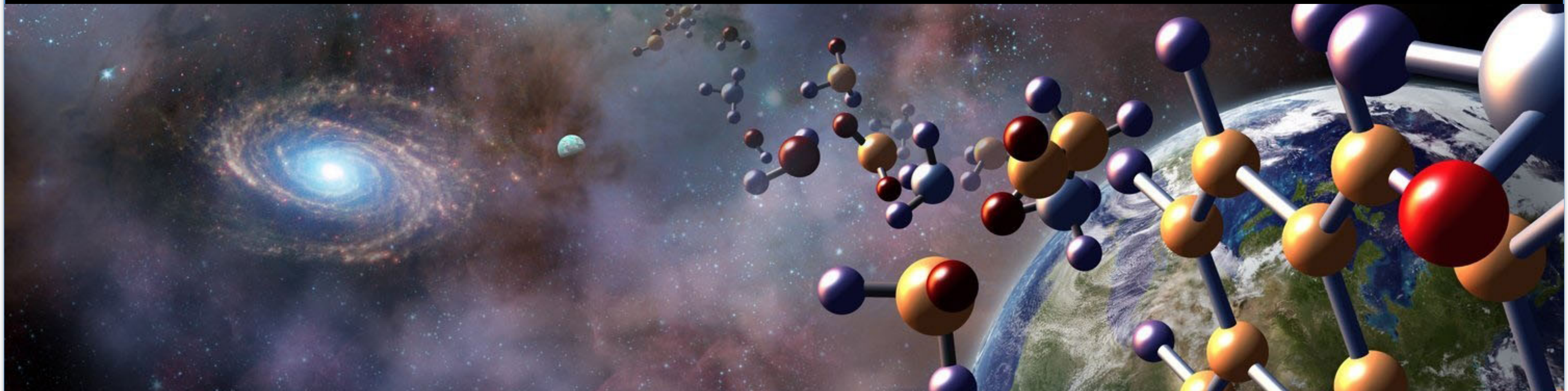
ORIGINS Space Telescope

From the Rise of Metals to Water for Habitable Worlds

NASA

Mid-Infrared Imager, Spectrometer, Coronagraph (MISC) for the Origins Space Telescope (OST)



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Aoi Takahashi (ISAS/JAXA), Takehiko Wada (ISAS/JAXA), Denis Burgarella (LAM),
Origins Space Telescope (OST) /MISC Team, OST STDT

OST/MISC Study team

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Study team

from JAXA and related Institutes		
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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
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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

Instrument Science Goals and Objectives

Providing Mid-Infrared (6-38 μm) Capabilities to Address the Following Science Goals:

- Transit spectroscopy of exoplanets to look for biogenic compounds (#14)
- The rise of metals (#19)
- Water content of Planet Forming Disks (#9)
- The first dust (#27)
- Connection between black hole growth and star formation over cosmic time (#21)
- Birth of galaxies during cosmic dark ages (#26)
- Galaxy feedback from SNe and AGN to Z~3 (#18)
- Galaxy feedback mechanisms at z<1(#5)
- Jupiter/Saturn Analogues (#16)

Instrument Science Requirements

- Science Observable and Measurement Requirement

  - Ten of the top fourteen science cases (#5, 9, 14, 15, 18, 19, 21, 22, 26, 27), for OST, plus the goal to provide a coronagraph to enable science case #16, require an instrument that covers < 40um.

  - Of these cases, they can fall into a need for an imager (#14, 17), spectrometer R~few hundred (#14,16, 19, 21, 22, 26), spectrometer R~few thousand (#18) to R~few ten's thousand (#5, 9, 15) and transit spectrometer (#14).

  - Most of the science targets are point sources, with three cases (#19, 21, 22) in need of an instrument to map large areas of sky.

  - Science case #9 (Water content of planet-forming disks) and #15 (Direct detection of protoplanetary disk mass) requested R>25,000 for 25-200um.

  - Science case #5 (Galaxy feedback mechanisms at z<1) requested R=10,000 for 10-500um.

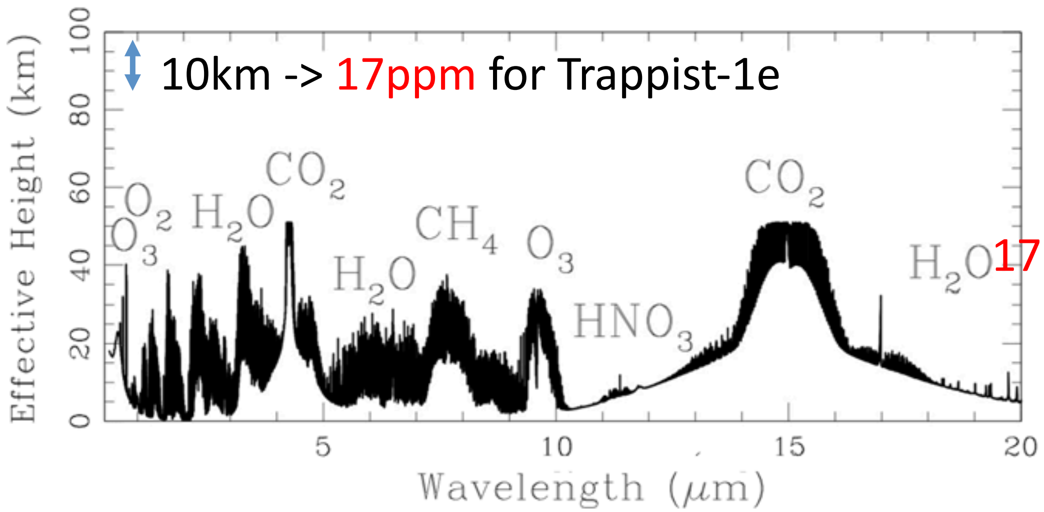
MIR Coronagraphy; 10^{-7} contrast at 0.5" (~2λ/D at 10μm)

Transit observations; stability better than 10 PPM on timescale of hours to days

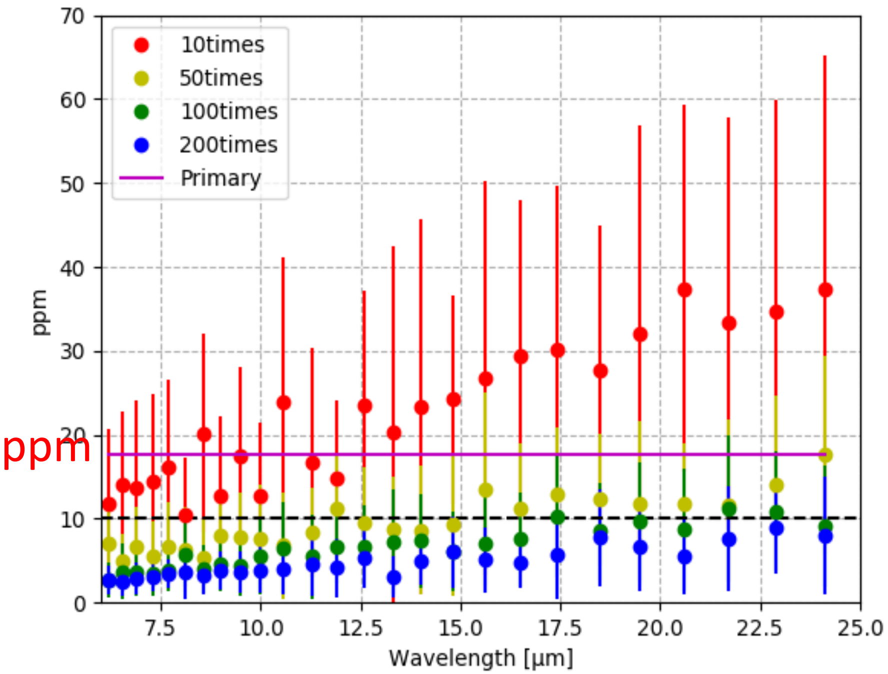
Compelling science (1)

- 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)



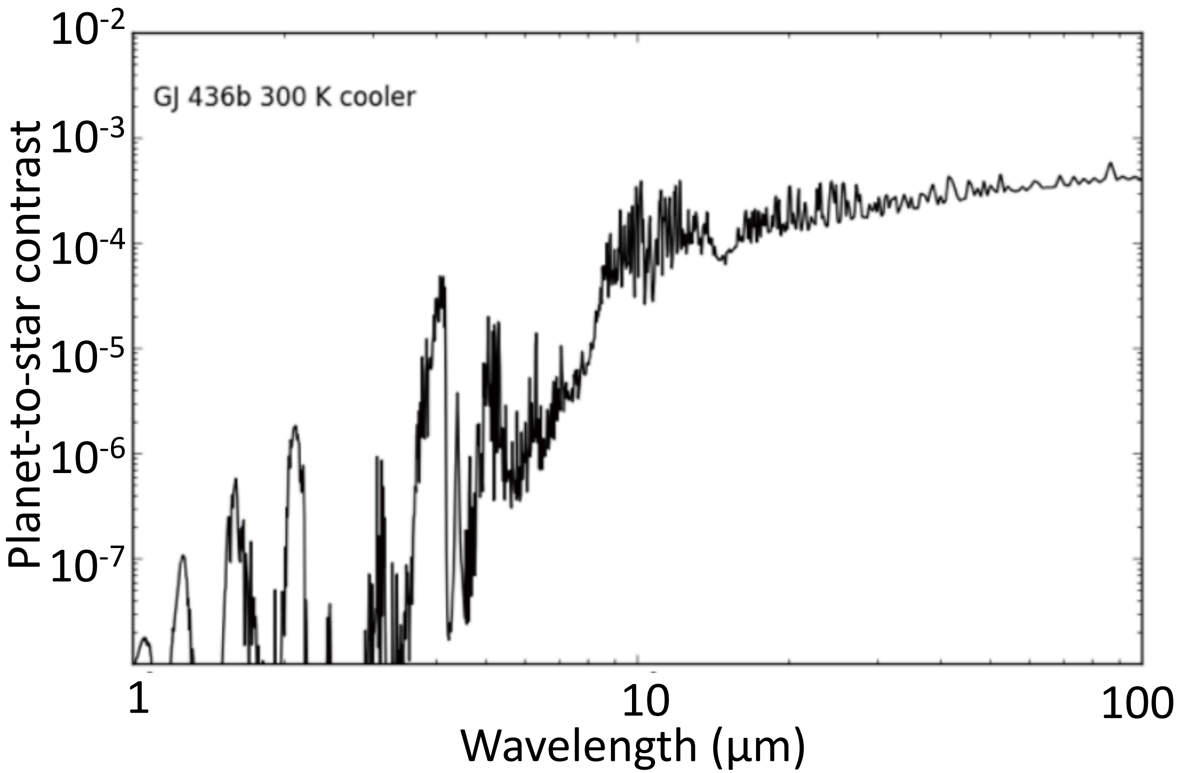
Performance of the transit spectrograph for transmission of Trappist-1e.

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 (NH3, CO2, O3, H2O and possibly CH4).
(Science case [#16])

7-8μm; Stratospheric emission from CH4
9.1-11.6μm; Tropospheric NH3
11.9-12.5μm; Stratospheric C2H6
13.8μm; Stratospheric emission from C2H2
17μm; H2 S(1)
28μm; H2 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.

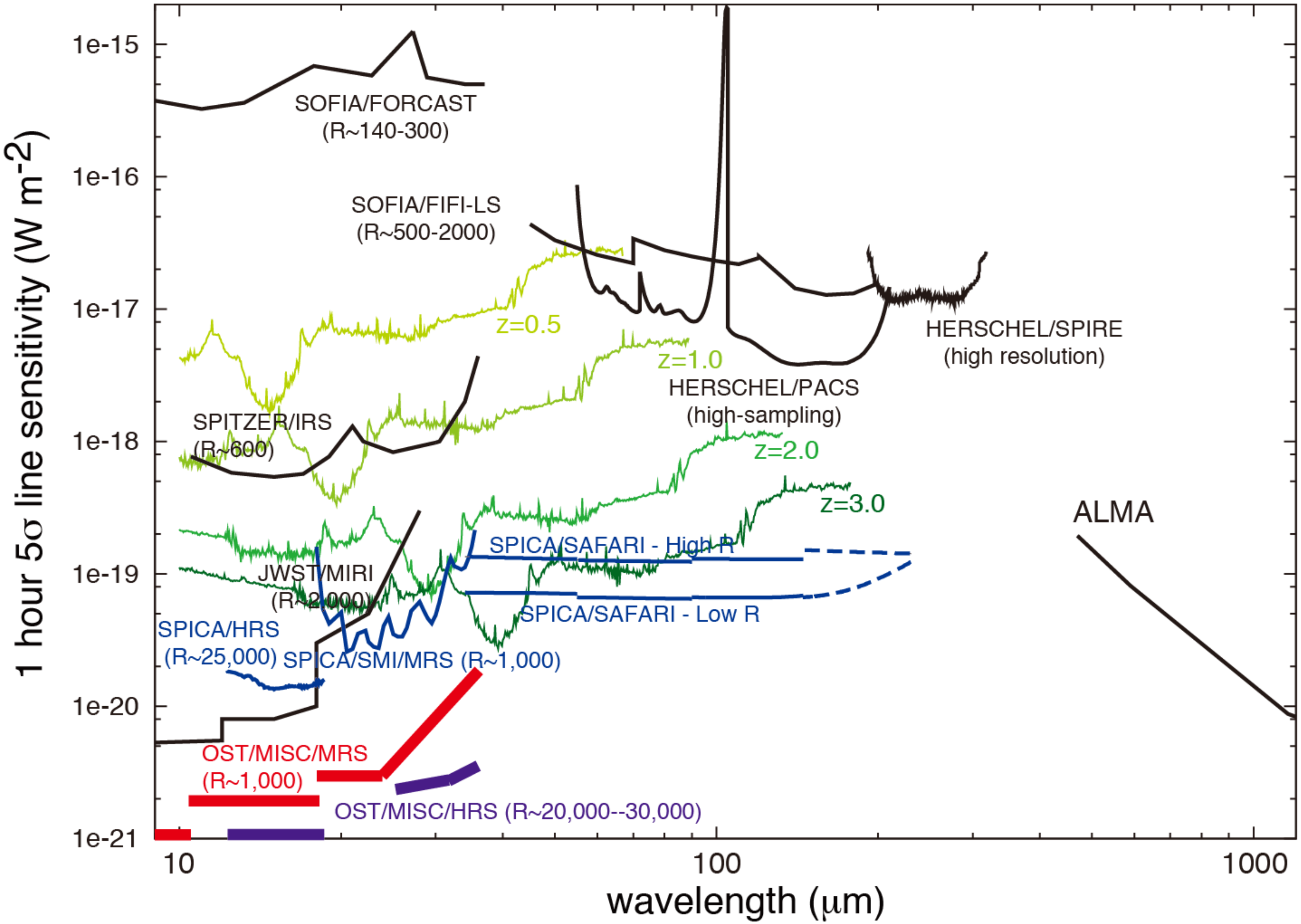
A Baseline design and specification of OST/MISC

(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--26	6-38
Spectral Resolution	5-10 [Imager] 300 [Low-Res Spec.]	1000-1500	20,000-30,000	>100 (TRA-S, TRA-M) 300 (TRA-L)	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/MRS-M/MRS-L) Width; 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;** better than 10 ppm 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

Measurement Capability

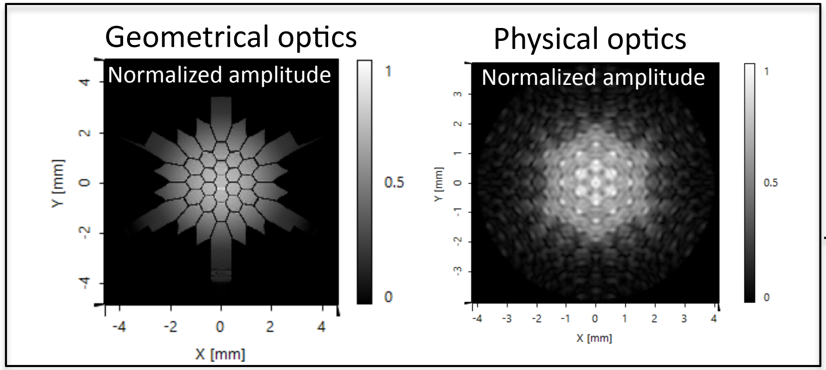
(1) MISC Imager and Spectrometer Module



Measurement Capability

(2) MISC Coronagraph Module

PIAA CMC Coronagraph (Guyon et al. 2012)

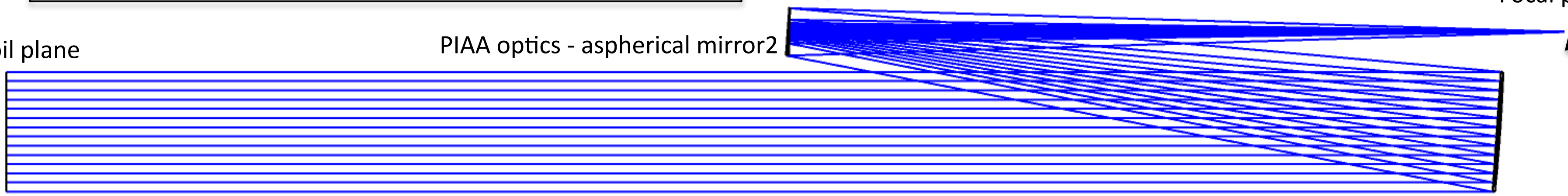


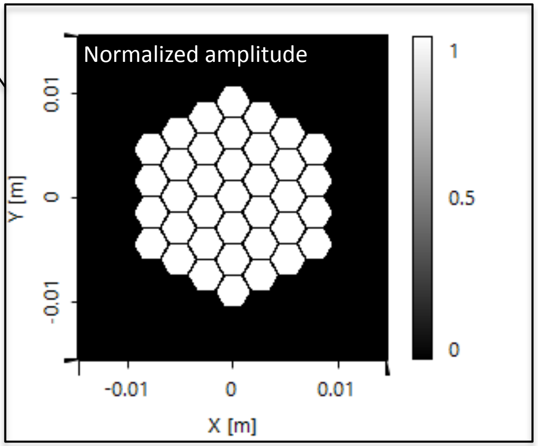
Optimization of PIAA optics has not been completed

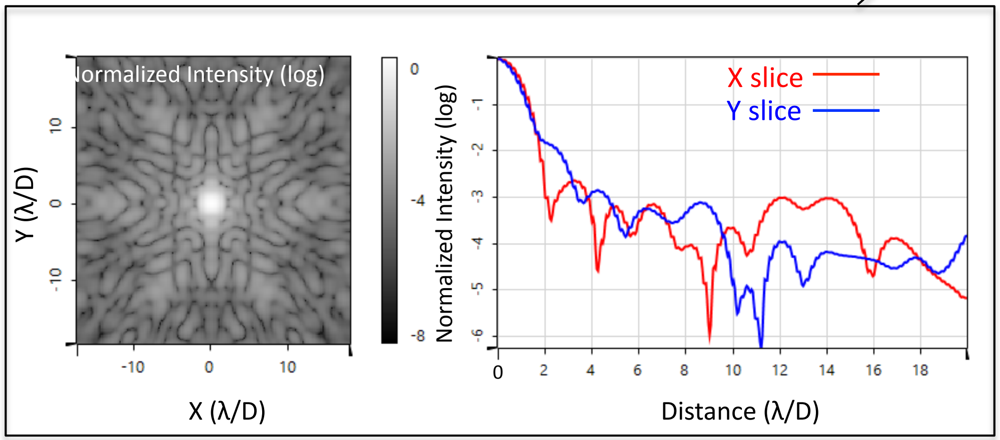
Goal; Average contrast in 0.88-3.6 λ/D

→ 7.07×10^{-6} for 10% band (@1.65um)

→ 1.16×10^{-6} for 4% band (@1.65um)







Beam shaping optical element to cancel the segment gap of Pupil apodization should be added

Wavelength: 15micron

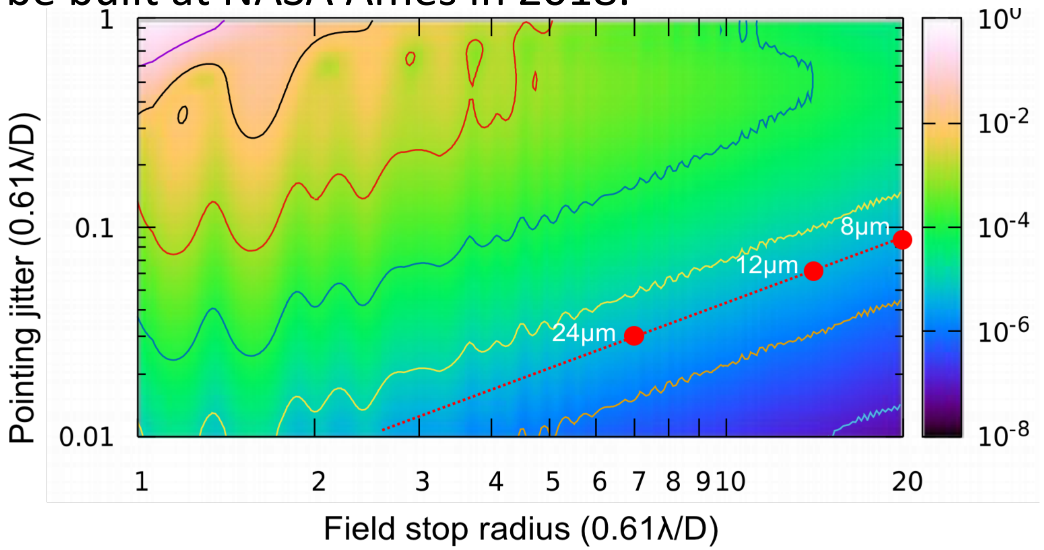
Measurement Capability

(3) MISC Transit Spectroscopy Module

Densified Pupil Spectrograph (Matsuo et al. 2016)

- 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.

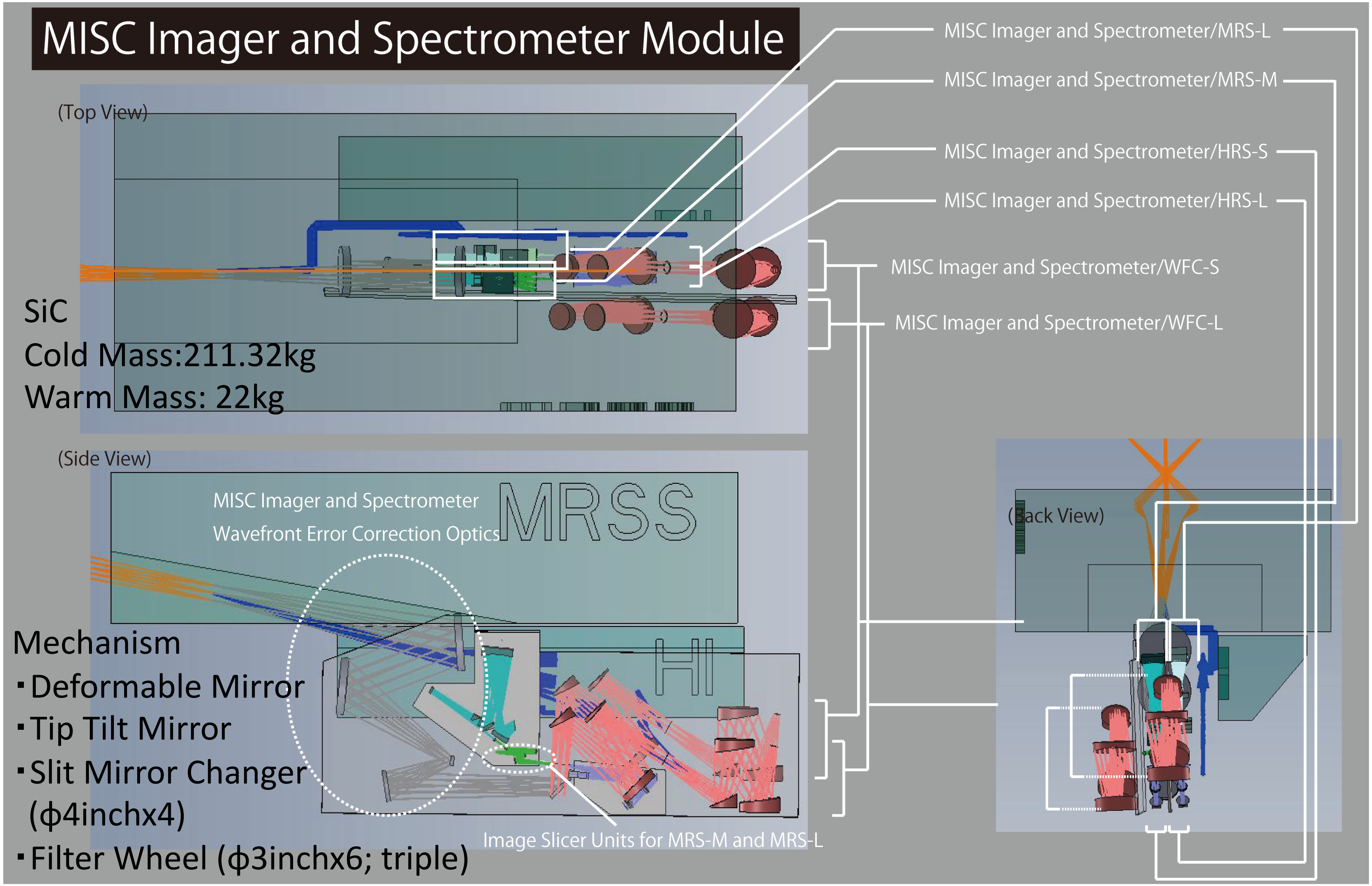
  Note that the slit-loss-variation could be mitigated because the telescope pointing jitter is symmetry to some extent (e.g., Deming et al. PASP, 2009).
- The noise floor will be determined through investigation of a prototype system, which will be built at NASA Ames in 2018.



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

Optical and Mechanical Design

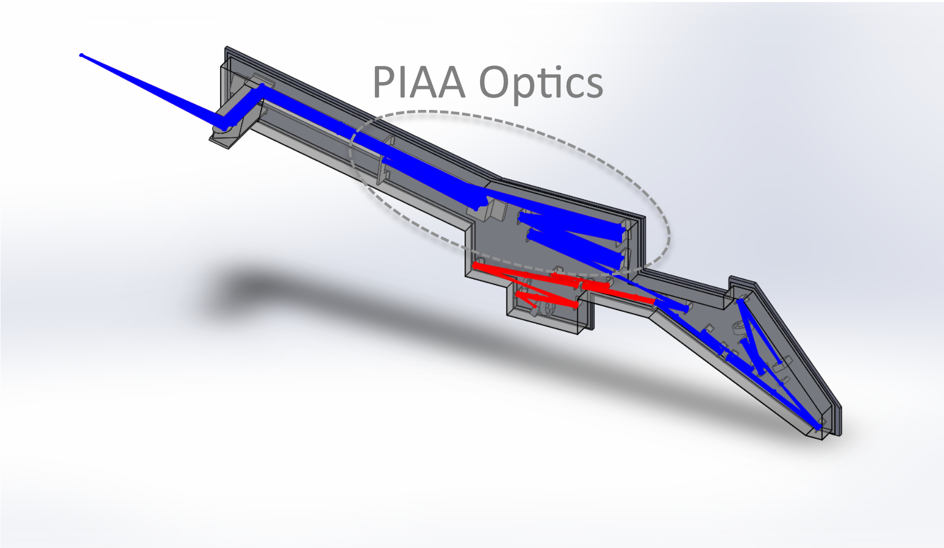
(1) MISC Imager and Spectrometer Module



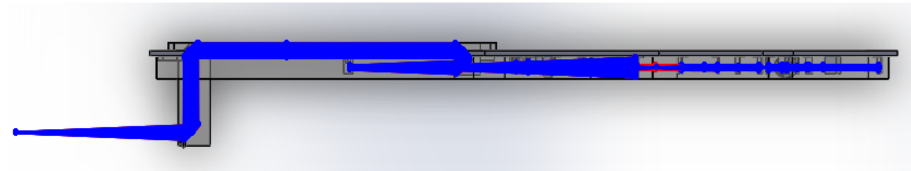
Optical and Mechanical Design

(2) MISC Coronagraph Module

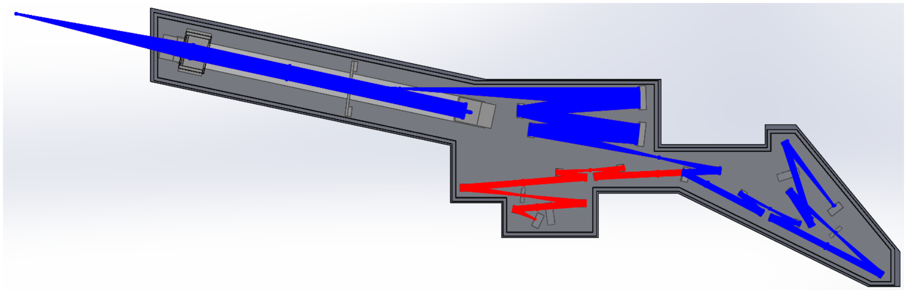
Bird's eye view



Top view



Side view

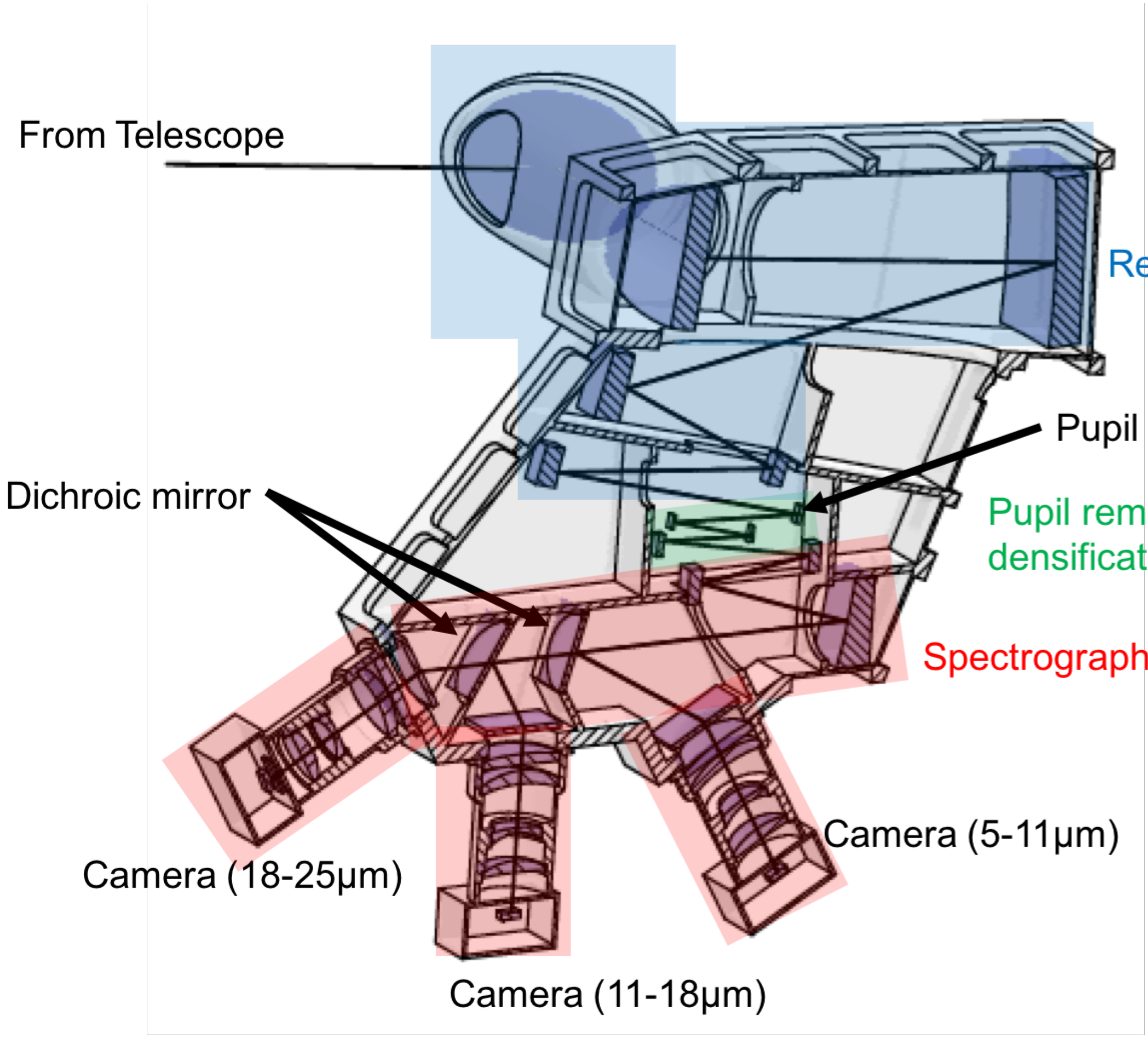


A6061-T6
Cold Mass:50.23kg
Warm Mass: 10kg

Mechanism

- Deformable Mirror
- Tip Tilt Mirror
- Slit Wheel #1 (ϕ0.5inchx6)
- Filter Wheel #2 (ϕ1inchx6; triple)

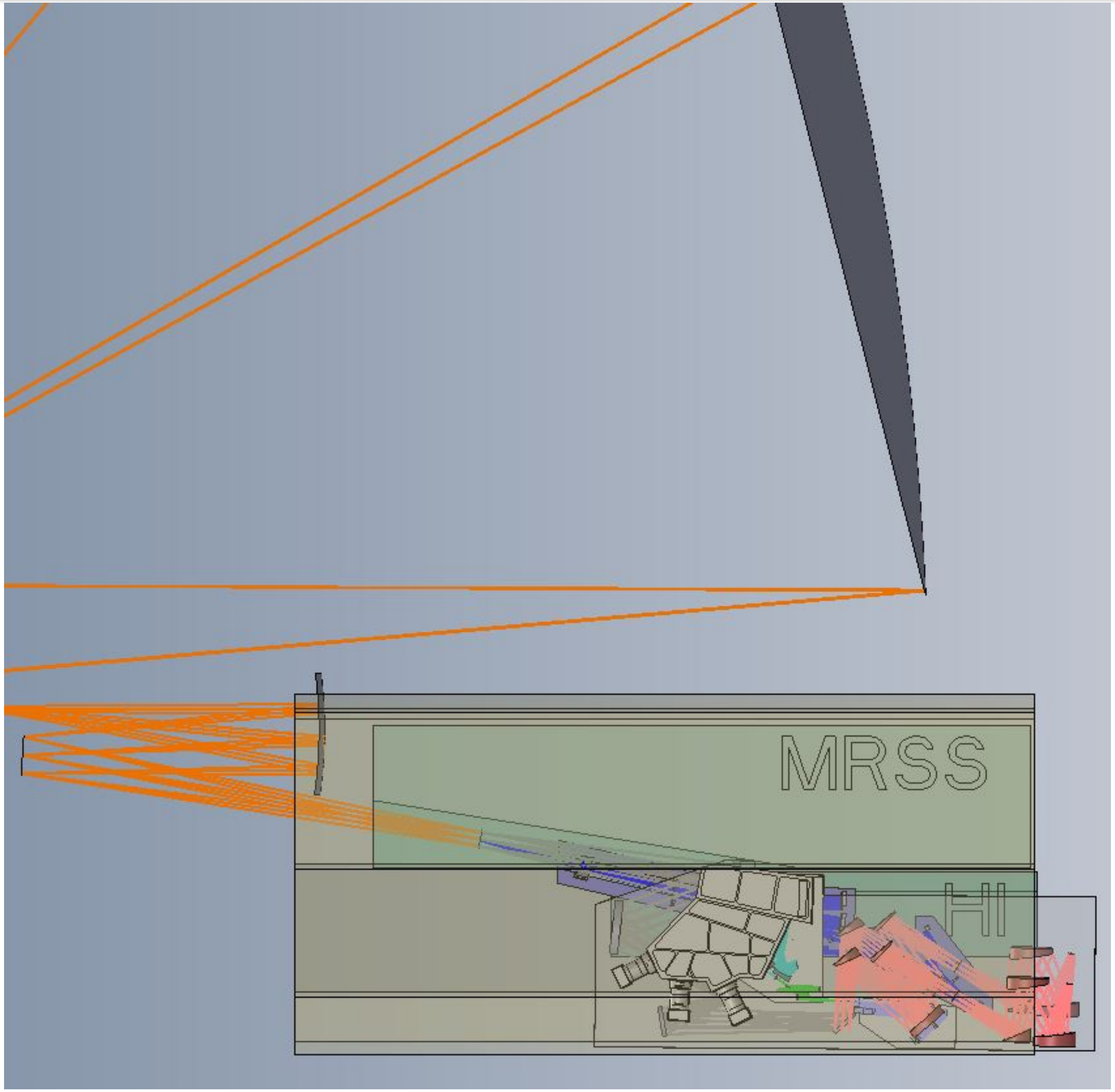
Mechanical Design
(3) MISC Transit Spectrometer Module



A6061-T6
Cold Mass:120.20kg
Warm Mass: 6 kg

Mechanisms
・no moving part

MISC in OST



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	λ/Δλ ~ 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]	λ/Δλ ~ 10
Resolving power [spectroscopy]	λ/Δλ ~ 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)	3×10^{-21} W m^{-2} (zodiacal emission limit) 3×10^{-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

Technical challenges

Description	Subsystem/ Component	TRL	Heritage
Deformable Mirror	Component	3	SPICA/SCI, LAM
Tip Tilt Mirror	Component	3	SPICA/SCI, JWST/NIRCAM, TAO/MIMIZUKU
2K x 2K Si:As, 2K x 2K Si:Sb (*)	Component	4-5	JWST/MIRI, SPICA/SMI
PIAACMC Coronagraph	Subsystem	3	
8-Octa Phase Mask for MIR (8-36um)	Component	2	
Binary Pupil Mask	Component	4	SPICA/SCI
Beam Splitter, Band-pass Filters (Multi-Layer Interference Filter)	Component	5	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.

Summary: A fact sheet of OST/MISC

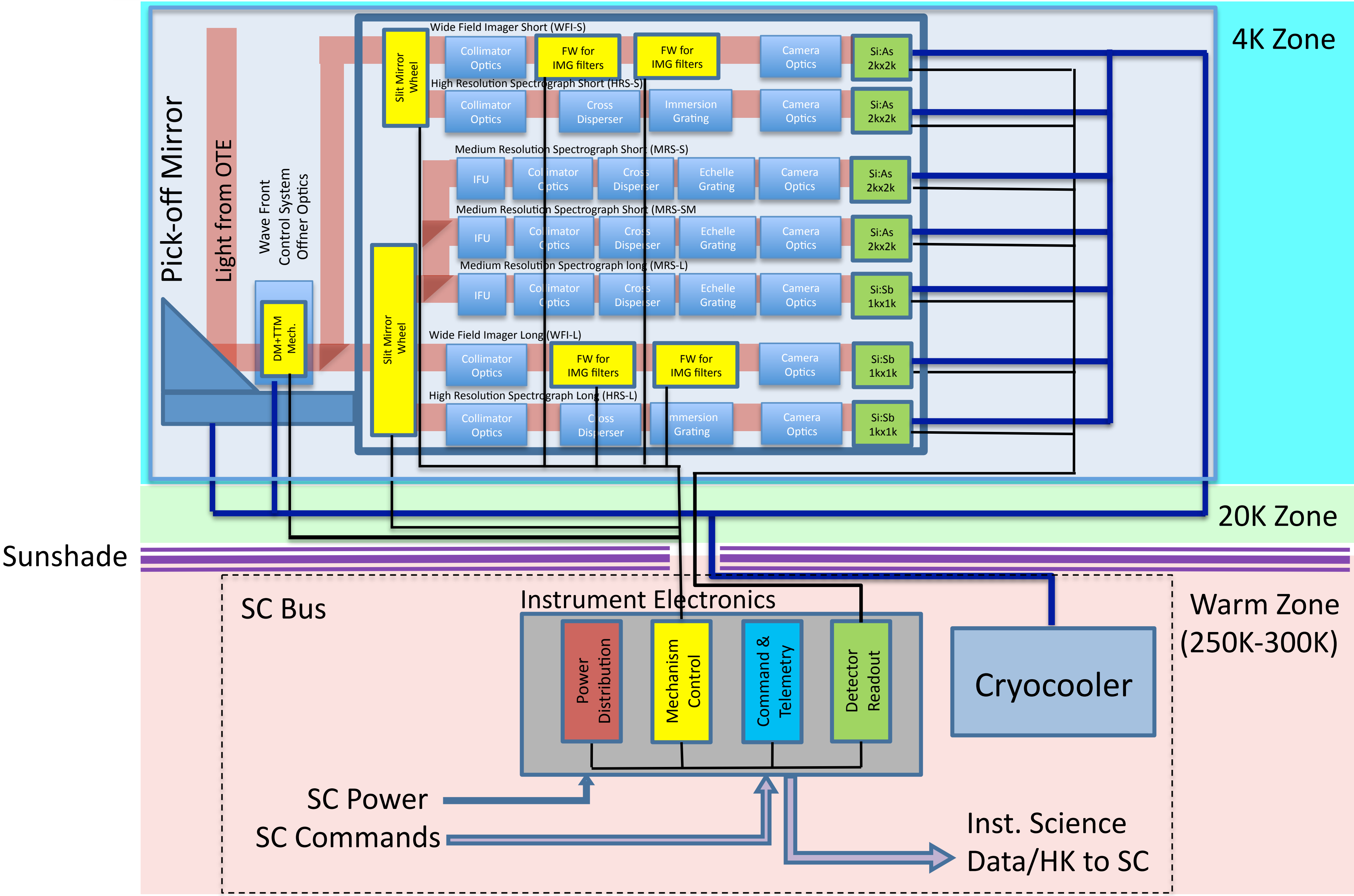
(http://exoplanets.astron.s.u-tokyo.ac.jp/OST/MISC/index_misc_case_A.html)

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--26	6-38
Spectral Resolution	5-10 [Imager] 300 [Low-Res Spec.]	1000-1500	20,000-30,000	>100 (TRA-S, TRA-M) 300 (TRA-L)	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/MRS-M/MRS-L) Width; 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 1×10^{-21} W/m^2 @7μm, 2×10^{-21} W/m^2 @15μm, 3×10^{-21} W/m^2 @24μm, 1×10^{-20} W/m^2 @32μm	**Sensitivity;** 1-hour 5s Line Sens. for a Point Source 1×10^{-21} W/m^2 @15μm, 3×10^{-21} W/m^2 @30μm	**Photometric stability;** better than 10 ppm on timescales of hours to days (excluding the fluctuation of detector gain)	**Average contrast;** 7×10^{-6} for 10% band 1×10^{-6} for 4% band in 0.88-3.6λ/D

appendix

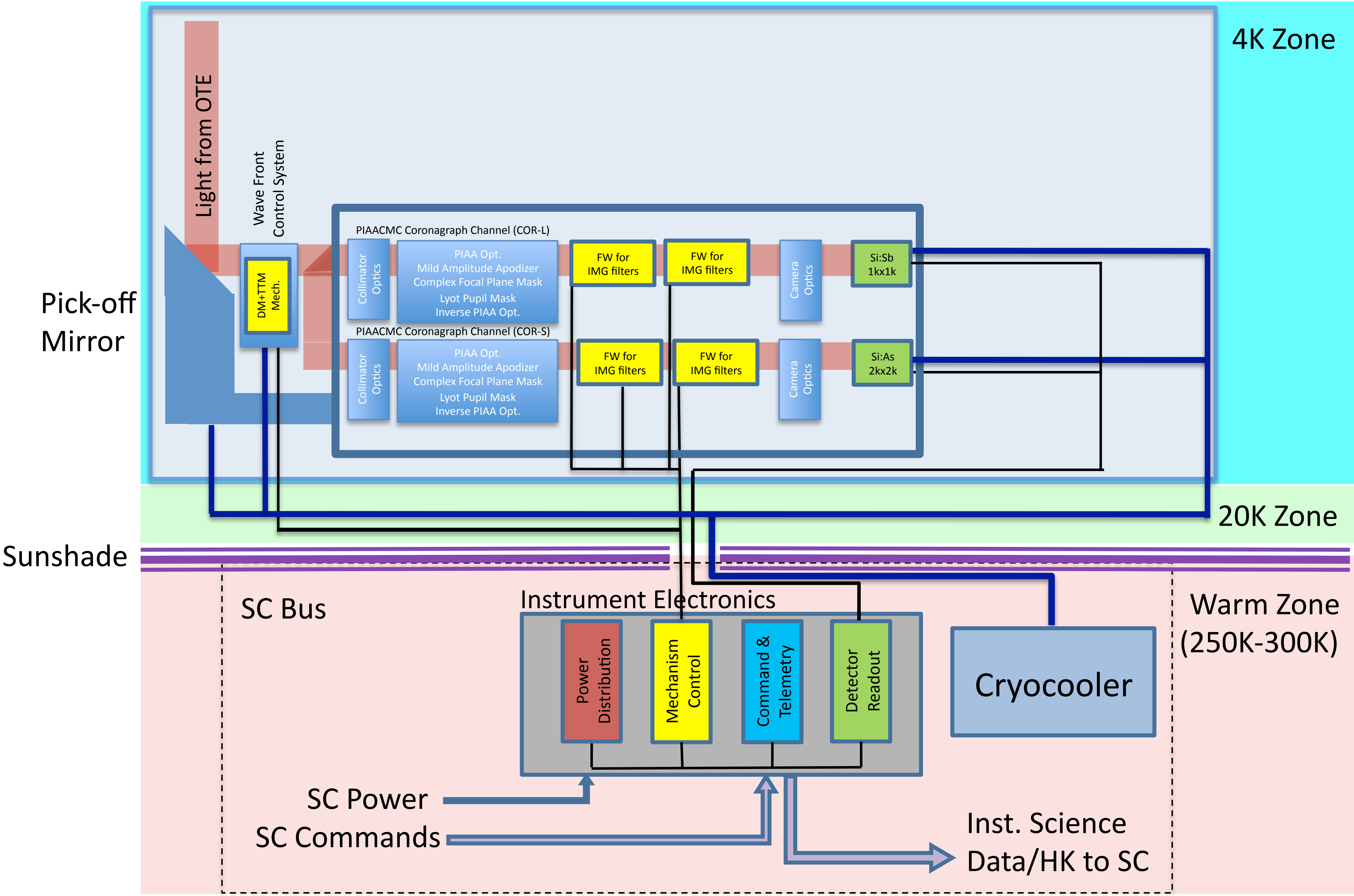
Block diagram

MISC Imager and Spectrometer Module

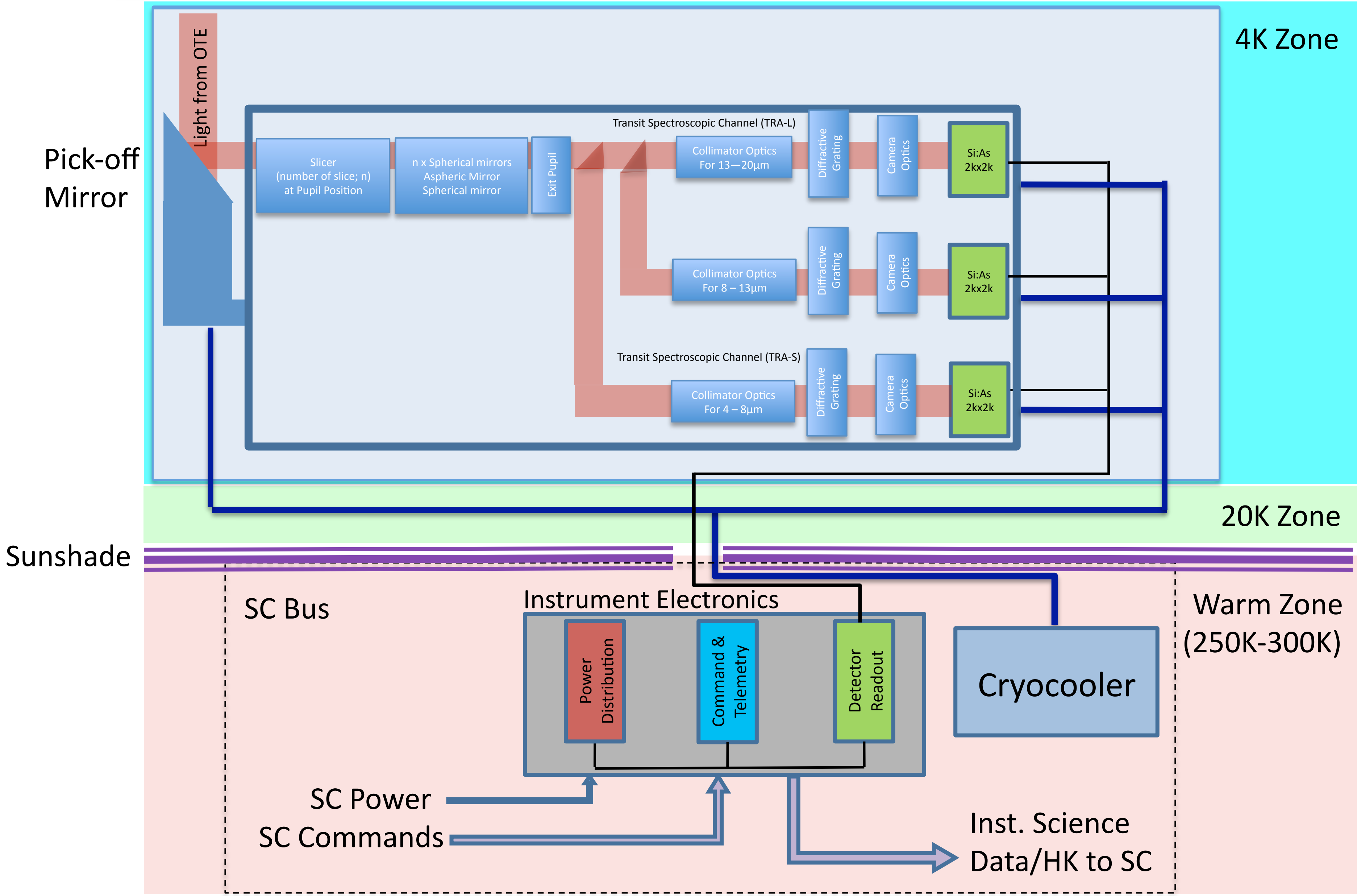


Block diagram

MISC Coronagraph Module



Block diagram
MISC Transit Spectrometer Module



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