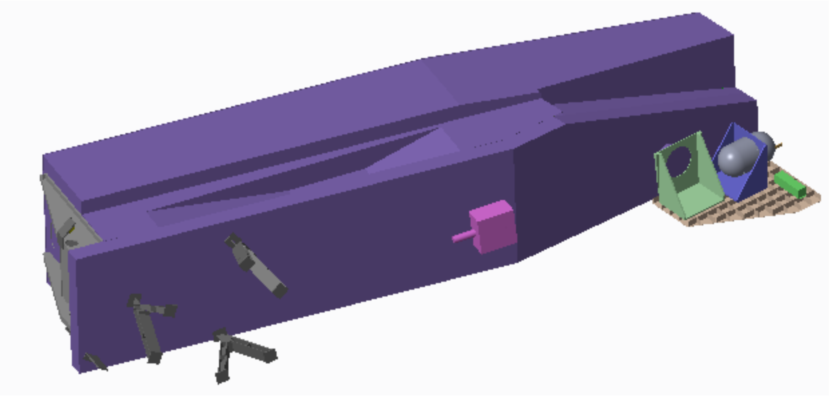
Band 4, 5 Spectrometers



Additional optical elements required to deliver beams to Band 1,2,3 Spectrometers need to be designed.

HI-Res Spectrometer (HRS)

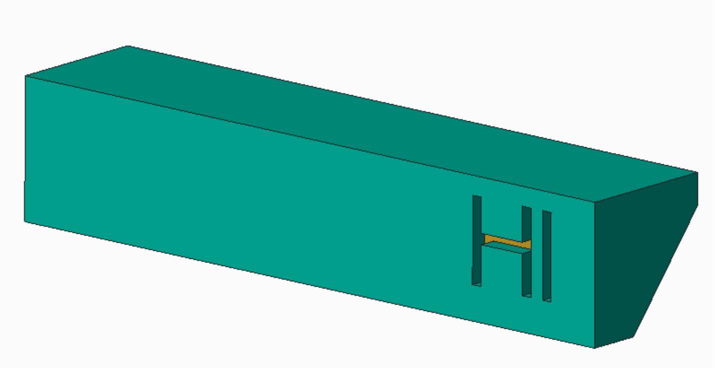
1	Name	**HI-Res Spectrometer (HRS)**
a	Study Lead	GSFC
b	Science Lead	Edwin Bergin
c	Instrument Lead	S. Harvey Moseley
2	Optical Design Form	Synthetic Grating
3	Bandpass (µm)	25 - 160
4	Design Wavelength (µm)	35
5	Spectral Resolution	100,000 at 50 µm
6	Telescope Aperture (m)	8
7	Telescope Shape	circular
8	sensitivity or PSF shape?	-
9	Telescope F/#	any
10	On vs Off-axis pupil ?	Neutral
11	Full FOV	7 beams (spatial)
12	Pixel Sampling	lambda / D at 50 µm
13	Detector?	10^5 pixels, 0.5 to 1mm pitch, arbitrary format
14	Scanning?	not a design driver
15	Image quality	Diffraction limited at design wavelength
16	Sensitivity	1/2 in-band background of R = 100,000
17	Stability	-
18	Mechanisms?	-
19	Interfaces?	2.5 meter grating
20	Special Considerations?	-
21	Detector driven beam steering?*	



- Mass being worked, initial mass estimates need to be scrubbed
- Optical layout not completed, being worked as well as integration of model with IAM model
- IDL completed and results need to be reviewed and continued to be worked by team
- Mass: 936 Kg
- Volume: 6 m^3
- Power: 599W
- Data Rate: 12 Mbps average, 480 Mbps peak

Heterodyne Instrument (HI)

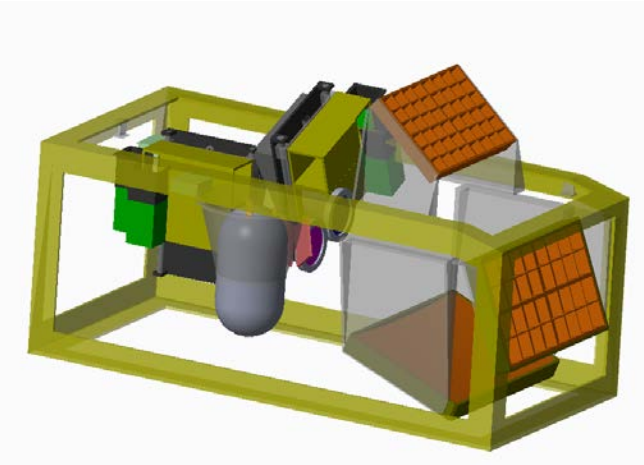
1	Name	**Heterodyn Instrument (HI)**
a	Study Lead	Europe (France, CNES)
b	Science Lead	Maryvonne Gerin Gary Melnick
c	Instrument Lead	Martina Wiedner
2	Optical Design Form	relay
3	Bandpass (µm)	500-600, 250-270, 157, 205, 122, 112, 63
4	Design Wavelength (µm)	63
5	Spectral Resolution	1.00E+08
6	Telescope Aperture (m)	>10
7	Telescope Shape	circular preferred
8	sensitivity or PSF shape?	both
9	Telescope F/#	-
10	On vs Off-axis pupil ?	Require small blockage; beware of standing waves
11	Full FOV	1 x 1 arcmin
12	Pixel Sampling	2 beams
13	Detector?	feed horns
14	Scanning?	Drift scanning of telescope over degrees
15	Image quality	Diffraction limited at design wavelength
16	Sensitivity	-
17	Stability	1/10 of one "beam" for pointing
18	Mechanisms?	chopping mirror
19	Interfaces?	-
20	Special Considerations?	Local Oscillator
21	Detector driven beam steering?*	



- Some initial design details have been sent
- Volume being reserved and optical team is making some assumptions for pickoff for now
- Special requirement for an optical path from warm selection of electronics to IAM
- Mass: 383kg +26kg
- Volume: ~ 1 m^3
- Power: 704 W
- Data Rate:

FIR Imager / Polarimeter (FIP)

1	Name	**FIR Imager / Polarimeter (FIP)**
a	Study Lead	GSFC
b	Science Lead	Joaquin Vieira Margaret Meixner Kate Su
c	Instrument Lead	Johannes Staghun
2	Optical Design Form	wide field relay
3	Bandpass (µm)	40 - 500
4	Design Wavelength (µm)	40
5	Spectral Resolution	-
6	Telescope Aperture (m)	9
7	Telescope Shape	circular
8	sensitivity or PSF shape?	-
9	Telescope F/#	4
10	On vs Off-axis pupil ?	Off-axis pupil preferred; not required
11	Full FOV	30 x 30 arcmin
12	Pixel Sampling	0.9 lam/D
13	Detector?	large array of 0.5 mm pixels
14	Scanning?	1 square degree
15	Image quality	Diffraction limited at design wavelength
16	Sensitivity	NEP 10e-19 W/sqrt(Hz)
17	Stability	
18	Mechanisms?	Scan mirror desired
19	Interfaces?	-
20	Special Considerations?	-
21	Detector driven beam steering?*	

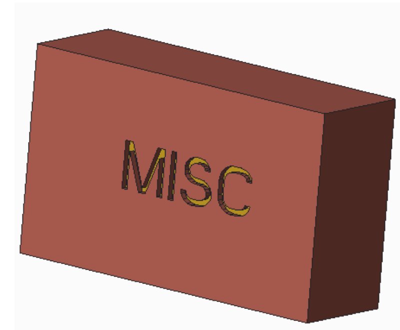


- Optical Traces and CAD model are integrated into IAM
- MEL is being developed
- IDL complete and results will to be refined as design develops
- Mass: 508 Kg
- Volume: 2m^3
- Power: 1804W
- Data Rate: 50Mbps average, 10Gbps peak

ORIGINS Space Telescope

MID-IR Imager Spectrometer Coronagraph (MISC) – one option shown

1	Name	**MID-IR Imager Spectrometer w/Coronagraph (MISC)**
a	Study Lead	JAXA
b	Science Lead	Kimberly Ennico Smith
c	Instrument Lead	Tom Roellig/Itsuki Sakon
2	Optical Design Form	various
3	Bandpass (μm)	7 to 38
4	Design Wavelength (μm)	20
5	Spectral Resolution	various
6	Telescope Aperture (m)	9
7	Telescope Shape	circular (Coronagraph strongly prefers a circular aperture without obstruction by a secondary mirror nor support structures).
8	sensitivity or PSF shape?	shape
9	Telescope F/#	-
10	On vs Off-axis pupil ?	Off-axis pupil preferrred, important for exoplanet observing
11	Full FOV	3 x 3 arcmin plus slits
12	Pixel Sampling	FWHM span 4 pixels in Coronagraph, 2 pixels in imager
13	Detector?	1k x 1k array of 18 or 30 micron pix
14	Scanning?	N/A
15	Image quality	diff limited at 20 microns
16	Sensitivity	Yes
17	Stability	3mas pointing, aided by internal tip/tilt mirror
18	Mechanisms?	DM for coronagraphy and MIR Imager and Spectrometer, plus tip-tilt mirror
19	Interfaces?	-
20	Special Considerations?	-
21	Detector driven beam steering?*	



- Optical Traces being worked work has been shared with optical team
- Focal Plane has gone through some iterations and we are settling on a path forward
- Volume is current being exceeded, but we are working with MISC to resolve
- Excellent webpage, content provided describing design
- Mass: 108 Kg
- Volume: .85 m^3
- Power: 242 W
- Data Rate:

Instruments Summary Table

OST Instrument Specification and Accomodation Requirements													
Instrument	Quanity	CBE Mass (kgs)	Total Mass (Kgs)	CBE Power (W)			Operating Duty Cycle(%)	Data Rate		Data Interface	Dimension (m) L x W X H	Volume (m³)	Temperature
				Average	Peak	Standby		Average	Peak				Operating
Med-Resolution Survey Spectrometer (MRS)	1	435	435	2200				0.5 Gbit/sec					
Cold Side											2.5 x 2 x 2	~10	
Grating & Array Packages													
Interferometers													
Warm Side													
TBD													
Heterodyne Instrument (HI)	1	383	383	704								~1	
Cold Side	1	165											
Focal Plane Unit	1	128											
Local Oscillator Unit	1	25											
IF Unit	1	12											
Warm Side	1	218		704									
FPU Control Unit	1	50		74									
LO Unit Warm (multipliers, amplifiers)	1	55		128									
LO Control Unit (bias electronics)	1	25		10									
LO Source Unit	1	40		60									
FFTS	1	28		384									
Instrument Control Unit	1	20		48									
Far-IR Polarimeter/ Imager (FIP)	1		507.62	1804.1				50 Mbps	10 Gbps			~2	
Cold Side Instrument	1		326.6								2 x 1 x 1		4K
Detectors/Pre-amps at 4K	1			0.03									<0.1 K
HEMT Amplifiers (20K)	1			0.09									20K
Warm Side Electronics/Components			137.69	1804									
MEB	2												~300 K
FPE	2												
RF Box	1												
ADRC	1												
Harnesses	1		43.33										
Mid-infrared Imager, Spectrometer, Corornagrapgh (MISC	1	107.9	107.9	242							2 x 1.6 x (0.1 - 0.4)	~0.85	
Cold Side			71.9										
Mid-Infrared Imager and Spectrometer Channel	1	40.6	40.6										
Mid-Infrared PIAACMC Coronograpgh Channel	1	24.3	24.3										
Mid-Infrared Transit Spectrometer Channel	1	7	7										
Warm Side Electronics			36	242									
Mid-Infrared Imager and Spectrometer Channel	1	22	22	127									
Mid-Infrared PIAACMC Coronograpgh Channel	1	10	10	109									
Mid-Infrared Transit Spectrometer Channel	1	4	4	6									
High Res Spectrometer (HRS)	1	936.5	936.5	599.1				12 Mbps	480 Mbps		~1 x ~1.5 x ~5	~6	
Cold Side													<4 K
Detectors/Pre-amps at 2K				0.021									<0.1 K
HEMT Amplifiers (20K)				0.06									20K
Warm Side				599									~300 K
MEB													
FPE													
RF Box													
ADRC													
Total			2370.0		0	0						~22 - 25	

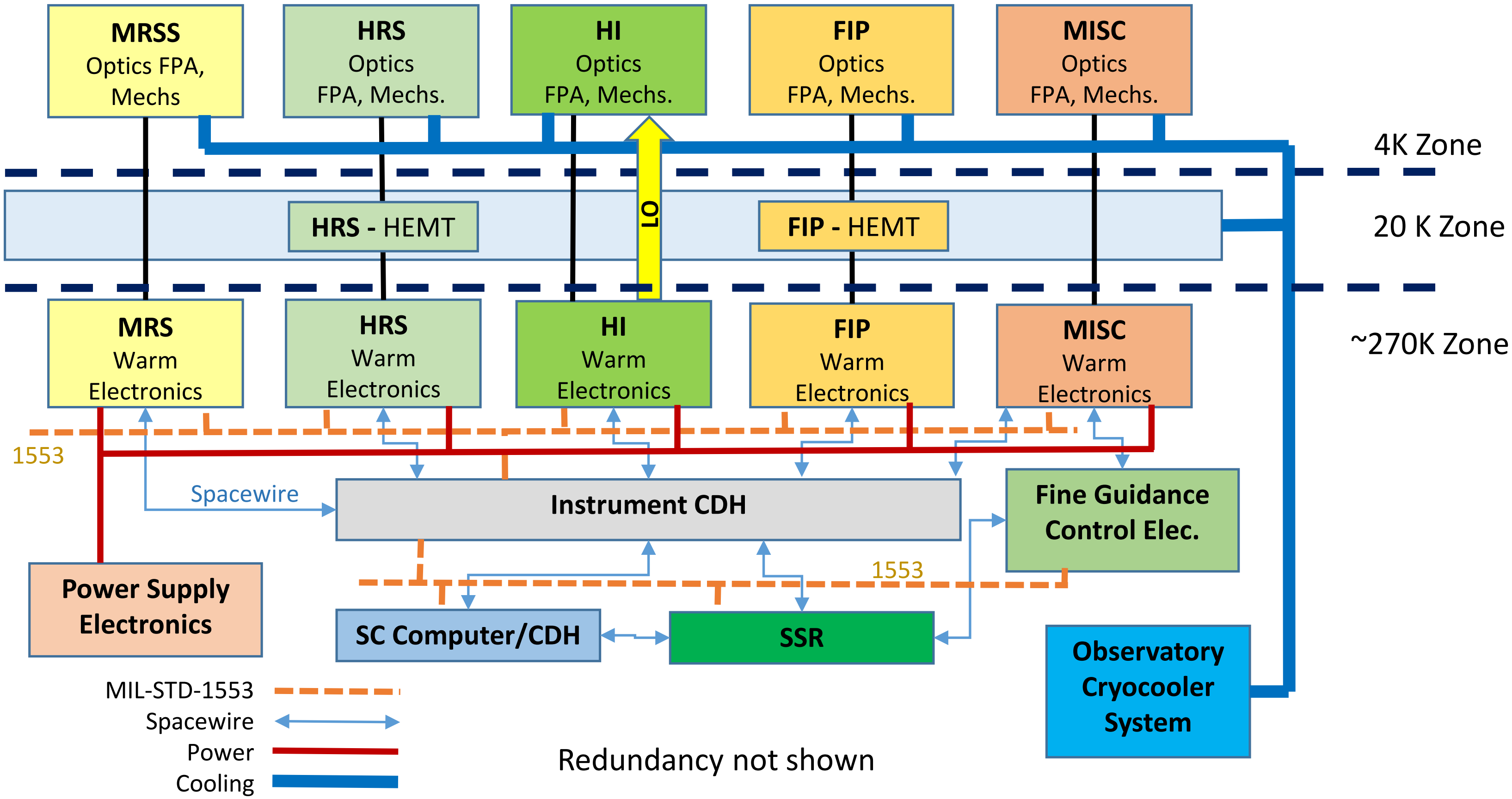
Instrument Mass Summary

Item	Mass Estimate (kg)	Comments
Instruments (Total of 5)	**2370**	**Initial allocation total of ~825 or ~165 kg per instrument**
FIR Imager/Polarimeter (FIP)	508	Mass being reduced as we work the MEL
Hetrodyne Instrument (HI)	383	Martina's Estimate
High Resolution Spectrometer (HRS)	936	Initial IDL's mass estimate
Medium Resolution Survey Spectrometer (MRSS)	435	Initial Estimate from JPL Team X study provided by Mike Dipirro
MID-IR Imager Spectrometer Coronograpgh (MISC)	108	Initial estimate from Itsuki Sakon, March 2017 F2F meeting

~ 77kg increase due to MRSS increasing and HI increasing

~2447 Kg is the new total

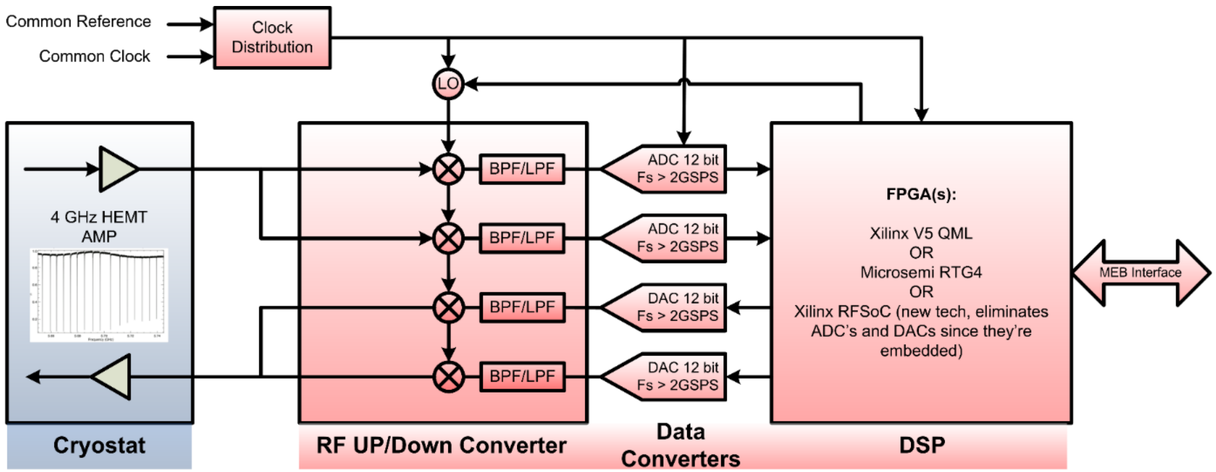
OST Instrument Block Diagram



4 GHz, TRL-4/5 Hardware (DSP System)

Dr. Damon Bradley
Code 564 DSP Technology Group

Power requirements for digital processing are coming in very high, Damon is looking at technology to help reduce the power needs and get our power estimates down from 5-6kW to 1.5-2kW for digital processing. (Details are in backup charts)



- Proposed architecture: Scalable Digital Backend Processor Card
  - One per 4 GHz, or 1600 resonators
  - Common clock and reference signals distributed across cards
  - Use the worst-case number of cards (MRSS) for OST, and share across 3 instruments
  - Use New TI JESD204B High-Speed data converters (dual 3.2GHz/Single 6.4 GHz)
  - Use Xilinx V5 QML Part on SpaceCube and GEDI Instrument
- One Card has the complexity of GEDI Lidar Instrument electronics

Issues/Challenges

- Instrument packaging is still a challenge
  - Providing all 5 instruments access to the focal surface is probably doable, but difficult.
- Instrument mass is higher than allocation
- Instrument volume is being exceeded in current volume allocated for IAM
- Heterodyne Local Oscillator requires path from warm to cold side
- Still working Optical Paths and CAD models for several instruments – they need to be integrated by IAM IDL Study

Near Term Path Forward

- Continue to gather and refine instrument designs and interface information
- Optimize instrument layout
  - Package the 5 instruments into the allowable volume
  - Define optical pickoffs for each instrument
- Determine warm side volume available for instrument electronics
- Complete Optical layout for IAM based on instrument payload determined by science trades
  - Could consider larger launch vehicle solution, instrument refinements, instrument de-scopes, etc.
- Understand Con Ops and refine trade for allocation of power and data rates

Backup

OST Overview

- OST – Origins Space Telescope
- NASA flagship class mission concept for the 2020 Decadal review
  - 6 µm – 600 µm (diffraction limit around 20-40 µm)
  - 4 K actively-cooled 8-13m aperture operating at L2
  - large gain in sensitivity => new spectroscopic capabilities
  - exoplanet study capabilities via a mid-IR coronagraph
  - modular instrument suite with robotic serviceability at L1
  - Mission aimed at mid 2030s: post JWST, concurrent with WFIRST, Athena, LISA, and 25m-35m ground-based optical/IR facilities.
  - Science goals and measurement requirements in 2030+
  - Serviceable and upgradable
- Mission Schedule:
  - New mission start after WFIRST launch (~2024)
  - Launch 2030-2035
  - Cruise ~30 days to SEL2 halo orbit
  - Mission Class A Risk Classification
  - Instrument Nominal Operations – 5 years nominal
- Target launch vehicle: Vulcan Aces or similar
- LV Fairing Size: 5-m Atlas V fairing or similar

OST Optical Overview

- **OST Instrument Design Wavelengths:**

1) Far Infrared Imager / Polarimeter (FIP): 40 µm
2) Heterodyne Instrument (HI): 63µm
3) High-Resolution Spectrometer (HRS): 35µm
4) MID-IR Imager Spectrometer Coronagraph (MISC): 20 µm
5) Medium Resolution Survey Spectrometer (MRSS): 30 µm

- **Telescope:**

1) Off-axis, Unobstructed
2) Aperture Diameter: 9.1-m
3) Number of Segments: 37
3) Mirror Segment Size: 1.294 m
4) Temperature: 4 K

Instrument Requirements

Science Case	Measurement Requirements	Instrument Requirements	Instrument(s)
19, Rise of Metals, Dust, and the First Galaxies Trace the dust and metal enrichment history of the early Universe. Find the first cosmic sources of dust, and search for evidence of the very earliest stellar populations forming in pristine environments.	• 3 ? Not sure what this is referring to • Identify galaxies in a tiered spectral mapping survey • Measure line flux densities of identified galaxies	• Wavelength: 25-200 µm (most important 112 µm HD, 179.5 µm H2O) • Spatial resolution: 5 arcsec at 200 µm (min. 9 m Telescope) • Spectral line sensitivity: 1e-21 W m-2 (driven by MIR lines) • Spectral Resolving power: λ/Δλ = 500 • survey area, instantaneous FOV, FoR: 10 deg^2	incoherent spectrometer, low res mode

Instrument Requirements

Science Case	Measurement Requirements	Instrument Requirements	Instrument(s)
9, Tracing the signatures of life and the ingredients of habitable worlds	• Measure fluxes of multiple (>10) emission lines spanning the full range of upper level energy. • Spectrally resolve lines beyond the snow line to independently determine the emitting area of the detected gas (using Keplerian line profiles). • Measure line flux densities of identified galaxies	• Wavelength: 25-200 µm (most important 112 µm HD, 179.5 µm H2O) • Bandwidth: 1000 km/s (for HD at 112 µm) ~ 9 GHz bandwidth • Spatial resolution: < 2" at 30µm (>3.4 m telescope) • Spectral line sensitivity: 10-21 W/m2 (5σ) • Spectral Resolving power: $\lambda/\Delta\lambda$ > 25,000 • survey area,	incoherent spectrometer, high res mode

Instrument Requirements

Science Case	Measurement Requirements	Instrument Requirements	Instrument(s)
27, Rise of Metals, Dust, and the First Galaxies Trace the dust and metal enrichment history of the early Universe. Find the first cosmic sources of dust, and search for evidence of the very earliest stellar populations forming in pristine environments.	• High-quality mid-IR spectra of galaxies, appearing as point sources. • Measure PAH flux densities with sensitivity down to 3x1011 Lsun	• Wavelength: 35 µm <λ<275 µm • Spatial resolution: < 5” at 100µm (min. 4.5m telescope) • Spectrometer sensitivity: 1x10-20 Wm-2 (5σ) in R=50 bin • Spectral Resolving power: λ/Δλ = 50 • Calibration / gain accuracy across spectrometer: 3% relative calibration in R=50 bins across the spectrometer	incoherent spectrometer, low res mode

Instrument Requirements

Science Case	Measurement Requirements	Instrument Requirements	Instrument(s)
14, Tracing the signatures of life and the ingredients of habitable worlds Explore whether planets around other stars could harbor life (NASA Roadmap Plan)	• Spectrally resolve CH_4, CO_2, CO, N_2O, O_3, NH_3, SO_2, and H_2O absorption features in the emission spectrum • Separate thermal emission from the planet from the host star	• Wavelength: 6 µm (minimum 7.7µm for CH_4) < λ < 40 µm • Spatial resolution: 2 arcsec at 10 µm (min. 1.1 m telescope) • Spectral Resolving power: $\lambda/\Delta\lambda = 30$ (up to ~ 200) • Photometric precision: 10ppm λ < 10 µm, 50 ppm λ > 10 µm • Transit Monitoring Cadence: ~ 5 minute	incoherent spectrometer, low res mode

Instrument Requirements

Science Case	Measurement Requirements	Instrument Requirements	Instrument(s)
4, Tracing the signatures of life and the ingredients of habitable worlds Trace the trail of water from interstellar clouds, to protoplanetary disks, to Earth itself in order to understand the abundance and availability of water for habitable planets.	• Spectrally resolve lowest rotational lines of ortho and para H_2O plus isotopologues at 509-557 GHz and 1107-1113 GHz	• Wavelength: 538-589 and 269-271 mm to cover key H_2O lines and isotoplogues (509-557 and 1107-1113 GHz) • Spectral Resolving power: $\lambda/\Delta\lambda$ = 5e6 (0.6 km/s to resolve velocity structure) • Bandwith: < 20 Ghz • Angular resolution: 30 arcsec (to resolve star forming clouds in the Milky Way) • Spectral line sensitivity: 4 mK in 0.1 km/s @ 600 GHz = 1.6e-21 W m-2 for 6 m telescope	incoherent spectrometer, low res mode

Instrument Requirements

Science Case	Measurement Requirements	Instrument Requirements	Instrument(s)
21, Understanding the co-evolution of BH and galaxies over cosmic time “How did we get here?”	• Spatial-spectral mapping of 5 sq. degree area to generate samples and for each source, measure line fluxes and equivalent widths of key dust and gas diagnostic lines: 6.2-12.7 µm PAHs, and [OIV] 26, [NeII] 12, [NeIII] 15, [NeV] 14. (At z=5 a 1012 LΘ source should have a [NeII] line flux ~6x10-21 W m-2). 5 deg2 results in at least 104 sources, with at least 500-1000 galaxies at z > 5.	• Wavelength: 15-300 µm • Spatial resolution: 5 arcsec at 100mm (min. 4.5m telescope) • Spectral line sensitivity: 3x10-21 W m-2 (5σ) • Spectral Resolving power: λ/Δλ = 300 (maximize PAH and fine structure line detections)	incoherent spectrometer, low res mode

Instrument Requirements

Science Case	Measurement Requirements	Instrument Requirements	Instrument(s)
26, Rise of Metals, Dust, and the First Galaxies Trace the dust and metal enrichment history of the early Universe. Find the first cosmic sources of dust, and search for evidence of the very earliest stellar populations forming in pristine environments.	• Detect at least 3 H2 rotational lines from S(0) (28 microns) and S(5) (6.9 microns) lines, over 4 < z < 15. • Sensitivity to reach and identify 1010 solar mass halo at z=7 (per current H2 models), including 10x lensing boost.	• Wavelength: 32 µm <λ<455 µm • Spatial resolution: < 5” at 100µm (min. 4.5m telescope) • Spectral line sensitivity: 2x10-22 Wm-2 (5σ) • Spectral Resolving power: λ/Δλ > 500 • Spectrometer relative calibration accuracy: 3% from channel to channel	incoherent spectrometer, low res mode

Instrument Requirements

Science Case	Measurement Requirements	Instrument Requirements	Instrument(s)
18, Understanding the co-evolution of BH and galaxies over cosmic time	• Ability to detect OH emission and absorption, with the requirement to detect 79 µm line at z=3, • Perform spectral fits to OH and fine-structure lines to get velocities of blue-shifted absorption (OH) and line wings (fine-structure lines). Measure line fluxes, profiles of bright fine structure lines - [NeII] [OIV], [NeIII] and H2	• Wavelength: 20 - 350 µm • Spatial resolution: 5" at 150µm (min. 7m telescope) • Spectral line sensitivity: 1x10-21W m-2 (5σ) • Spectral Resolving power: λ/Δλ = 3000	incoherent spectrometer, low res mode

Instrument Requirements

Science Case	Measurement Requirements	Instrument Requirements	Instrument(s)
29, Tracing the signatures of life and the ingredients of habitable worlds	• Spectrally resolve H_2O and HDO lines	• Wavelength range: 547, 538, 303, 301, 271, 269 µm (548, 557, 988, 995, 1107, 1113 GHz) H_2O & isotopo-logues 589, 500, 335, 326, 297 µm (509, 600, 894, 919, 1010 GHz) HDO • Spectral Resolving power, resolve lines for ΔV~1.3 km/s: $\lambda/\Delta\lambda$ = 2e5 • Bandwidth (to cover both isotopes simultaneously): 1GHz • Spectral line sensitivity: 2e-21 W m-2 (5σ) • Moving Target tracking: 60 mas/s	incoherent spectrometer, high res mode

Instrument Requirements

Science Case	Measurement Requirements	Instrument Requirements	Instrument(s)
7, Revealing the interplay between stars, black holes, and interstellar matter over cosmic	• 1000 deg2 photometric and polarization mapping and photometry across the dust SED peak	• Wavelength range: 200 µm $<\lambda<$ 500 µm • Spatial Resolution: <2” at 100µm (min. 11 m telescope) • Sensitivity to high-dynamic range targets: Dynamic range 1000 • Polarization capabilities: 0.1% in linear and circular polarization, ±1° in pol. Angle • Broadband, Wide-area Mapping: 1mJy at 250 µm (5σ)	continuum imager for polarimetry? heterodyne spectrometer or incoherent spectrometer, high res mode
	• Detailed (high spatial and spectral resolution) maps of spectral lines in particular of [CII], and the CO Spectral Line Energy Distribution (CO SLED).	• Spatial Resolution: <2” at 100µm (min. 11 m telescope) • Spectral Resolution: $\lambda/\Delta\lambda$ > 3e6 • Spectral line sensitivity: 3 x 10-19 W m-2	

Instrument Requirements

Science Case	Measurement Requirements	Instrument Requirements	Instrument(s)
5, Reveal the interplay between stars, black holes, and interstellar matter over cosmic time.	• Resolve and map dust continuum, PAH emission, and H2, HD, [CII] and molecular ions around galaxies to measure mass outflow rates • Determine speed of outflowing neutral gas by resolving P-Cygni line profiles.	• Wavelength: 10 - 500 µm • Angular resolution: 5" at 100µm (min. 4.5m telescope) • Continuum Sensitivity 50µJy (5σ) • Surface Brightness Sensitivity: 1e-12 W/m2/sr • Spectral line sensitivity: 6.6e-22 W m-2 • Spectral Resolving power: λ/Δλ = 10^4 • Bandwidth: 1 GHz	incoherent spectrometer, high res mode

Instrument Requirements

Science Case	Measurement Requirements	Instrument Requirements	Instrument(s)
30, Tracing the signatures of life and the ingredients of habitable worlds	• Image a large area of the sky (>1000 square deg.) and capture >1,000 TNOs (desire multiple wavelengths). • Cadence: 4 times over a year over 1,000 sq. deg. with a cadence of few days to weeks.	• Wavelength range: 75 µm < λ < 250 µm • Instantaneous field of view (to track motions): 14 x 14 arcmin • Continuum Sensitivity: 50 mJy at 125 µm (5σ) • Angular resolution: 3" at 125 µm (min. 9.5 m telescope)	FIR imager (incoherent spectrometer, low res mode?)

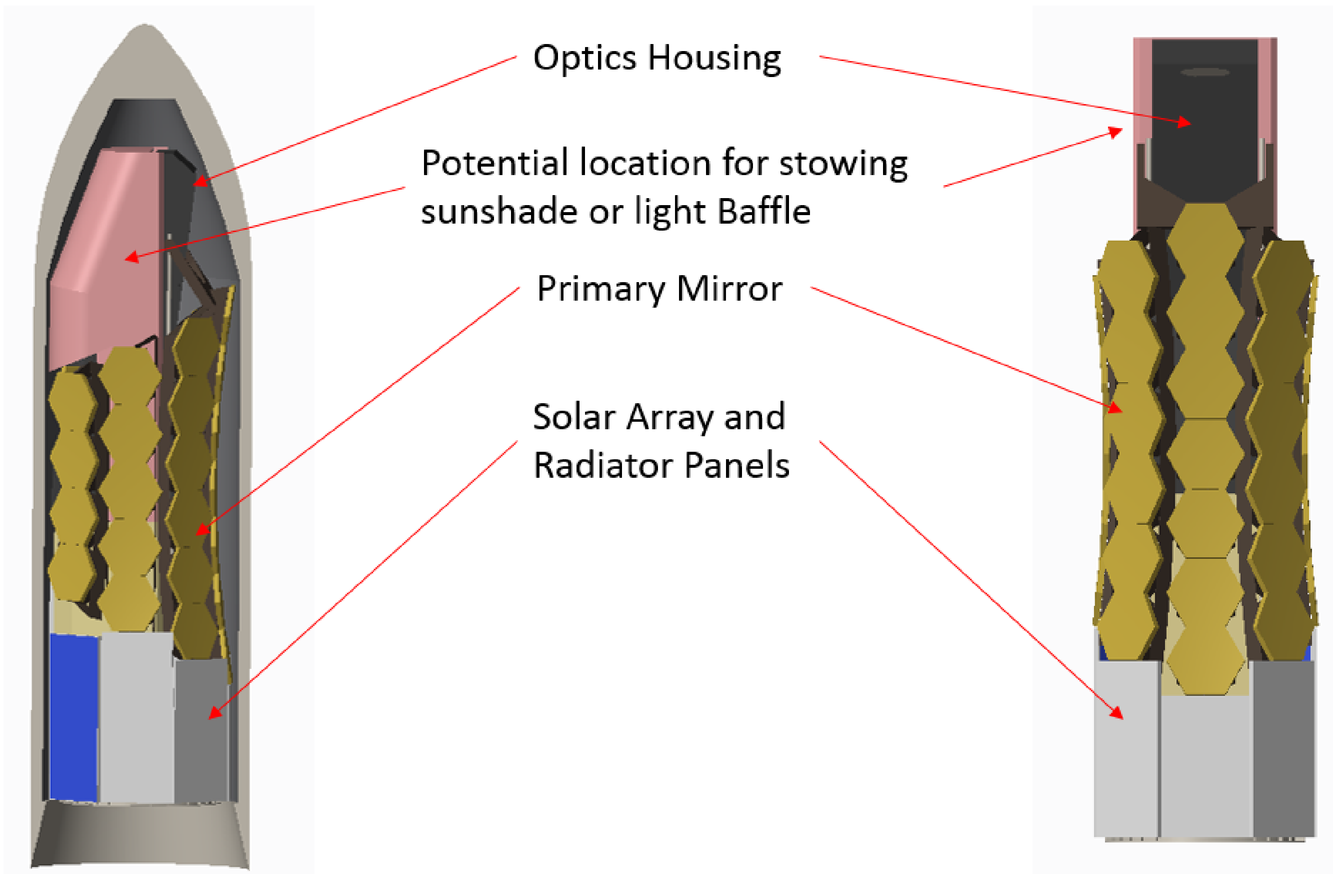
Additional Cases in traceability not listed since not in Top 14 (Top 12 combined cases) – will be revisited with Concept 2 discussions by STDT

Slides for folks to use in presentations June F2F

Greg Martins

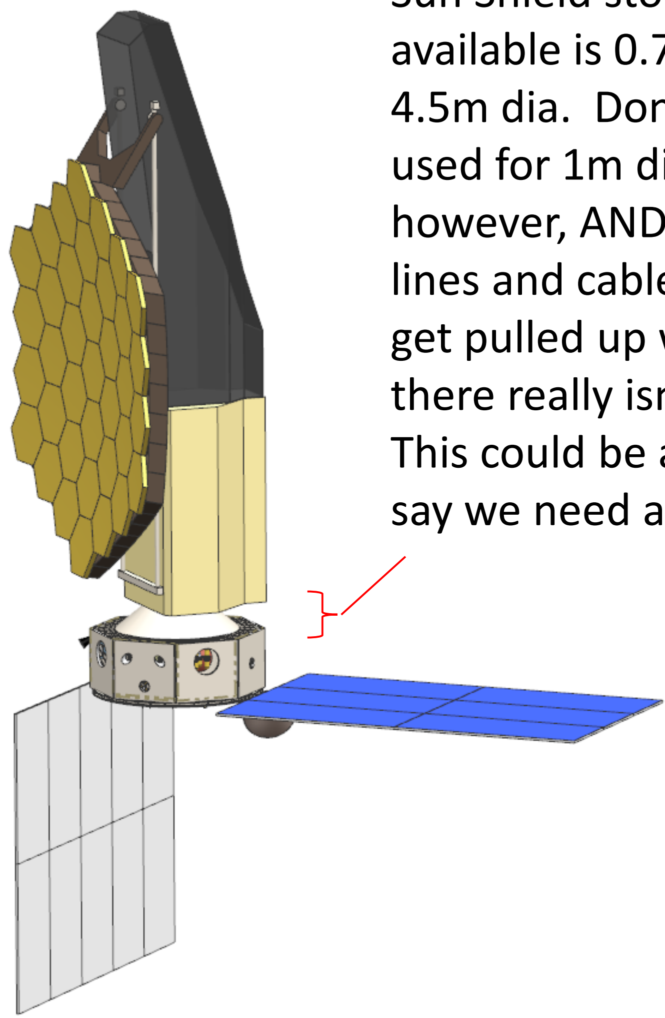
6-11-2017

Off-axis configuration
Unobstructed Observatory Launch Configuration in a 5-m x 19.8m Fairing



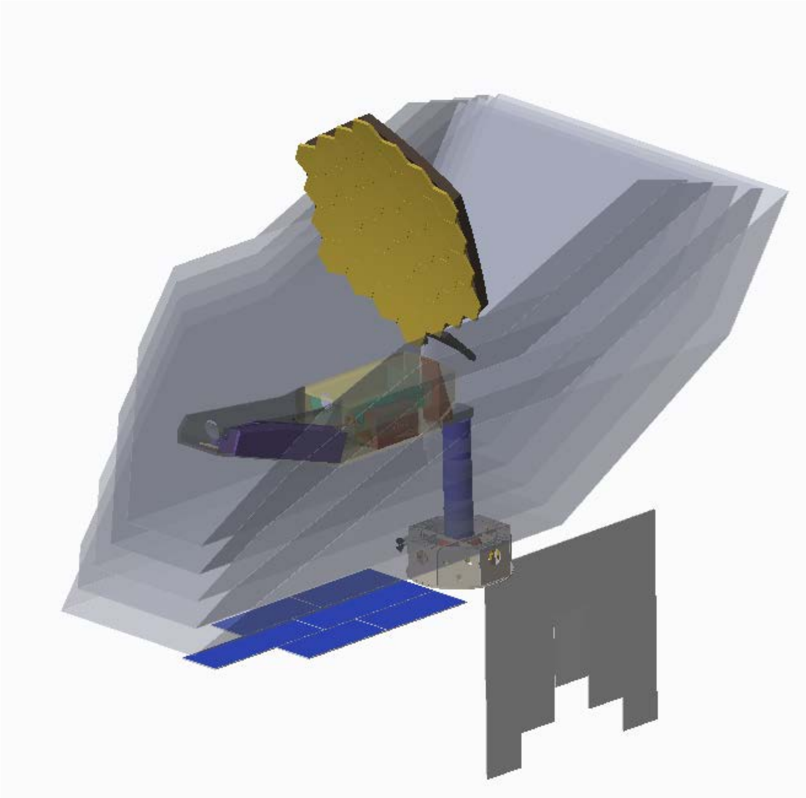
OST partially deployed

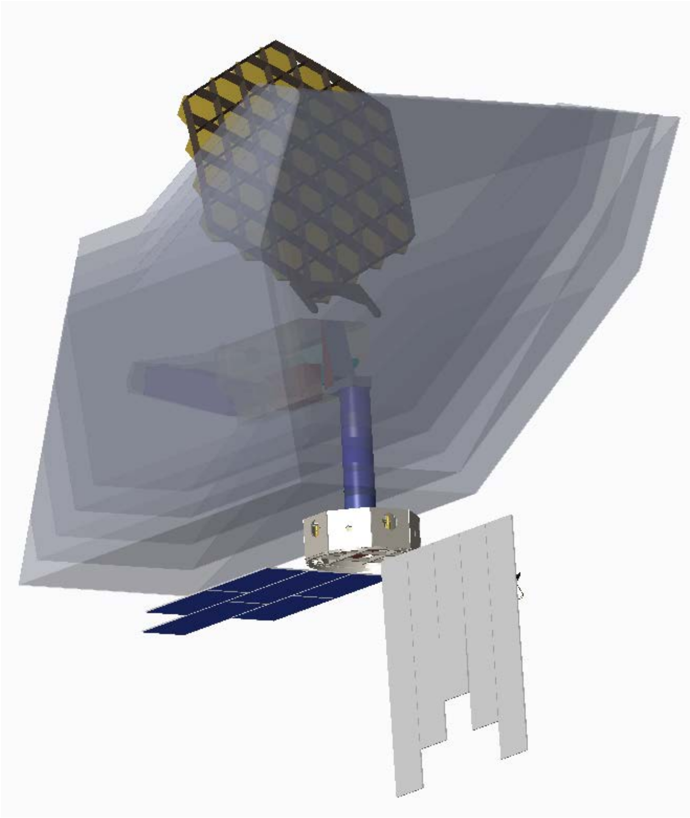
G. Martins
6-9-2017

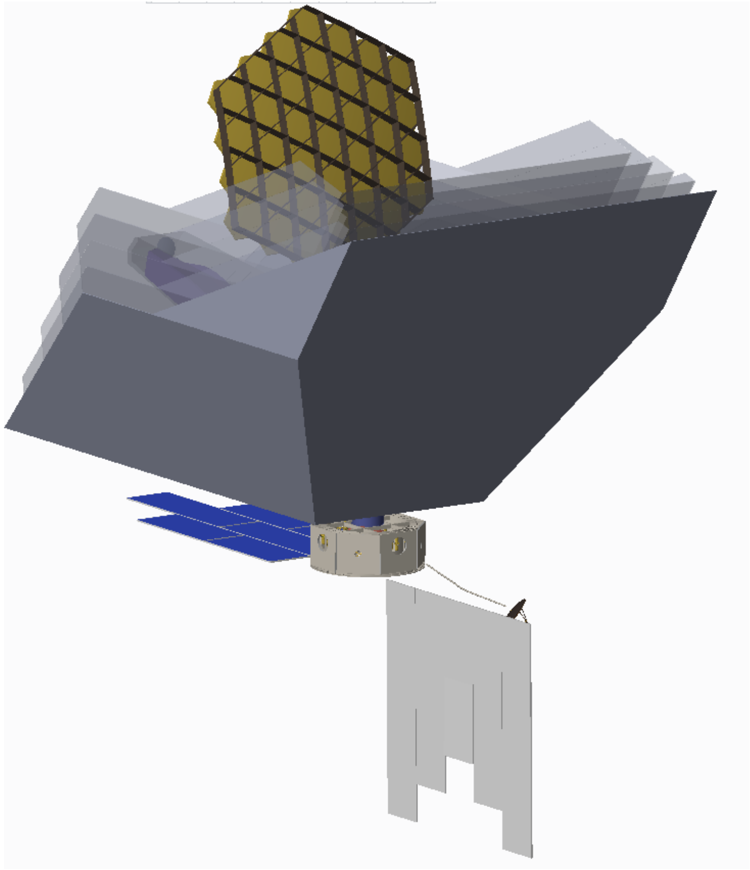


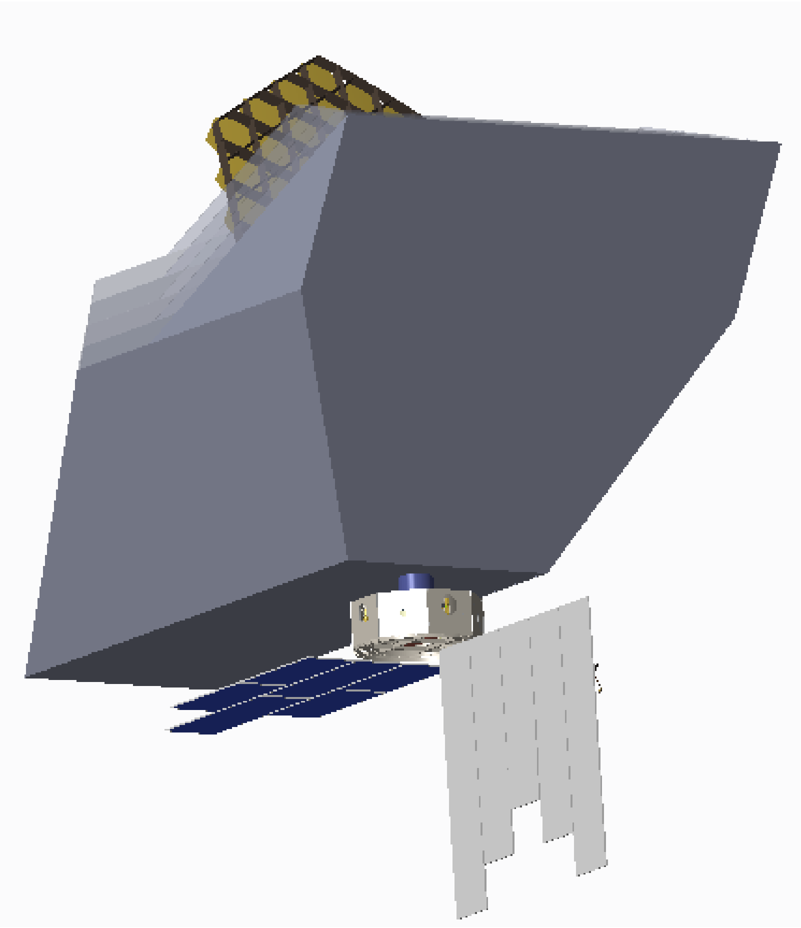
Sun Shield stowage area available is 0.75m high x approx. 4.5m dia. Donut in middle is used for 1m dia DTA space, however, AND stowage of cryo lines and cable harnesses that get pulled up with DTA. So, there really isn't much room. This could be a good reason to say we need a bigger fairing!

Baffle not shown

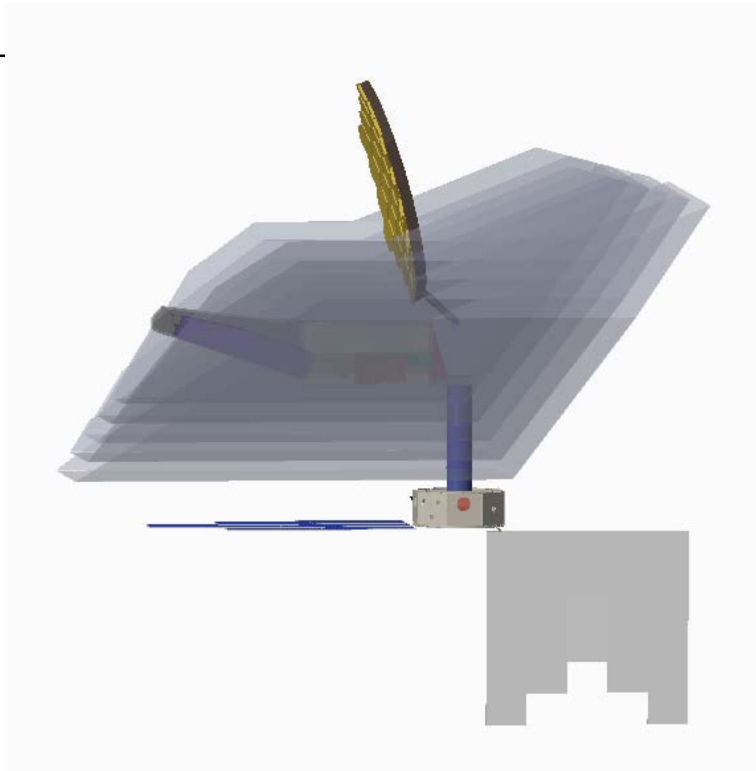


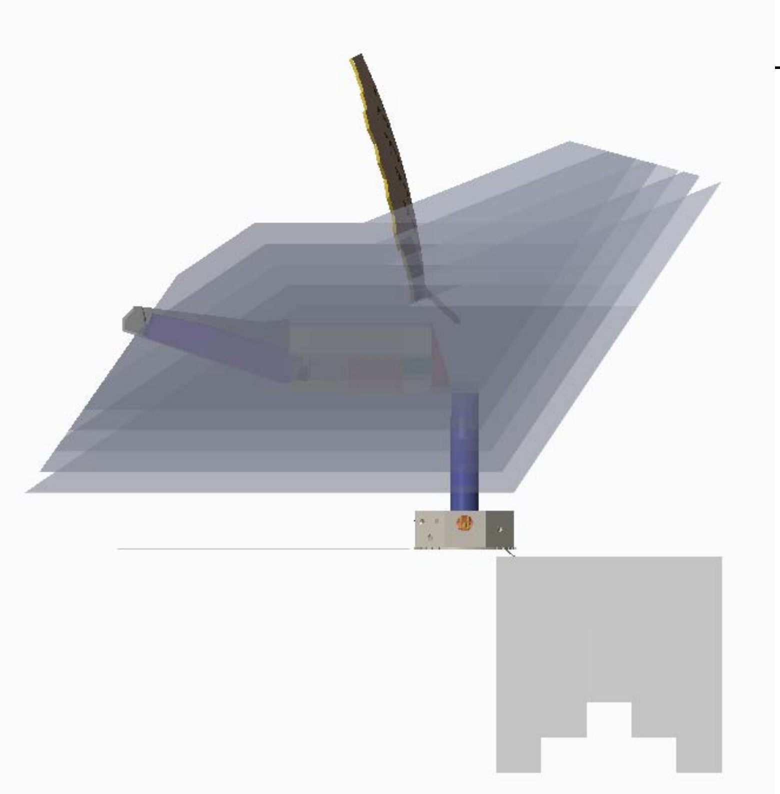






The only difference between these two is that one on left is rotated slightly.

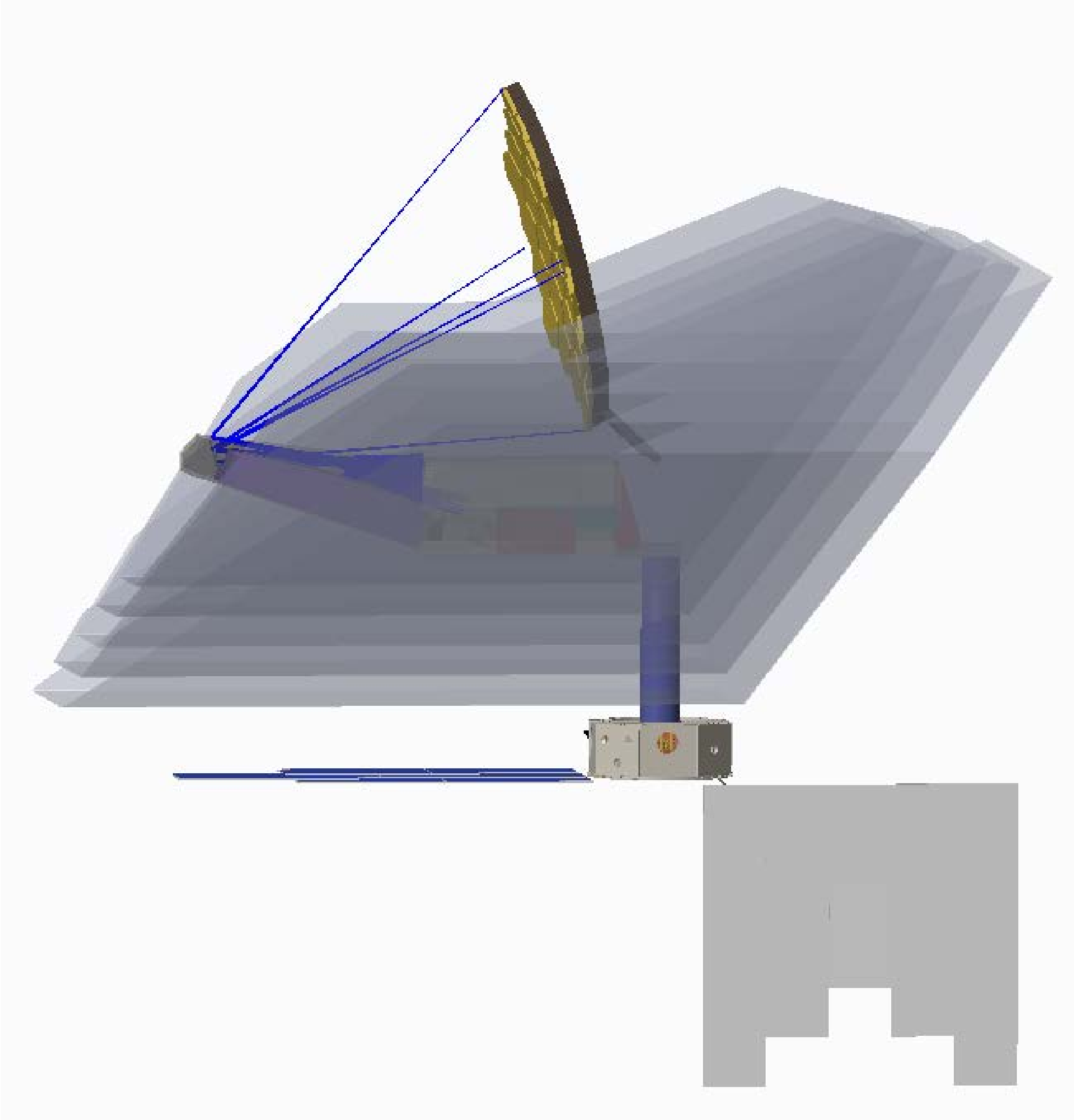




<u>CAD model of Sunshades - updates to come:</u>

1. Sun Shield needs to extend out further to protect front of IAM.
2. Add Baffle around IAM

This image includes the main Ray Trace

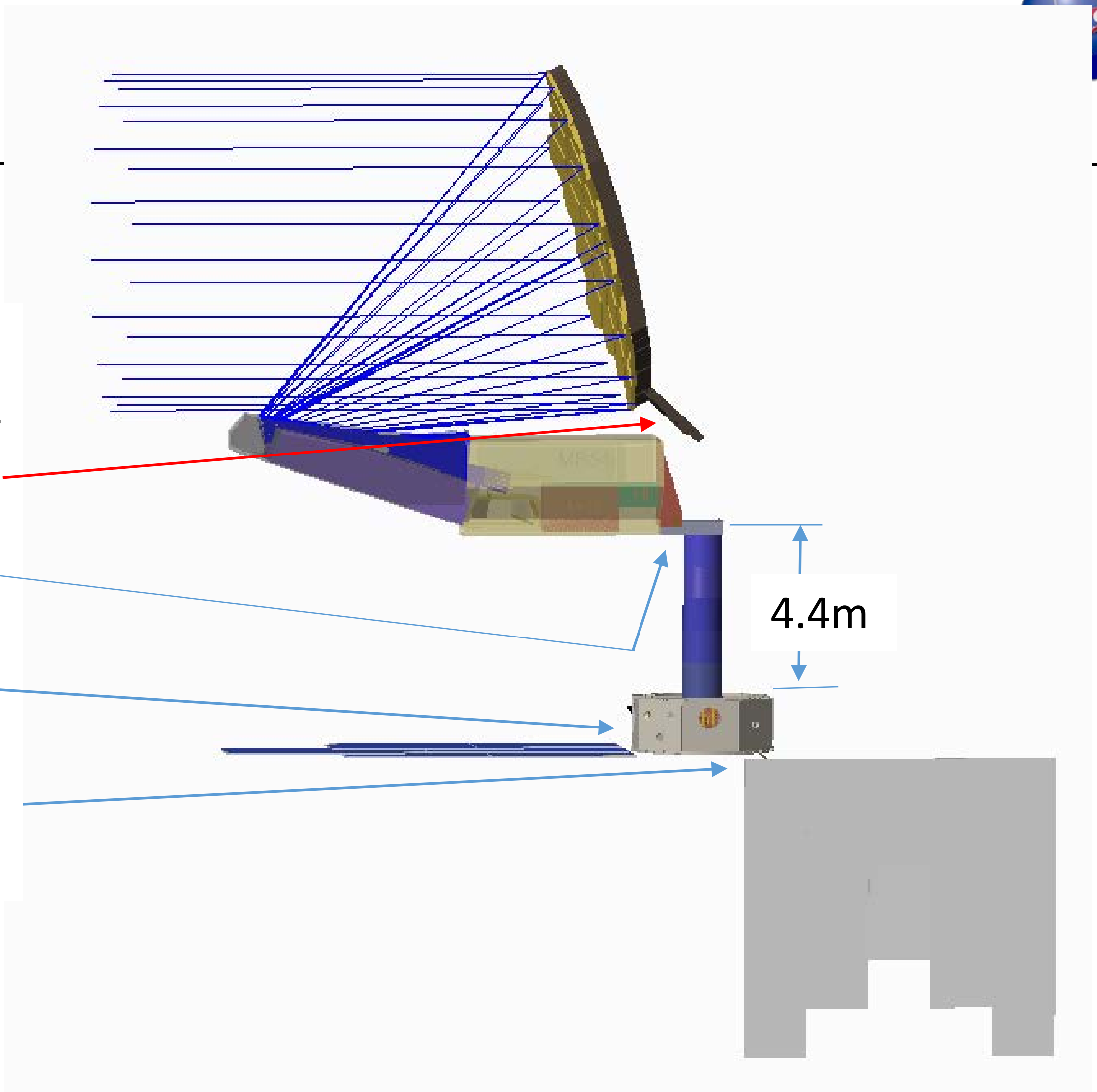


ORIGINS Space Telescope

This image just shows the incoming rays as well

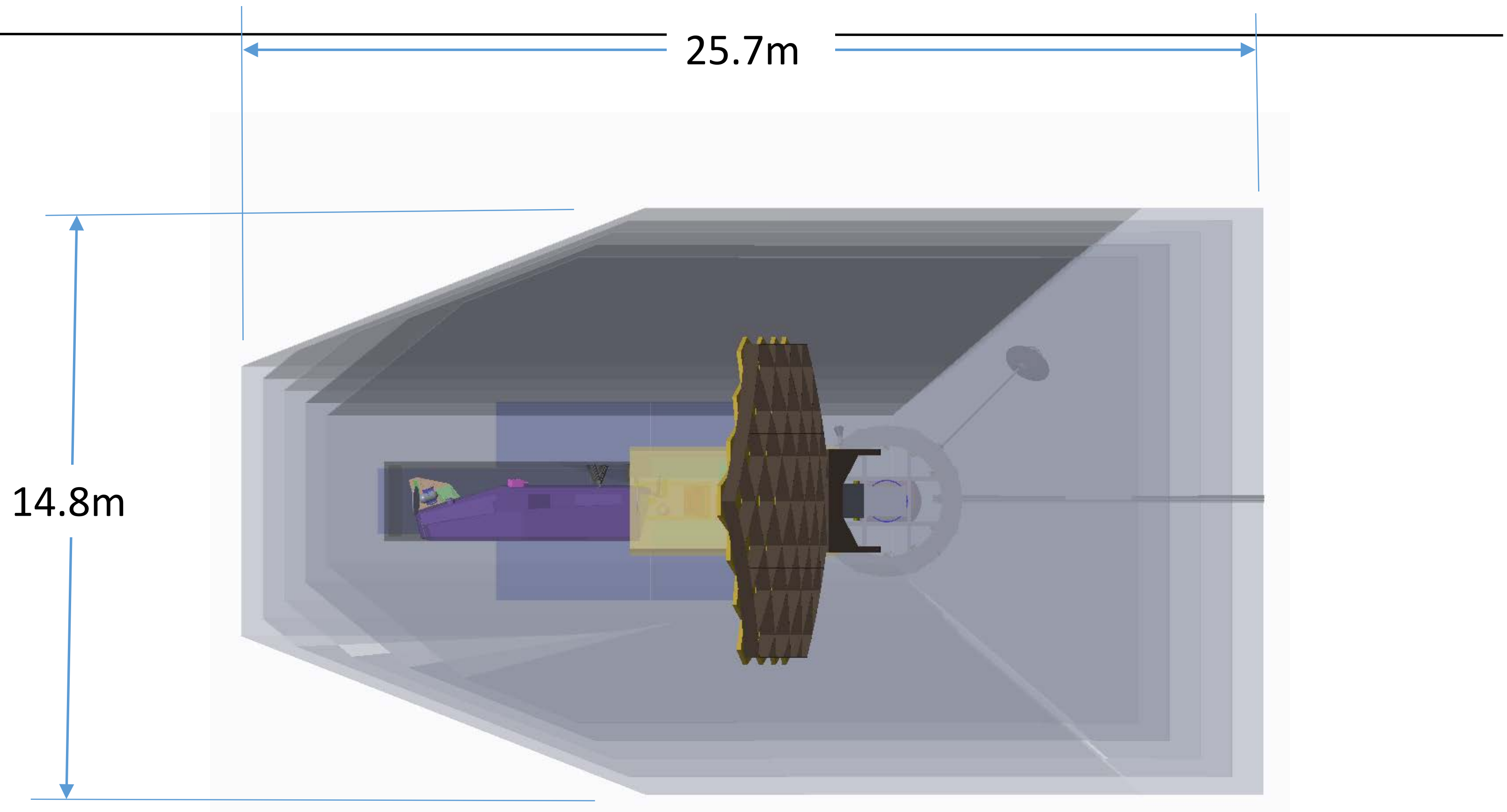
CAD models of deployment mechanisms - updates to come:

1. Attach PM to IAM with a 2-axis gimbal.
2. Develop IAM single-axis gimbal concept shown.
3. Attach Solar Array to Bus with a single-axis gimbal.
4. Attach Thermal Radiator to Bus with a 2-axis gimbal.



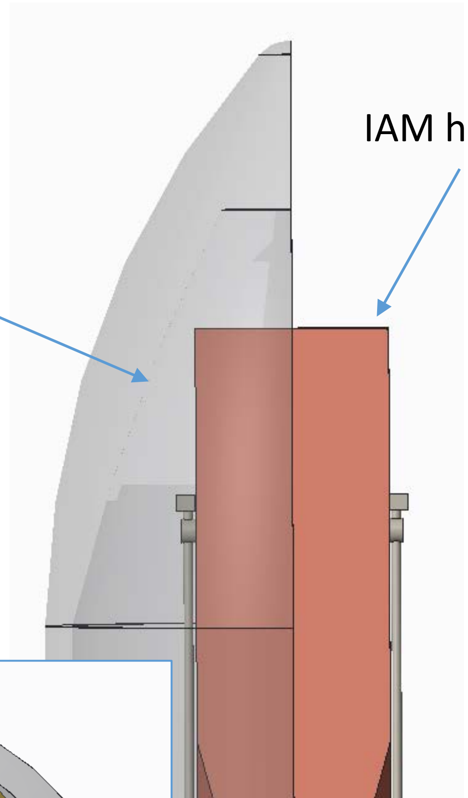
ORIGINS Space Telescope

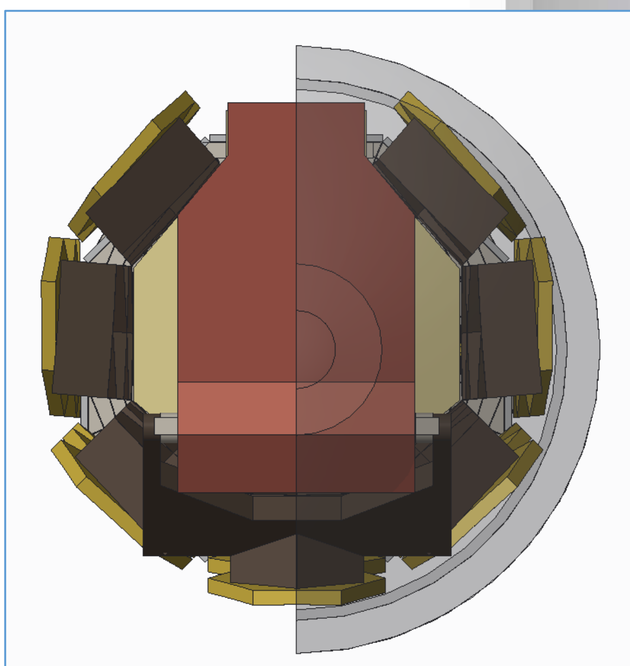
NASA

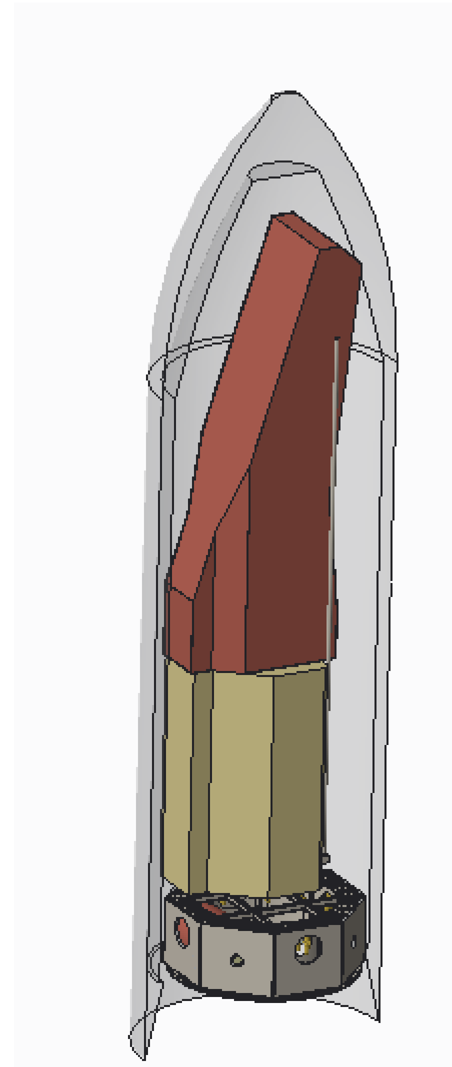


Fairing inside wall allows for the orange IAM growth to accommodate HRS size and position. So I can expand the IAM if needed.

IAM housing the HRS





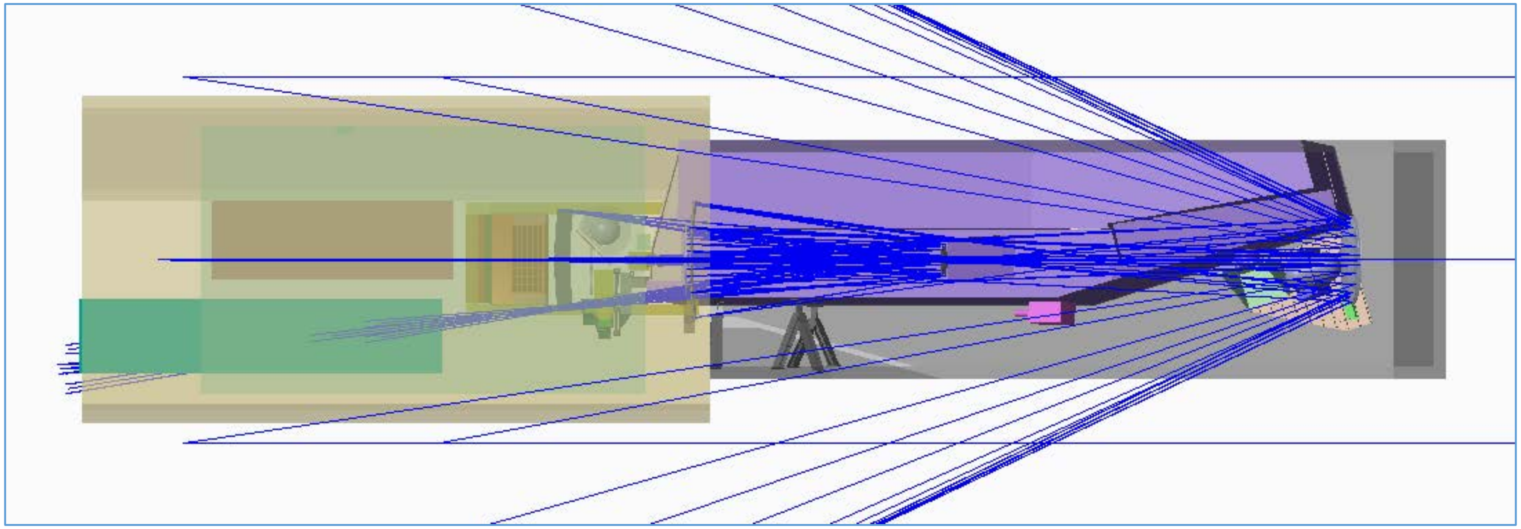


Old geometry, but the IAM clearances still apply

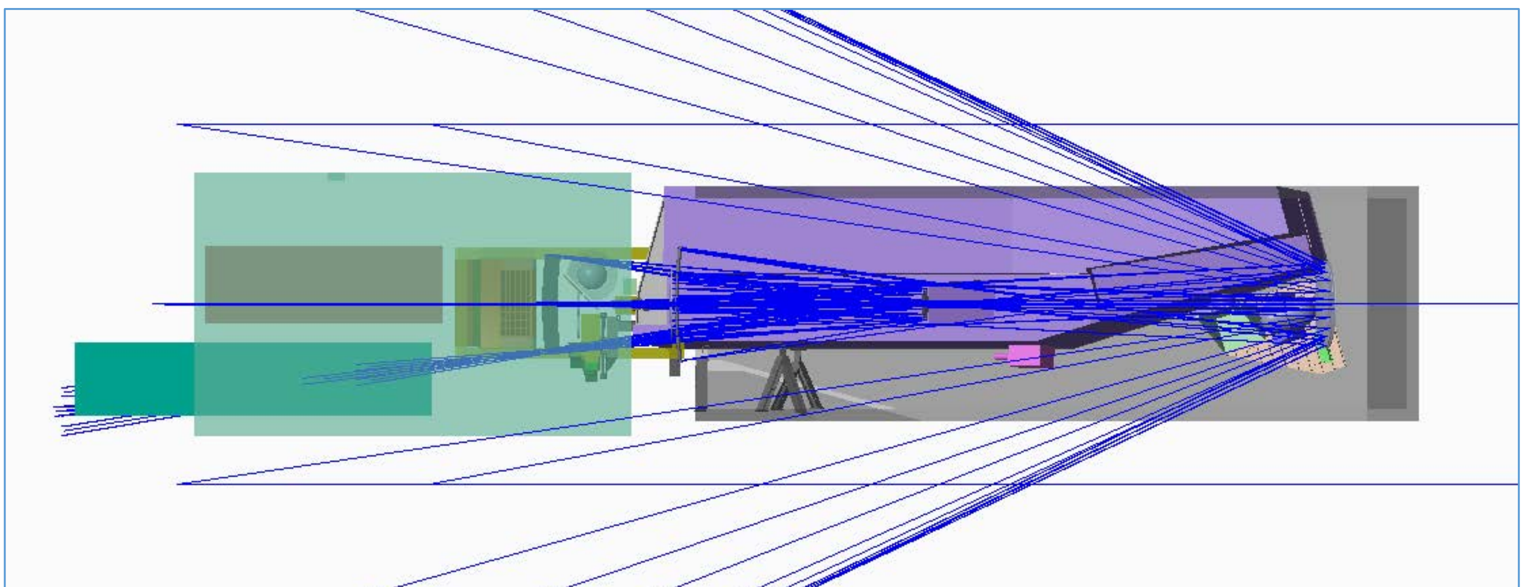
CAD model of IAM with instruments - updates to come:

1. Lay in support brackets to secure instruments to IAM
2. Assess space needed for cable harnessing and cryo lines.
3. Develop instrument servicing strategy.
4. Develop more mature designs for IAM, so they are not simply solid walls.
5. Develop interfaces for IAM gimbal and PM gimbal
6. More…

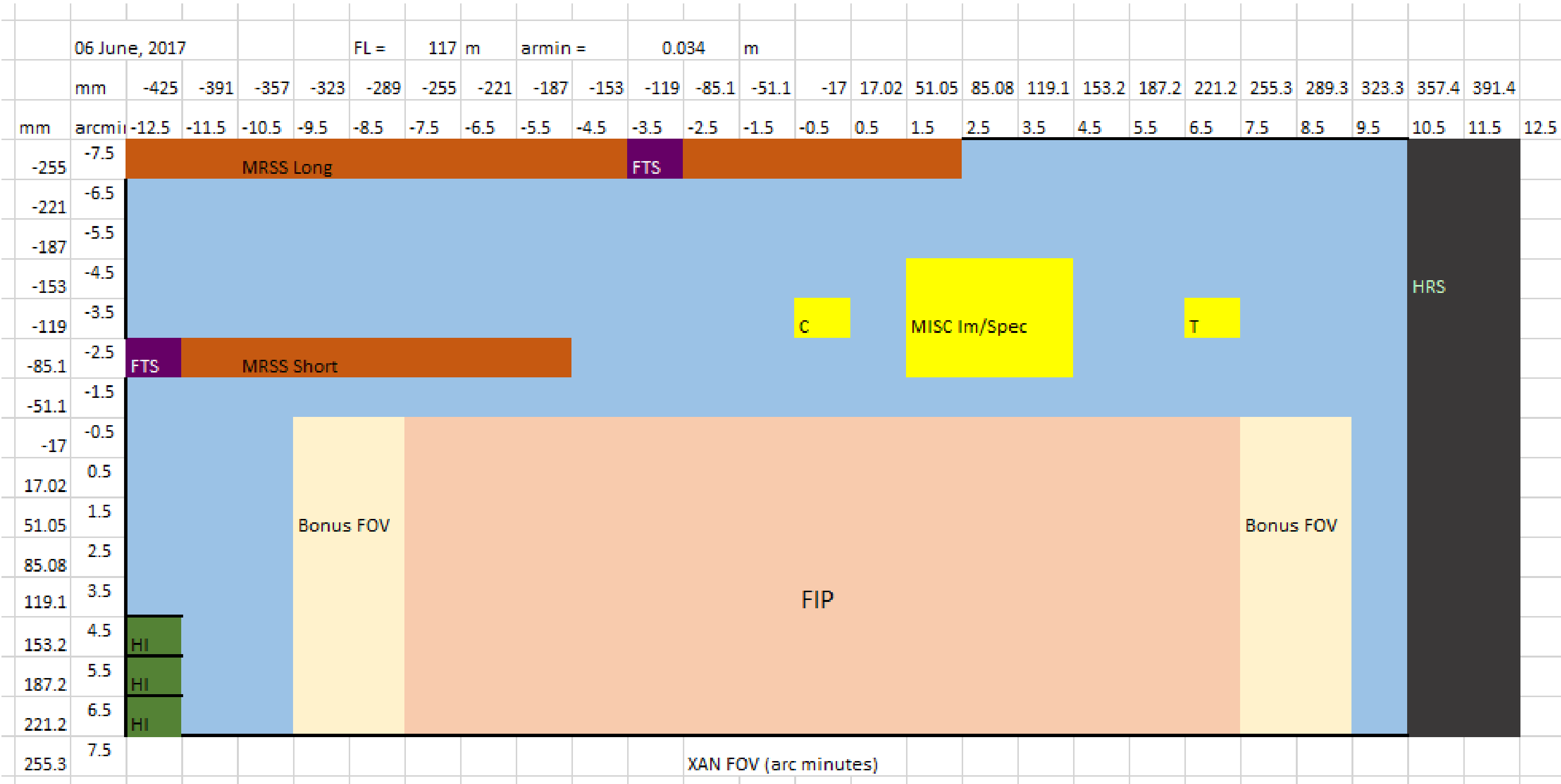
Top View of IAM with instruments

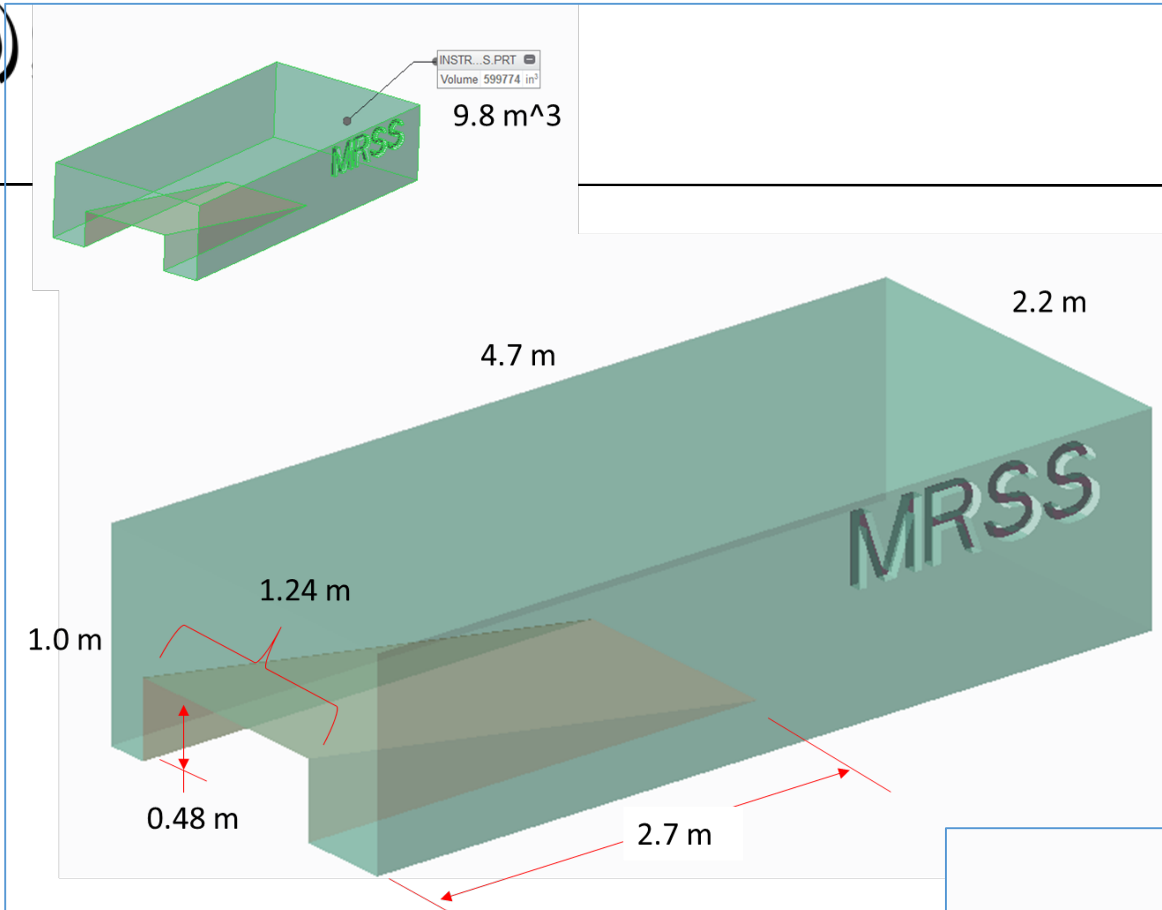


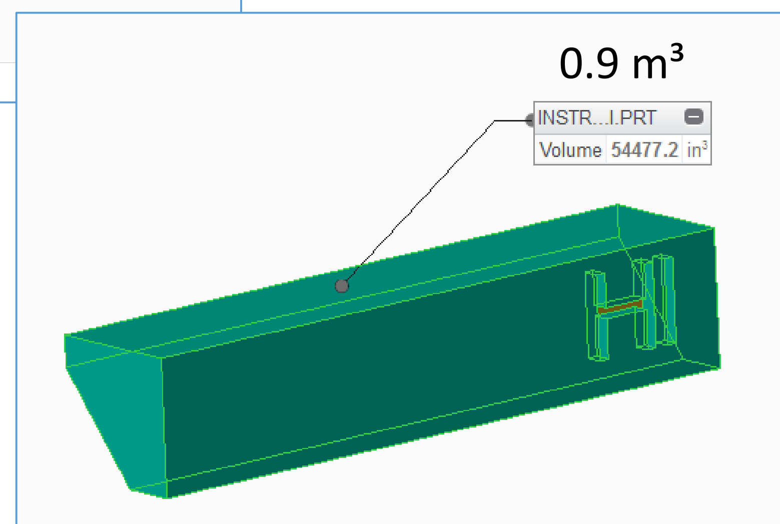
Top View WITHOUT aft IAM housing



Field of View (FOV) layout

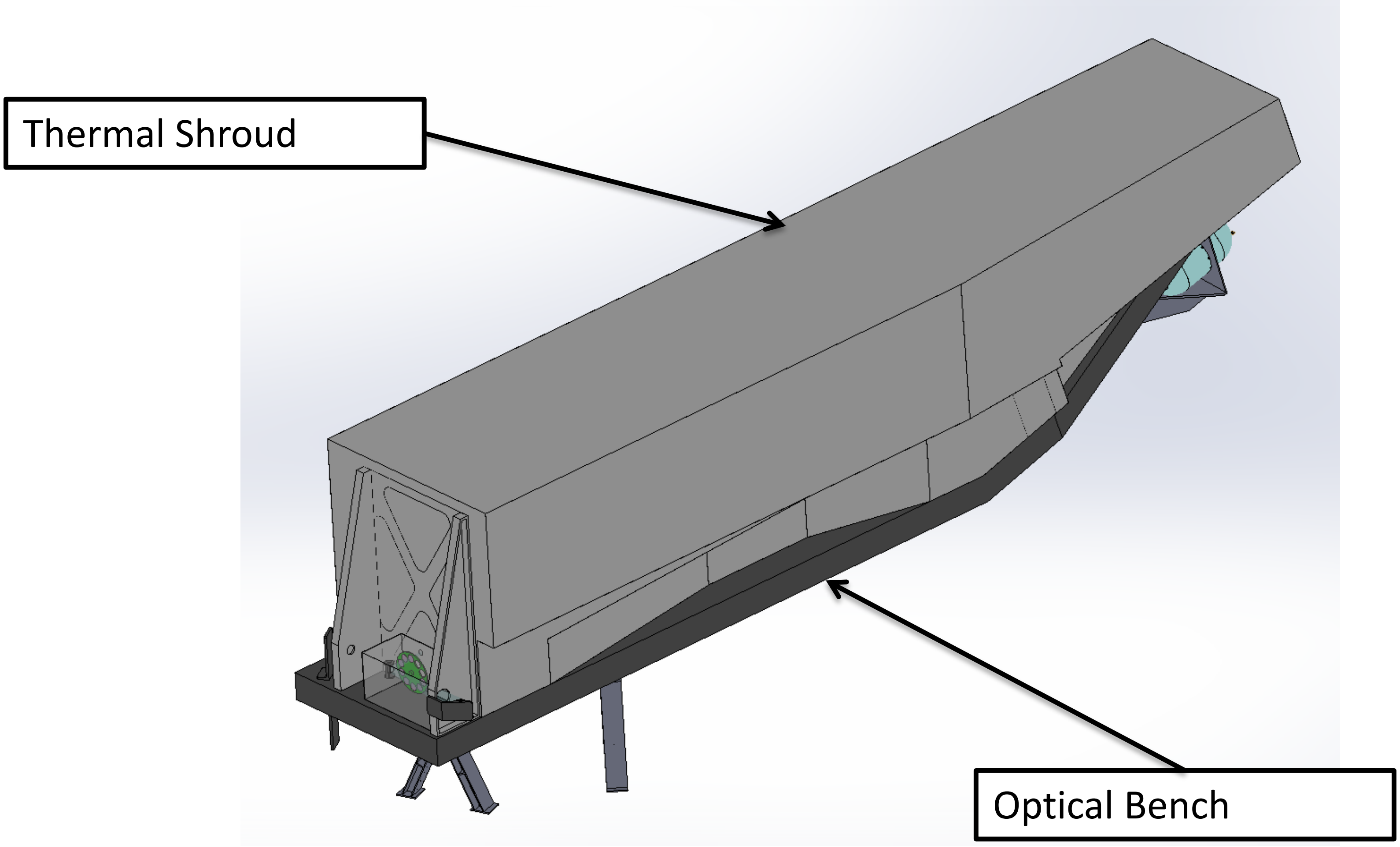



INSTR...S.PRT
Volume 599774 in³
9.8 m^3
MRSS
2.2 m
4.7 m
MRSS
1.24 m
1.0 m
0.48 m
2.7 m


0.9 m³
INSTR...I.PRT
Volume 54477.2 in³

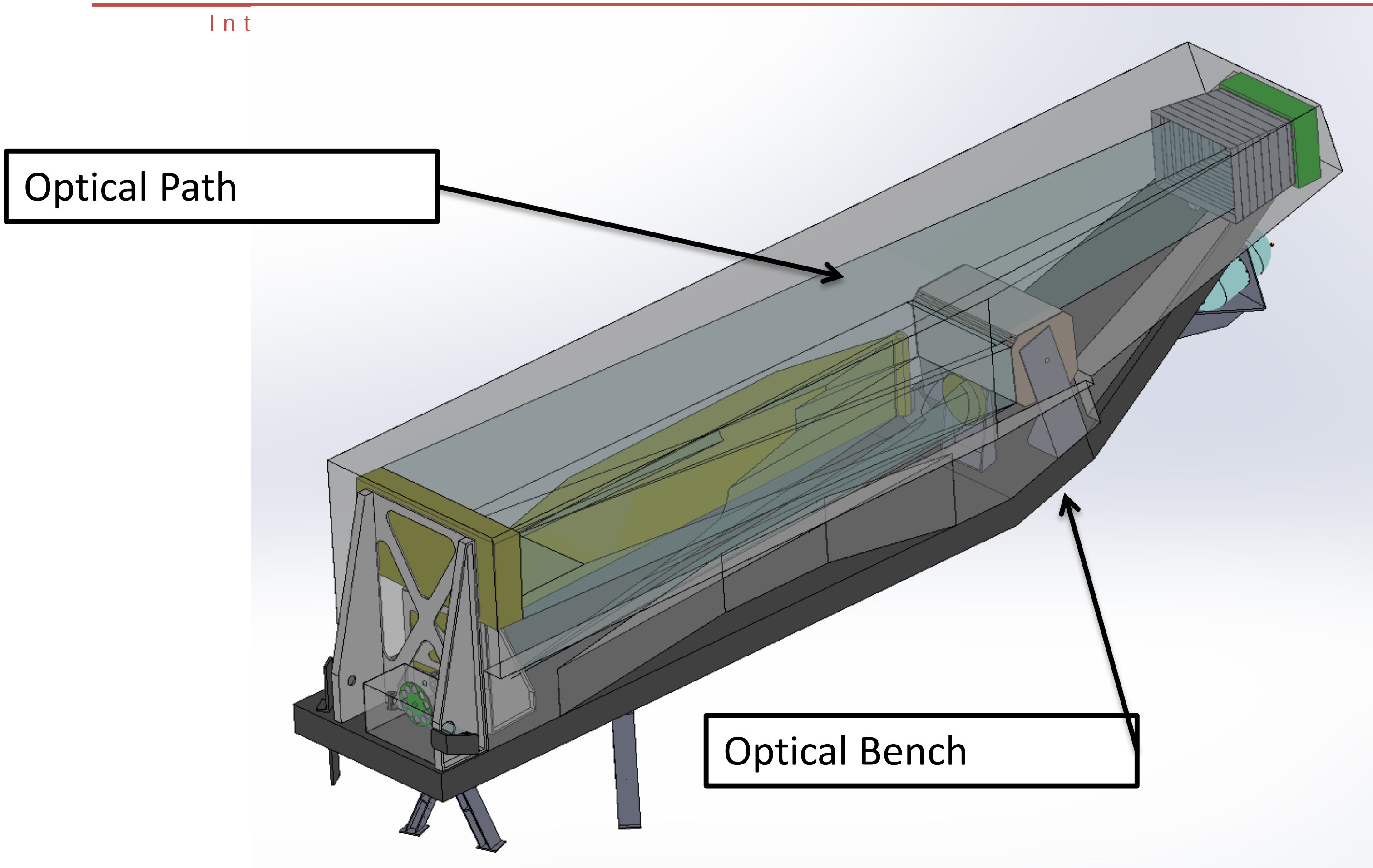
Mechanical Design Iso-1

Integrated Design Center / Partial Uncosted Instrument Design Study



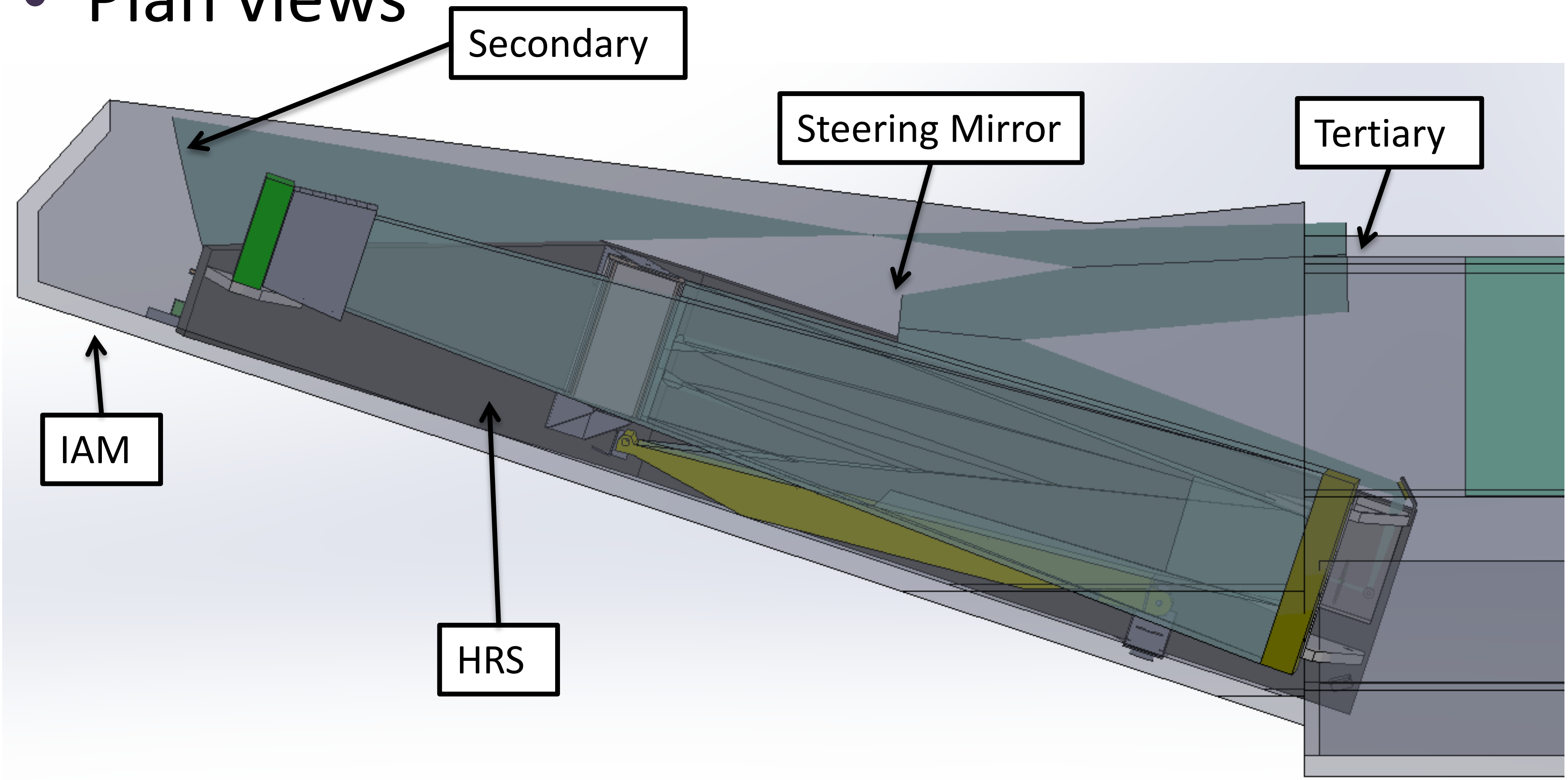
Mechanical Design Iso-1

Int

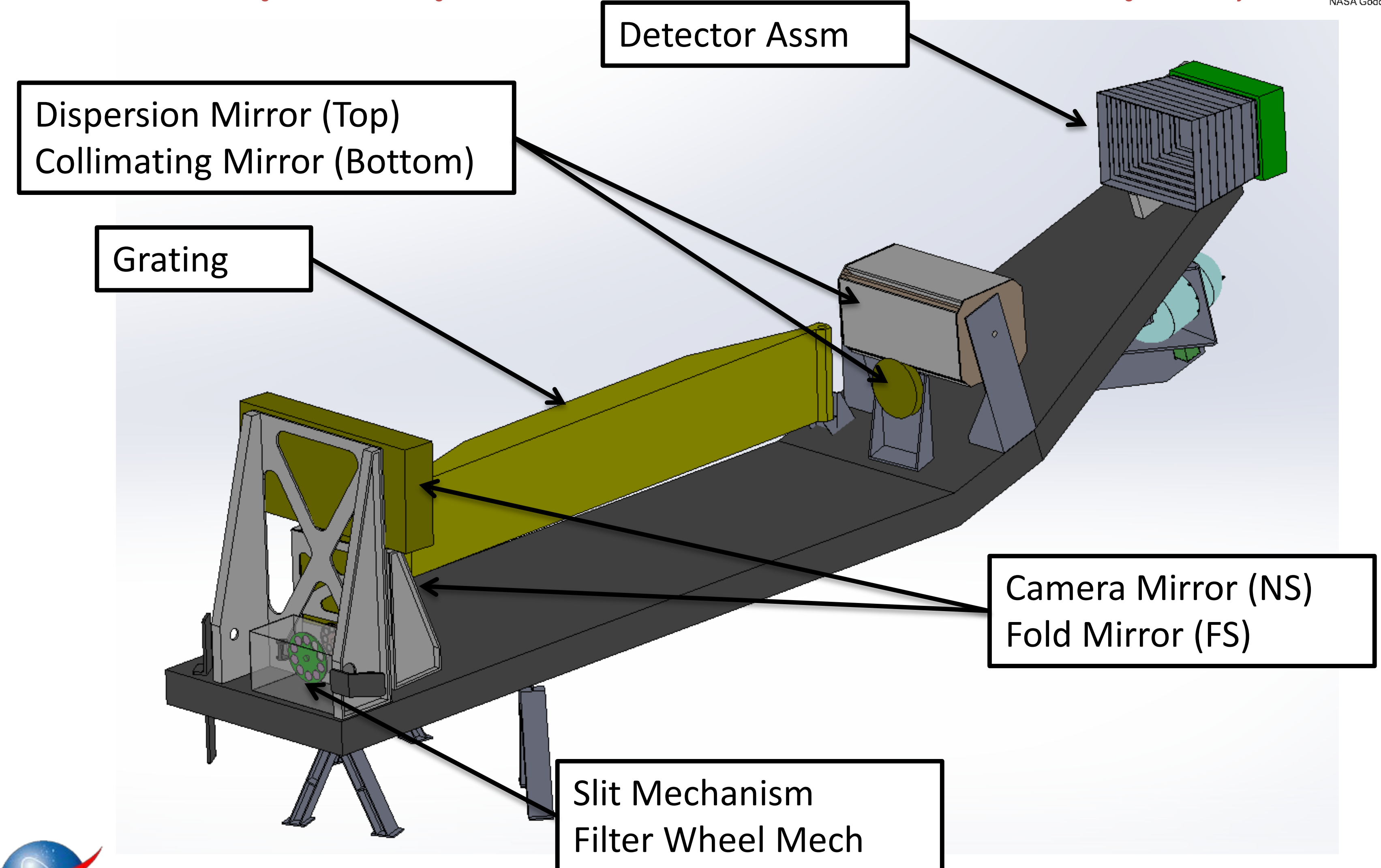


Mechanical Design Top

- Plan views

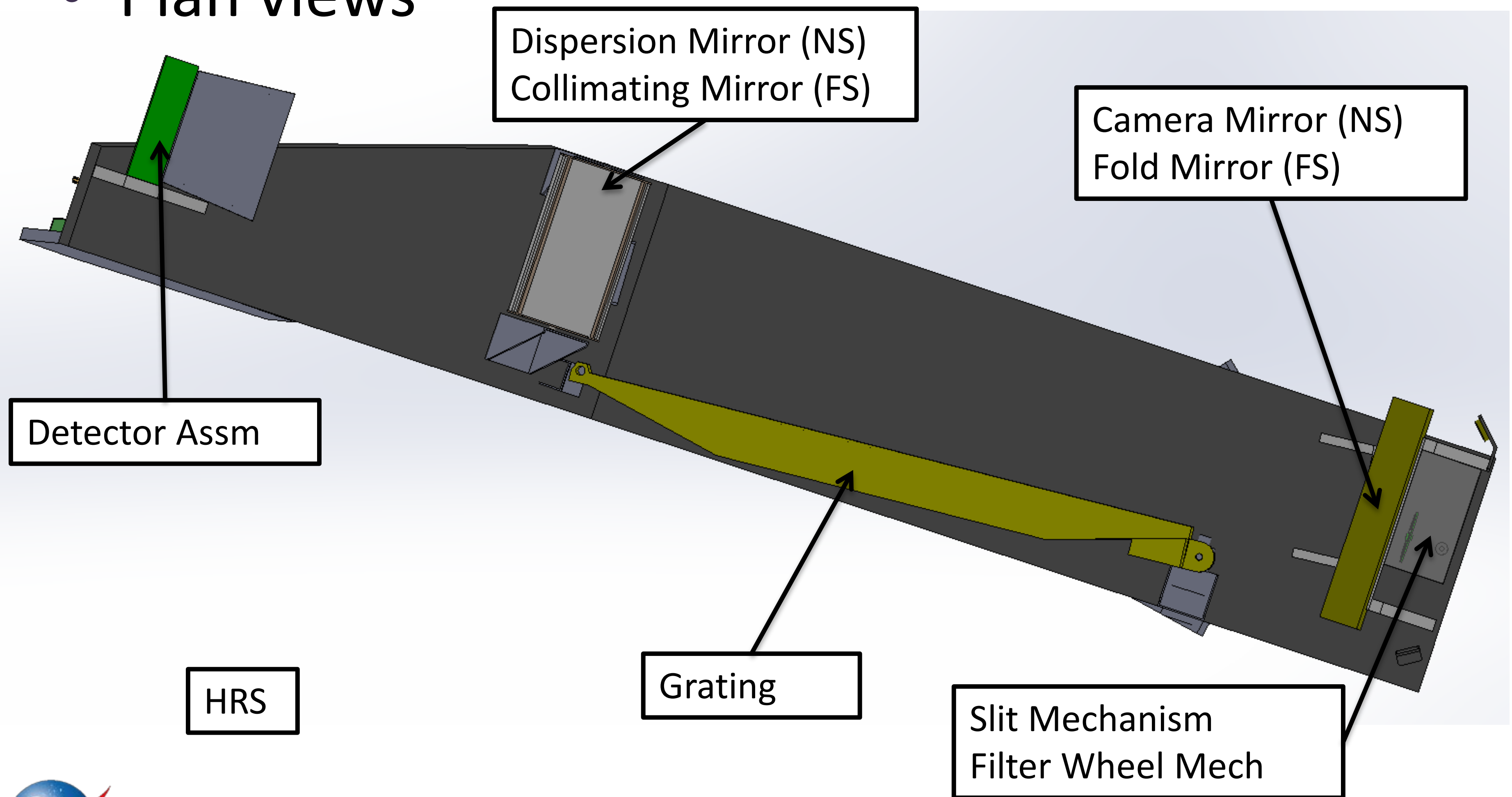


Mechanical Design Iso3



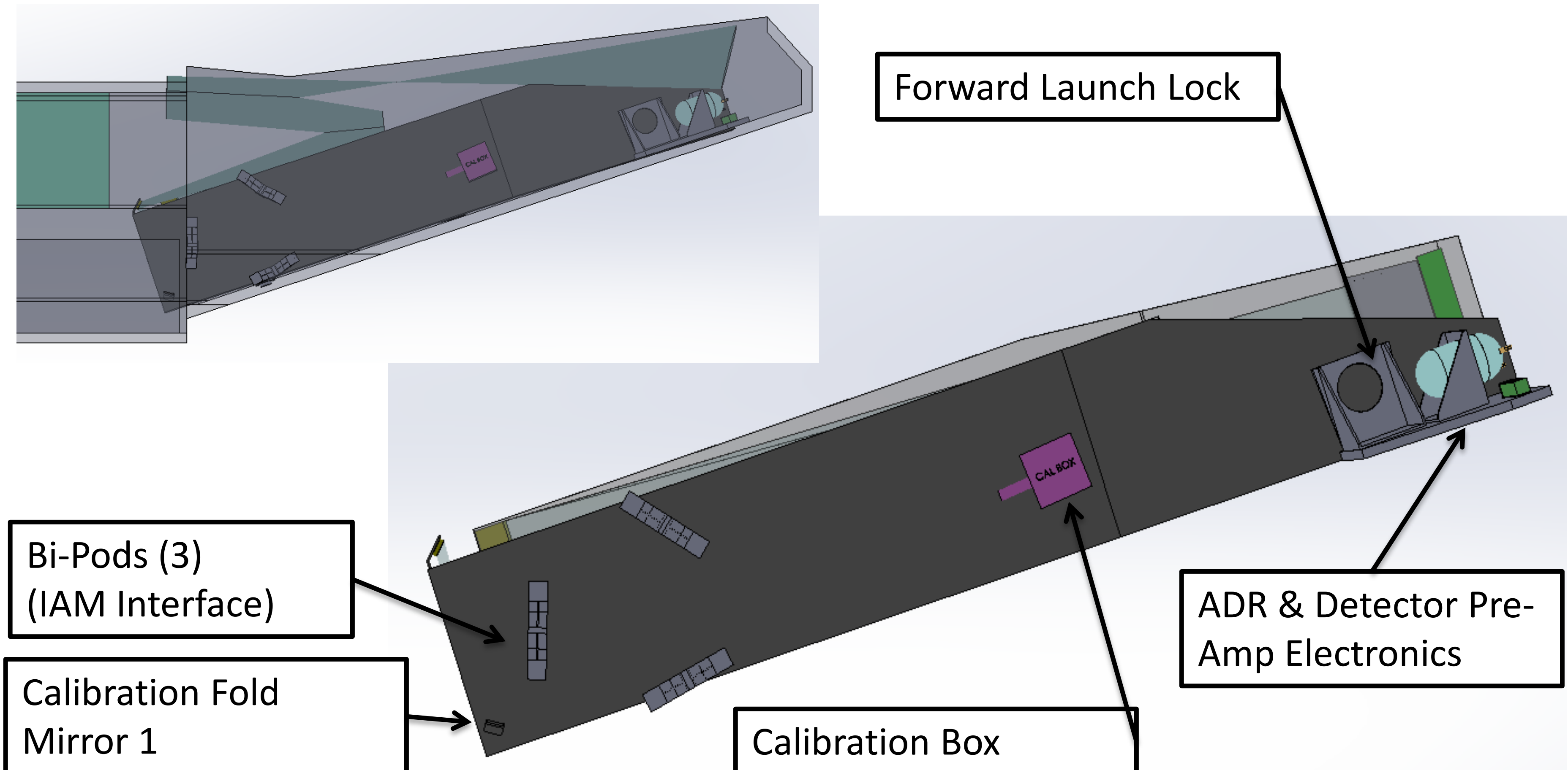
Mechanical Design Top

- Plan views



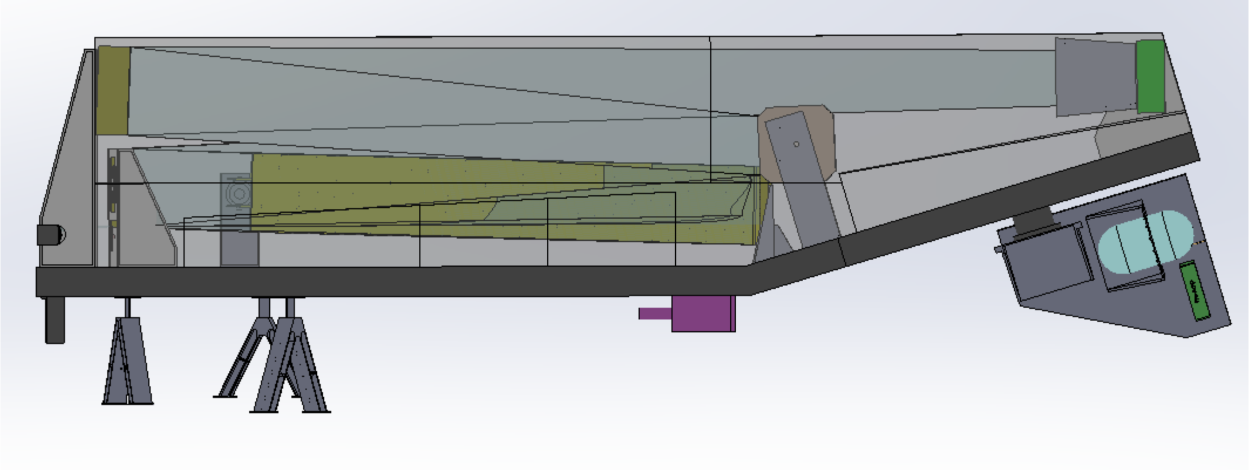
Mechanical Design Bottom

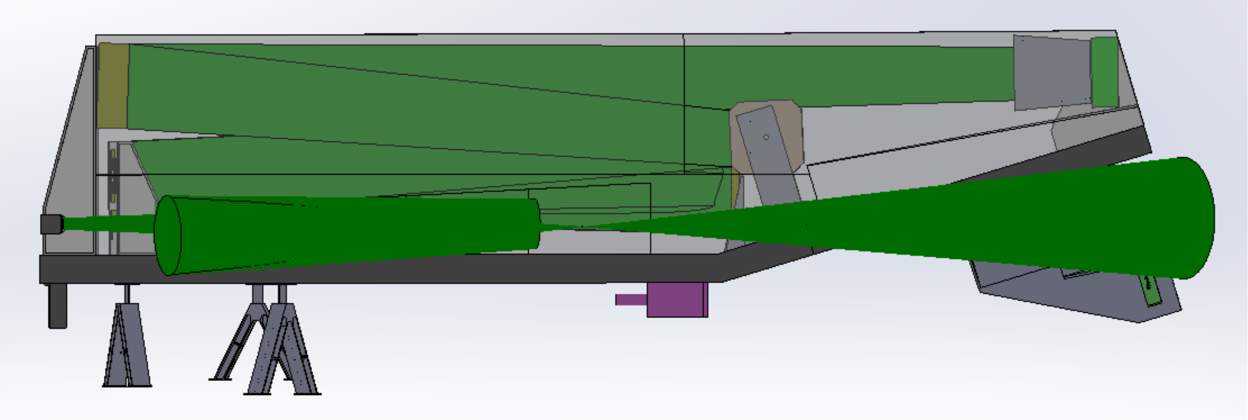
- Plan views



Mechanical Design Side

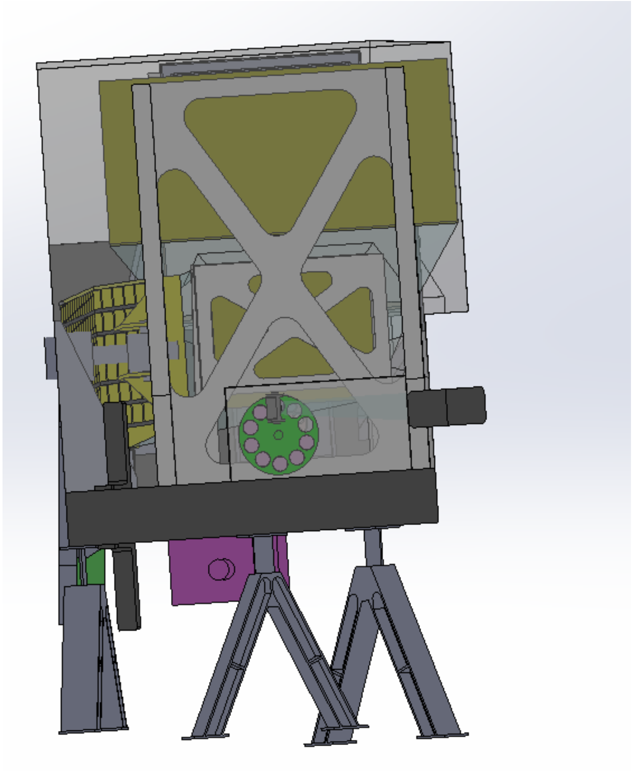
- Plan views

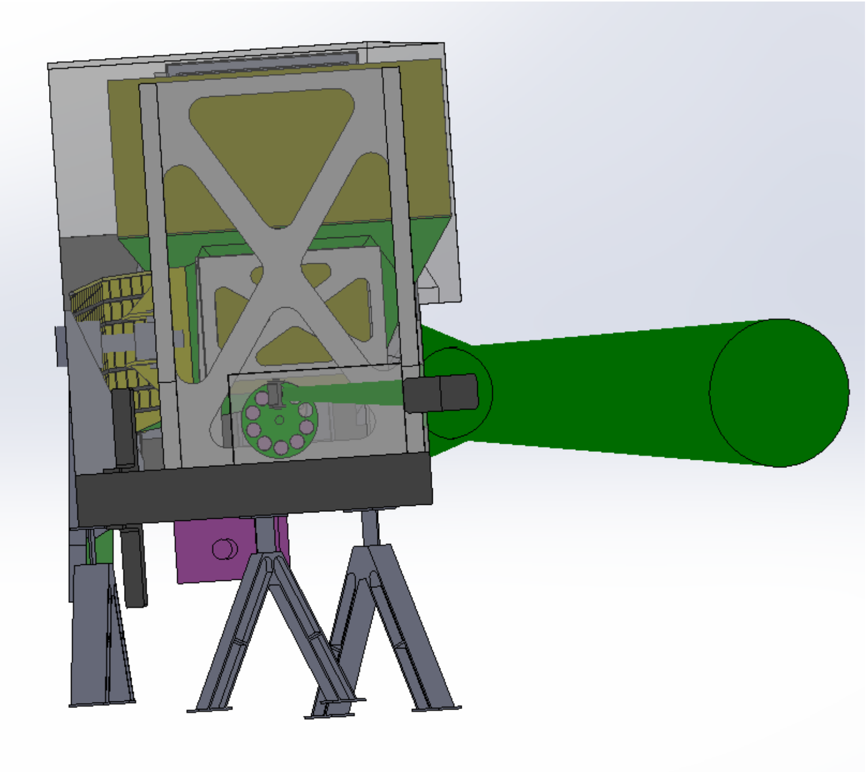




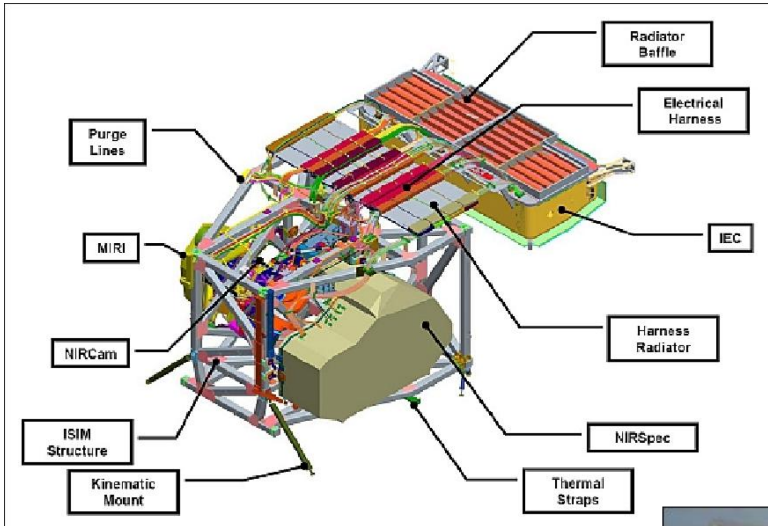
Mechanical Design Aft End

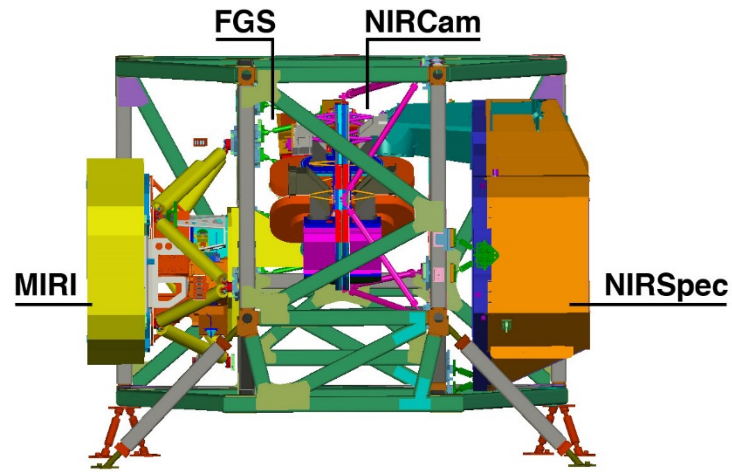
- Plan views





JWST ISIM


Radiator Baffle
Electrical Harness
Purge Lines
IEC
MIRI
NIRCam
Harness Radiator
ISIM Structure
NIRSpec
Kinematic Mount
Thermal Straps


FGS
NIRCam
MIRI
NIRSpec

Key Instrument Interfaces

- Mechanical
  - **Overall dimensions, shape***
  - **Mass***
  - Mounting concept
- Electrical
  - **Power***
  - Voltages
  - Max Currents
  - **Wire count and kind (hot to cold side)***
  - Data Interfaces
  - **Data Volume/Rates***
- Optical
  - **Optical pick-off interface***

***Key interface information needed ASAP**

Key Instrument Interfaces

- Thermal
  - Cryo-cooler interface
- Software
  - Data formats/packetizing etc.
- Pointing/Alignment
  - Pointing stability
  - Jitter
  - Dithering requirements
- Any special accommodations or services

***Key interface information needed ASAP**

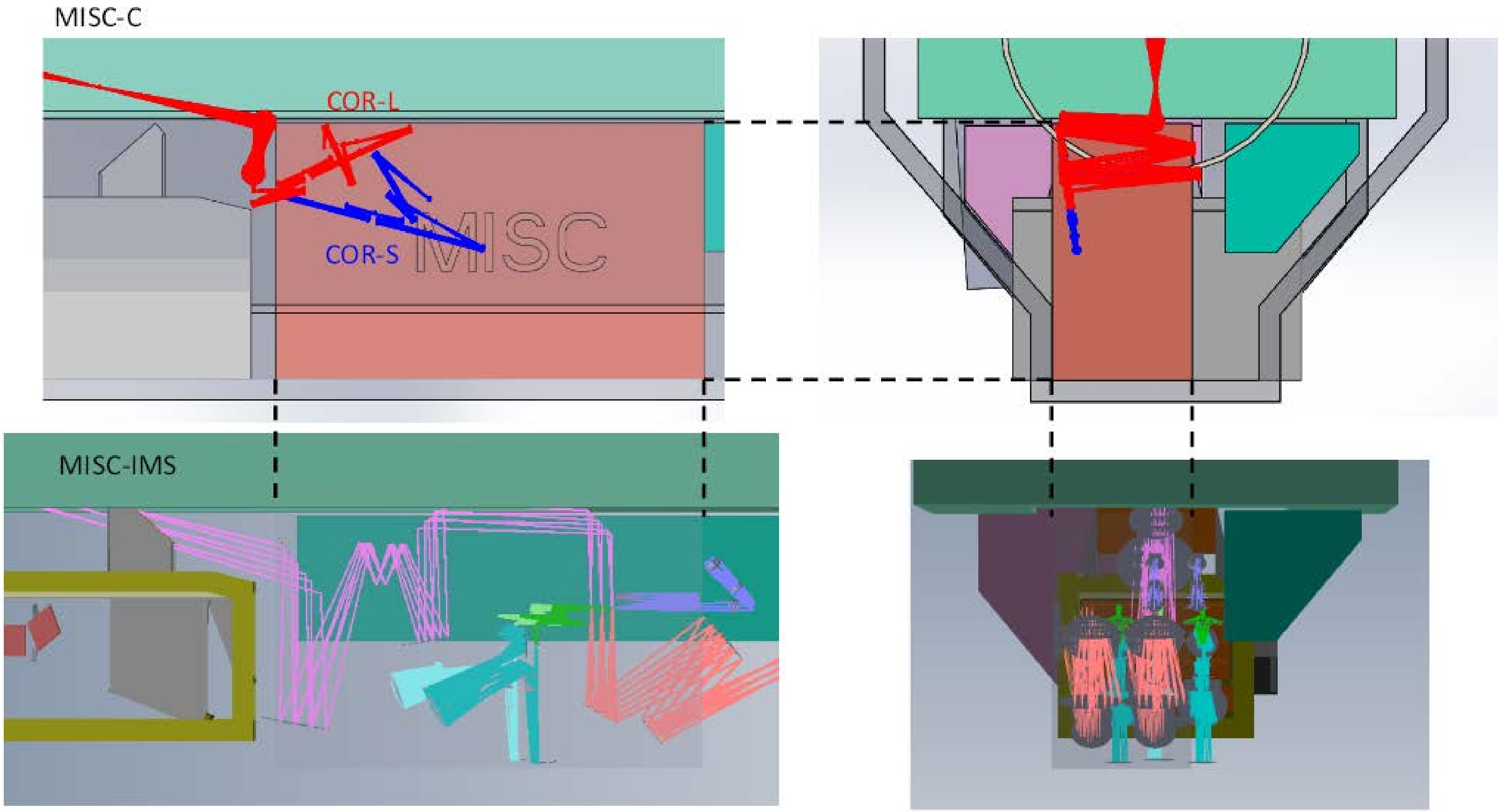
Issues/Challenges

- Instrument packaging is still a challenge
  - Providing all 5 instruments access to the focal surface is probably doable, but difficult.
- Instrument mass is higher than allocation
- Instrument volume is being exceeded in current volume allocated for IAM
- Heterodyne Local Oscillator requires path from warm to cold side
- Still working Optical Paths and CAD models for several instruments – they need to be integrated by IAM IDL Study

MISC Layout and comments during Instrumenter Face to Face Meeting

Greg Martins

June 13, 2017

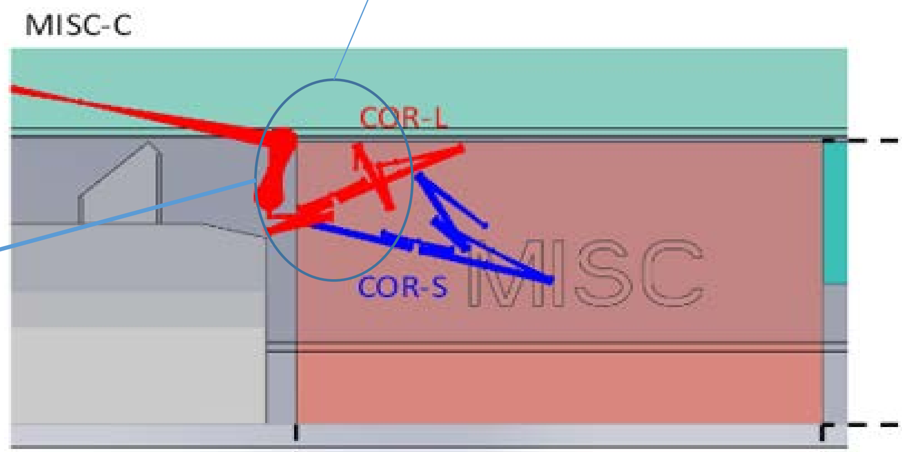

MISC-C
COR-L
COR-S
MISC
MISC-IMS

ORIGINS Space Telescope

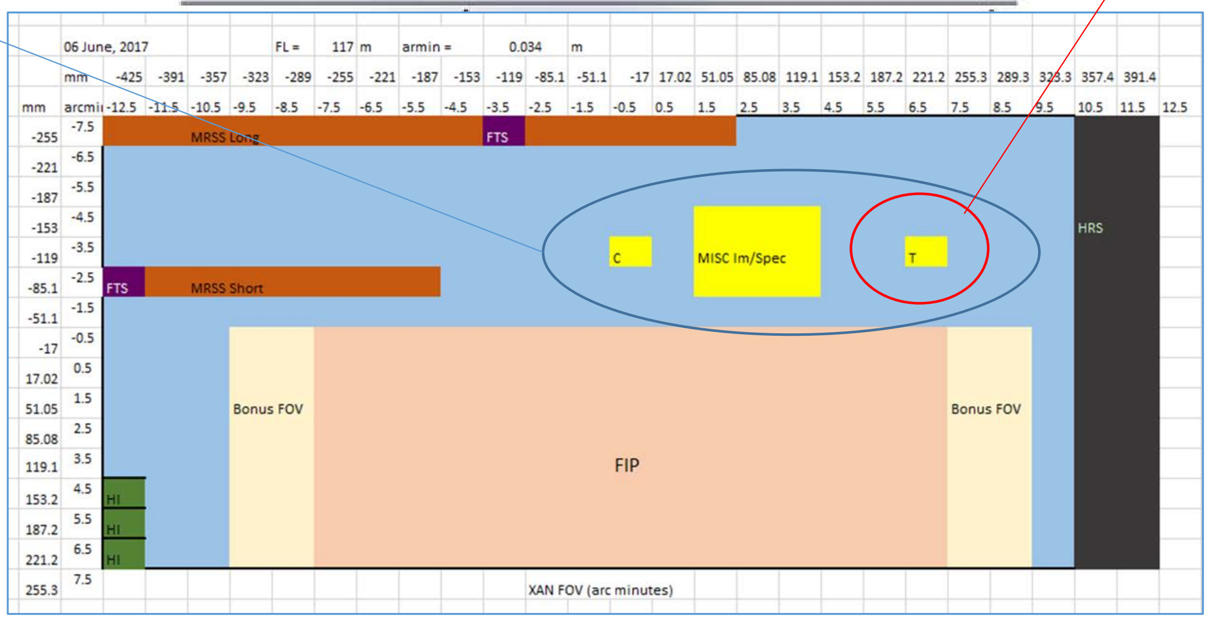
NASA

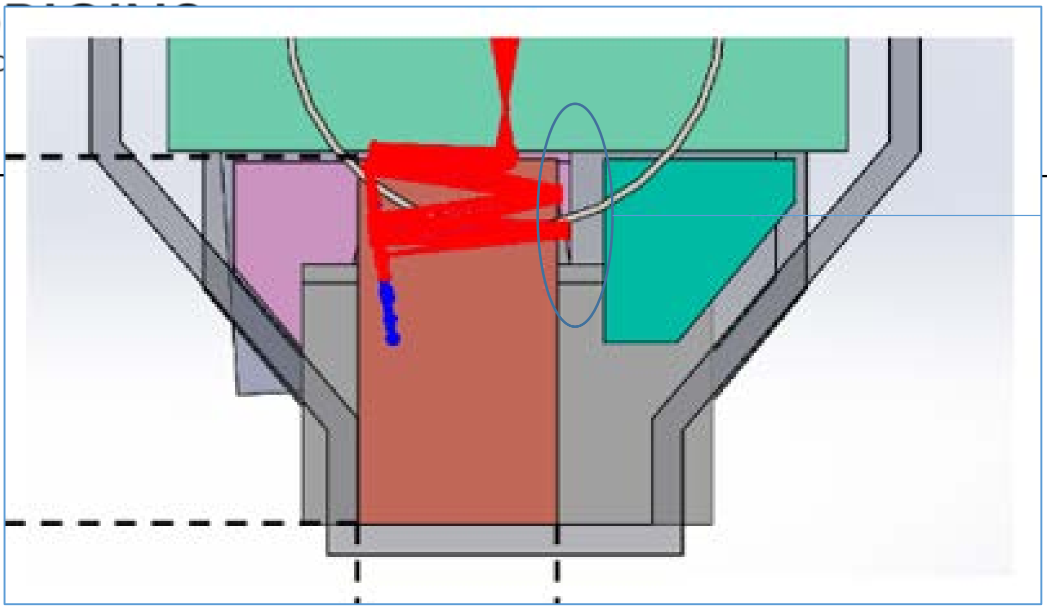
This ray trace is out of the box and too close to FIP instrument. Can we push your ray trace to the right to get it in the box, and I'd give you more volume on back of box?

Is this raytrace coming in from the location shown in yellow in field of view below? I assume yes, but need to verify. The incoming rays look higher than in IMS's incoming ray image.

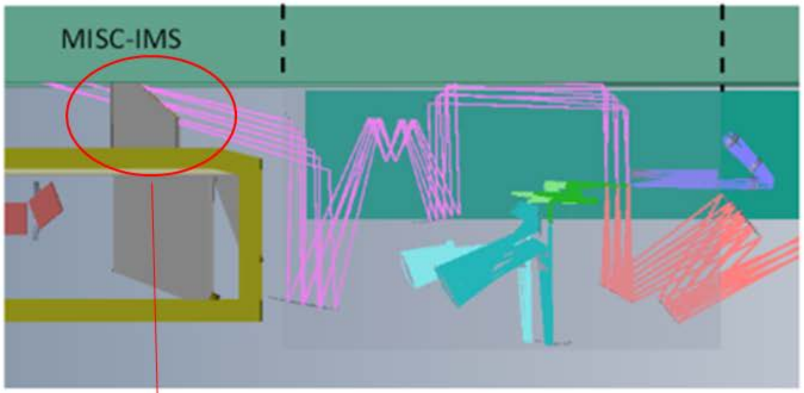


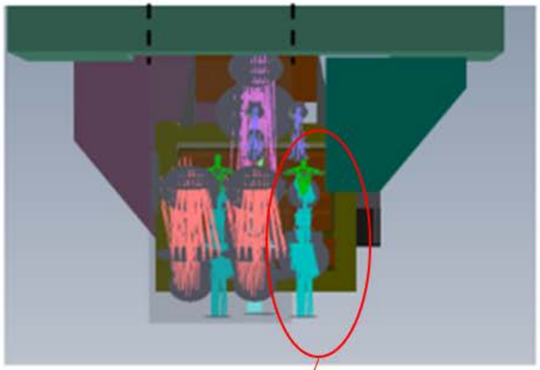
PDF image of "T" available?





This comes out of the box. I could potentially expand your box volume out to the right if you can't pull it in.

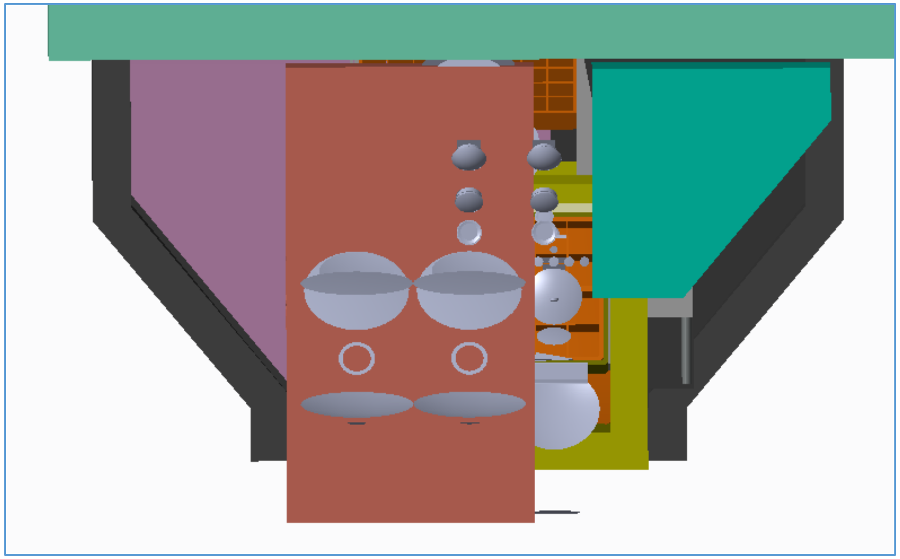


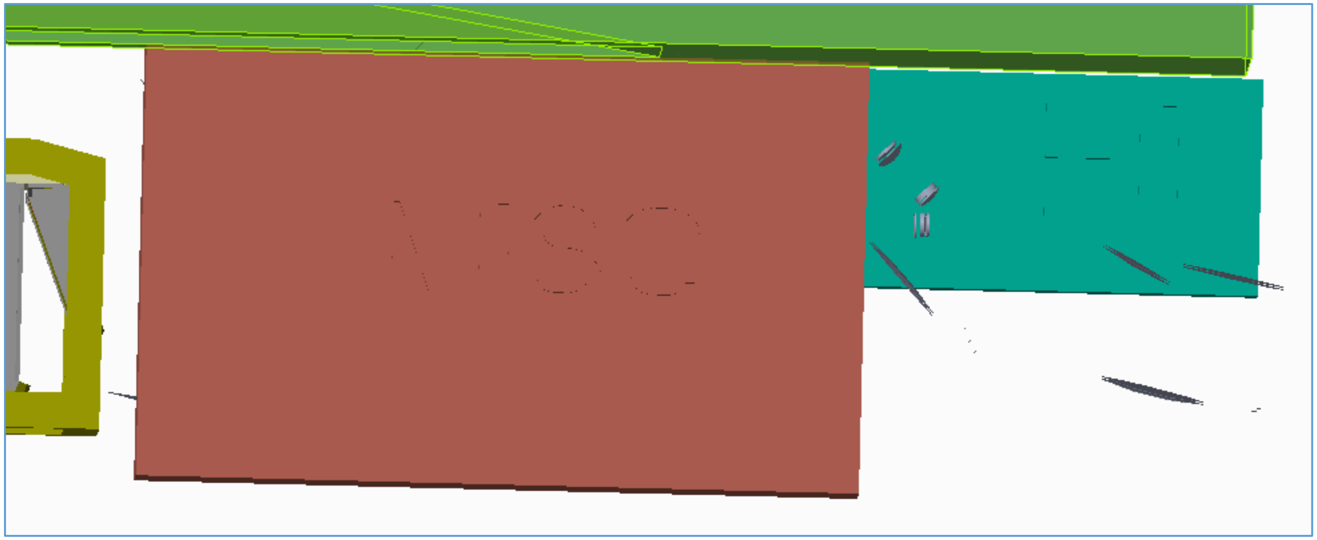


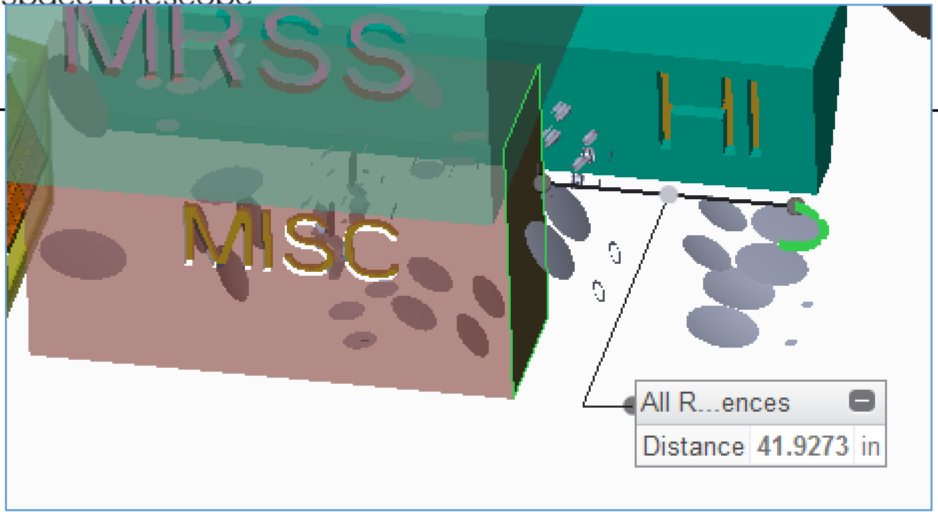
Moving FIP down by 5" will not fix this much interference. I will need to look into this.

Can this be pulled into box to the left, since it appears that in the image to the left, there is room? It wouldn't interfere with the pink ray trace.

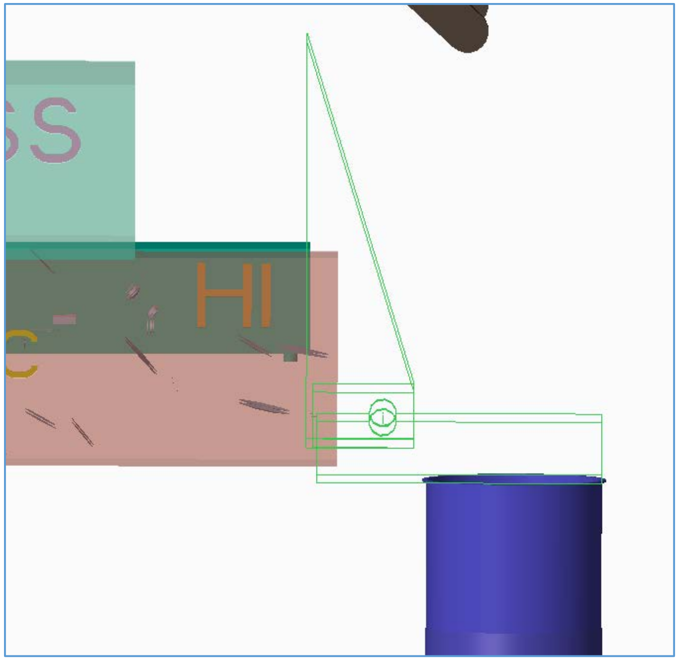
STEP file from Itsuki“: “OST with FIP prelim update”



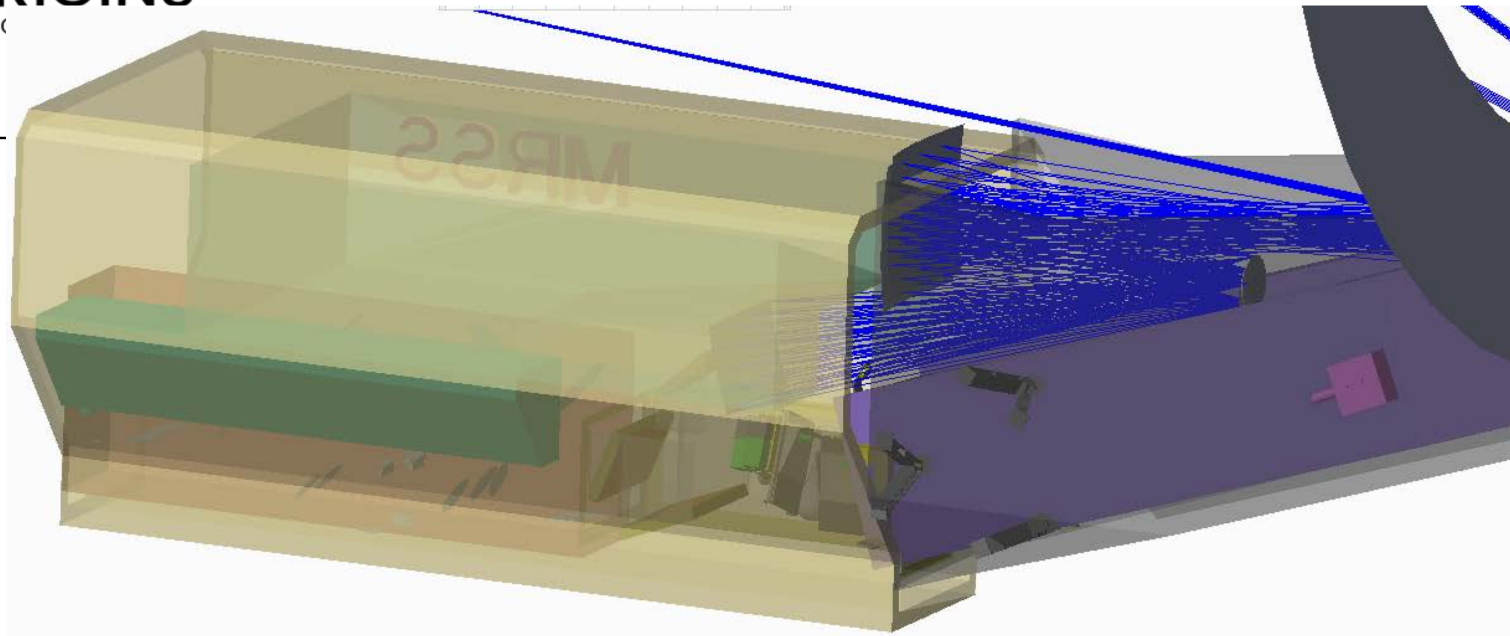




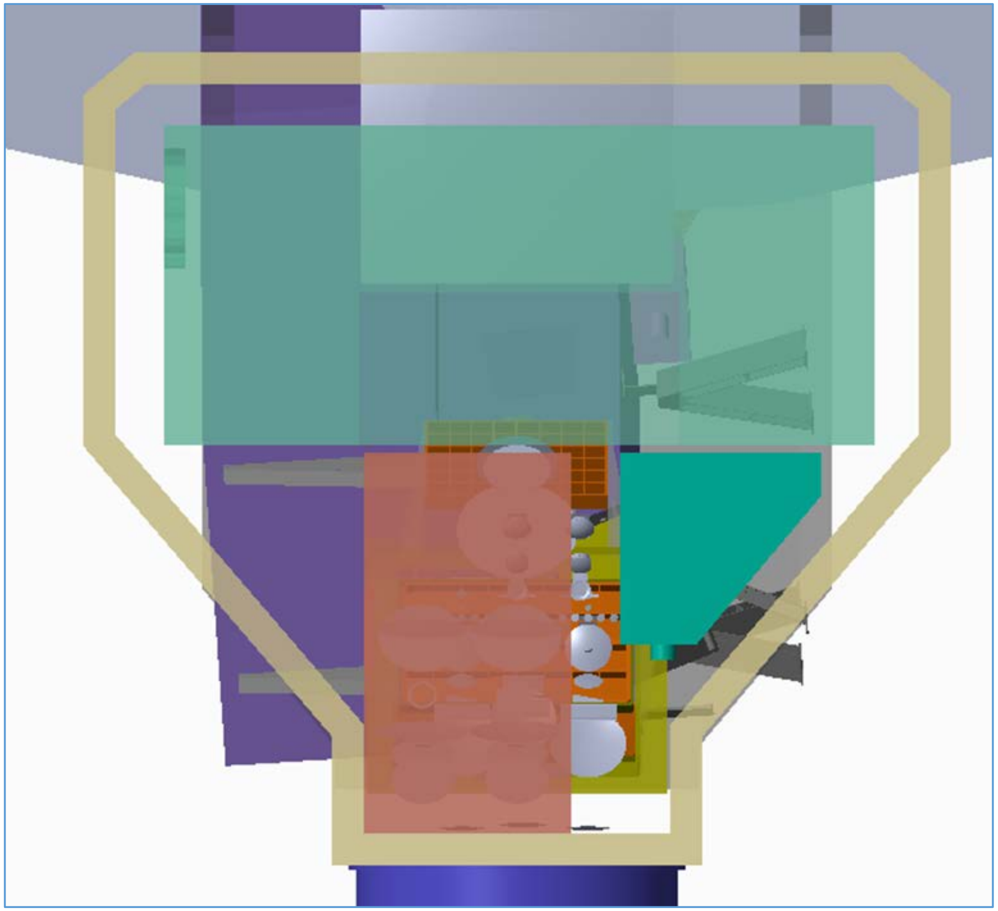
Extend length of MISC by 42"+ 8" = 50".

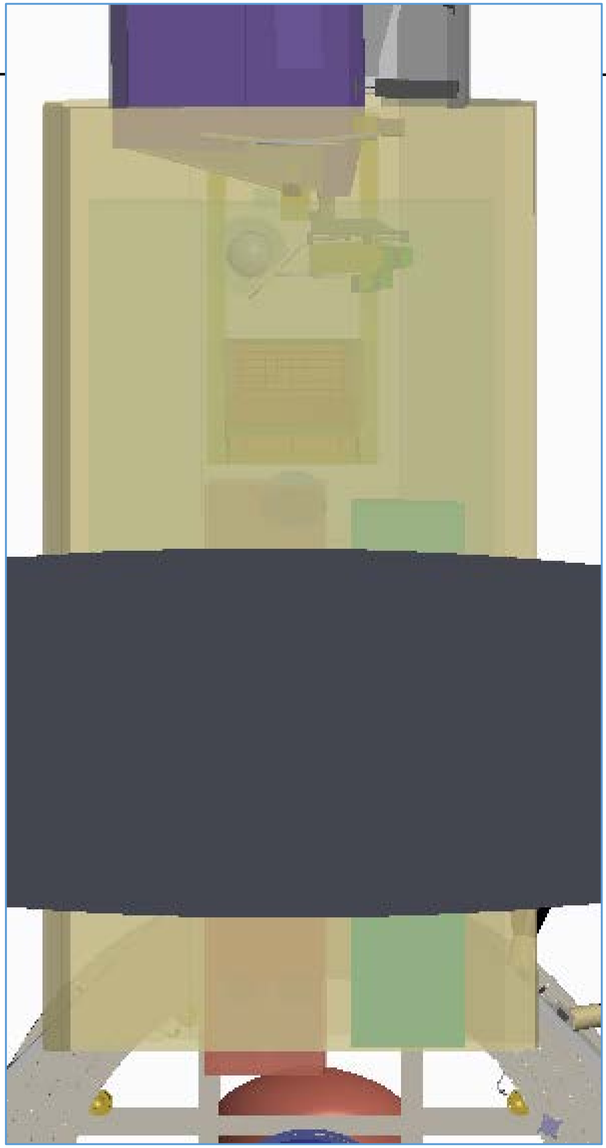


Itsuki - Extending the MISC box as shown in image eats into the green outlined hinge assembly. I can give you some of the interference there, but giving it all to you wouldn't be wise, at this time. Can you pull those optics back a bit?

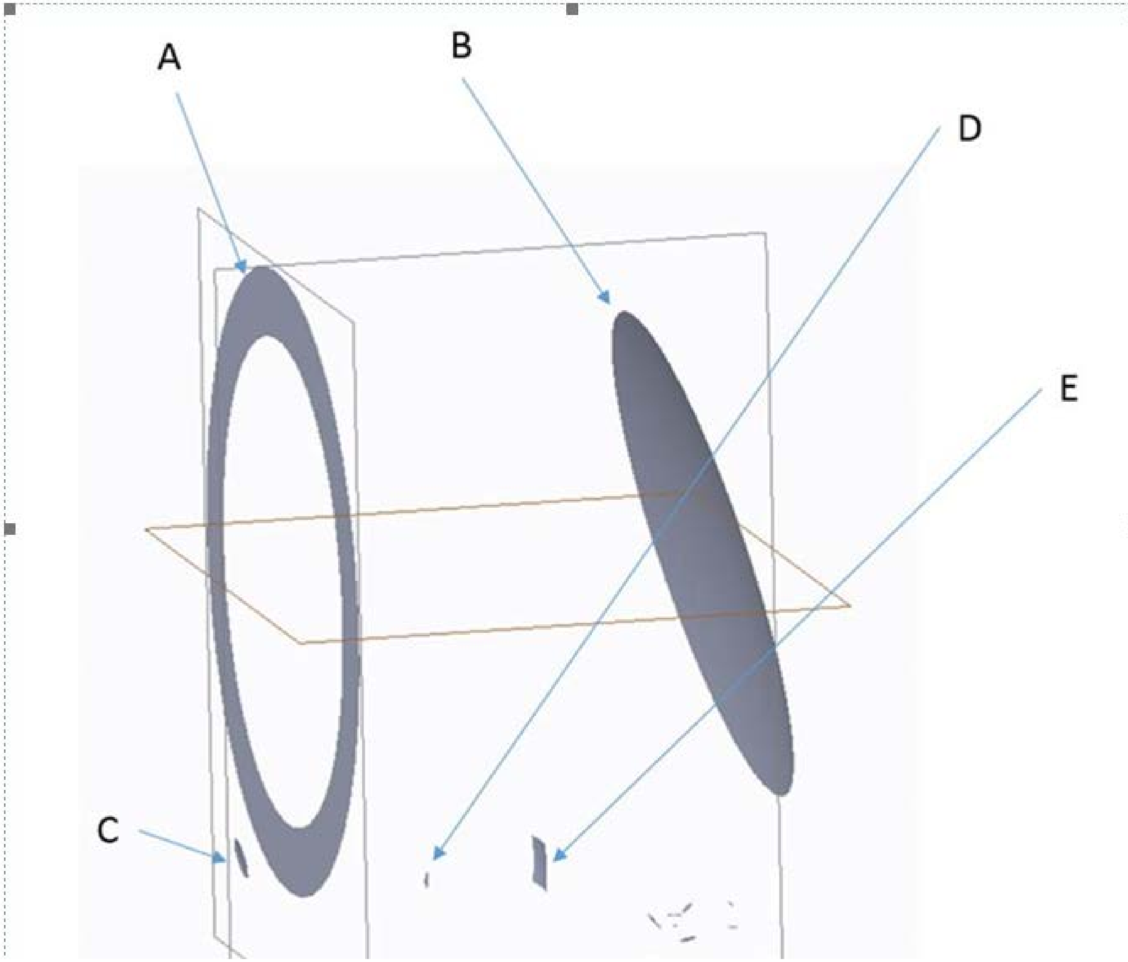


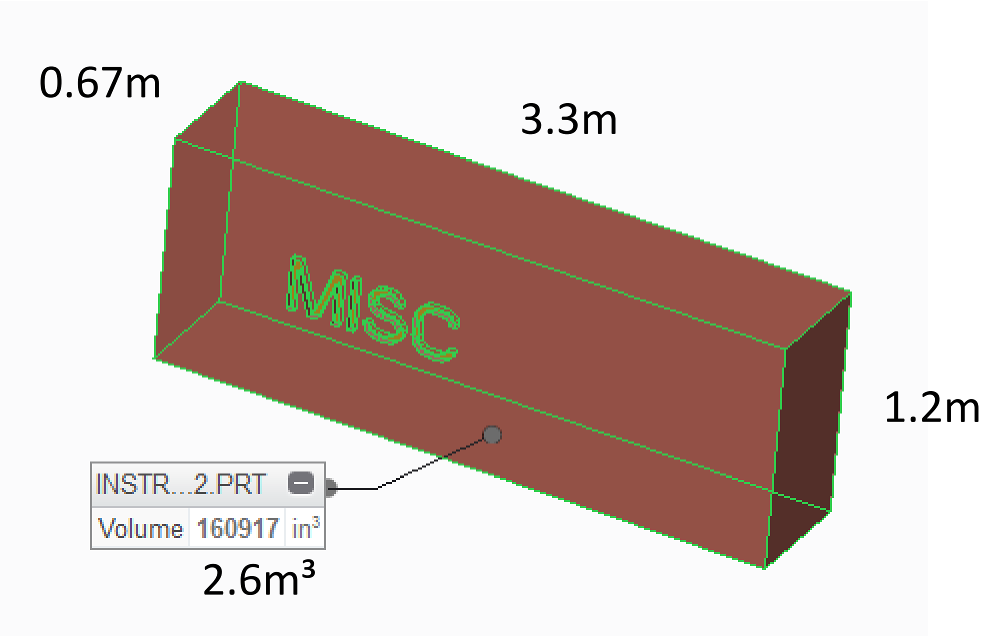

MRSS
MISC
HI



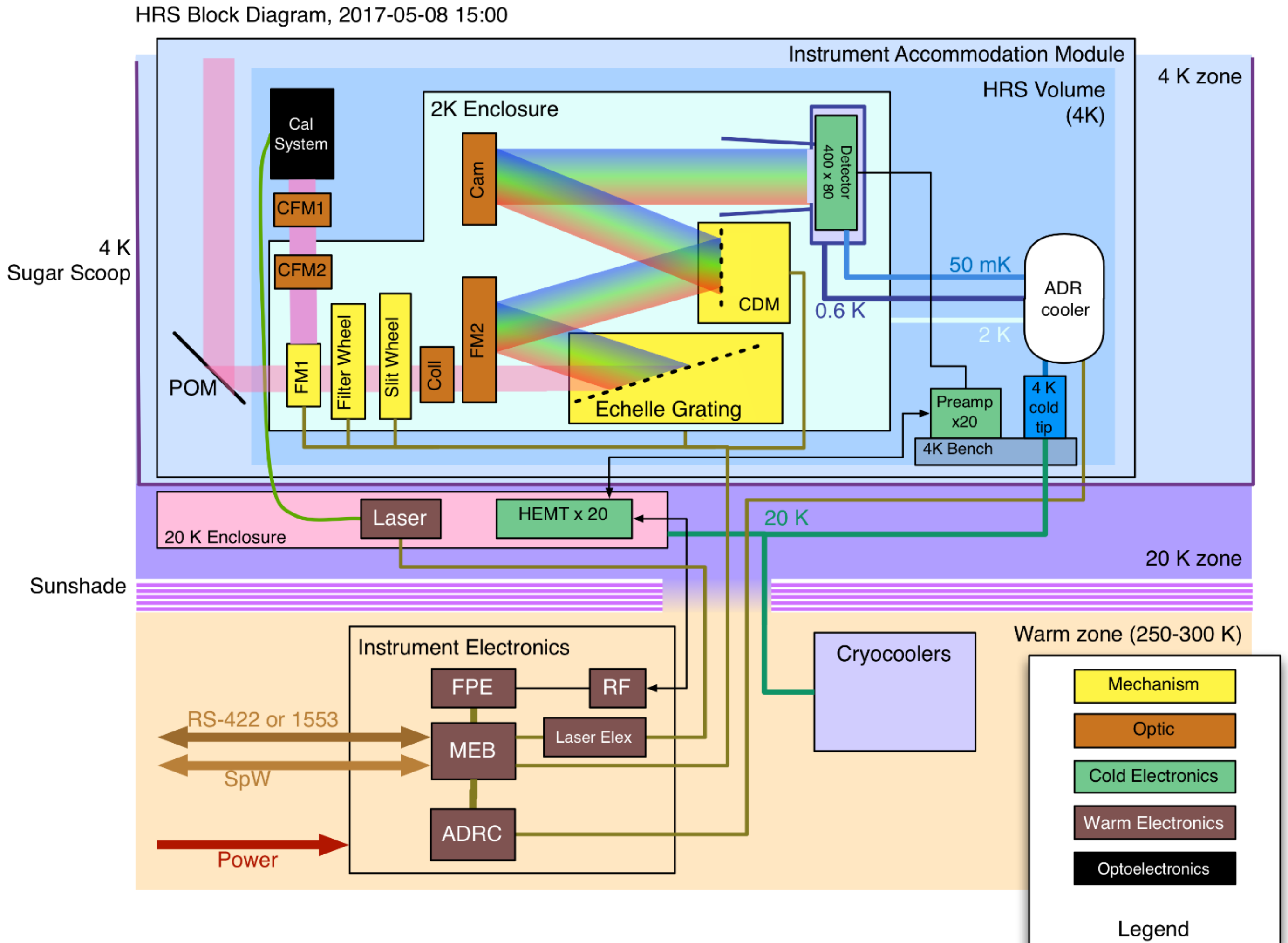


Hi Itsuki – In the part file below, is there an easy way you can make the items A, B, C, D & E be separate from your MISC box optics? I can't hide A thru E. If that's too hard, perhaps you can make A & B as a separate part from the rest?

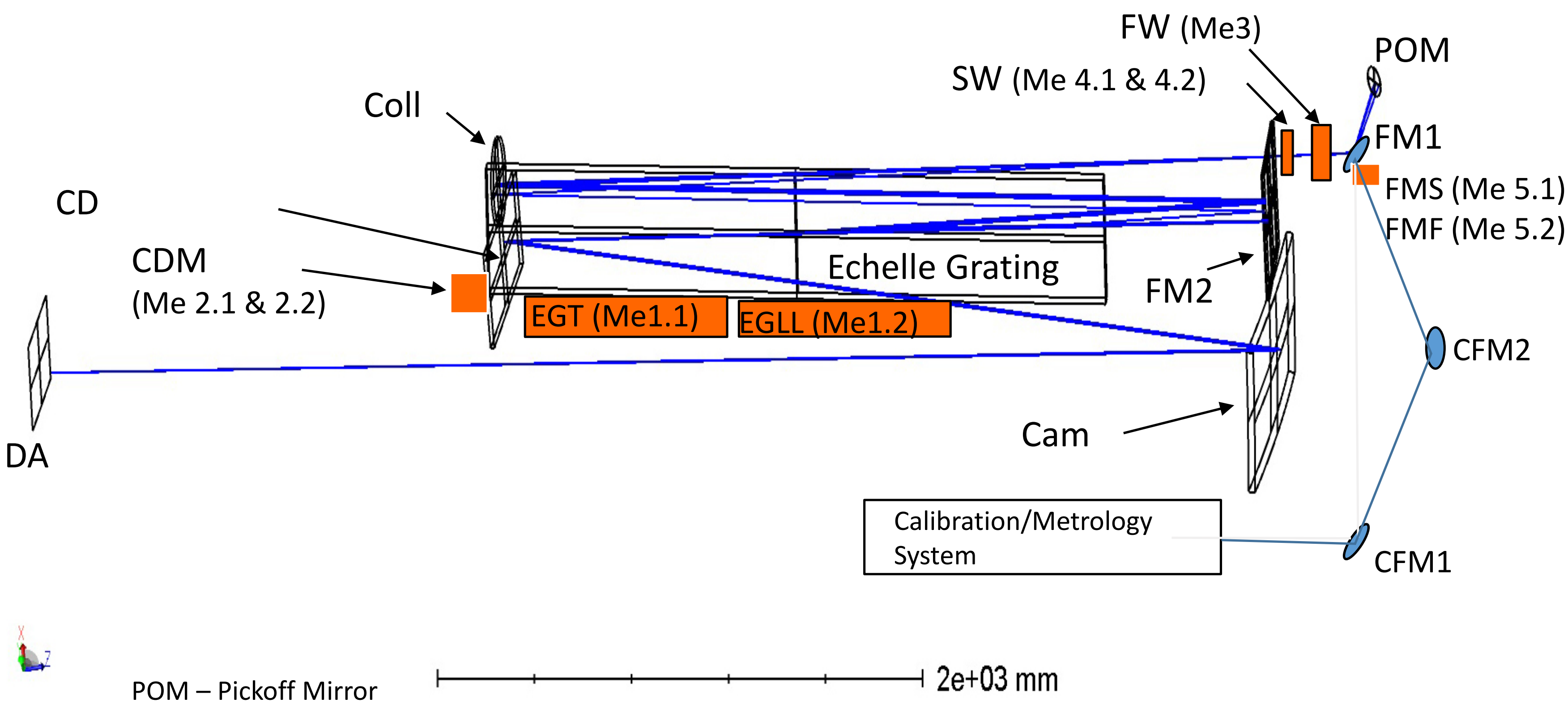



0.67m
3.3m
MISC
1.2m
INSTR...2.PRT
Volume 160917 in3
2.6m3

HRS Block Diagram



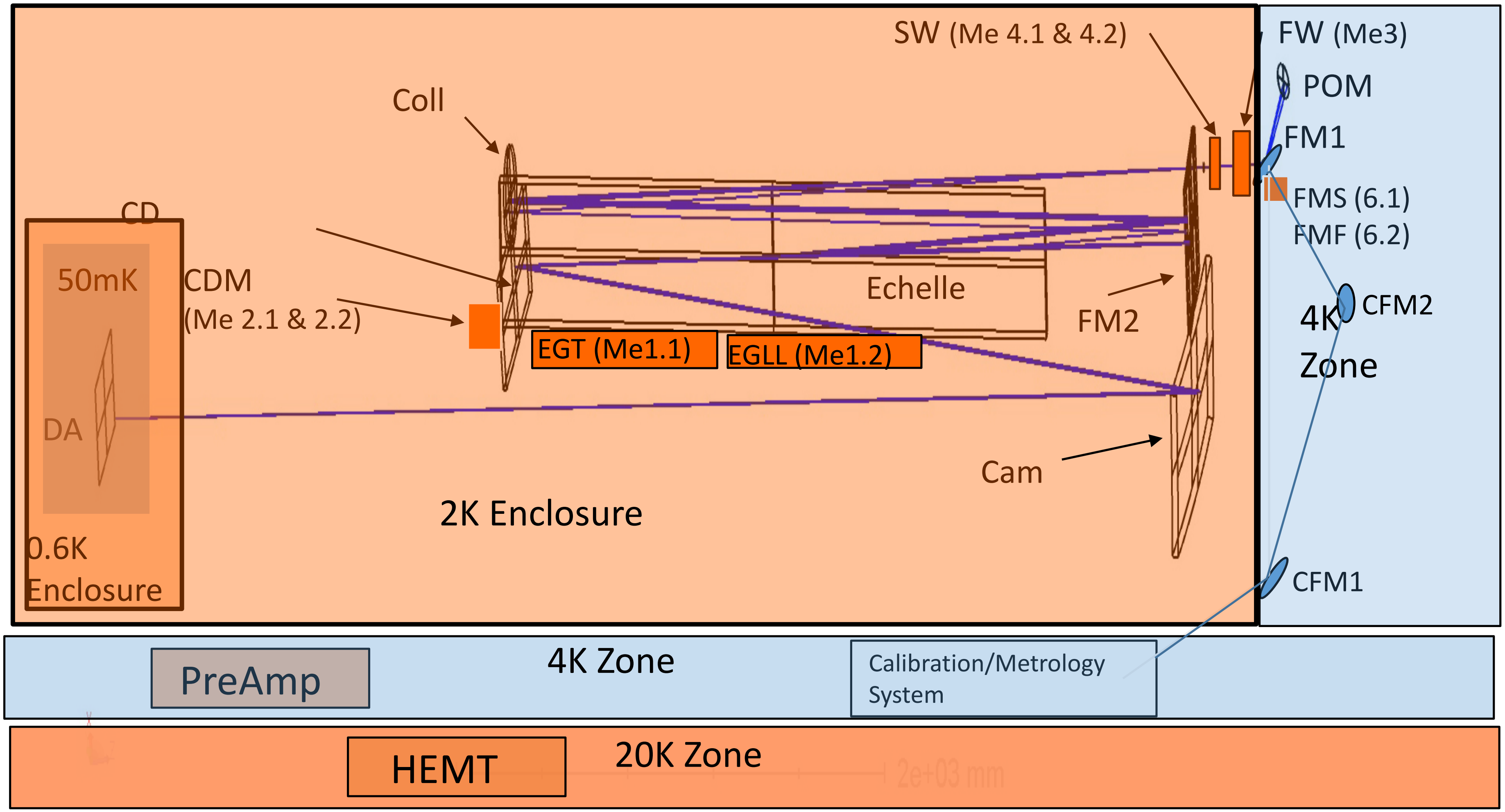
Optical Block Diagram



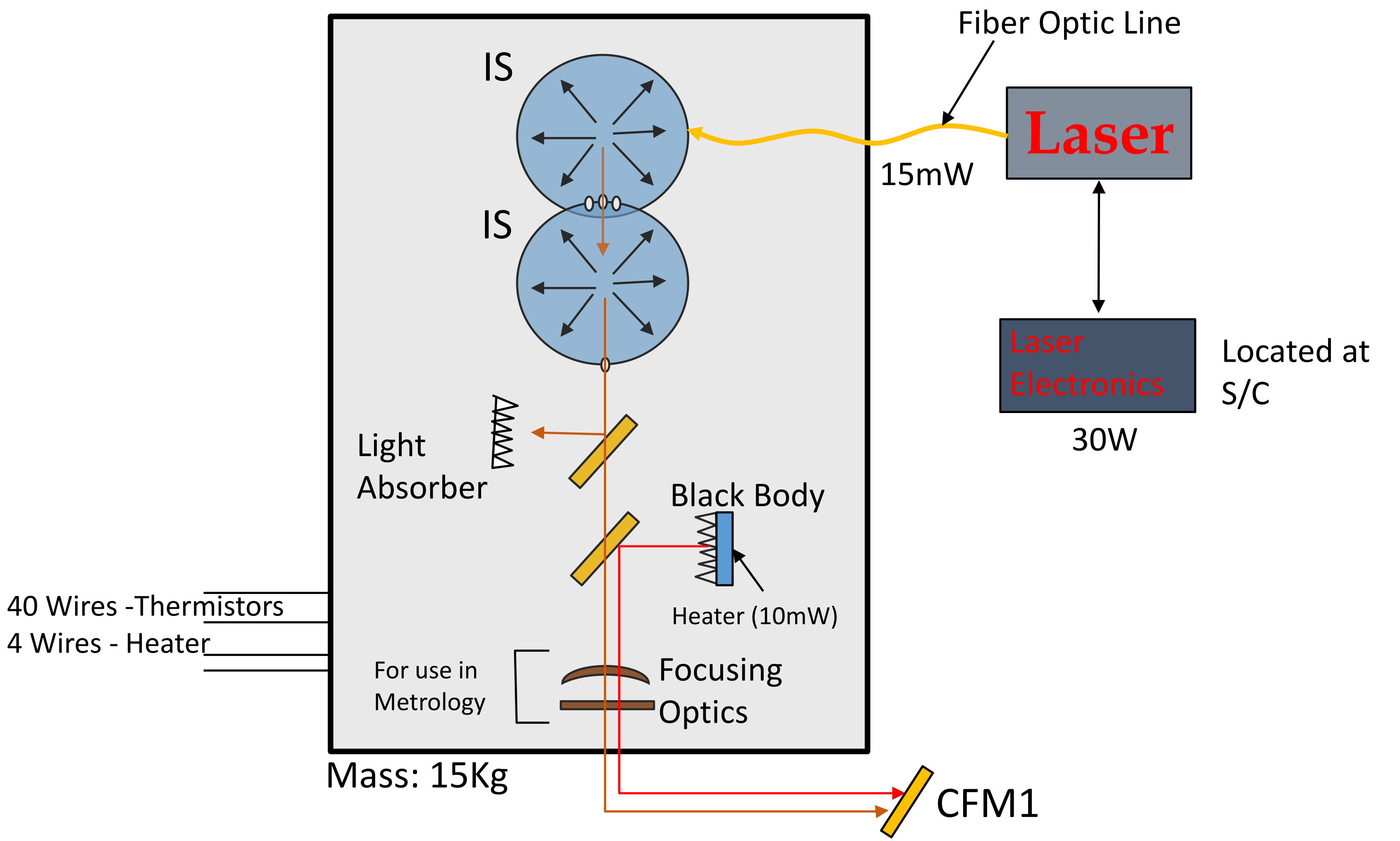
POM – Pickoff Mirror
FM1 – Fold Mirror 1
FMS – Fold Mirror Select mech(Me#6.1)
FW – Filter Wheel (Me#)
SW – Slit Wheel (Me#)
Coll – Collimator (OAP)
DA – Detector Assembly
EGLL – Echelle Grating Launch Lock (Me1.2)

FM2 – Fold Mirror 2
CD – Cross-Dispersion Grating
CDM – Cross-Dispersion Mechanism (Me#2.2 & 4.2)
SW – Slit Wheel (Me 4.1 &4.2)
CFM1&2 – Calibration Fold Mirror 1 & 2
EGT – Echelle Grating Tip Select Mechanism (Me 1.1)
Cam – Camera (OAP)

Thermal Zones



Calibration & Metrology System Block Diagram



Instrument Parameters

- Single-slit Echelle spectrometer
- Wavelength: 25 μm to 200 μm, in 4 bands
  - 25-50 μm
  - 45-90 μm
  - 80-160 μm
  - 140-200 μm
- Each band has high-flux and low-flux sub-bands
  - Total of 8 sub-bands, each with its own sub-array of detectors
  - Low-flux subarrays can view 3 orders at once
  - High-flux subarrays can view 1 order
- Spectral resolution: 10^5 at 50 μm

Concept of Operations

- Orbit: Sun-Earth L2
- Mission Duration: 5 years nominal with up to 10 years extended
- Mission Classification: Class A, fully redundant and cross strapped
- Operate in 4K environment with Detectors at 50mK
  - 4K cooling provided by S/C
  - 50mK cooling provided by HRS
- Operational scripts uploaded to S/C for verification, commanding of observatory and sent subsequently to instrument for mode operational setup
- Operational Modes:
  - Boot Mode
    - Initialization/Configuration
  - Calibration Mode
    - Laser or blackbody
    - Capture and send standard science data
  - Science Mode
    - Select position of all mechanisms (filter and slit wheel only change between major bands)
    - Co-add raw data to 50Hz rate for allocated science period
    - Send packets to S/C
- HRS data sent to S/C for integration with observatory ACS telemetry for ground transmission

Instrument Operational Modes

- Calibration
- Science
  - Observe for ~30 minutes
  - Move cross-disperser to select next set of orders
  - When done with all orders in current detector, move Echelle to select next detector
    - May need to move filter wheel
  - Repeat

ORIGINS Space Telescope

Mechanisms

- Fold Mirror 1 (Me5.1/5.2)
  - Selects sky or calibration input
- Filter Wheel (Me3)
  - 10 positions, including open
- Slit Wheel (Me4.1/4.2)
  - 8 positions, including open
  - High repeatability required (relative to wavelength)
- Echelle grating (Me1.1/1.2)
  - 5.9° adjustment of Echelle grating
  - High repeatability required (relative to wavelength)
- Cross-Dispersion grating (Me2.1/2.2)
  - Selects one of 4 gratings
  - Adjusts angle to put desired orders on desired detector sub-array
- NOTE: Required servicing mechanisms not addressed in this study.

Instrument Resource Summary

(no contingency included)

OST HRS	Total Mass	Total Operating Power (Effective Average)	Data Rate	Instrument Enclosure Dimensions [m x m x m]
2K Optical Bench **Pick Off Mirror Assembly** **Filter Wheel (FW) Assembly** **Calibration System** **Fold Mirror Assemblies** **Slit Wheel (SW) Assembly** **Collimator Assembly** **Echelle Grating Assembly** **Cross Dispersion (CD) Assembly** **Camera Assembly** **Detector** **4k Bench** **Preamp Assembly and HEMT** **ADR** **Electronics Boxes** **Harness** **Thermal Subsystem**	936.474 Kg *Details in MEL*	1000 W *Details in Electrical Presentation*	4.8 Mbps *Details in Electrical Presentation*	*Details in Mechanical Systems Presentation*

Preliminary Study Resource Estimations

Resource	HRS Allocation	Basis	Study Outcome: Resource Estimation
Mass	165 kg*	1/5 of total resource	TBD
Power Warm Side	200 W*	Assumes duty cycling of instruments	~1000 W
Power Cold Side	20 mW*	1/5 of total resource	33 mW
Volume Warm Side	TBD		FPE – 66 x 23 x 18 MEB – 23 x 16 x 18 cm ADRC - TBD
Volume Cold Side	4 m^3*	Based on initial layouts	Exceeds given boundary in several places
Data Volume	47 Gbit/day	1/5 of total resource	415 Gbit/day
Wave-Front Error	921 nm	Initial optical error budget	Not addressed in this study

Concerns with Allocations

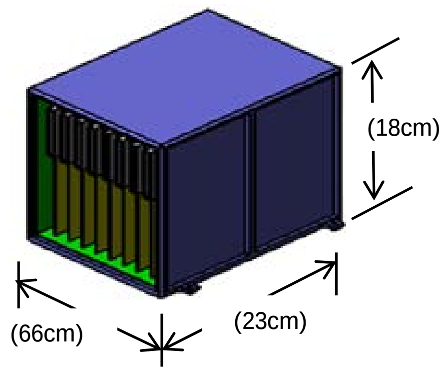
- Detectors not well defined, low TRL
- Power allocation exceeded by factor of 5
- Mass allocation exceeded by factor of TBD
- Volume (shape) allocation is notional, and exceeds supplied envelope
- 4 K heat load exceeded by factor of TBD
- No physical location or volume limits provided for any electronics:
  - HEMT amplifiers (somewhere in the 20 K region)
  - ADR Controller
  - RF electronics
  - Focal Plane Electronics
  - Main Electronics Box

HRS Top Level Mass Summary

OST-HRS Instrument	Mass CBE (kg)	% of total
Optical Bench	180.000	19.2%
2K Shroud/Enclosure Sub-Assembly	25.600	2.7%
HRS BiPods (2K to IAM)	27.000	2.9%
Pick Off Mirror Assembly (4K) (mounted on 2K bench)	1.005	0.1%
Filter Wheel (FW) Assembly (2K) (FW,Mech,Enclosure) (2K)	0.795	0.1%
Calibration System Sub-Assembly (4K) (mounted to 2K Shroud)	15.015	1.6%
Calibration System Fold Mirror Assemblies	2.020	0.2%
Fold Mirror 1 Assembly (2K)	3.005	0.3%
Slit Wheel (SW) Assembly (2K)	2.746	0.3%
Collimator Sub-Assembly (2K)	7.996	0.9%
Fold Mirror 2 Sub-Assembly (2K)	24.306	2.6%
Echelle Grating Sub-Assembly	5.000	0.5%
Cross Dispersion (CD) Sub-Assembly	152.672	16.3%
Camera Mirror Sub-Assembly (2K)	106.382	11.4%
Detector Sub-Assembly	77.630	8.3%
4k Bench (houses ADR & preamp and LL to 2K bench)	10.000	1.1%
Preamp Assembly (4K)	0.000	0.0%
ADR Sub-Assembly (4K)--add ADR tab	38.800	4.1%
Launch Lock Sub-Assembly Hardware (4K)	15.000	1.6%
ADR Heatstraps to Detectors @ 50mK	0.110	0.0%
ADR Heatstrap to Detector enclosure @ 0.6K	0.023	0.0%
HEMT Assembly (20K Zone)	0.000	0.0%
ADR Controller (ADRC) Assembly	26.333	2.8%
Main Electroincs Box (MEB) Assembly	9.000	1.0%
Focal Plane Electronics Box (FPE) Assembly	36.400	3.9%
Radio Frequency (RF) Translator Box Assembly	0.000	0.0%
Harness (single-string)	41.350	4.4%
Harness (dual-string redundant)	60.740	6.5%
Thermal Subsystem	20.950	2.2%
Purge Hardware, etc.	2.000	0.2%
Total	891.880	95.2%
5% Miscellaneous Hardware	44.594	4.8%
Total (+ 5% misc. hardware and no margin):	936.474	100.0%

FPE Mass / Power Estimates

ITEMS	Power (each) Watts	Qty	Power Total Watts	Mass (each) (Kg)	Qty	Mass Total (Kg)
Detector (SQUIDs+Pixels)	0.001	1	0.00			
Pre-Amps	0.001	20	0.02			
HEMTs	0.003	20	0.06			
		1	0.00			
Sub Total:			**0.1**		**0**	**0**
FPE						
FPE C&DH Card (FPGA)	4.0	1	4.0	0.5	2	1.0
Readout/Digitizer Card (FPGA)	38.0	10	380.0	0.5	20	10.0
Power Card (@ 80% efficiency)	96.0	1	96.0	0.5	2	1.0
Backplane				0.8	2	1.6
Housing (A/B partition)				4.6	1	4.6
Sub Total:		**12**	**480.0**	**6.9**		**18.2**
Total:			**480.1**			**18.2**

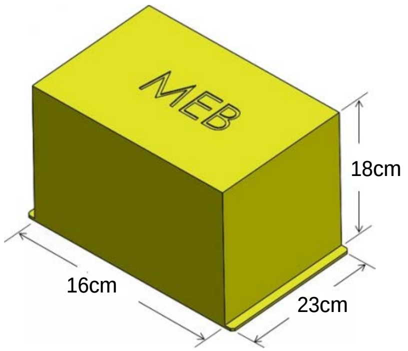


FPE Size, Mass & Power Summary:
Volume ~ **(23 x 18 x 66)cm**, Mass ~ (13.6Kg PCB + 4.6Kg Housing) ~ **18.2Kg** Total, **480Watts**

Electrical Mass / Power CBE

ITEMS	Power (each) Watts	Qty	Avg. Power Total Watts	Mass (each) (Kg)	Qty	Mass Total (Kg)
Stepper Motors (@ 10% Duty Cycle)	5.0	8	0.5			
Blackbody	0.01	1	0.0001			
RF Translation Electronics	10.0	1	10.0			
Sub Total:			**10.5**		**0**	**0**
MEB						
Processor Card	8.0	1	8.0	0.5	1	0.5
Stepper Motor Drive Card (FPGA)	5.0	2	10.0	0.5	2	1.0
Housekeeping Card	2.0	1	2.0	0.5	1	0.5
Power Card (@ 80% efficiency)	7.6	1	7.6	0.5	1	0.5
Backplane				0.5	1	0.5
Housing				1.5	1	1.5
Sub Total:		**5**	**27.6**		**7**	**4.5**
Harnessing				107.8	1	107.8
Laser (@ < 1% duty cycle)	30.0	1	0.3			
FPE	480.0	2	960.0	18.2	2	36.4
Total:			**998.5**			**40.9**

Placeholder



<u>MEB Size, Mass & Power Summary</u>:
Volume ~ **(23 x 18 x 16)cm**, Mass ~ (3.0Kg PCB + 1.5Kg Housing) ~ **4.5Kg** Total, **27.6Watts**

Instrument Data Rates

Detector Size: (20 x 400)pix each of 4 segments

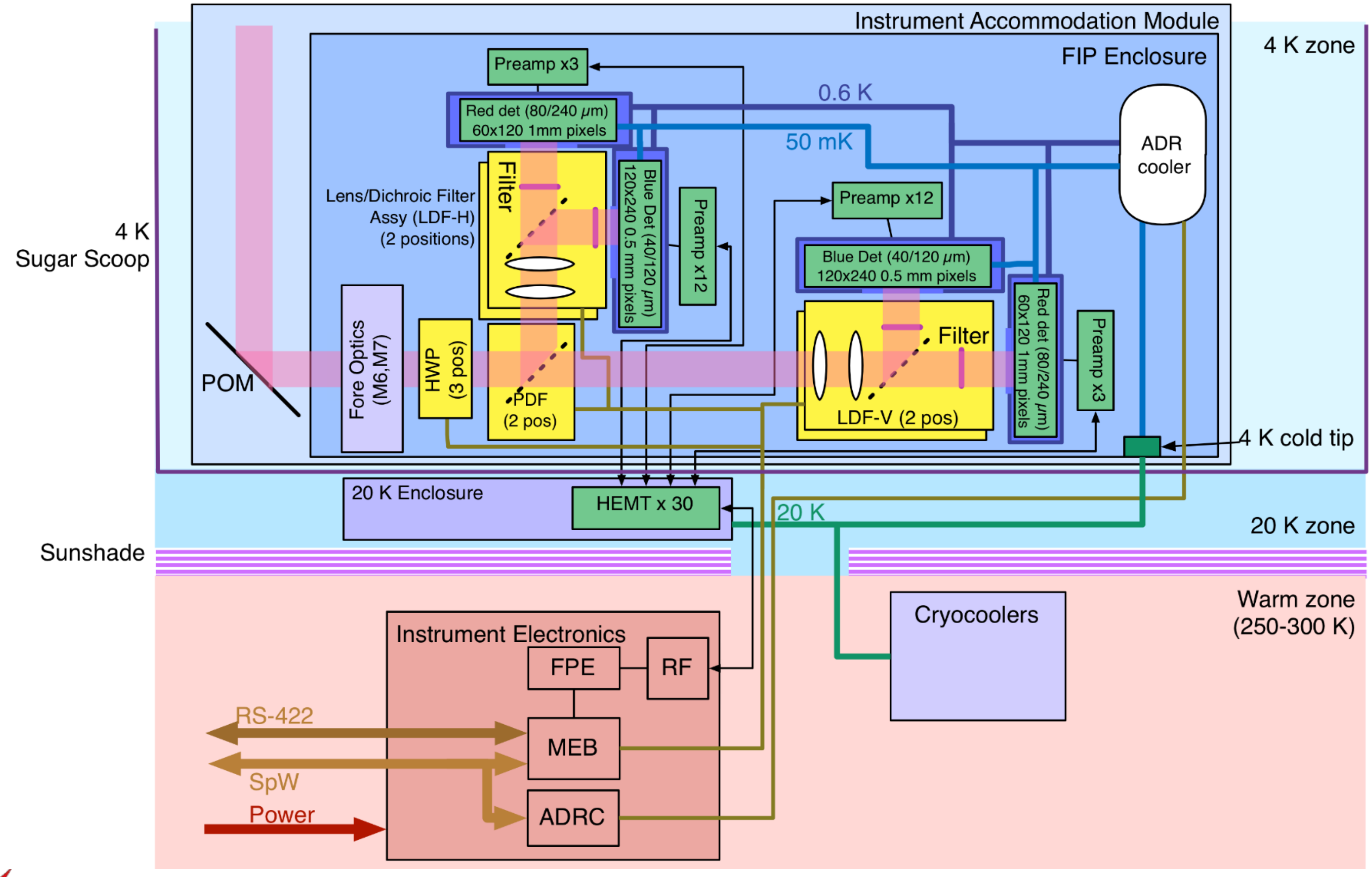
ADC Sample Rate ~ 2GHz @ 12bits/sample
⇒ ~ **24Gbps** readout to the FPGA each ADC (ie. 48Gbps each FPGA/PCB)

Sampling period for FPGA Data processing ~ 0.5msec
⇒ 2KHz Frame rate
⇒ Raw Data Rate ~ (400 x 20)pix x (12bits/pix) x (2KHz) ~ **192Mbps**

Assume 50Hz co-added Frames to Spacecraft for storage/downlink
⇒ Co-Added Data Rate ~ (400 x 20)pix x (12bits/pix) x 50Hz ~ **4.8Mbps**

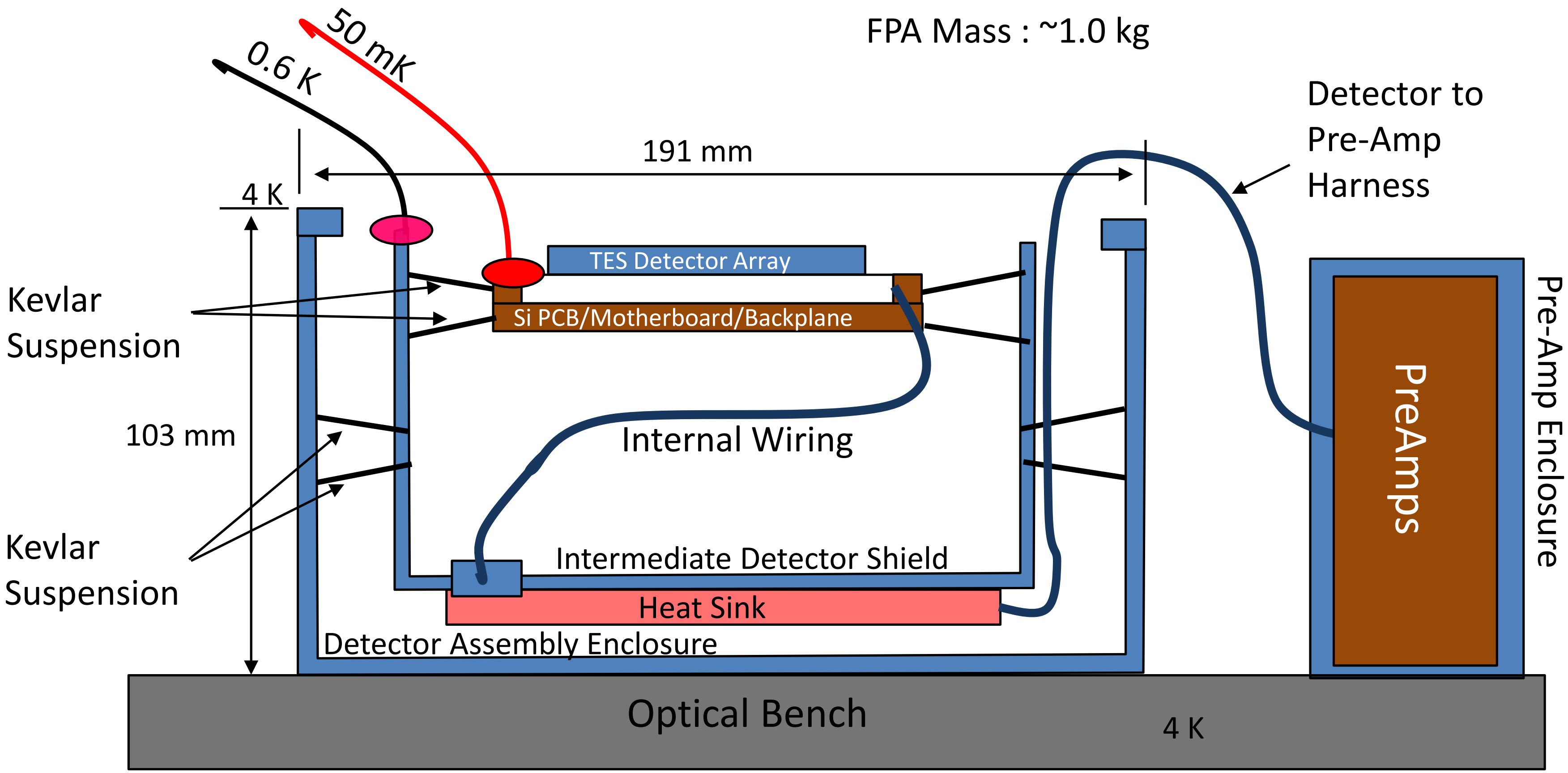
FIP Block Diagram

FIP Block Diagram, 2017-04-24 14:00

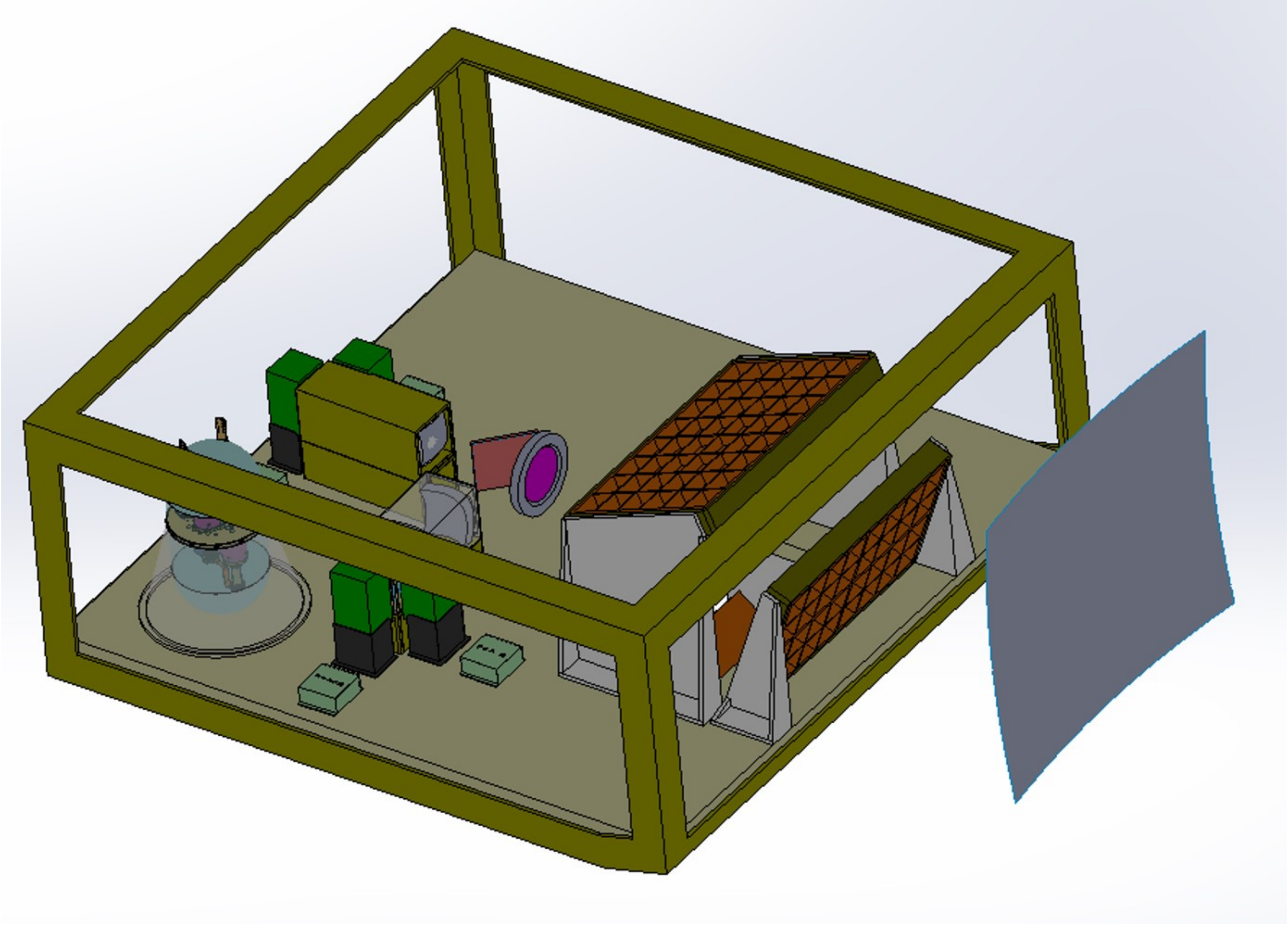


Detector Assembly Block Diagram

Volume: 191 mm x 110 mm x 103 mm
FPA Mass : ~1.0 kg



Instrument Layout



Instrument Parameters

- FOV: 7.5 x 15 arcmin
- Wavelength: 40 µm to 240 µm

Wavelength bands

	Blue	Red	Optical speed
Short	40 µm	80 µm	f/7
Long	120 µm	240 µm	f/2
Pixel pitch	0.5 mm	1.0 mm	

Concept of Operations

- Orbit: Sun-Earth L2
- Mission Duration: 5 years nominal with up to 10 years extended
- Mission Classification: Class A, fully redundant and cross strapped
- Operate in 4K environment with Detectors at 50mK
  - 4K cooling provided by S/C
  - 50mK cooling provided by FIP
- Operational scripts uploaded to S/C for verification, commanding of observatory and sent subsequently to instrument for mode operational setup
- Operational Modes:
  - Boot Mode
    - Initialization/Configuration
  - Characterization Mode
    - Filter, HWP, PDF configuration
    - Raw data capture at full detector readout rate (10Khz) for 5 seconds
    - Data buffered and FIFO packets sent to S/C
  - Science Mode
    - Filter, HWP, PDF configuration
    - Co-add raw data to 50Hz rate for allocated science period
      - FIFO packets sent to S/C
- FIP data sent to S/C for integration with observatory ACS telemetry for ground transmission

Instrument Operational Modes

- Polarization (40-80 µm)
  - HWP: *HWP-short*, stepping every step period (couple minutes)
  - PDF: *Polarizer*
  - LDF-H: *Short (f/7)*
  - LDF-V: *Short (f/7)*
- Polarization (120-240 µm)
  - HWP: *HWP-long*, stepping every step period (couple minutes)
  - PDF: *Polarizer*
  - LDF-H: *Long (f/2)*
  - LDF-V: *Long (f/2)*
- Full-band
  - HWP: *Open*, not stepping
  - PDF: *Dichroic*
  - LDF-H: *Short (f/7)*
  - LDF-V: *Long (f/2)*

Mechanisms

- Half-Wave Plate
  - 3 positions: *HWP-short, open, HWP-long*
  - middle position is truly open (no positioning requirements other than "Don't get in the way of the beam"
- Polarizer/Dichroic
  - 2 positions: *Polarizer, Dichroic*
- Lens/Dichroic/Filter Barrel – Horizontal (LDF-H)
  - 2 positions: *short (f/7), long (f/2)*
  - High repeatability required (relative to wavelength)
- Lens/Dichroic/Filter Barrel – Vertical (LDF-V)
  - 2 positions: *short (f/7), long (f/2)*
  - High repeatability required (relative to wavelength)
- NOTE: no focus mechanism or Pick-off Mirror mechanism is needed, per customer direction
- NOTE: Required servicing mechanisms not addressed in this study.
- NOTE: Launch locks not addressed in this study.

Preliminary Study Resource Estimations

Resource	FIPS Allocations	Basis	Study Outcome: Resource Estimation
Mass	165 kg*	1/5 of total resource	~781 kg
Power Warm Side	200 W*	Assumes duty cycling of instruments	~590 W
Power Cold Side	20 mW*	1/5 of total resource	45mW in 4K Zone 90 mW in 20K Zone
Volume Warm Side	TBD		FPE - TBD MEB – TBD ADRC - TBD
Volume Cold Side	4 m^3*	Based on initial layouts	Kept inside a 2m x 2m x 1m envelope – except for POM and 20K HEMT Enclosure
Data Volume	47 Gbit/day	1/5 of total resource	154 Gbit/hr based on 43Mbps – no compression
Wave-Front Error	921 nm	Initial optical error budget	Not addressed in this study

Concerns with Allocations

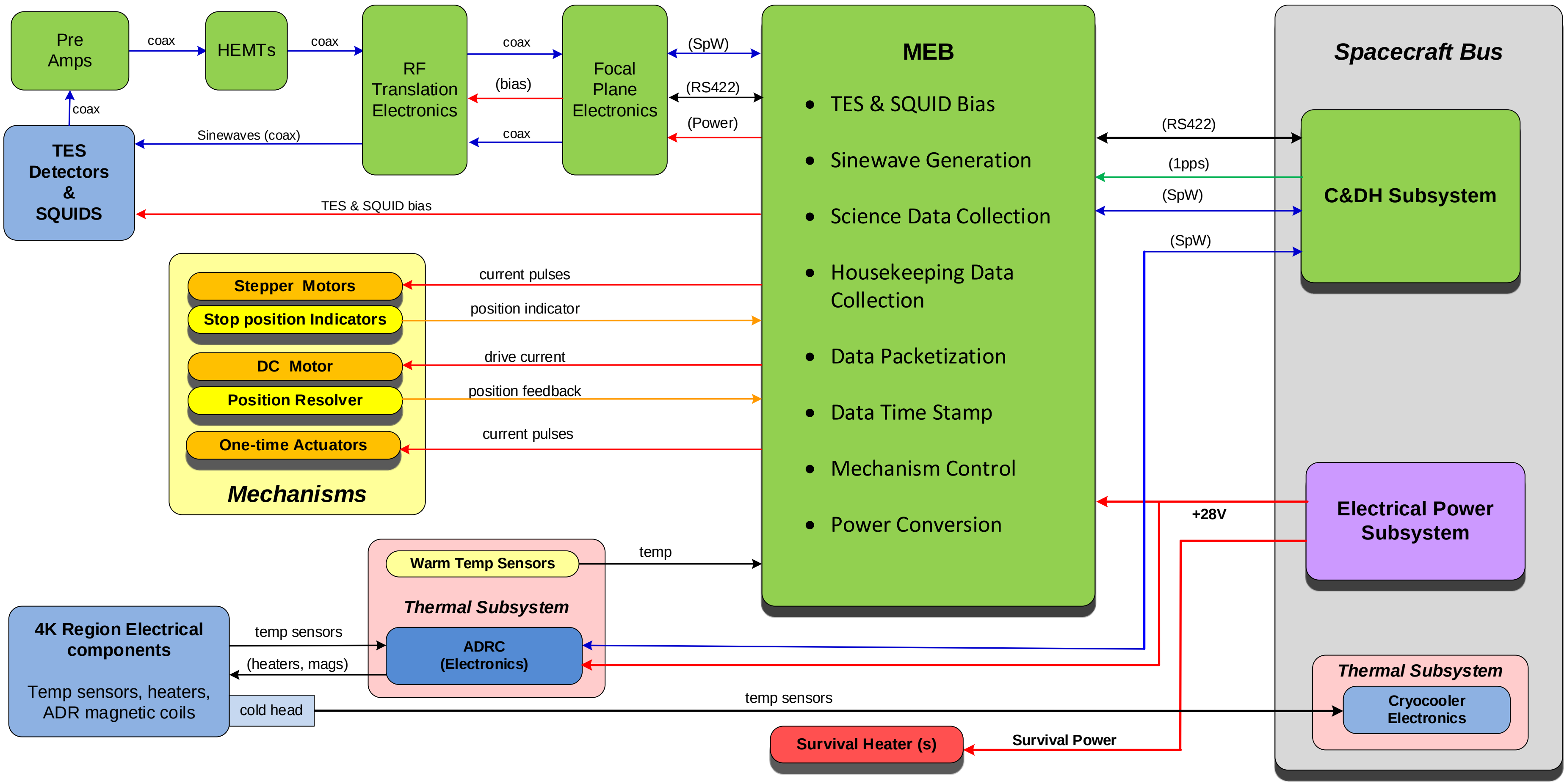
- Detectors not well defined, low TRL
- Data volume exceeded
- Power allocation exceeded by factor of 3
- Mass allocation exceeded by factor of 4.5
- Volume (shape) allocation is notional
- 4 K heat load exceeded by factor of 2
- No physical location or volume limits provided for any electronics:
  - HEMT amplifiers (somewhere in the 20 K region)
  - ADR Controller
  - RF electronics
  - Focal Plane Electronics
  - Main Electronics Box

Instrument Resource Summary

(no contingency included)

OST FIP	Total Mass [kg]	Total Operating Power [W] (Effective Average)	Data Rate [Mbps]	Instrument Enclosure Dimensions [m x m x m]
FIP	781 kg	590 W	43 Mbps	1 x 2 x 2 (notional)
Optical Bench Assembly **Pick Off Mirror Assembly** **Fore Optics M6 Assembly** **Fore Optics M7 Assembly** **Half-Wave Plate Mechanism Assembly** **Polarizer/Dichroic Flip Assembly** **Lens/Dichroic/Filter /Mechanism Assembly** **Detector Assemblies (x4)** **PreAmp Assembly (x4)** **ADR Assembly** **ADRC Assembly** **4K Enclosure Assembly** **Electrical Subsystem** **Harnesses** **Thermal Subsystem** **FSW**		*Details in Electrical Presentation*	*Details in Electrical Presentation*	*Details in Mechanical Systems Presentation*

Electrical Architecture



Electrical Mass / Power Estimates

ITEMS	Power (each) Watts	Qty	Power Total Watts	Mass (each) (Kg)	Qty	Mass Total (Kg)
Stepper Motors	5.000	4	2.00			
DC Motor	5.000	2	10.00			
RF Translation Electronics	10.000	1	10.00			
		1	0.00			
		1	0.00			
		1	0.00			
Sub Total:			**22.0**		**0**	**0**
MEB						
Processor Card	8.0	1	8.0	0.5	1	0.5
DC Motor Drive Card (FPGA)	5.0	1	5.0	0.5	1	0.5
Stepper Motor Drive Card (FPGA)	5.0	1	5.0	0.5	1	0.5
Housekeeping Card	2.0	1	2.0	0.5	1	0.5
Power Card	10.5	1	10.5	0.5	1	0.5
Backplane				0.5	1	0.5
Housing				1.5	1	1.5
Sub Total:		**5**	**30.5**		**7**	**4.5**
Harnessing				0.0	2	0.0
FPE	473.8	1	473.8	12.8	2	25.6
ADRC	67.0	1	67.0			
Total:			**593.3**			**4.5**

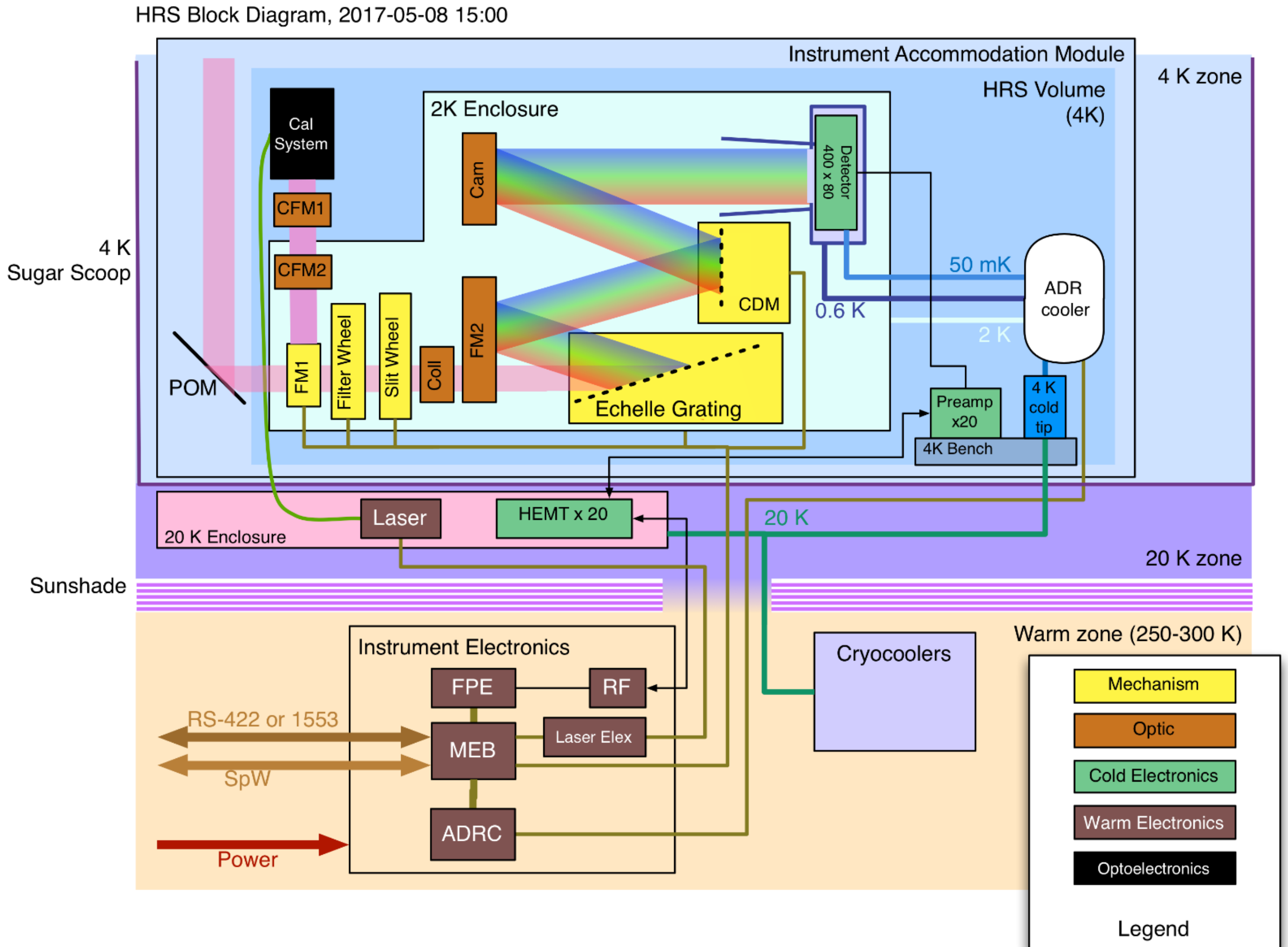
Redundancy Approach

Component	Zone	Redundancy Approach
Commissioning Heaters near detector	0.5K	Redundant
Thermistors	0.5K/4K	Redundant
PreAmp (single stage HEMT) Boxes (4)	4K	Single String
2-stage HEMT Amplifier Box	20K	Single String
Digital Signal Processing Electronics Boards in the Focal Plane Electronics (FPE) Box	S/C 293K	Redundant
ADRC Box	S/C 293K	Single String (has internal redundancy)
Microwave Electronics Box	S/C 293K	Single String
Main Electronics Box	S/C 293K	Redundant

OST Instruments

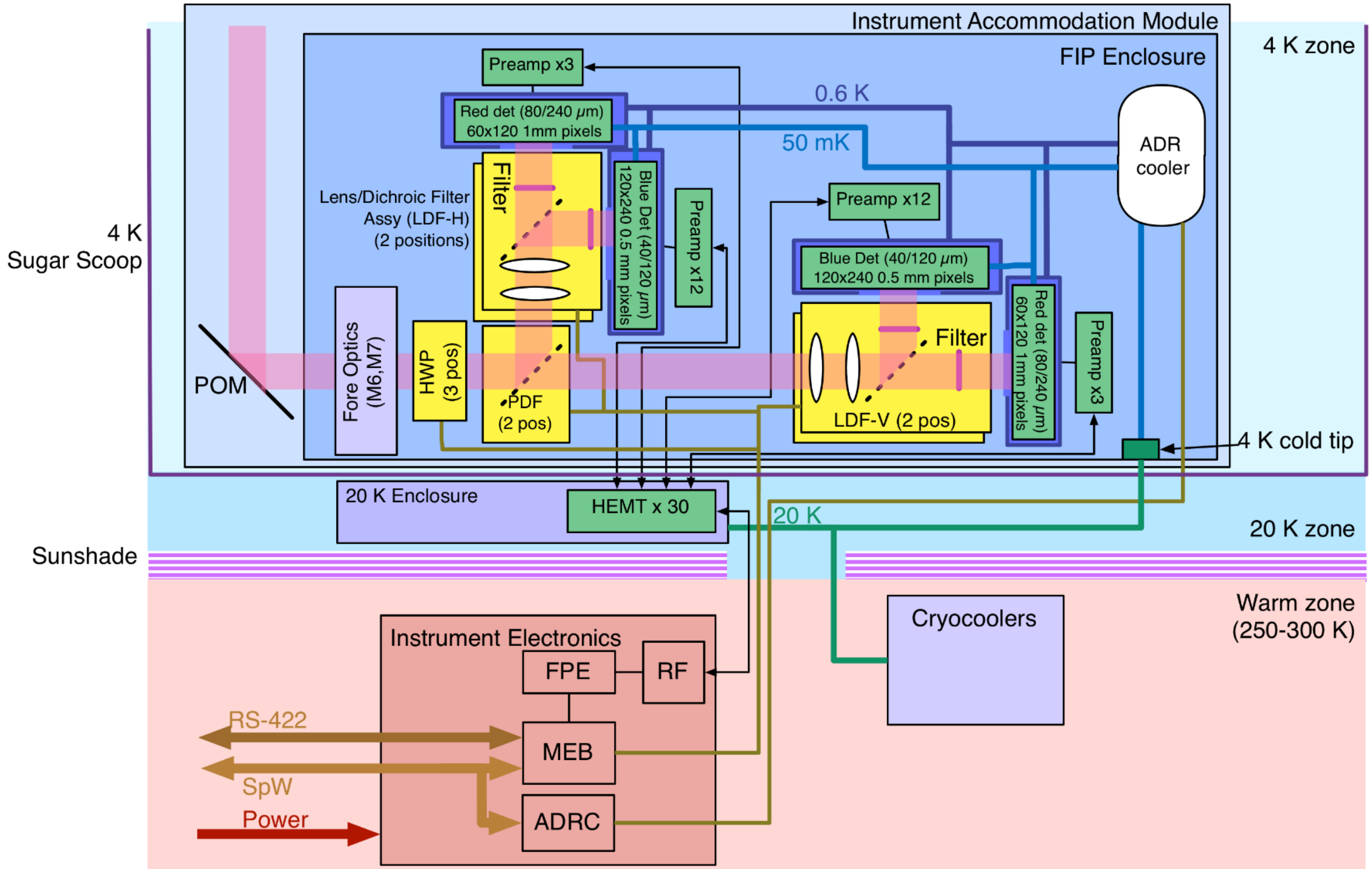
FUNCTIONAL BLOCK DIAGRAMS

HRS Block Diagram

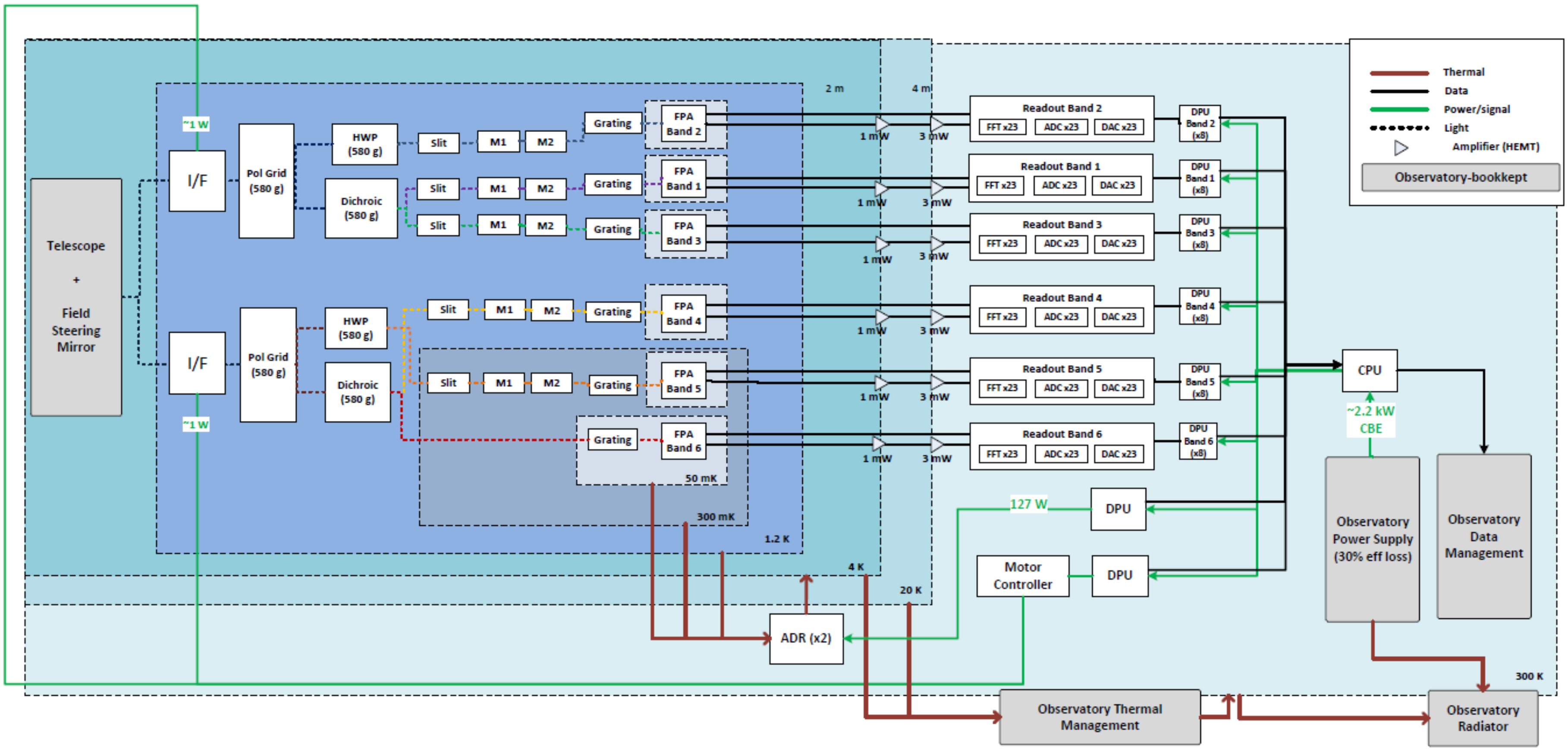


FIP Block Diagram

FIP Block Diagram, 2017-04-24 14:00



MRSS Functional Block Diagram

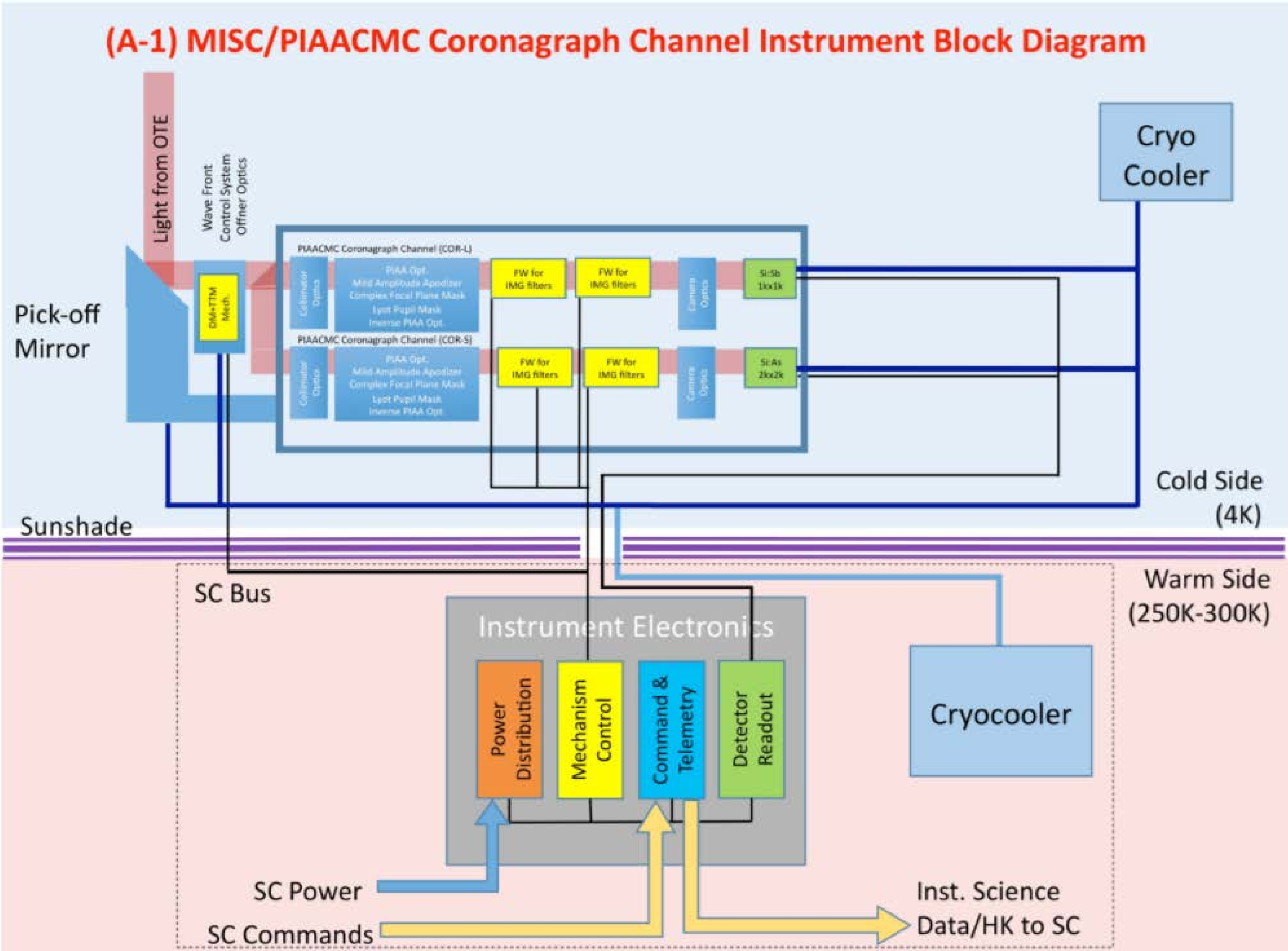


ORIGINS Space Telescope

MISC (http://exoplanets.astron.s.u-tokyo.ac.jp/OST/MISC/index_misc_case_A.html)

Module	Mid-IR Imager Spectrometer Channel			Transit Channel	Coronagraph Channel
	Imager/Low-Res Spec.	Medium-Res Spec.	High-Res Spec.	(Densified Pupil Spec.)	(PIAACMC)
	WFI-S/-L	MRS-S/-M/-L	HRS-S/-L	TRA-S/-M/-L	COR-S/-L
Bandpass (μm)	6-38	5-36	12-18, 25-38	5--20	6-38
Spectral Resolution	5-10 [Imager] 300 [Low-Res Spec.]	1000-1500	20,000-30,000	300	300
Full FOV	3 arcmin x 3 arcmin [Imager]	3 arcsec x 5 arcsec [with IFU]		3 arcsec x 3 arcsec	5.5 arcsec x 5.5 arcsec
Slit for Spectroscopy	Length; 3 arcmin Width; 0.26 arcsec (WFI-SG1) 0.40 arcsec (WFI-SG2) 0.65 arcsec (WFI-LG1) 1.00 arcsec (WFI-LG2) [low-resolution Spec.]	Length; 3 arcsec (MRS-S/-M/-L) Wdth; 0.33 arcsec (MRS-S) 0.55 arcsec (MRS-M) 1.0 arcsec (MRS-L) Mum of Slices; 11 (MRS-S) 9 (MRS-M), 5 (MRS-L)	Length; 1.0 arcsec (HRS-S) 2.0 arcsec (HRS-L) Width; 0.5 arcsec (HRS-S) 1.0 arcsec (HRS-L)		Length; 1 arcmin Width; 0.26 arcsec (COR-SG1) 0.40 arcsec (COR-SG2) 0.65 arcsec (COR-LG1) 1.00 arcsec (COR-LG2)
Detectors	2kx2k Si:As (30μm/pix) [S] 2kx2k Si:Sb (18μm/pix) [L]	2kx2k Si:As (30μm/pix) [S] 2kx2k Si:As (30um/pix) [M] 1kx1k Si:Sb (18μm/pix) [L]	2kx2k Si:As (30μm/pix) [S] 1kx1k Si:Sb (18μm/pix) [L]	2kx2k Si:As (30μm/pix) [S] 2kx2k Si:As (30μm/pix) [M] 2kx2k Si:As (30um/pix) [L]	2kx2k Si:As (30μm/pix) [S] 1kx1k Si:Sb (18μm/pix) [L]
pixel scale	0.088 arcsec/pix	0.0615 arcsec/pix (MRS-S) 0.10 arcsec/pix (MRS-M) 0.15 arcsec/pix (MRS-L)	0.17 arcsec/pix [S] 0.34 arcsec/pix [L]	0.1 arcsec/pix	0.05 arcsec/pix (COR-S) 0.10 arcsec/pix (COR-L)
Specification (Sensitivity/ Stability/ Contrast)	**Sensitivity [Imager] ;** *1-hour 5σ Continuum Sens .* *for a Point Source* 0.027μJy@5μm, 0.16μJy@10μm, 0.26μJy@15μm, 0.37μJy@20μm, 0.55μJy@25μm, 0.63μJy@30μm, 0.7μJy@35μm **Sensitivity [Low-Res Spec.];** *1-hour 5s Continuum Sens.* *for a Point Source* (R=300) 0.6μJy@5μm, 1.3μJy@10μm, 4.0μJy@15μm, 5.0μJy@20μm, 8.8μJy@25μm, 11.2μJy@30μm, 37.5μJy@35μm	**Sensitivity;** *1-hour 5s Continuum Sens.* *for a Point Source (R˜1200)* 3μJy@7μm, 10μJy@15μm, 30μJy@24μm,100μJy@32μm 1-hour 5s Line Sens. for a Point Source 1x10^{-21} W/m^2 @7μm, 2x10^{-21} W/m^2 @15μm, 3x10^{-21} W/m^2 @24μm, 1x10^{-20} W/m^2 @32μm	**Sensitivity;** 1-hour 5s Line Sens. for a Point Source 1x10^{-21} W/m^2 @15μm, 3x10^{-21} W/m^2 @30μm	**Photometric stability;** 1ppm on timescales of hours to days (excluding the fluctuation of detector gain)	**Average contrast;** 7x10^{-6} for 10% band 1x10^{-6} for 4% band in 0.88-3.6λ/D

MISC (http://exoplanets.astron.s.u-tokyo.ac.jp/OST/MISC/index_misc_case_A.html)



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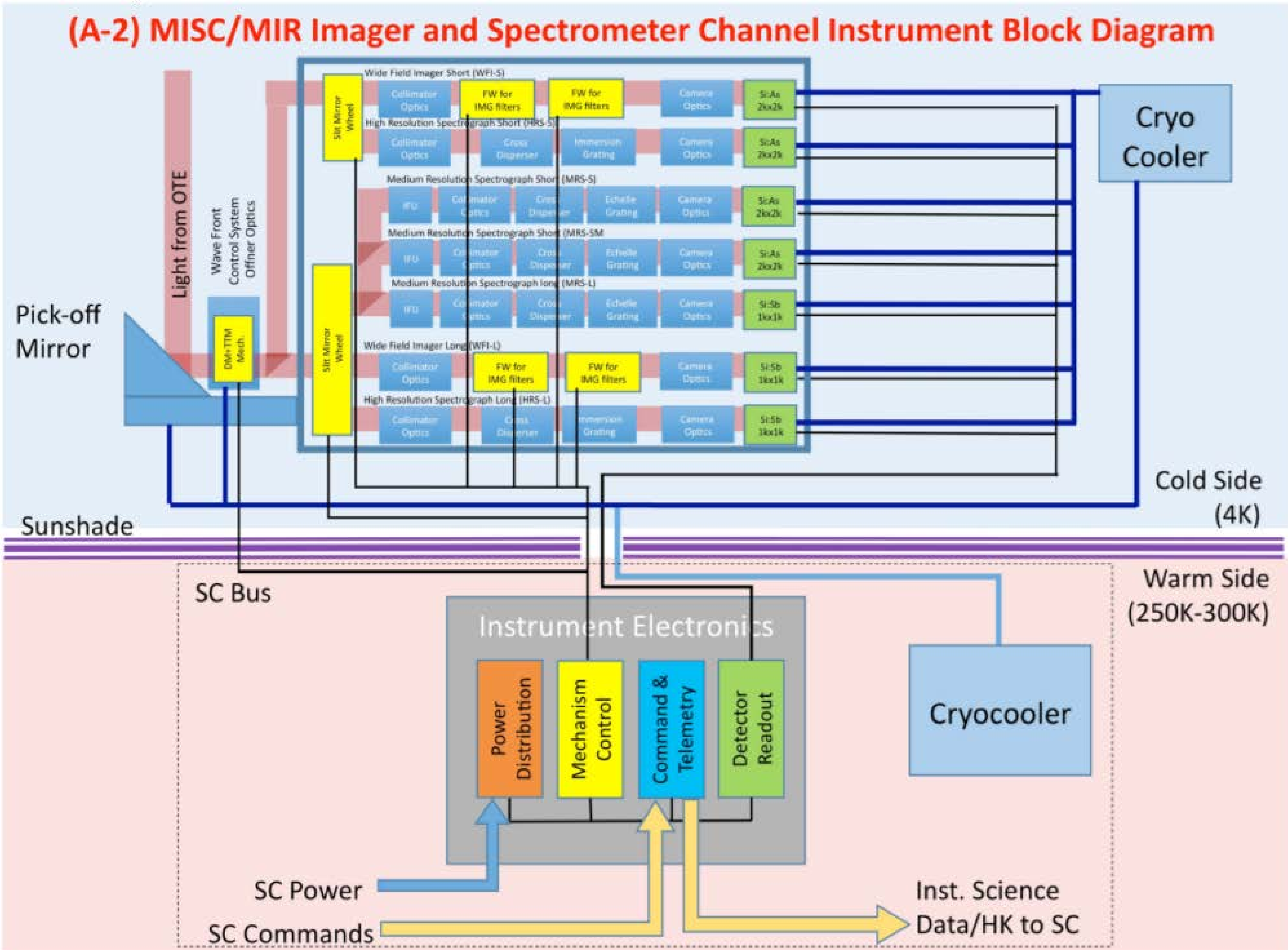

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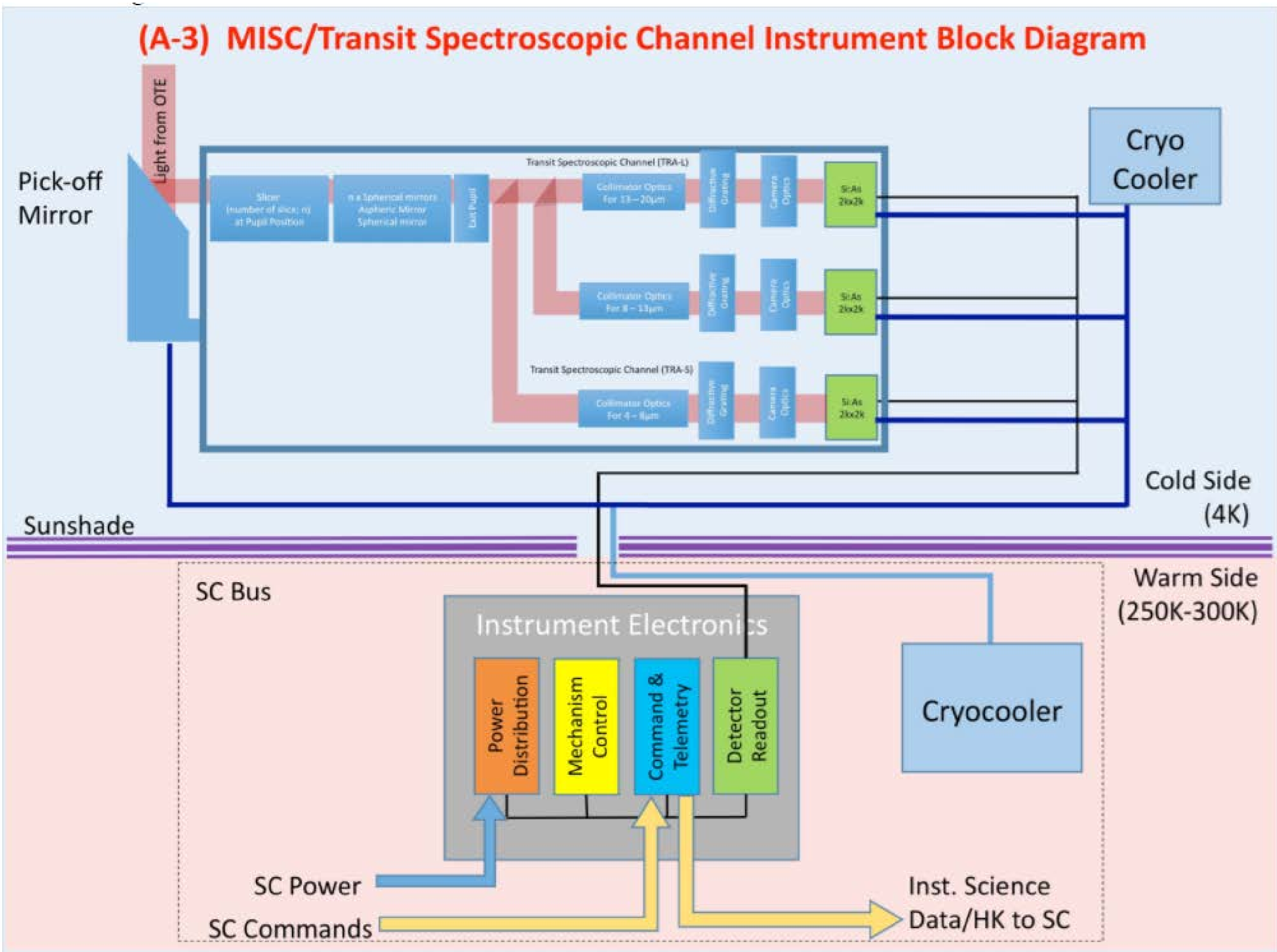


ORIGINS Space Telescope

OST Heterodyne Instrument

Instrument Specifications, Accommodation and Interface Requirements (very preliminary estimates)

	name	volume (l)	weight (kg)	power (W)
cold	Focal Plane Unit	509	128	
	Local Oscillator Unit	20	25	
	IF Unit	8	12	
warm	FPU Control Unit	126	50	74
	LO Unit Warm (multipliers, amplifiers)	44	55	128
	LO Control Unit (bias electronics)	108	25	10
	LO Source Unit	64	40	60
	FFTS	90	28	384
	Instrument Control Unit	26	20	48

.995 m^3 383 kg 704 W

Common Detector Readout for OST: FIP, HRS, & MRSS

Dr. Damon Bradley

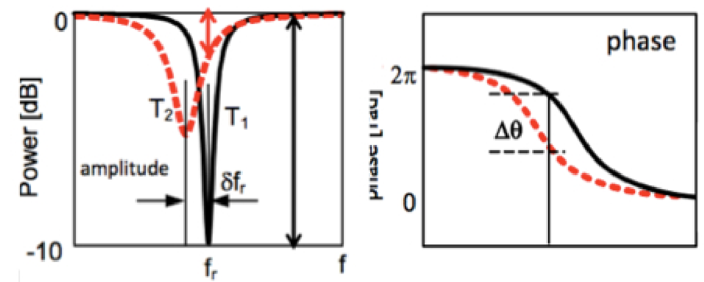
Code 564 DSP Technology Group

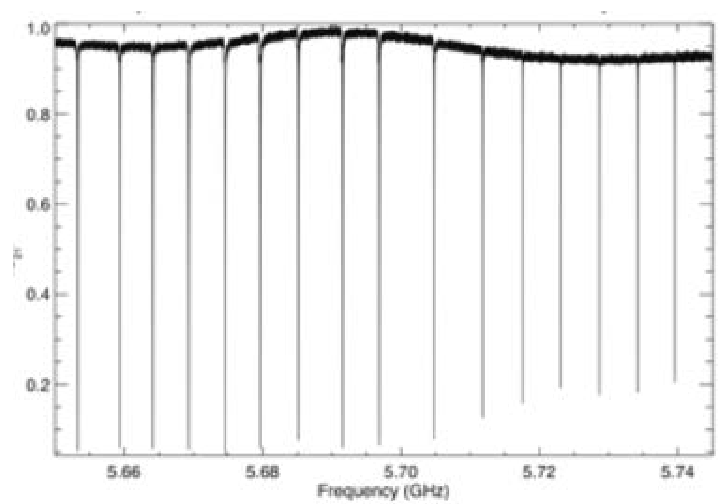
Readout ConOps

- Three of the 5 OST instruments read out detectors in exactly the same manner.
- Works similar to a comm or radar system. DSP electronics is identical.
- Detector signals are packed (in frequency) into a series of 4GHz bandwidth low-noise cryogenic amplifiers called HEMT's.

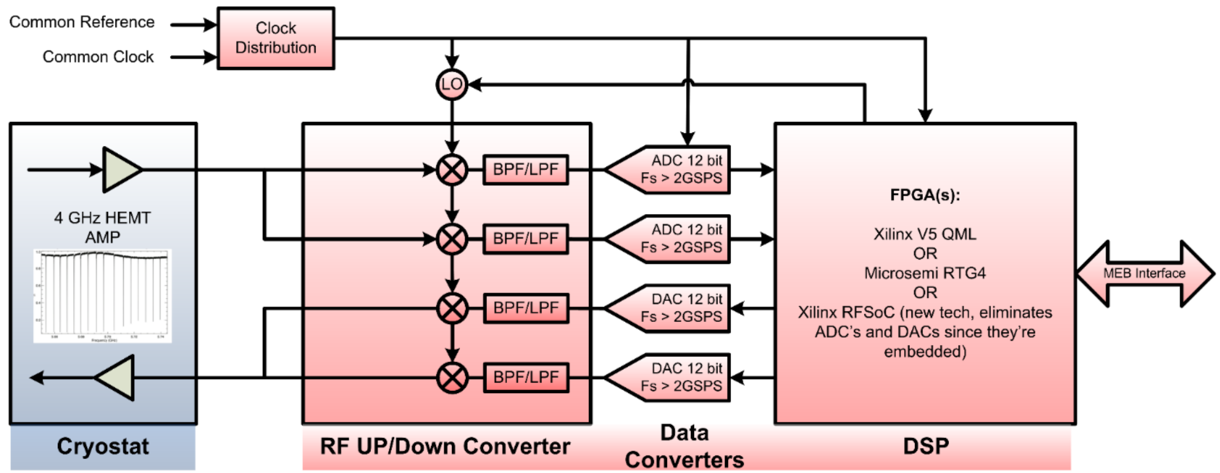
Readout signal processing

- Generate a FDM "comb" signal digitally, and output through DAC to interrogate array state. Each frequency f_k is that of every resonator.
- The resonator array (TES/MKID) will modulate each and every tone in the comb signal, individually – shifting its frequency, phase, and amplitude.
- Resulting modulated comb signal output from array, through HEMT amplifiers, to digitizers. FIP and HRS operate from 4GHz to 8GHz.
- The parameter shift for <u>every</u> tone must be detected in real-time, simultaneously. This requires signal processing similar to a spectrum analyzer.
- Science data is then a continuous record of these shifts, which synthesize into images since the microwave array is actually a rectangular array of resonators, each resonator being a pixel.





4 GHz, TRL-4/5 Hardware (DSP System)



- Proposed architecture: Scalable Digital Backend Processor Card
  - One per 4 GHz, or 1600 resonators
  - Common clock and reference signals distributed across cards
  - Use the worst-case number of cards (MRSS) for OST, and share across 3 instruments
  - Use New TI JESD204B High-Speed data converters (dual 3.2GHz/Single 6.4 GHz)
  - Use Xilinx V5 QML Part on SpaceCube and GEDI Instrument
- One Card has the complexity of GEDI Lidar Instrument electronics

Calculations and Assumptions

- 2.5 MHz spacing between pixels (resonators)
- 4 GHz bandwidth per HEMT (coax line)
- **400 pixels per 1GHz**
- Design goal: 1 Digitizer card per HEMT i.e. 1600 pixels/card
- HRS: 80k pixels (read 20k at a time)
- FIP: 72k pixels (read all at the same time)
- MRSS: 200k pixels (assumed read at the same time)

Power Assumptions

- Critical components – FPGAs and Signal Converters
  - Rule of thumb digitization: 1W/GHz digitization
  - Rule of thumb FPGA-DSP: 30W/FPGA
- Assume:
  - 2 FPGAs per 4GHz: **60W**
  - Complex-valued signal processing: 2 data converters per GHz
  - 1 GHz Nyquist Bandwidth per converter (current flight tech)
  - Therefore – 8 data converters per card = **8W**
  - **68W per card just for critical components.**
  - **Safe estimate ~ 120W per card accounting for all else and power system inefficiency.**
  - **(125 Cards for MRSS, 45 Cards for FIP, 13 Cards for HRSS)**
- **Not assumed here:**
  - **Corresponding RF frequency-translation subsystem required per card**
  - **Local oscillator that drives RF translation and system clocking**

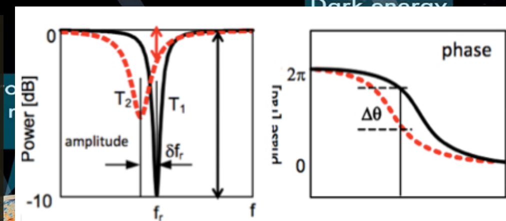
TRL Maturation

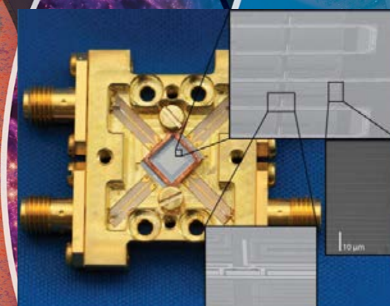
- Overall SWaP can be reduced by the following means
  - Replace FPGAs by all-digital ASIC's. Expected order of magnitude power savings here. Currently in talks with Lynx team studying this.
  - Use the state-of-the-art Ultrascale RFSoC FPGAs from Xilinx. Available Summer 2018 as commercial, Xilinx roadmap is to make this part rad-tolerant. Groundbreaking here is the fact that all digitizers are within the FPGA package are RF-sampling (2 GSPS each ADC, 6 GSPS each DAC, 16x16 system from DARPA)
  - Build Custom RFSoC for each HEMT that includes RF/Analog/Digital in same package.

Backup Material

HISTORY OF THE UNIVERSE

- **Science question**: What did the universe look like between the Big Bang and now?
  - Galactic and spatial structure formation
  - Formation of heavy elements
  - Exoplanet spectroscopy
- **Enabling technology: Microwave Kinetic Inductance Detectors (MKIDs)**
  - Cryogenic integrated RF integrated circuits
  - 10,000x more sensitive than state-of-the-art
  - Build astrophysics observatories using MKIDs
- **Engineering research**: Develop a signal processing system to read out MKIDs
  - Using UC Berkeley's Reconfigurable Open-Architecture Computer Hardware (ROACH-2)
  - Readout signal processing common across many RF instruments





t = Time (seconds, years)
E = Energy of photons (units GeV = 1.6 x 10^{-10} joules)

Key

quark, gluon, electron, muon, tau, neutrino, bosons, meson, baryon, ion, atom, photon, star, galaxy, black hole

The concept for the above figure originated in a 1986 paper by Michael Turner.

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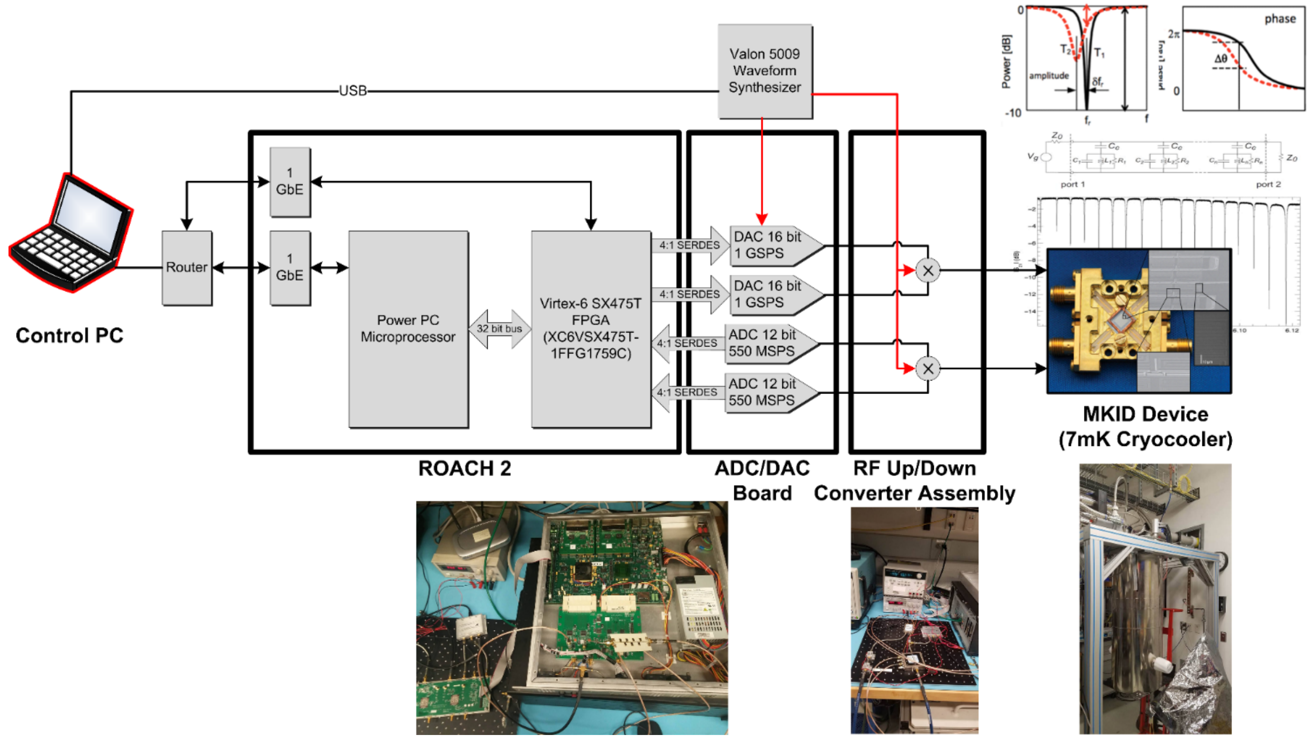
MicroSpec-DSP

Significant Accomplishments: MKID Signal Processing



Completed hardware, software, and RF design to make MKID readout system.

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MicroSpec-DSP

Significant Accomplishments: Results