Mid-Infrared Imager, Spectrometer, Coronagraph (MISC)

OST/MISC Instrument Team

Study team

from Science and Technology Definition Team, Ex-Officio Non-Voting Members, Internation Ex-Officio Non-Voting Members		
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Study team

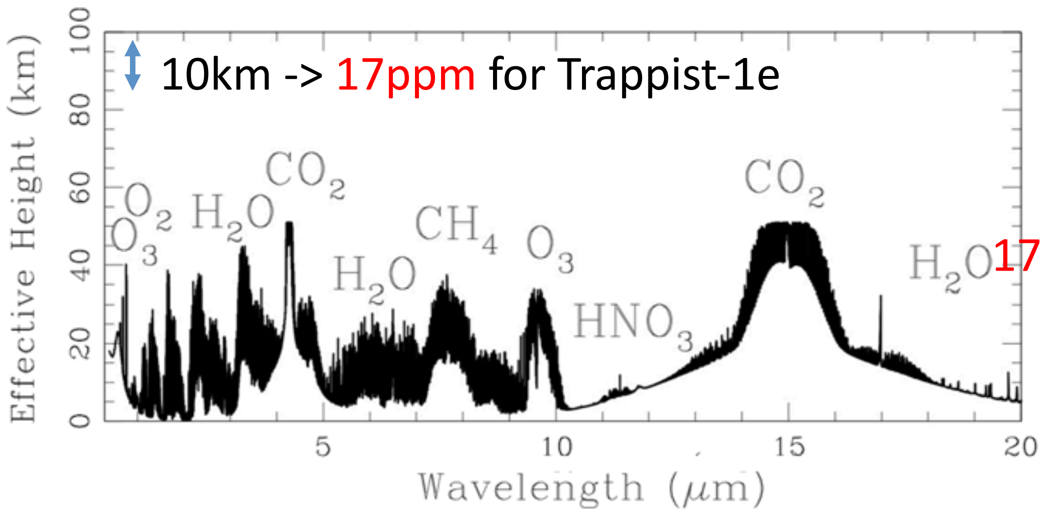
from JAXA and related Institutes		
Keigo Enya	ISAS/JAXA	MISC Coronagraph Module (PIAA CMC Coronagraph)
Taro Matsuo	Osaka University	MISC Transit Spectrograph Module (Densified Pupil Spectrogaraph)
Yuji Ikeda	Photocoding	Optica/Structural Design of MISC Imager and Spectrometer Module
Naofumi Fujishiro	Teikyo University	Optical/Structural Design of MISC Coronagraph module
Tomoyasu Yamamuro	Opto Craft	Optical/Structural Design of MISC Transit Spectrograph Module
Mitsunobu Kawada	ISAS/JAXA	Structural Design
Takehiko Wada	ISAS/JAXA	Warm Electronix, Detectors, Deformable Mirror, Tip-Tilt Mirror, Thermal Design
Olivier Guyon	Subaru Telescope/ABC/U Arizona	MISC Coronagraph Module (PIAA CMC Coronagraph)
Jun Nishikawa	NAOJ	MISC Coronagraph Module
Takayuki Kotani	NAOJ	MISC Coronagraph Module, MISC Transit Spectrograph Module
Naoshi Murakami	Hokkaido University	MISC Coronagraph Module (8-OPM Coronagraph)
Yuki Sarugaku	U Tokyo	Immersion grating
Aoi Takahashi	ISAS/JAXA	MISC Coronagraph Module, Deformable Mirror
Koji Tsumura	Tohoku University	MISC Imager and Spectrometer Module (Guider of OST)
Satoshi Itoh	Osaka University	MISC Transit Spectrograph
Masayuki Ido	Osaka University	MISC Transit Spectrograph
Shohei Goda	Osaka University	MISC Transit Spectrograph
Hiroshi Shibai	Osaka University	MISC Transit Spectrograph
Motohide Tamura	U Tokyo	MISC Coronagraph Module

~20 people from 8 institutes and 2 companies in Japan

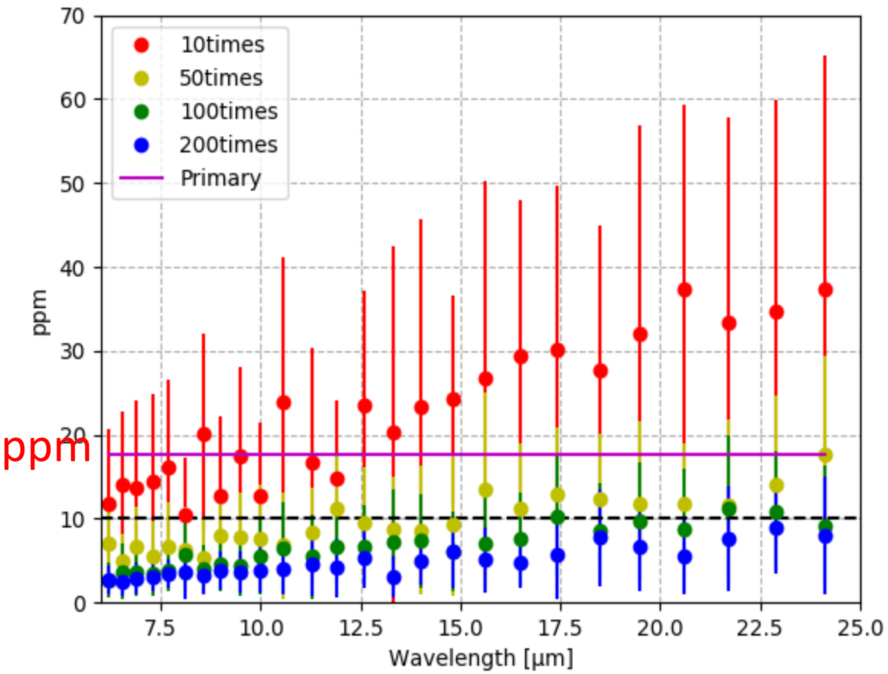
Compelling science (1)

- Search for bio signatures (ozone and methane) in habitable worlds.
- Characterization of thermal emission from small temperate planets.

(science case [#14])



Transmission spectrum model of cold planet. Kaltenegger et al. (2013)



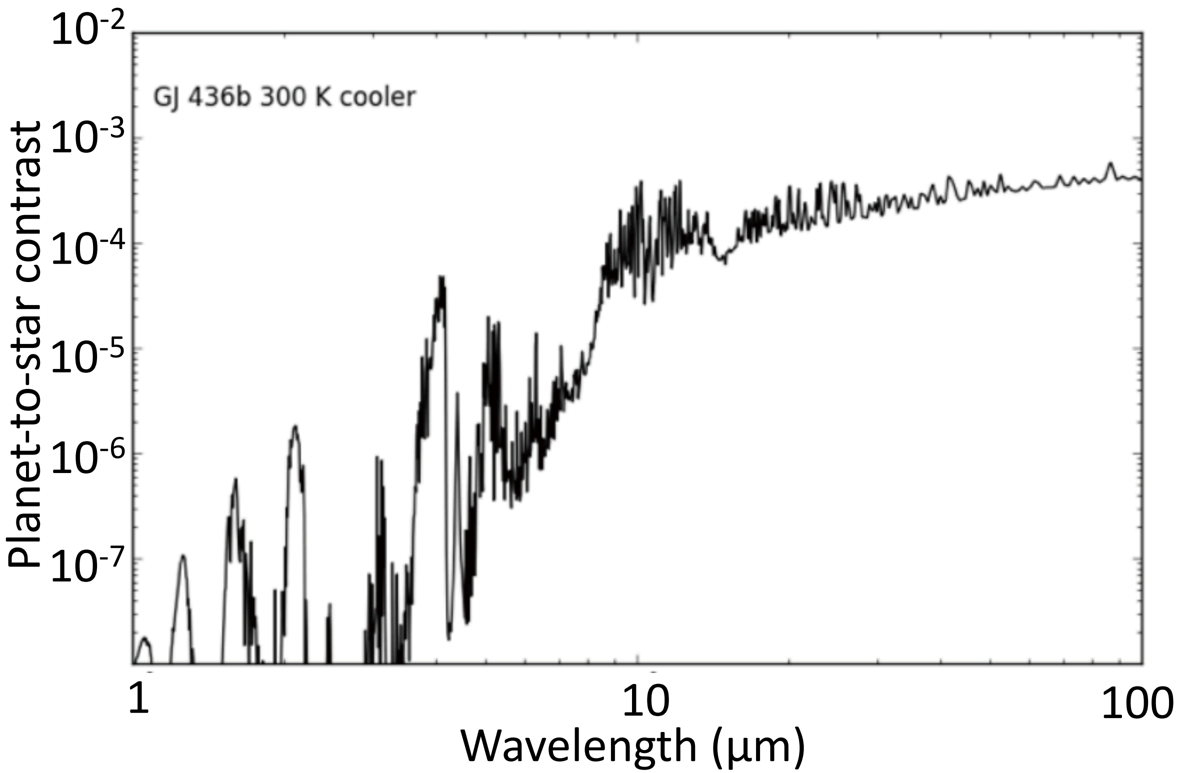
Performance of the transit spectrograph for transmission of Trappist-1e.

Compelling science (2)

・Direct imaging and characterization of true exoplanet analogs of Jupiter and Saturn, as well as ice giants at habitable temperatures (~300 K).
・direct measurements of molecular abundances (NH_3, CO_2, O_3, H_2O and possibly CH_4).
(Science case [#16])

7-8μm; Stratospheric emission from CH_4
9.1-11.6μm; Tropospheric NH_3
11.9-12.5μm; Stratospheric C_2H_6
13.8μm; Stratospheric emission from C_2H_2
17μm; H_2 S(1)
28μm; H_2 S(0)

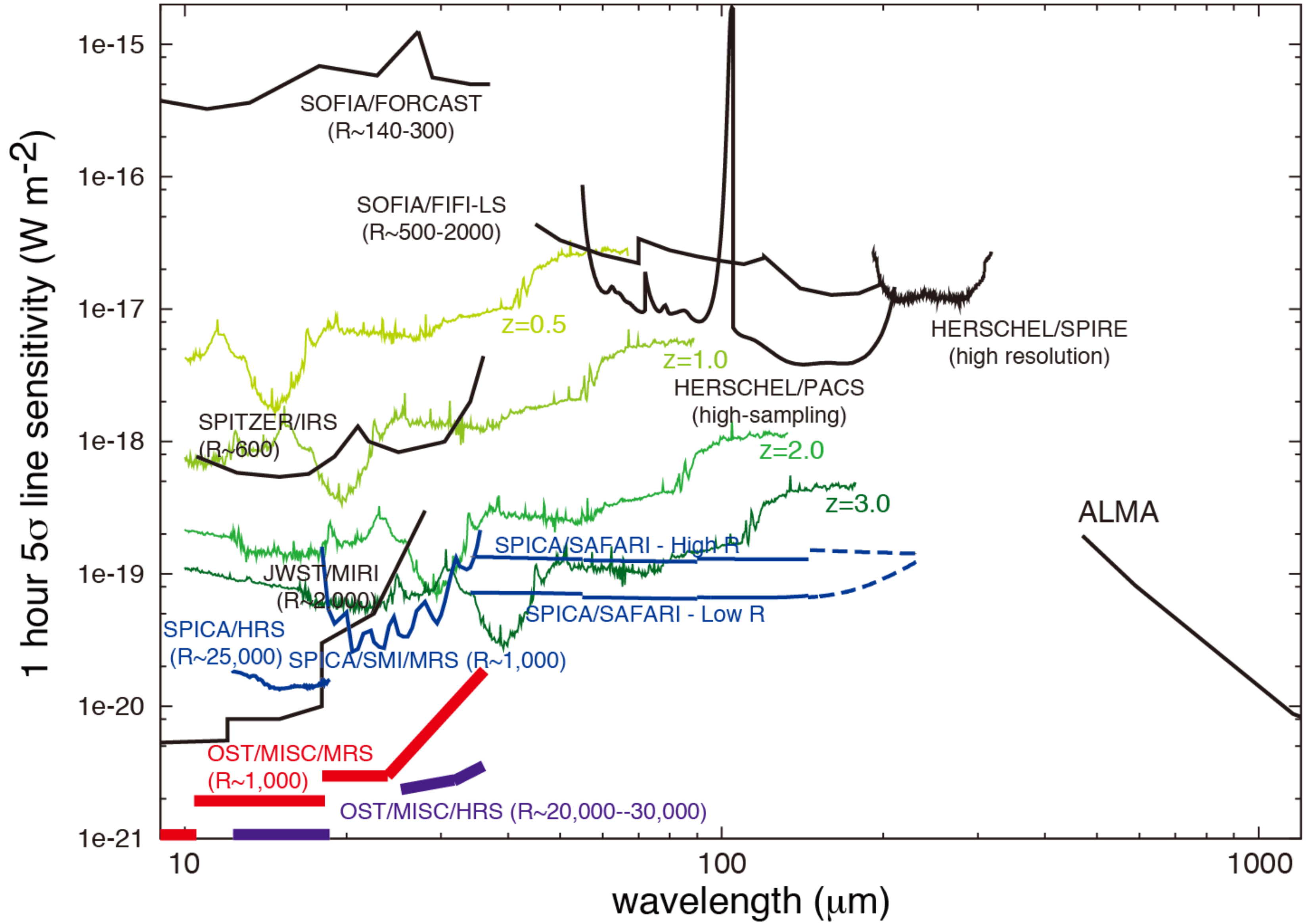
	8μm	15μm	24μm
Jupiter flux density (uJy)	0.01	2.1	10.3
Jupiter contrast	4.E-9	2.E-6	3.E-5
Jupiter separation (λ/D)	6.3	3.4	2.1
Saturn flux density (uJy)	~~3.E-5~~	0.07	1.0
Saturn contrast	~~1.E-11~~	8.E-8	3.E-6
Saturn separation (λ/D)	11.5	6.1	3.8



Planet-to-star contrast curve calculated for the model emission spectrum of GJ436B at 300K.

Measurement Capability

(1) MISC Imager and Spectrometer Module



Measurement Capability
(2) MISC Coronagraph Module

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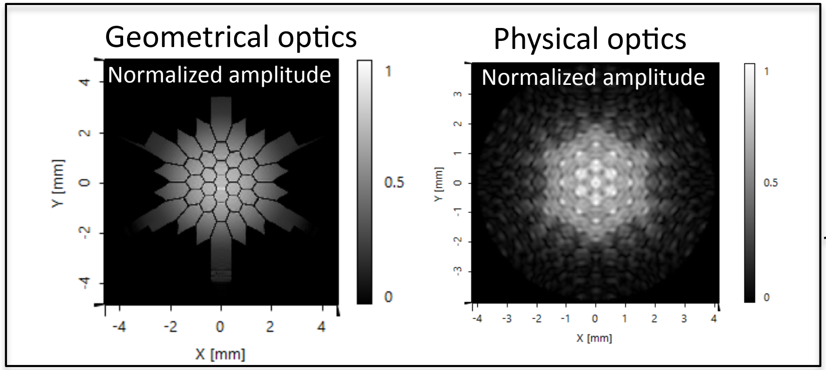
PIAA CMC Coronagraph

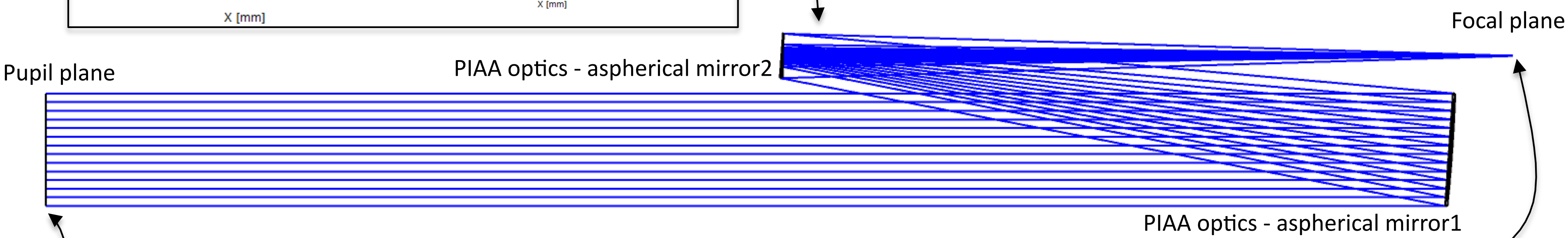


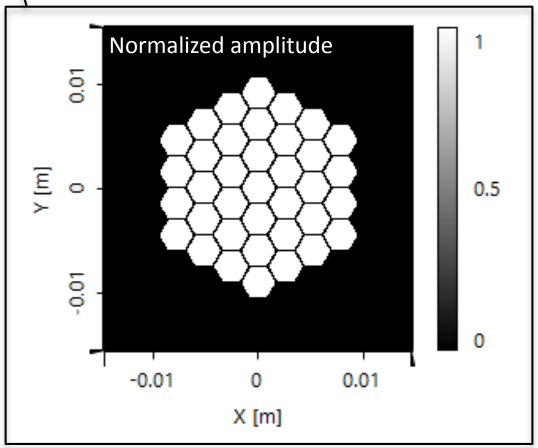
Optimization of PIAA optics has not been completed

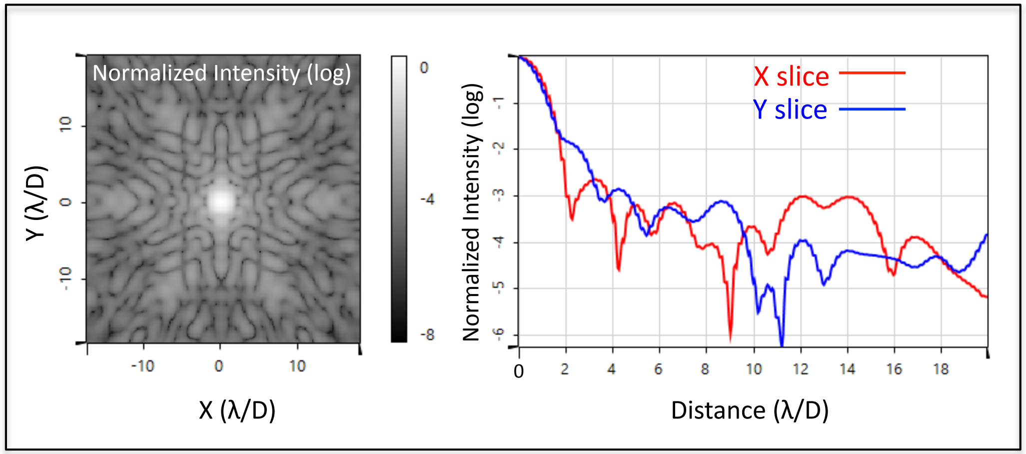
Goal; Average contrast in 0.88-3.6 λ/D

→ 7.07×10^{-6} for 10% band (@1.65um)

→ 1.16×10^{-6} for 4% band (@1.65um)







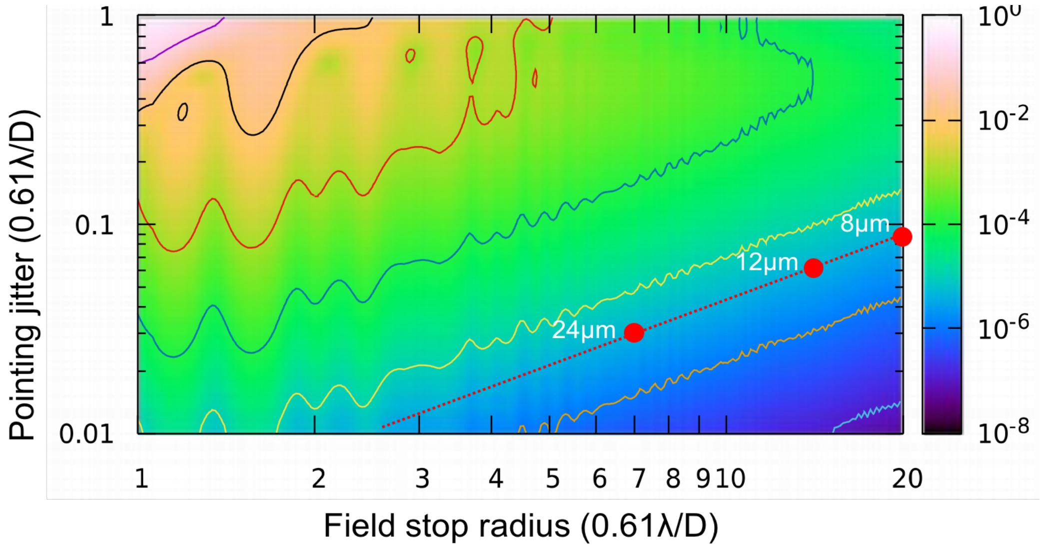
Wavelength: 15micron

Measurement Capability

(3) MISC Transit Spectroscopy Module

Densified Pupil Spectrograph

- Given that the gain fluctuation of detector system can be correctly calibrated, the final noise floor is determined by field-stop-variation.
- The current estimated performance is 3 to 5 ppm. Note the slit-loss-variation could be mitigated because the telescope pointing jitter is symmetry to some extent (e.g., Deming et al. PASP, 2009).
- The noise floor will be determined through investigation of a prototype system, which will be built at NASA Ames in 2018.



Field-stop-loss variation. The red dotted line shows the noise floor of the transit spectrograph.

Operating modes

[1] MIR Imaging
Pointed observation (WFI-S; ON, WFI-L; ON).
WFI-S and WFI-L share the same FOV by means of beam splitter and are operated simultaneously.

[2] MIR Low Resolution Spectroscopy (Long slit spectroscopy)
Pointed observation (WFI-S; ON, WFI-L; ON).
WFI-S and WFI-L share the same FOV by means of beam splitter and are operated simultaneously.

[3] MIR Medium Resolution Spectroscopy (IFU spectroscopy)
Pointed observation (WFI-S; ON, WFI-L; ON, MRS-S; ON, MRS-M; ON, MRS-L; ON).
MRS-S, MRS-M, and MRS-L share the same FOV by means of beam splitter and are operated simultaneously.
WFI-S and WFI-L are operated in parallel to obtain the slit viewer image.

[4] MIR High Resolution Spectroscopy (Short slit spectroscopy)
Pointed observation (WFI-S; ON, WFI-L; ON, HRS-S; ON, HRS-L; ON).
HRS-S and HRS-L share the same FOV by means of beam splitter and are operated simultaneously.
WFI-S and WFI-L are operated in parallel to obtain the slit viewer image.

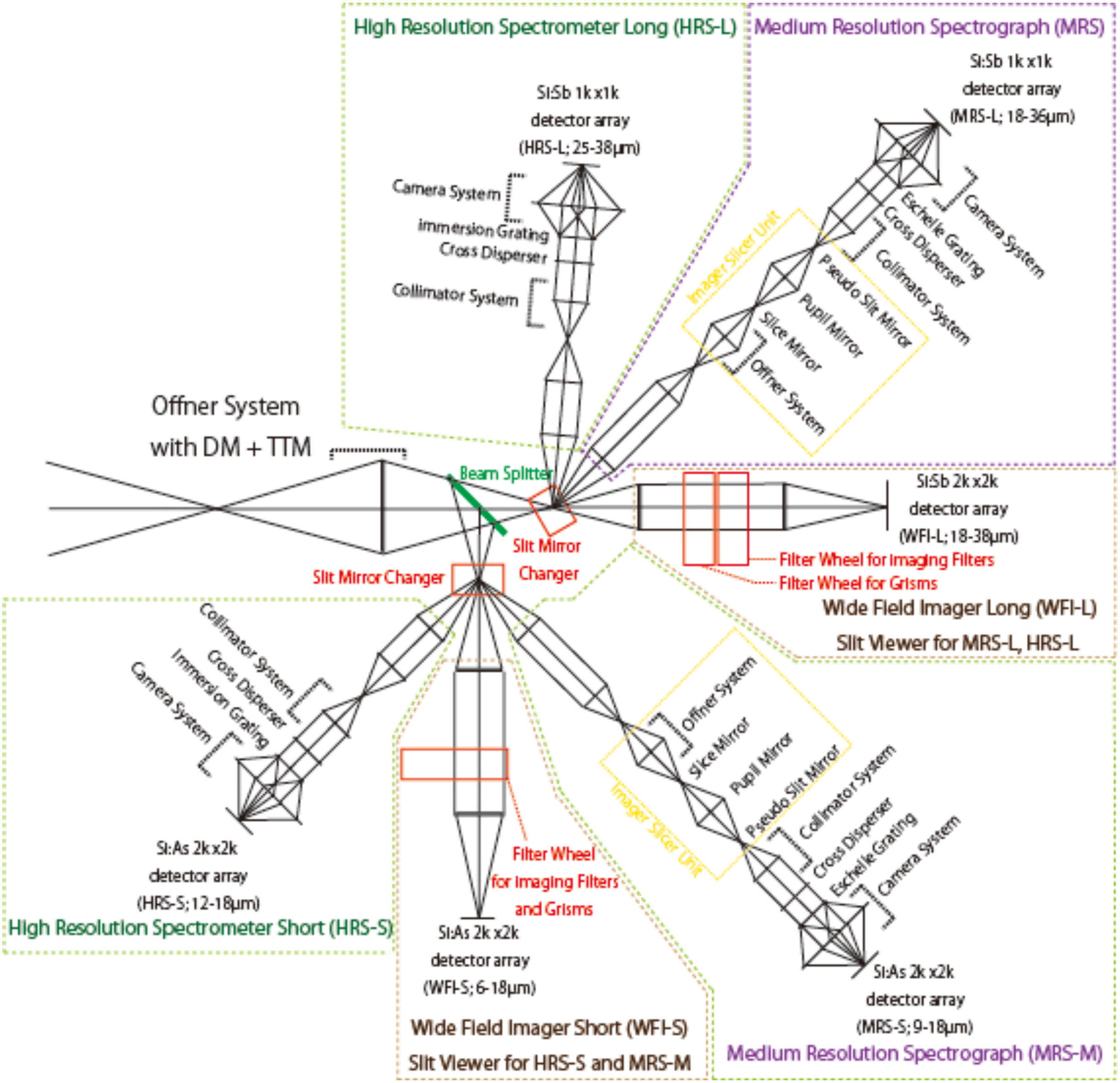
[5] MIR Coronagraph Imaging
Pointed observation (COR-S; ON, COR-L; ON, WFI-S; ON, WFI-L; ON).
COR-S and COR-L share the same FOV by means of beam splitter and are operated simultaneously.
WFI-S and WFI-L are operated in parallel to provide pointing knowledge

[6] MIR Coronagraph Spectroscopy
Pointed observation (COR-S; ON, COR-L; ON, WFI-S; ON, WFI-L; ON).
COR-S and COR-L share the same FOV by means of beam splitter and are operated simultaneously.
WFI-S and WFI-L may be operated in parallel to provide pointing knowledge

[7] MIR Transit Spectroscopy
Pointed observation (TRA-S; ON, TRA-M; ON, TRA-L; ON, WFI-S; ON, WFI-L; ON)
COR-S, TRA-M and COR-L share the same FOV by means of beam splitter and are operated simultaneously. WFI-S and WFI-L may be operated in parallel to provide pointing knowledge

Instrument Concept

(1) MISC Imager and Spectrometer

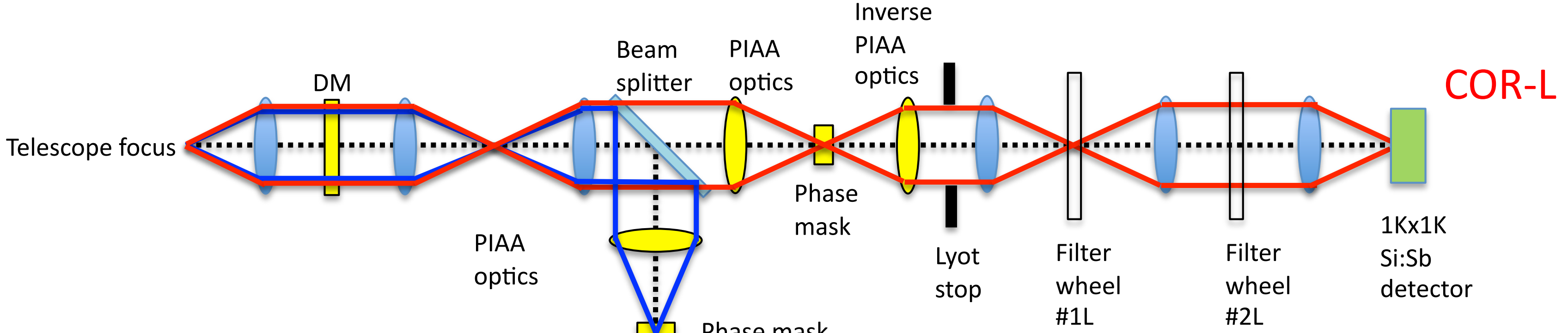


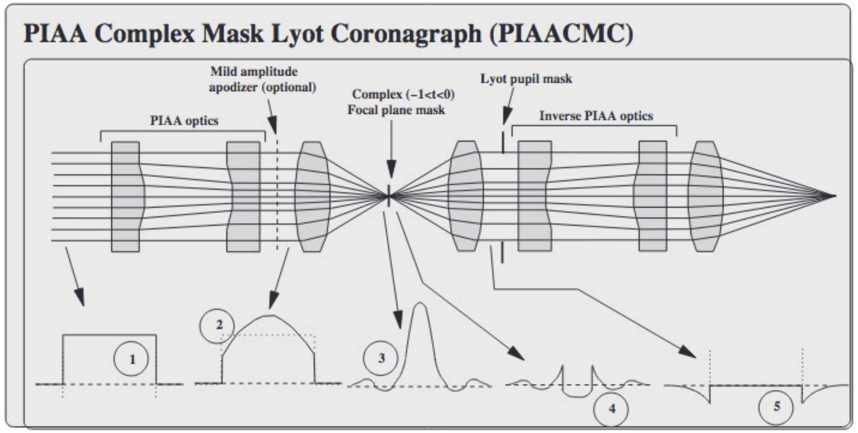
Wide Field Imager (WFI-S, WFI-L)
- -WFI-S and WFI-L share the same FOV
- -WFI-S and WFI-L provide the slit viewer image for MRS and HRS spectroscopy
- -Wave coverage; 6-38μm
- -FOV size; 3arcmin x 3arcmin
- -Low resolution (R~100-300) spectroscopic capability is available with grisms
- -WFI-S may be used as the OST guider (limited by the FOV size and the readout speed of the detector array)

Medium Resolution Spectrometer (MRS-S, MRS-M, MRS-L)
- -IFU spectroscopy (image slicer)
- -FOV size; 3 arcsec x 5 arcsec
- -MRS-M and MRS-L share the same FOV
- -Wave coverage; 9-36μm (goal; 5-36μm)
- -R~1000

High Resolution Spectrometer (HRS-S, HRS-L)
- -Emersion grating
- -Wave coverage; 12-18μm (S), 25-36μm (L)
- -R~25000

Instrument Concept
(2) MISC Coronagraph Module





Inner Working Angle (IWA) (Guyon et al. 2014)
→ 0.75 – 0.95 λ/D for the IWA of OST/MISC
(for D=9.1m, λ=9µm, IWA is 0.15-0.20 arcsec)
Contrast at the IWA (based on Guyon et al. 2014)
Average contrast in 0.88-3.6 λ/D
→ 7.07×10^{-6} for 10% band (@1.65um)
→ 1.16×10^{-6} for 4% band (@1.65um)

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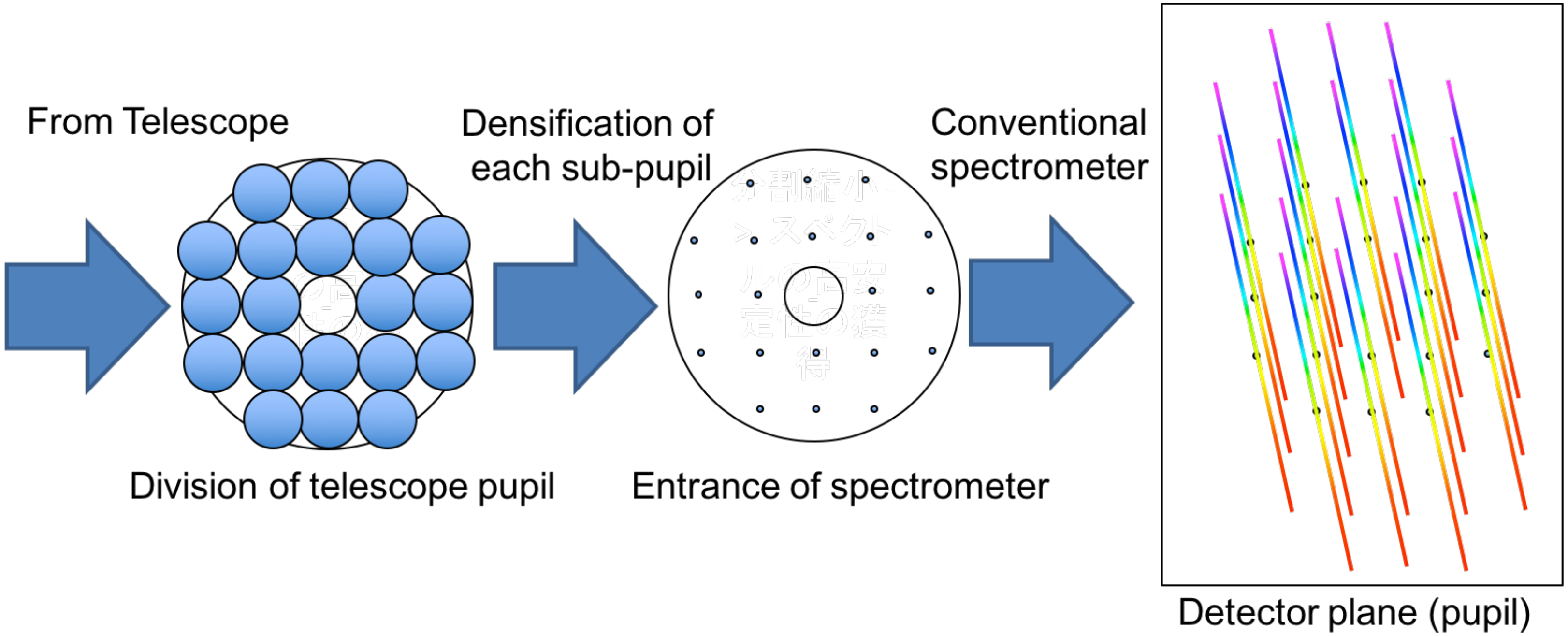
Instrument Concept

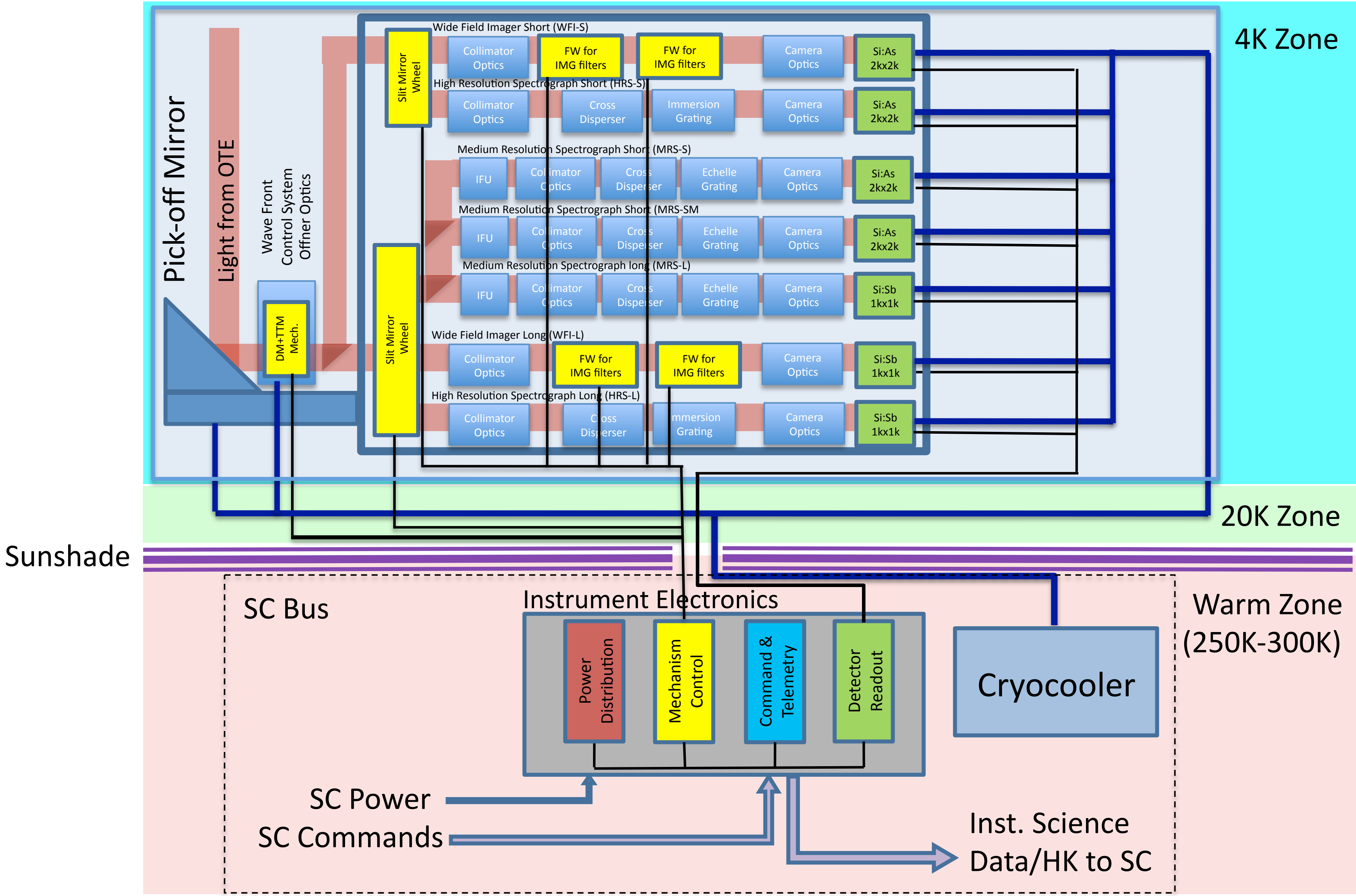
(3) MISC Transit Spectrometer Module



- The densified pupil spectroscopy method will greatly improves spectrophotometric accuracy against optical disturbance:
- The science image is not disturbed by telescope pointing jitter and deformation of primary mirror.
- A number of science pixels minimizes intra- and inter-pixel sensitivity variation.
- A number of reference pixels are also prepared for calibration of detector gain fluctuation with a cold-photon-shield mask.

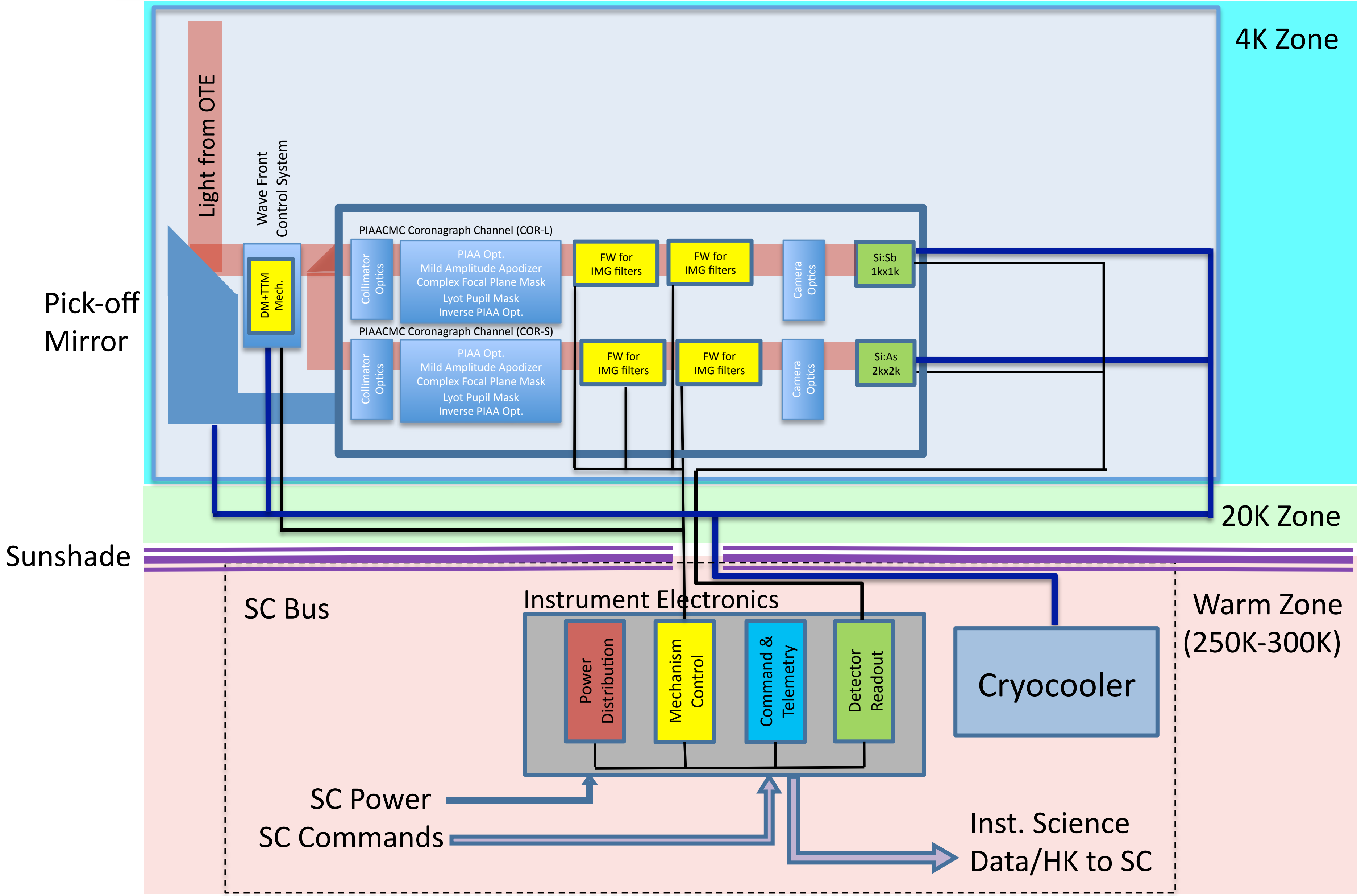
Block diagram

(1) MISC Imager and Spectrometer Module



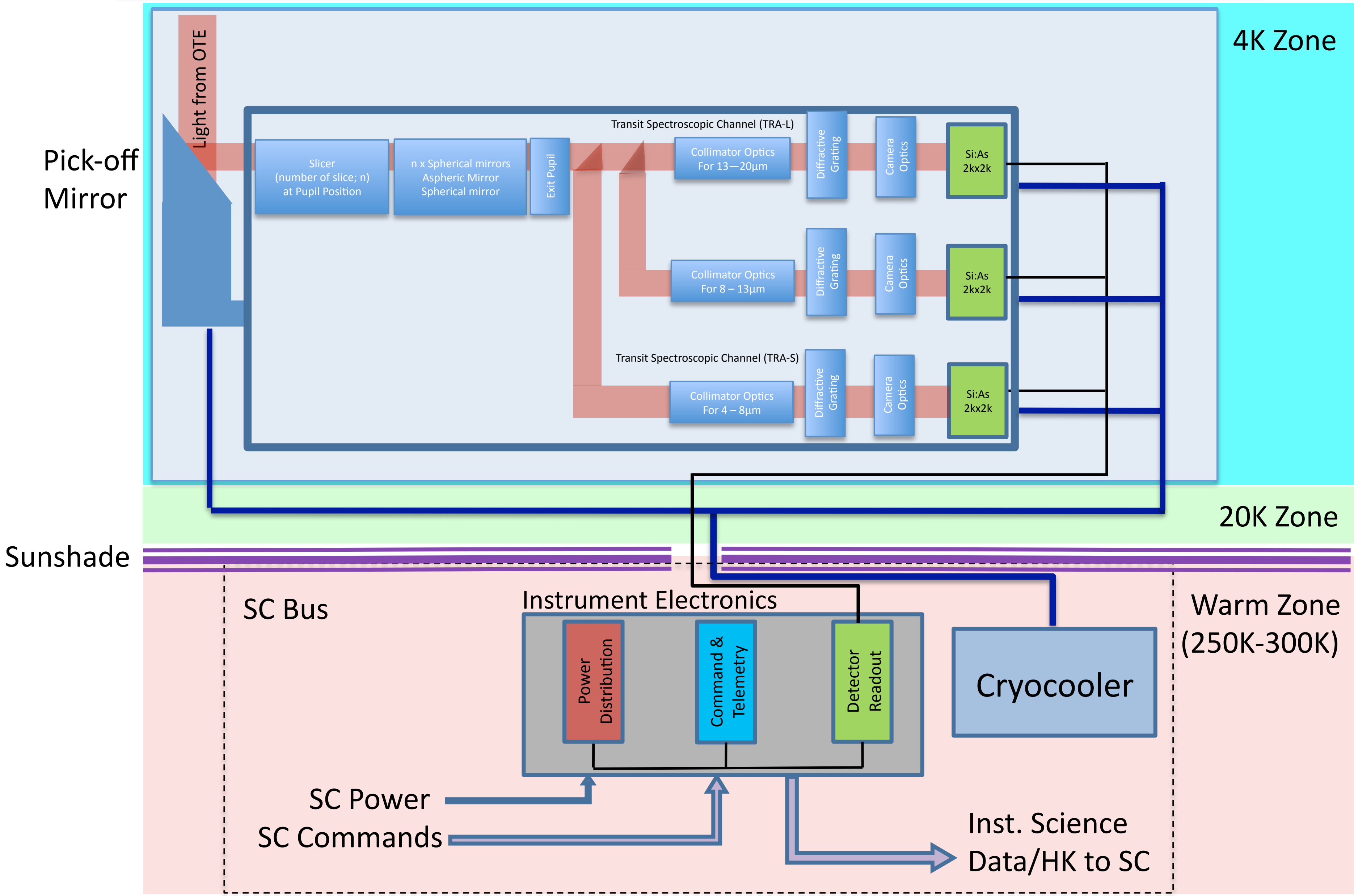
Block diagram

(2) MISC Coronagraph Module



Block diagram

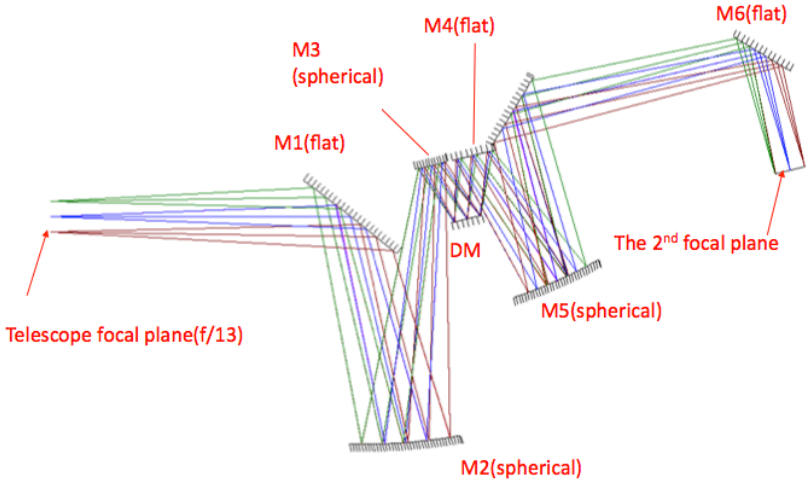
(3) MISC Transit Spectrometer Module



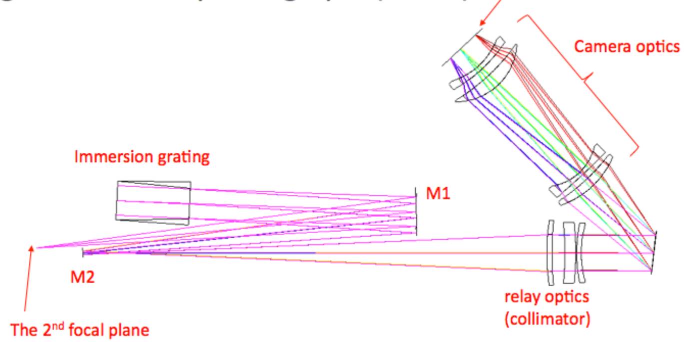
Optical Design

(1) MISC Imager and Spectrometer Module

Relay Optics



High-resolution spectrograph (HRS-S)



Field Imager (WFI-S)

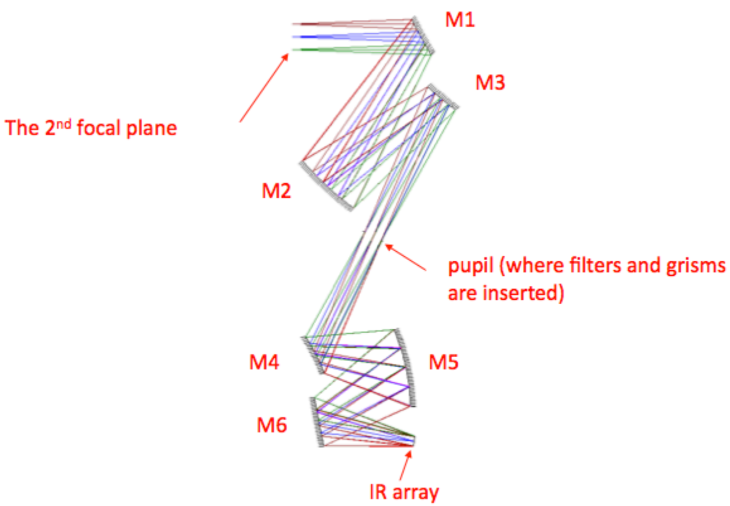
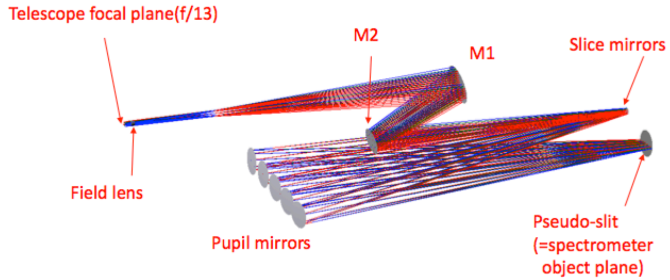
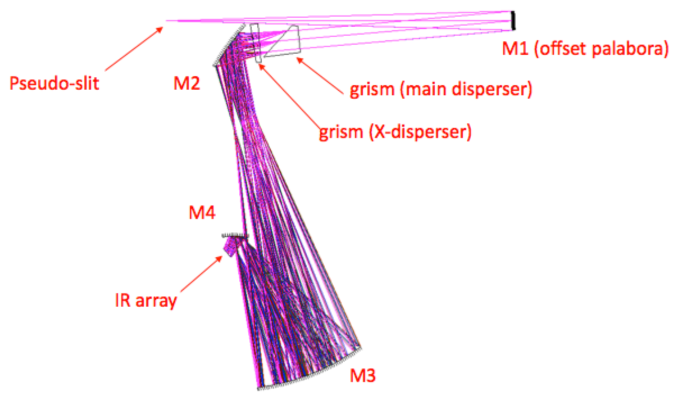


Image slicer unit for MRS-L

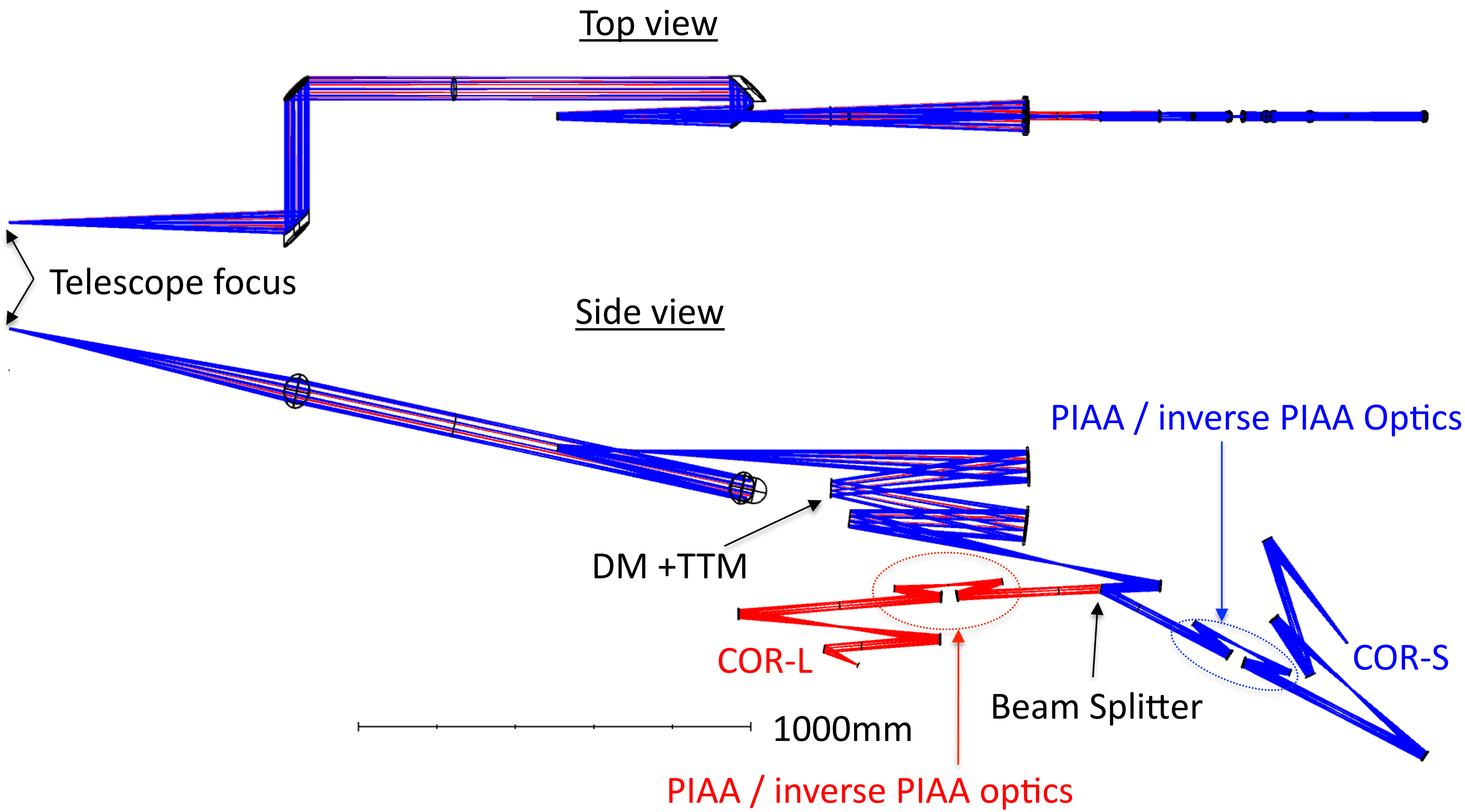


Medium Resolution Spectrometer (MRS-L)



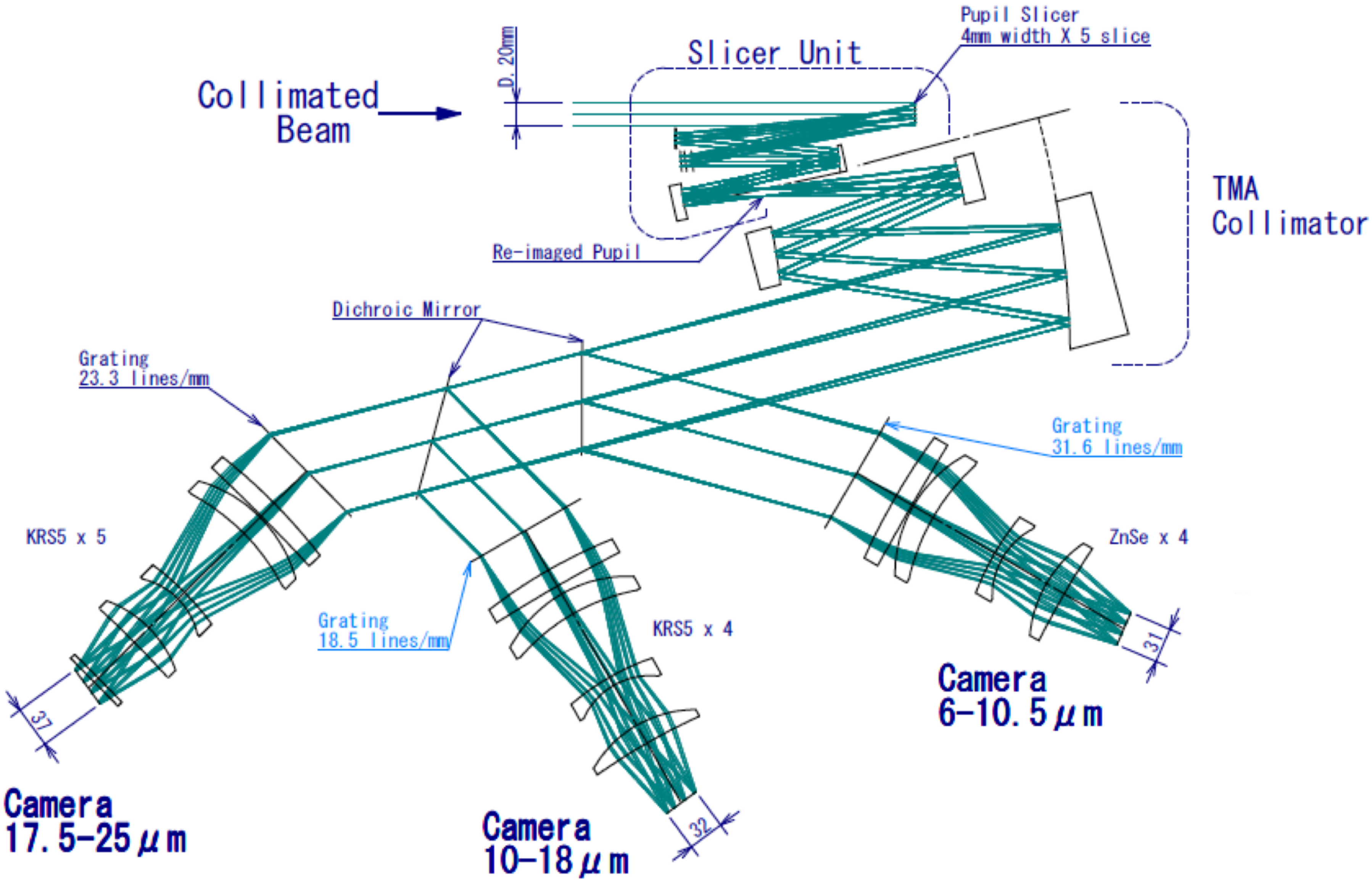
Optical Design

(2) MISC Coronagraph Module



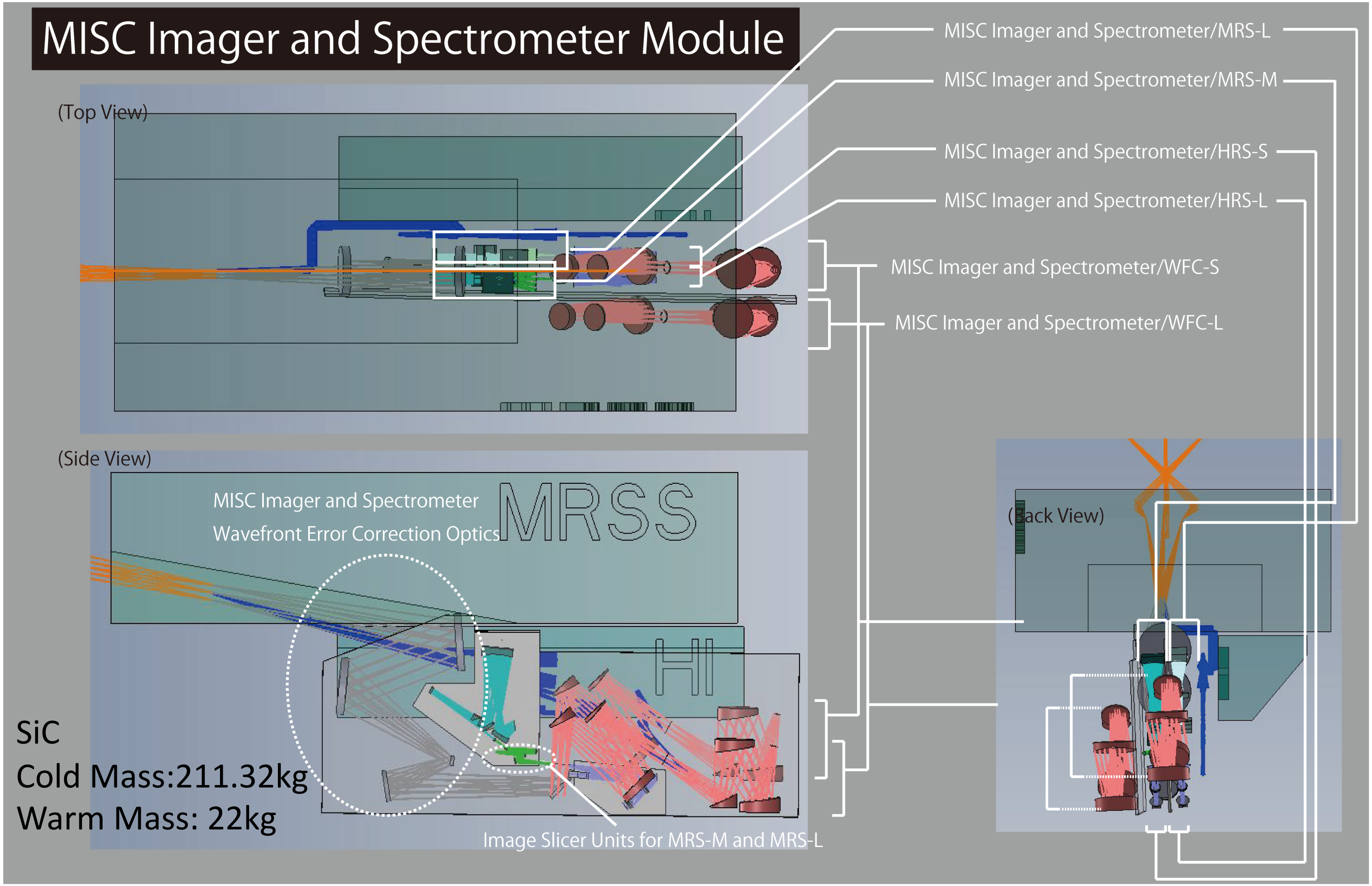
Optical Design

(3) MISC Transit Spectrometer Module



Mechanical Design

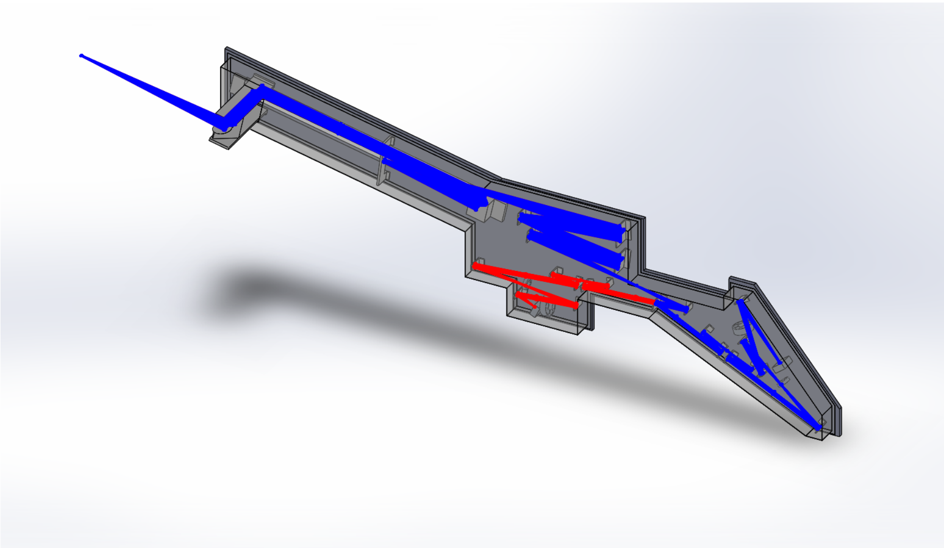
(1) MISC Imager and Spectrometer Module



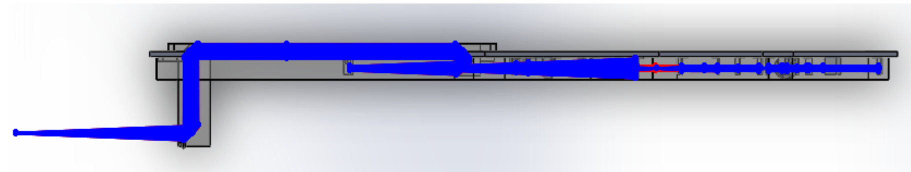
Mechanical Design

(2) MISC Coronagraph Module

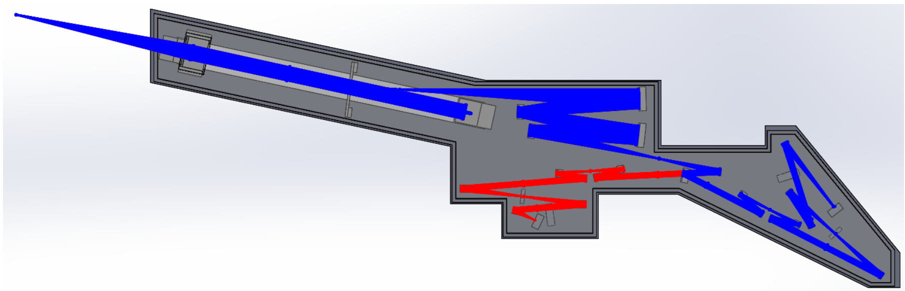
Bird's eye view



Top view



Side view



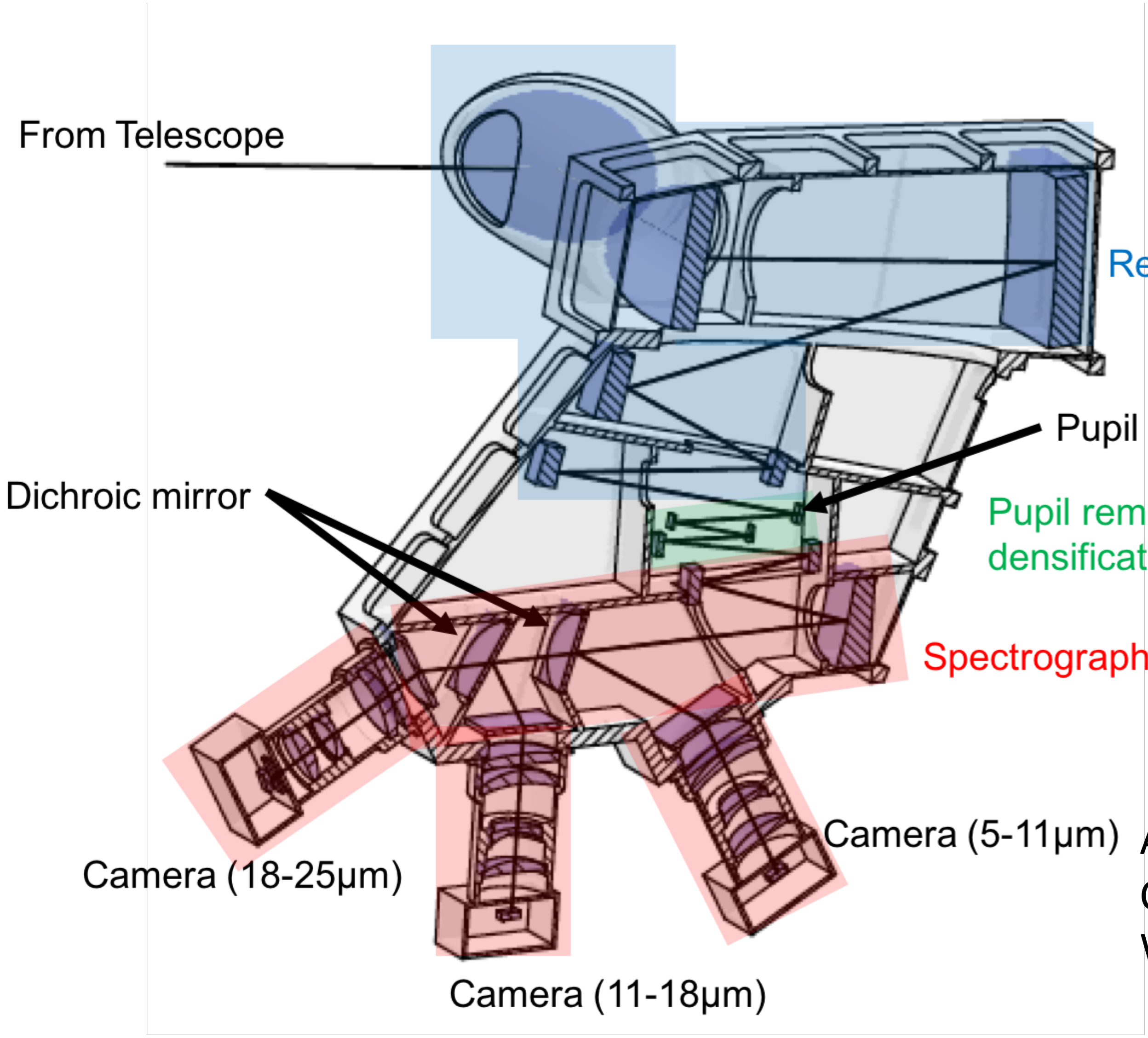
A6061-T6

Cold Mass:50.23kg

Warm Mass: 10kg

Mechanical Design

(3) MISC Transit Spectrometer Module



A6061-T6

Cold Mass:120.20kg

Warm Mass: 6 kg

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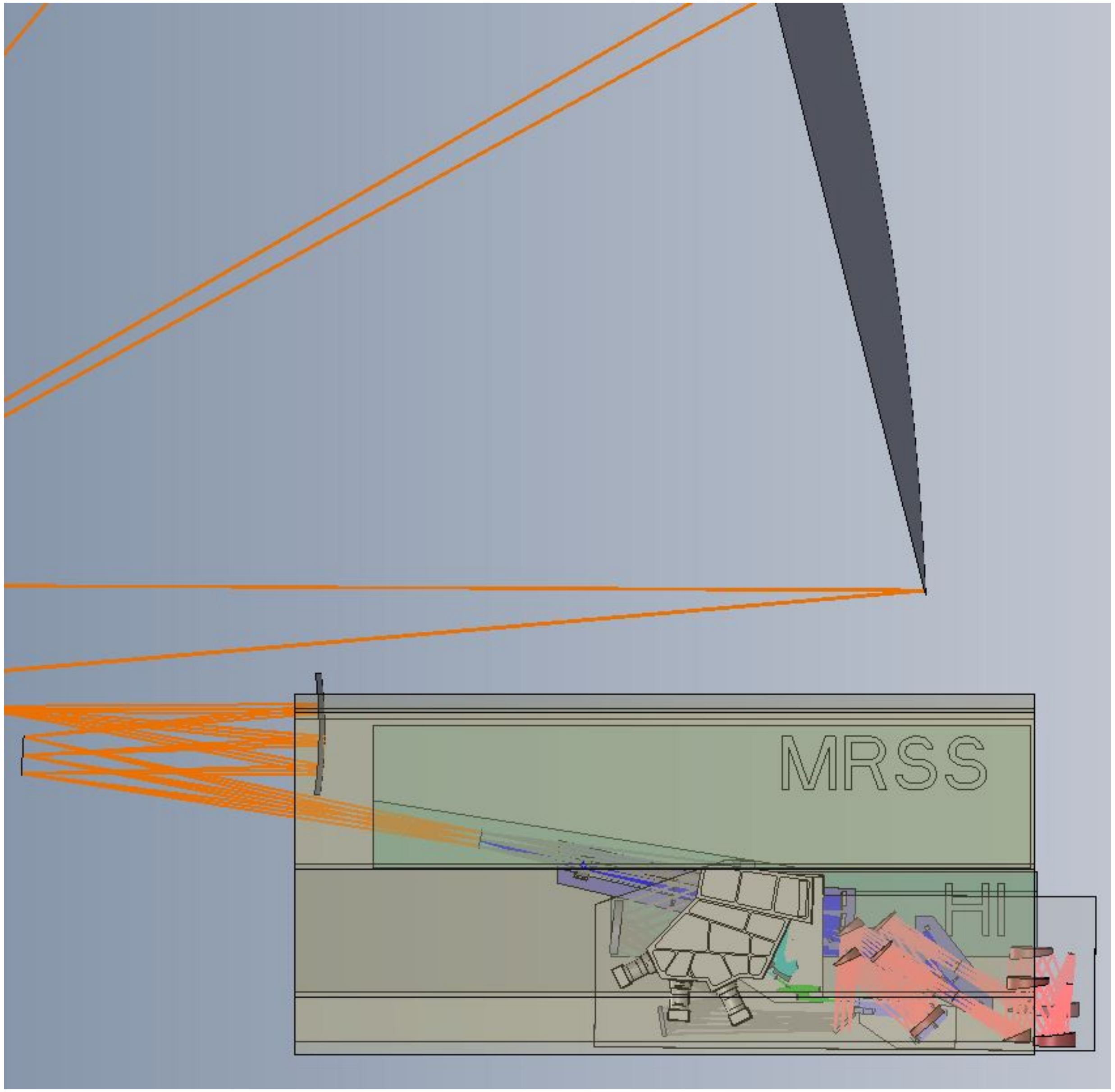
Space Telescope

MISC in OST



MISC instrument specification

Assumptions for the detector parameters

Exposure Time

-Longest exposure time; 300 sec for Si:As 2k×2k detector [Raytheon] (30μm/pix)
600 sec for Si:Sb 1kx1k detector [DRS] (18μm/pix)
taking account of the number of pixels affected by cosmic ray hit events during an exposure assuming the cosmic ray hit event rate at L2 as 5×10^4 m^{-2} sec^{-1} (Swinyard et al. 2004)

Detector Performance

- Detector Dark Current;
  - 0.06 $e^{-}sec^{-1}pixel^{-1}$ for Si:As 2k×2k detector
  - 0.8 $e^{-}sec^{-1}pixel^{-1}$ for Si:Sb 1kx1k and 2kx2k detectors

-Readout Noise (reduced up to ¼ by means of Fowler-16 sampling)
  - 10 e^{-} for Si:As 2k×2k detector
  - 25 e^{-} for Si:Sb 1kx1k and 2kx2k detectors

-Saturation Full Well
  - 2.5×10^5 e^{-} for Si:As 2k×2k detector
  - 1.0×10^5 e^{-} for Si:Sb 1kx1k and 2kx2k detectors

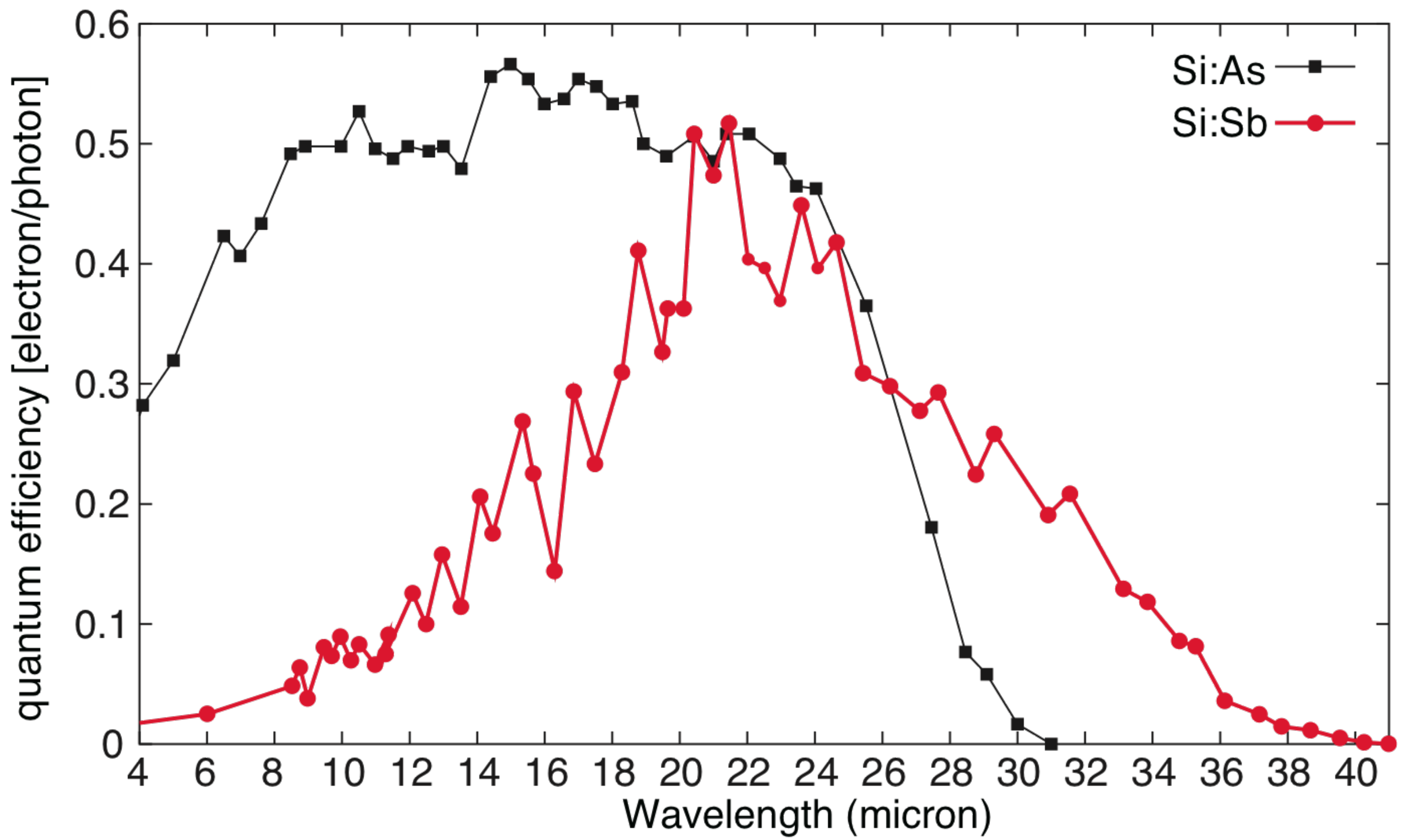
Background

-High Background Case; Zodiacal emission modeled with blackbody of 268.5K
normalized to 80MJy/sr at 25μm

-Low Background Case; Zodiacal emission modeled with blackbody of 274.0K
normalized to 15MJy/sr at 25μm

MISC instrument specification

Detector Quantum Efficiency for Si:As (black) and Si:Sb (red)



MISC instrument specification

(1) MISC Imager and Spectrometer; Wide Field Imager (WFI-S, WFI-L)

Parameter	Description
1 hour 5σ Continuum Sensitivity for a point source [imaging]	0.027μJy(@5μm), 0.16μJy(@10μm), 0.26μJy(@15μm), 0.37μJy (@20μm), 0.55μJy(@25μm), 0.63μJy(@30μm), 0.7μJy(@35μm)
1 hour 5σ Continuum Sensitivity for a point source [spectroscopy]	0.6μJy(@5μm), 1.3μJy(@10μm), 4.0μJy(@15μm), 5.0μJy (@20μm), 8.8μJy(@25μm), 11.2μJy(@30μm), 37.5μJy(@35μm)
Resolving power [Imaging]	$\lambda/\Delta\lambda$ ~ 5-10
Resolving power [spectroscopy]	$\lambda/\Delta\lambda$ ~ 300
FOV	3 arcmin x 3 arcmin
Angular resolution	0.27arcsec(@10μm), 0.5arcsec(@18.5μm), 0.65arcsec(@28μm) , 1.0arcsec(@37μm) [diffraction limited with the help of DM + TTM]
Spectral range	6 – 38 μm
Number of detector modules	2
Detector format	2048 x 2048 pixels (WFI-S, WFI-L)
Detector technology	BIB Si:As (WFI-S), BIB Si:Sb (WFI-L)

MISC instrument specification

(1) MISC Imager and Spectrometer; Medium Resolution Spectrometer (MRS-S, MRS-M, MRS-L)

Parameter	Description
1 hour 5σ Continuum Sensitivity for a point source [imaging]	3μJy(@7μm), 10μJy(@15μm), 30μJy(@24μm), 100μJy (@32μm)
1 hour 5σ Line Sensitivity for a point source [spectroscopy]	1×10^{-21} Wm^{-2}(@7μm), 2×10^{-21} Wm^{-2}(@15μm), 3×10^{-21} Wm^{-2}(@24μm), 1×10^{-20} Wm^{-2}(@32μm)
Resolving power	$\lambda/\Delta\lambda$ ~ 1000—1500
FOV	3 arcsec x 5 arcsec
IFU Format	3arcsec length x 0.33arcsec width x 11 slices (MRS-S) 3arcsec length x 0.55arcsec width x 9 slices (MRS-M) 3arcsec length x 1.0arcsec width x 5 slices (MRS-L)
Slit Width	0.33 arcsec (MRS-S), 0.55arcsec (MRS-M), 1.0arcsec (MRS-L)
Angular resolution	Point sources; diffraction limited, Extended sources; limited by the slit width
Spectral range	10 – 36 μm (goal; 5-36μm)
Number of detector modules	2 (MRS-M, MRS-L) + 1 (MRS-S)
Detector format	2048 x 2048 pixels (MRS-S, MRS-M), 1024 x 1024 pixels (MRS-L)
Detector technology	BIB Si:As (MRS-S, MRS-M), BIB Si:Sb (MRS-L)

MISC instrument specification

(1) MISC Imager and Spectrometer; High Resolution Spectrometer (HRS-S, HRS-L)

Parameter	Description
1 hour 5σ line Sensitivity for a point source [spectroscopy]	1×10^{-21} Wm^{-2}(@15μm), 3×10^{-21} Wm^{-2}(@30μm)
Resolving power	λ/Δλ ~ 20,000—30,000
Slit Width	0.5arcsec(HRS-S), 1.0arcsec(HRS-L)
Angular resolution	Point Sources; diffraction limited, Extended Sources; limited by slit width
Spectral range	12 – 18 μm (HRS-S), 25—38 μm (HRS-L)
Number of detector modules	2
Detector format	2048 x 2048 pixels (HRS-S), 1024 x 1024 pixels (HRS-L)
Detector technology	BIB Si:As (HRS-S), BIB Si:Sb (HRS-L)

MISC instrument specification

(2) MISC Coronagraph (COR-S, COR-L)

Parameter	Description
Contrast	7×10^{-6} for 10% band or 1×10^{-6} for 4% band in 0.88-3.6λ/D
Resolving power [Imaging]	$\lambda/\Delta\lambda$ ~ 10
Resolving power [spectroscopy]	$\lambda/\Delta\lambda$ ~ 300
FOV	5.5 arcsec x 5.5 arcsec
Angular resolution	0.27arcsec(@10μm), 0.5arcsec(@18.5μm), 0.65arcsec(@28μm) , 1.0arcsec(@37μm) [diffraction limited with the help of DM + TTM]
Spectral range	6 – 16.3 μm (COR-S), 15.4—38μm (COR-L)
Number of detector modules	2
Detector format	2048 x 2048 pixels (COR-S), 1024 x 1024 pixels (COR-L)
Detector technology	BIB Si:As (COR-S), BIB Si:Sb (COR-L)

MISC instrument specification

(3) MISC Transit Spectrometer (TRA-S, TRA-M, TRA-L)

Parameter	**Description**
Stability	3 – 5 ppm
Sensitivity (5s, 1 hour)	3x10^{-21} W m^{-2} (zodiacal emission limit) 3x10^{-21} W m^{-2} (readout noise limit)
Resolving power [spectroscopy]	$\lambda/\Delta\lambda$ ~ 100 (TRA-S), ~100 (TRA-M), ~300(TRA-L)
FOV	5.5 arcsec x 5.5 arcsec
Spectral range	6 – 10.5 µm (TRA-S), 10—18 µm (TRA-M), 17.5-25 µm (TRA-L)
Number of detector modules	3 (+ tip-tilt sensor if pointing jitter is monitored)
Detector format	2048 x 2048 pixels
Detector technology	Blocked Impurity Band (BIB) Si:As

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Technical challenges

Description	Subsystem/ Component	TRL	Heritage
Deformable Mirror	Component	4	SPICA/SCI, LAM
Tip Tilt Mirror	Component	4	SPICA/SCI, JWST/NIRCAM, TAO/MIMIZUKU
2K x 2K Si:As, 2K x 2K Si:Sb (*)	Component	2	JWST/MIRI, SPICA/SMI
PIAACMC Coronagraph	Subsystem	3	
8-Octa Phase Mask for MIR (8-36um)	Component	2	
Binary Pupil Mask Coronagraph	Component	4	SPICA/SCI
Beam Splitter, Band-pass Filters (Multi-Layer Interference Filter)	Component	4	SPICA/MCS
SiC Mirrors	Component	4	AKARI, JWST/NIRCAM
Image Slicer	Subsystem	4	SPICA/MCS, TMT/MICHI
Immersion grating (12-18µm)	Component	4	SPICA/MCS
Immersion grating (25-38µm)	Component	2	
Densified pupil spectrometer(**)	Subsystem	3	

(*) Detector stability (i.e., long-term fluctuation of gain generated in detector and readout electronics).

(**) This system provides a number of the science and reference pixels. One of the keys for improvement of the detector system is how to deal with the reference pixels. A calibration technique with the reference pixels will be developed at a testbed of a prototype system.