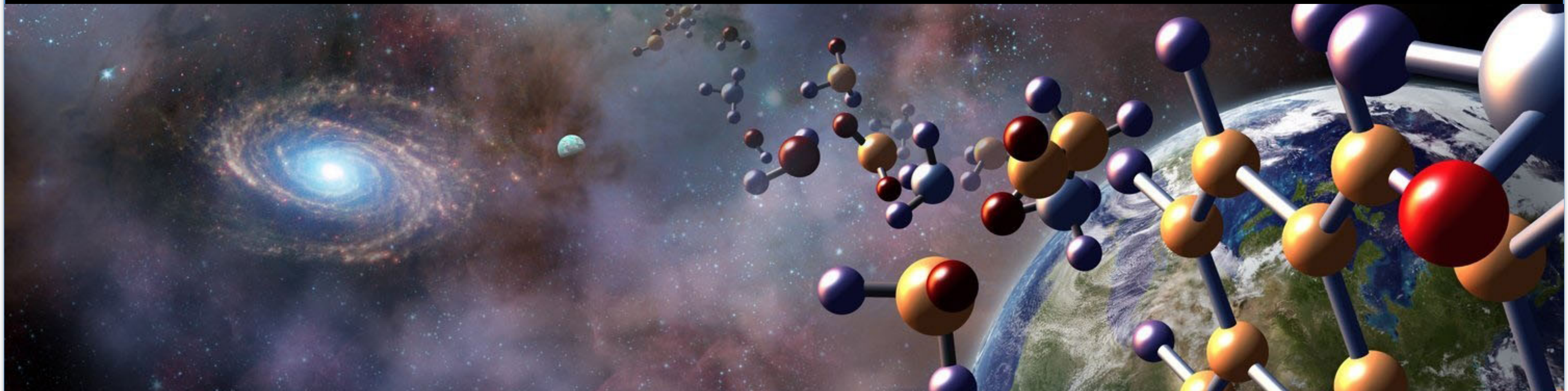
ORIGINS Space Telescope

From the Rise of Metals to Water for Habitable Worlds

NASA

Mission Concept Studies for the 2020 Decadal Survey ;

Origins Space Telescope



Itsuki Sakon (University of Tokyo),
Origins Space Telescope (OST) STDT,
OST/MISC instrument team

Origins Space Telescope STDT

Community Chairs: Margaret **Meixner,** STSCI, Asantha **Cooray**, UC Irvine

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Members appointed by NASA (> 90 applications):

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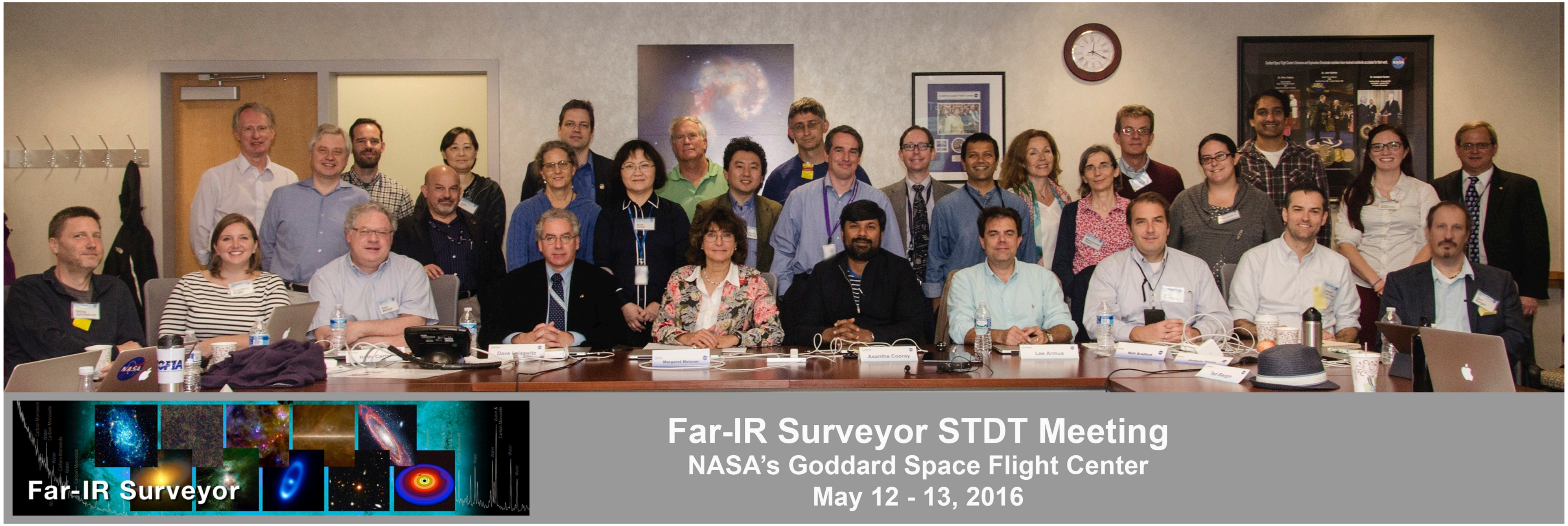


Tracing the signatures of life and the ingredients of habitable worlds

Origins will trace the trail of water from interstellar clouds, to proto-planetary disks, to Earth itself facilitating understanding of the abundance and availability of water for habitable planets.

Unveiling the Growth of Black Holes and Galaxies over Cosmic Time

Origins will reveal the co-evolution of super-massive black holes and galaxies, energetic feedback, and the dynamic interstellar medium from which stars are born.

Origins will trace the metal enrichment history of the Universe, probe the first cosmic sources of dust, the earliest star formation, and the birth of galaxies.

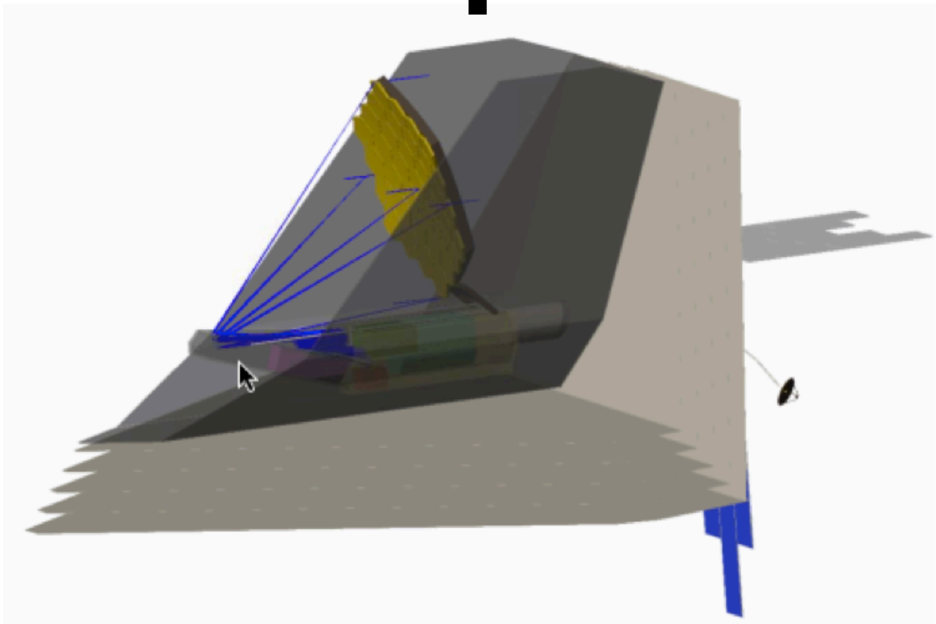
Charting the Rise of Metals, Dust, and the First Galaxies

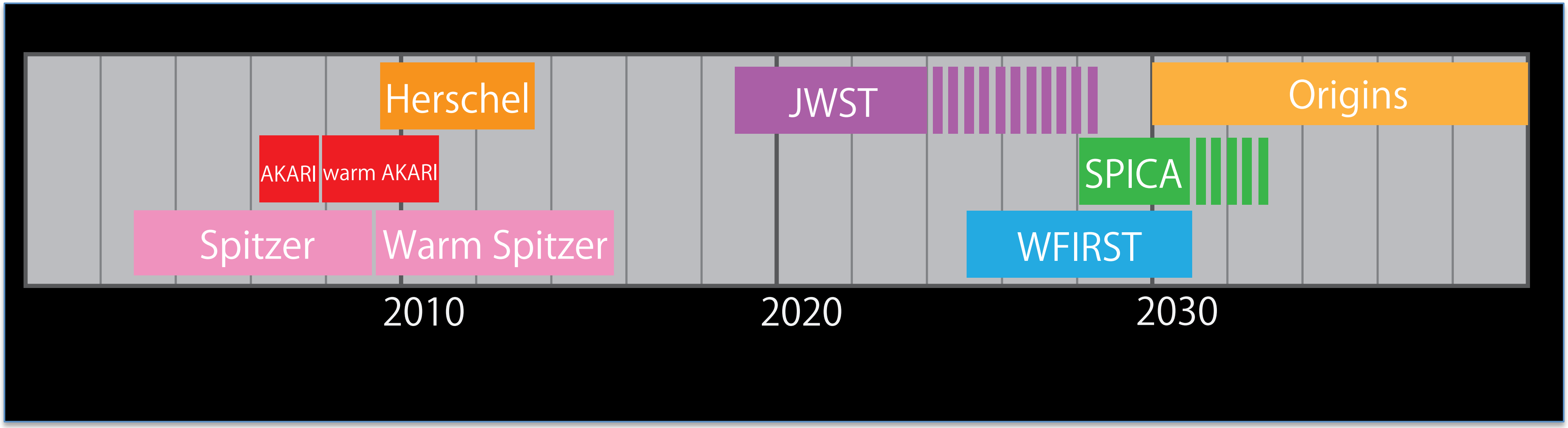
Origins will chart the role of comets in delivering water to the early Earth, and conduct a survey of thousands of ancient Trans Neptunian Objects (TNOs) in the outer reaches of the Solar System.

Characterizing Small Bodies in the Solar System

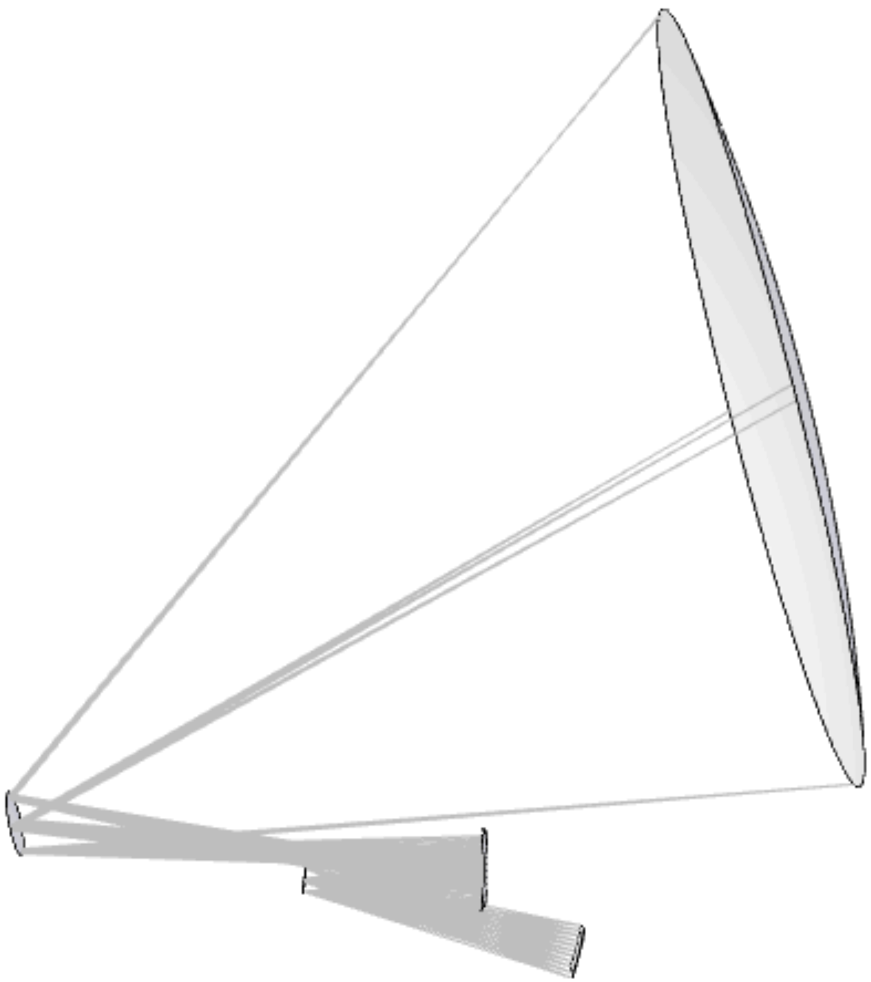
Origins Space Telescope

- 2020 Decadal
- 9.1m single aperture
- Off-Axis
- 6—1000μm (TBD)
- 4.5K
- Diffraction Limited at 20μm

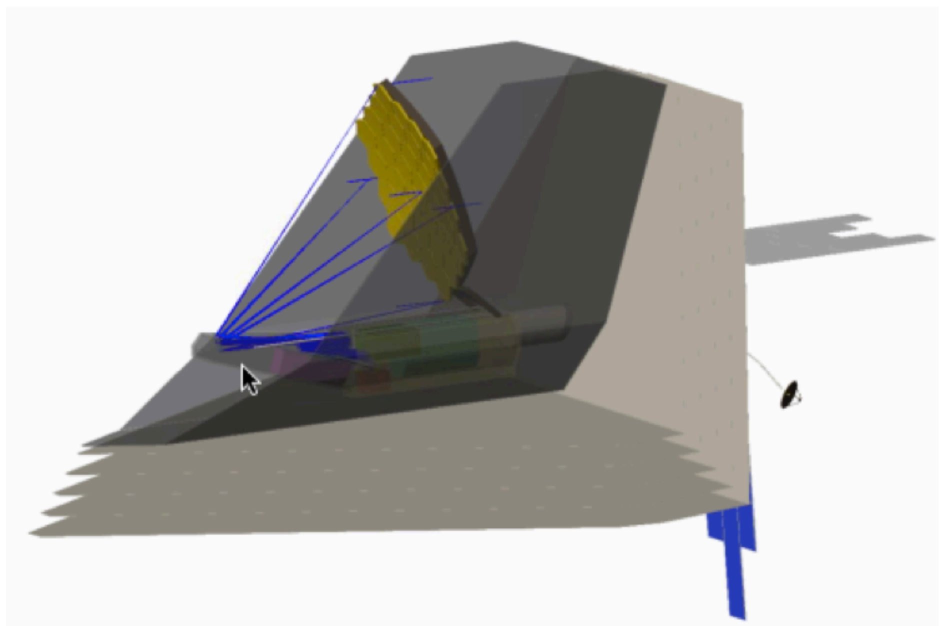




OST (Off-Axis) Telescope



The STDT decided to employ Off-Axis design at the F2F Meeting on March 2017



Top 14 Killer Apps.
- The Rise of Metals
- Water Content of Planet-Forming Disks
- The First Dust
- Direct Detection of Protoplanetary Disk Masses
- Super Earth Biosignatures And Climates
- Water Transport to Terrestrial Planetary Zone
- Connection Between BH Growth and Star Formation Over Cosmic Time
- Birth of Galaxies During Cosmic Dark Ages
- Galaxy Feedback from SNe and AGN to $z \sim 3$
- Thermo-Chemical History of Comets and Water Delivery to Earth
- Star Formation and Multiphase ISM at Peak of Cosmic Star Formation
- Magnetic Fields and Turbulence - Role in Star Formation
- Galaxy Feedback Mechanisms at $z<1$
- Survey of Small Bodies in the Outer Solar System

Baseline sets of Instruments studied for OST

Instrument	Wavelength Coverage (μm)	Spectral Resolution (λ/Δλ)	FOV # Spatial Pixels	Typical Required Sensitivity	Other
Low-Res Spectrometer	35 to 500	Low-res ~ 500 High-res ~ 10^4	100 per channel	10^{-21} W/m^2 (spectral line)	Multi-channel
High-Res Spectrometer	50 to 500	Low-res ~ $8x10^4$ High-res ~ $5x10^5$	100	10^{-21} W/m^2 (spectral line)	Photo-counting
Heterodyne Spectrometer	150 to 500	~ 10^7	10-100	2 mK in 0.2 km/s @1THz	Polarized, background limited
Far-Infrared Imager	35 to 500	15	100,000	1μJy–10mJy (confusion limit)	5 to 10 channels Polarimetry Spectral line filters
Mid-Infrared Imager, Spectrometer, Coronagraph	6 to 40	Imager ~ 15 Spectrometer > 500, $2x10^4$	10^6	Photometric 1μJy@10μm	Coronagraph; ~ 10^{-7} @ 0.5”, 10 μm Transit Spectroscopy; ~ 10ppm stability on timescales of hours and days

Instrument Science Goals and Objectives

- Provide 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}--10^{-8} contrast at 0.5" (~2λ/D at 10μm)

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

Instrument Science Requirements

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

OST MISC Instrument Requirements

Technical Parameter	Technical Requirement
Wavelength Range (microns)	6um-38um
Detector Bandwidth	Si:As : 6-28µm, Si:Sb: 20-38µm
Angular Resolution	<0.25” at 10µm
Spectral Resolving Power	3-300 (6-38um), >1000 (20-38um), 10000-20000 (10-38um)
Spectral Line Sensitivity (5σ, 1 hr)	$2x10^{-22}$ W/m-2
Continuum Point Source Sensitivity	1µJy (@6um, R=100) 10µJy (@30um, R=100)
Spectrometer Relative Calibration Accuracy	3%, but 10 ppm λ<10 µm, 50 ppm for λ>10µm for transits
Field of Regard (see note above)	4 pi
Field of View	Not set by science
Mapping Speed	Not set by science
Calibration / Gain stability [%]	1%

Technical Parameter	Technical Requirement
Photometric Accuracy –if available	N/A
Transit Monitoring Cadence	One measurement/10 minutes
Moving Target Tracking	Yes, up to 1”/second
Sensitivity to High Dynamic Range Targets	N/A for MISC science
Polarization Capabilities	No
Broadband, Wide-area Mapping	Yes, if 10 sq. deg is wide angle
Surface Brightness Sensitivity	N/A
Instantaneous Field of View	Not set by science
Coronagraphic Contrast	1e-7 at 0.5” at 10µm
Other	

Mid-Infrared Imager, Spectrometer and Coronagraph (MISC)

(1) Mid-Infrared Imaging and Spectroscopy Channel

- Wide Field Imager (WFI-S; 6-16um, WFI-L; 15-38um, R=3-10, R=100-300)
- Medium Resolution Spectrometer (MRS-S; 5-10um, MRS-M; 9.5-19um, MRS-L; 18-36um, R>1000)
- High Resolution Spectrometer (HRS-S; 12-18um, HRS-L; 25-38um)

Detectors; 4 2kx2k Si:As, 2 1kx1k Si:Sb, 1 2kx2k Si:Sb

Mechanisms; 2 wave front correction systems (DM + TTM), 6 Filter Wheels

Others; IFU for MIR-S, MIR-M and MIR-L, sharing the same FOV,
WFI can be used as the slit viewer when doing spectroscopy

(2) PIAACMC Coronagraph Channel (COR)

- PIAACMC Coronagraph (COR-S; 6-16um, COR-L; 15-38um, R=3-10, R=100-300)

Detectors; 1 2k x 2k Si:As and 1 1kx1k Si:Sb

Mechanisms; Deformable Mirror + Tip-tilt Mirror, 4 Filter Wheels

(3) Transit Spectroscopy Channel (TRA)

- densified pupil spectrometer (TRA-S; 5-9um, TRA-L; 15-38um, R~100 TBD)

Detectors; 3 2kx2k Si:As

Mid-Infrared Imager, Spectrometer and Coronagraph (MISC)

Mid-Infrared Imager, Spectrometer, Coronagraph (MISC) Team Members

(from Science and Technology Definition Team, Ex-Officio Non-Voting Members, Internation Ex-Officio Non-Voting Members)
-Asantha Cooray (California, Irvine)
-Deborah Padgett (GSFC)
-Eric Nielsen (SETI Institute)
-Itsuki Sakon (University of Tokyo) [Instrument lead]
-Joaquin Vieira (Illinois, Urbana Champaign)
-Margaret Meixner (STScI)
-Kimberly Ennico Smith (NASA/AMES) [Science lead]
-Tom Roellig (NASA/AMES) [Instrument lead]
-Klaus pontoppidan (STScI)

(from NASA/Ames)
- TBA

(from Laboratoire d'Astrophysique de Marseille and related Institutes)
-Denis Burgarella (LAM)
-David Le Miqnant (LAM)

(from JAXA and related Institutes)
-Keigo Enya (JAXA)
-Olivier Guyon (Subaru Telescope/Astrobiology Center, NINS/Steward Observatory, University of Arizona)
-Yuji Ikeda (Photocoding)
-Taro Matsuo (Osaka University)
-Naoshi Murakami (Hokkaido University)
-Jun Nishikawa (NAOJ)
-Takayuki Kotani (NAOJ)
-Yuki Sarugaku (University of Tokyo)
-Naofumi Fujishiro (Astro-Opt)
- And more

A Baseline design idea of OST/MISC

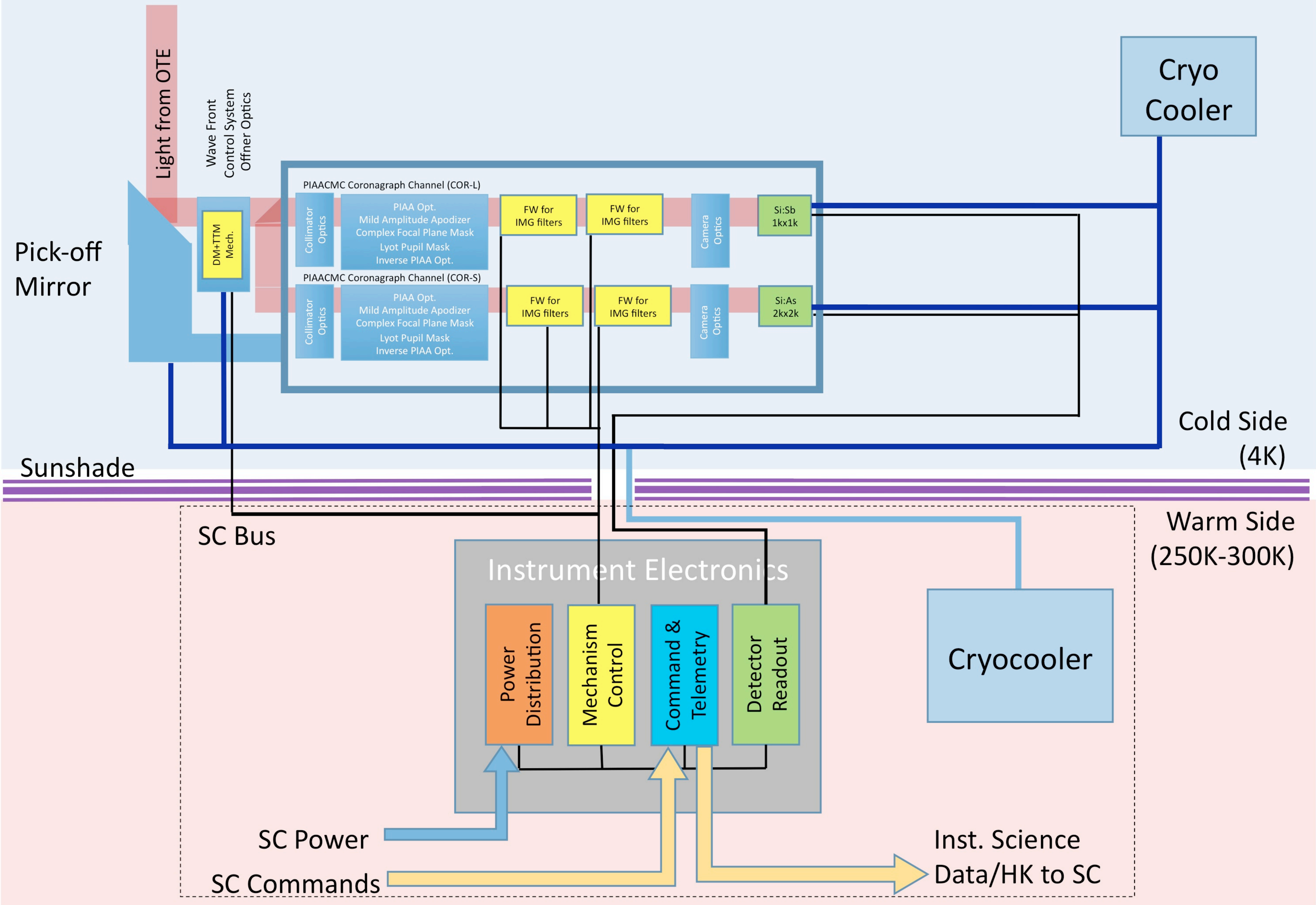
(http://exoplanets.astron.s.u-tokyo.ac.jp/OST/MISC/index_misc.html)

Summary of Specification (OST/MISC)

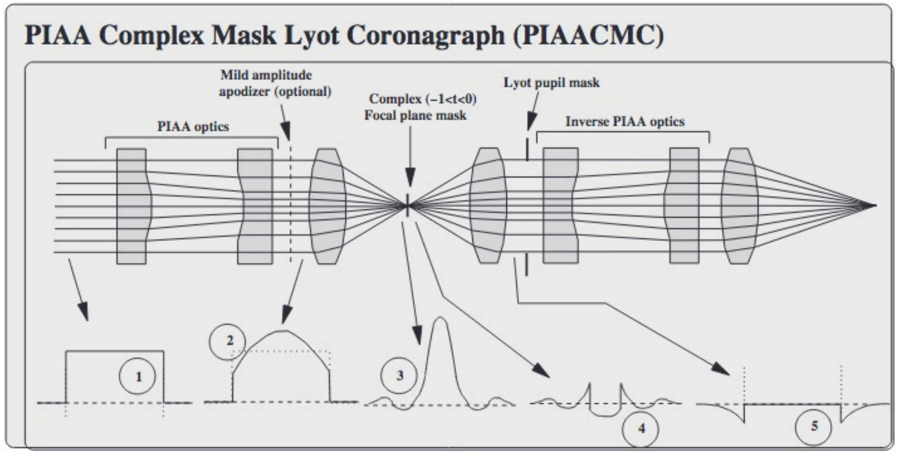
Module	Mid-IR Imager Spectrometer Channel			Transit Channel	Coronagraph Channel
	Imager/Low-Res Spec.	Medium-Res Spec.	High-Res Spec.	(Densified Pupil Spec.)	(PIAACMC)
	WFI-S/-L	MRS-S/-M/-L	HRS-S/-L	TRA-S/-M/-L	COR-S/-L
Bandpass (μm)	6-38	5-36	12-18, 25-38	5--20	6-38
Spectral Resolution	5-10 [Imager] 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

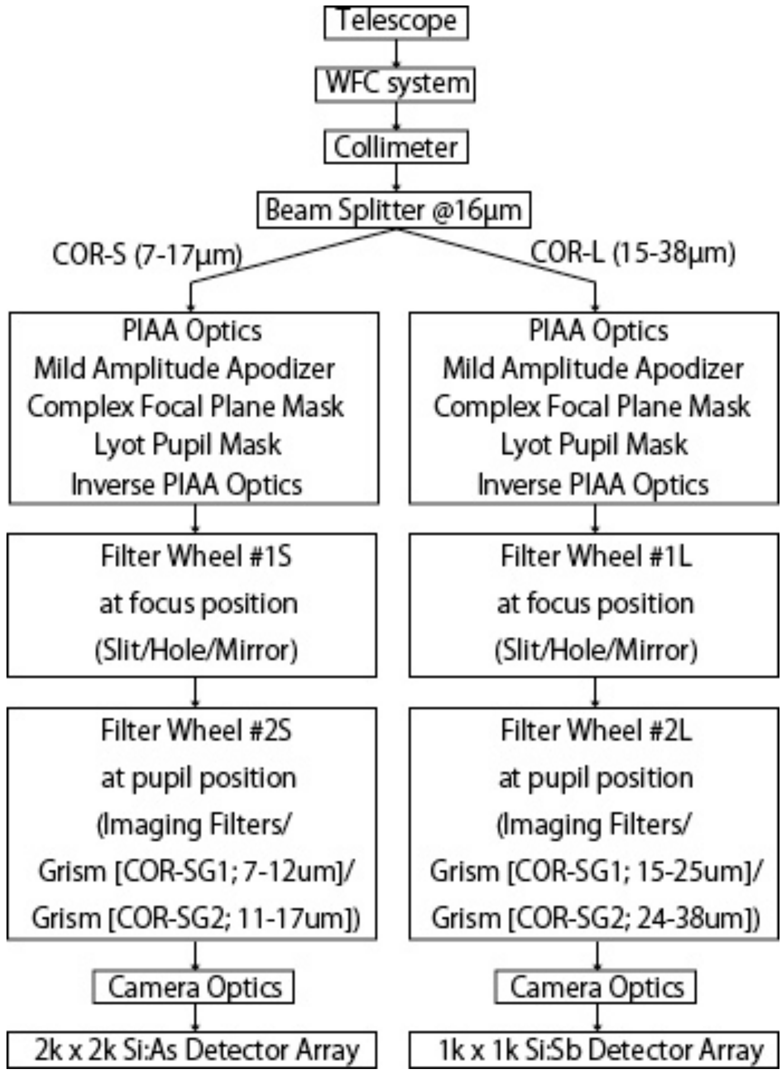
[1] OST/MISC Coronagraph Channel

(A-1) MISC/PIAACMC Coronagraph Channel Instrument Block Diagram



MISC Instrument Diagram or sketch
(MIR PIAACMC Coronagraph Channel)





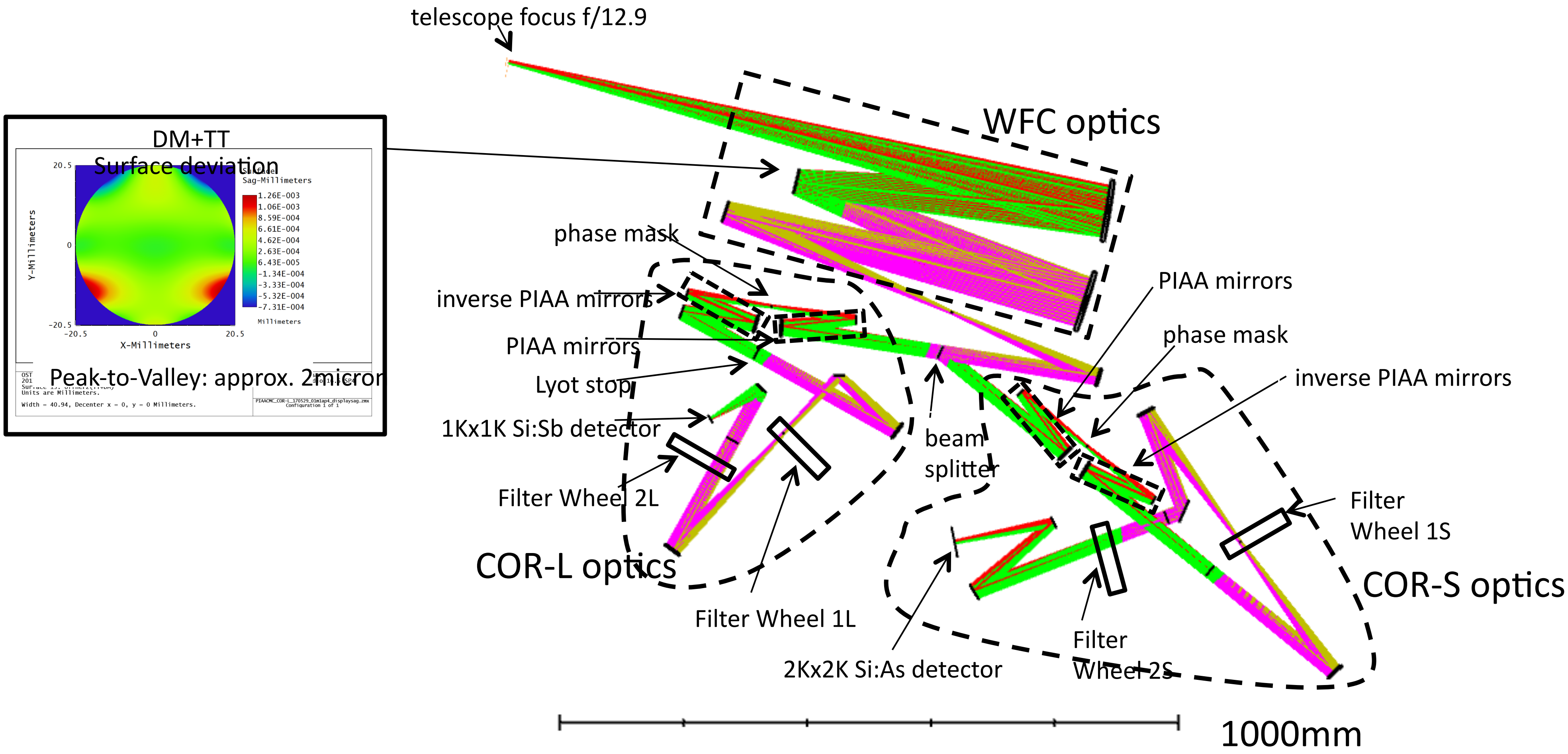
Inner Working Angle (IWA) (based on Guyon et al. 2014)
Obscured Circular Segmented pupils (GMT type);
- $0.72\lambda/D$ (aggressive design)
- $0.92\lambda/D$ (more conservative design)

Obscured Circular Highly Segmented pupils (E-ELT type)
- $0.8\lambda/D$ (aggressive design)
- $1.0\lambda/D$ (more conservative design)

→ 0.75 – 0.95 λ/D for the IWA of OST/MISC
(for D=9m, λ=9μm, IWA is 0.15-0.20 arcsec)

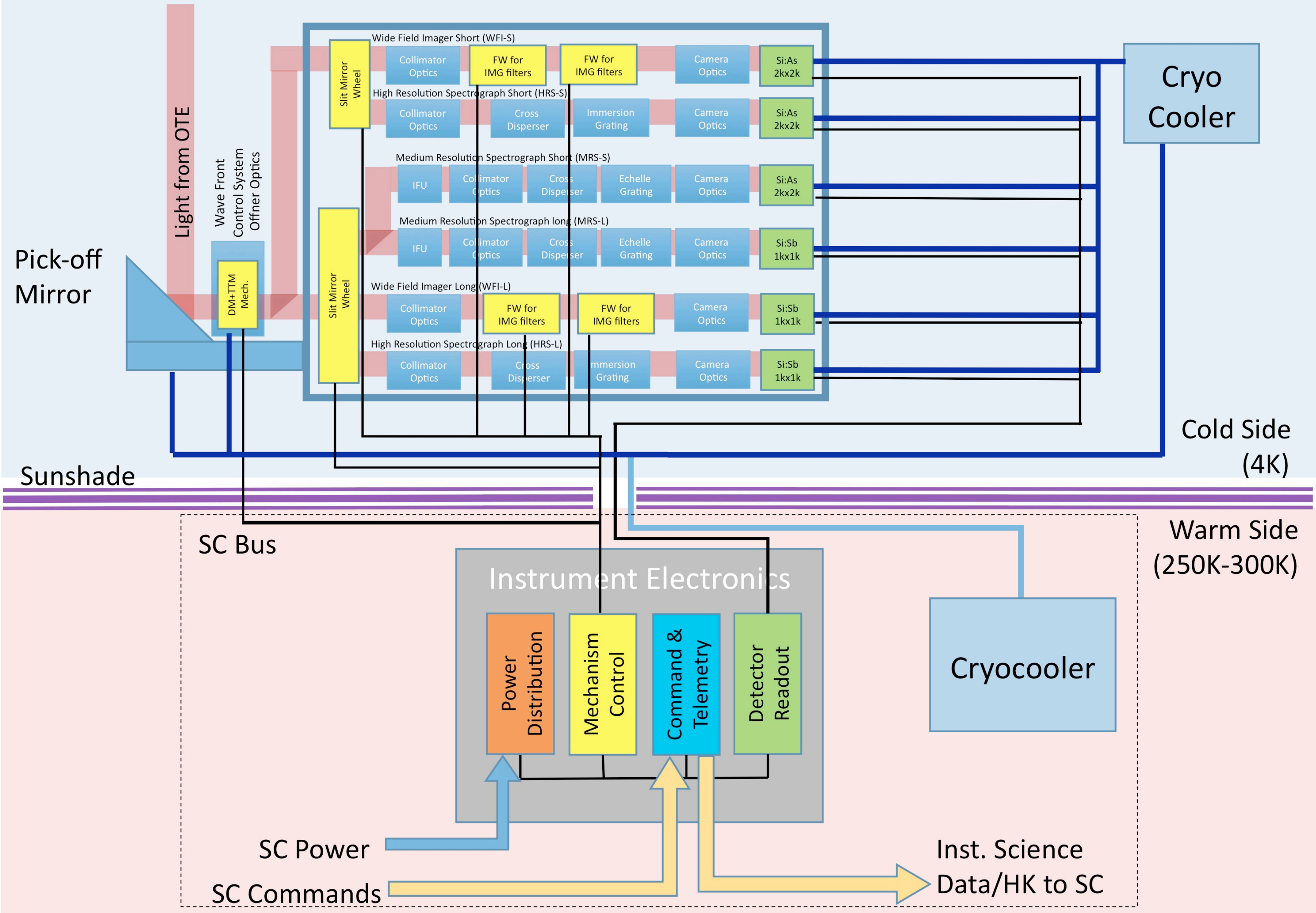
Contrast at the IWA (based on Guyon et al. 2014)
Average contrast in 0.88-3.6 λ/D
→ 7.07×10^{-6} for 10% band, 1.16×10^{-6} for 4% band (@1.65um)

Optical Design of MISC Coronagraph Channel



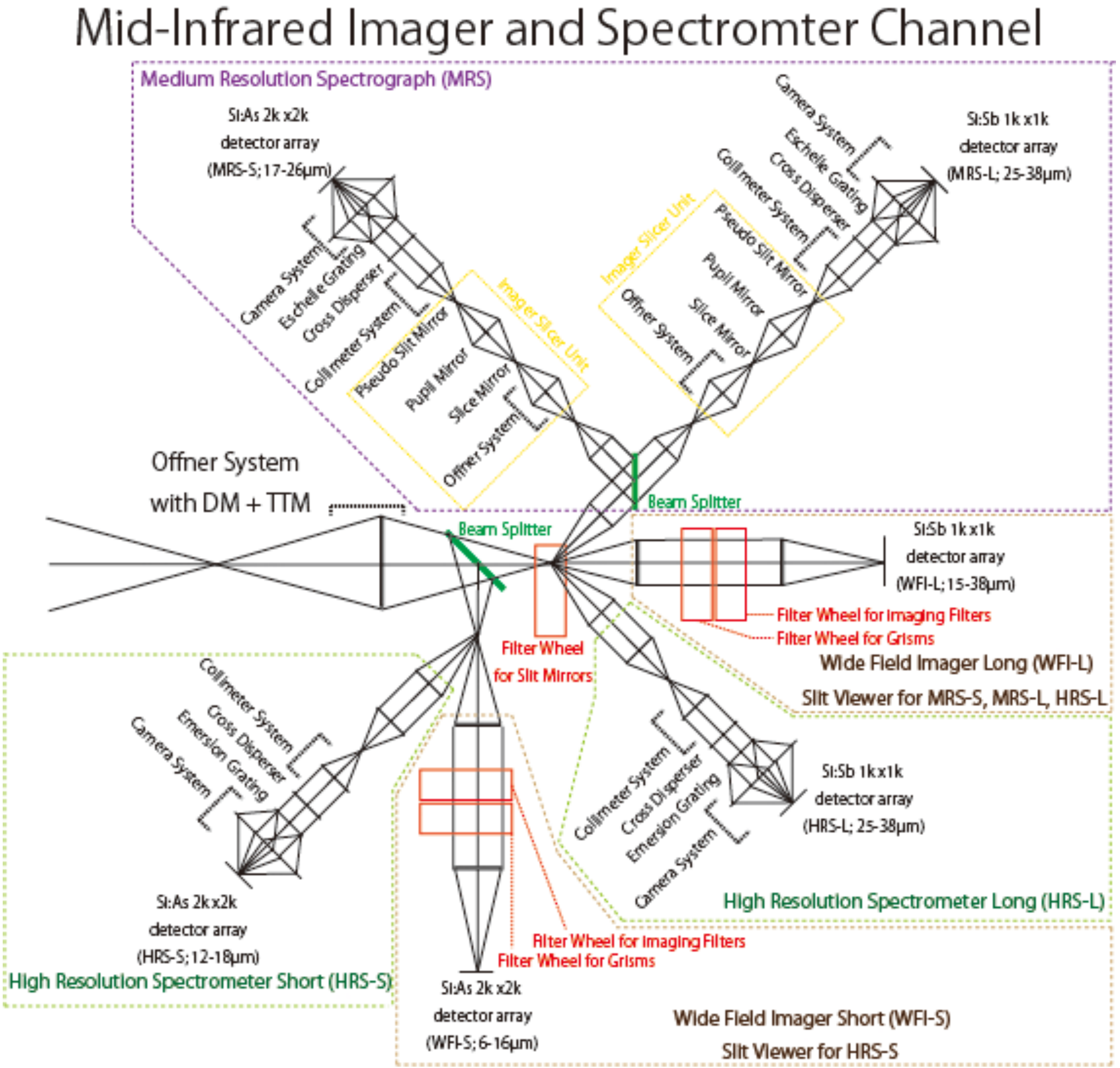
[2] OST/MISC Normal Imager and Spectrometer Channel

(A-2) MISC/MIR Imager and Spectrometer Channel Instrument Block Diagram

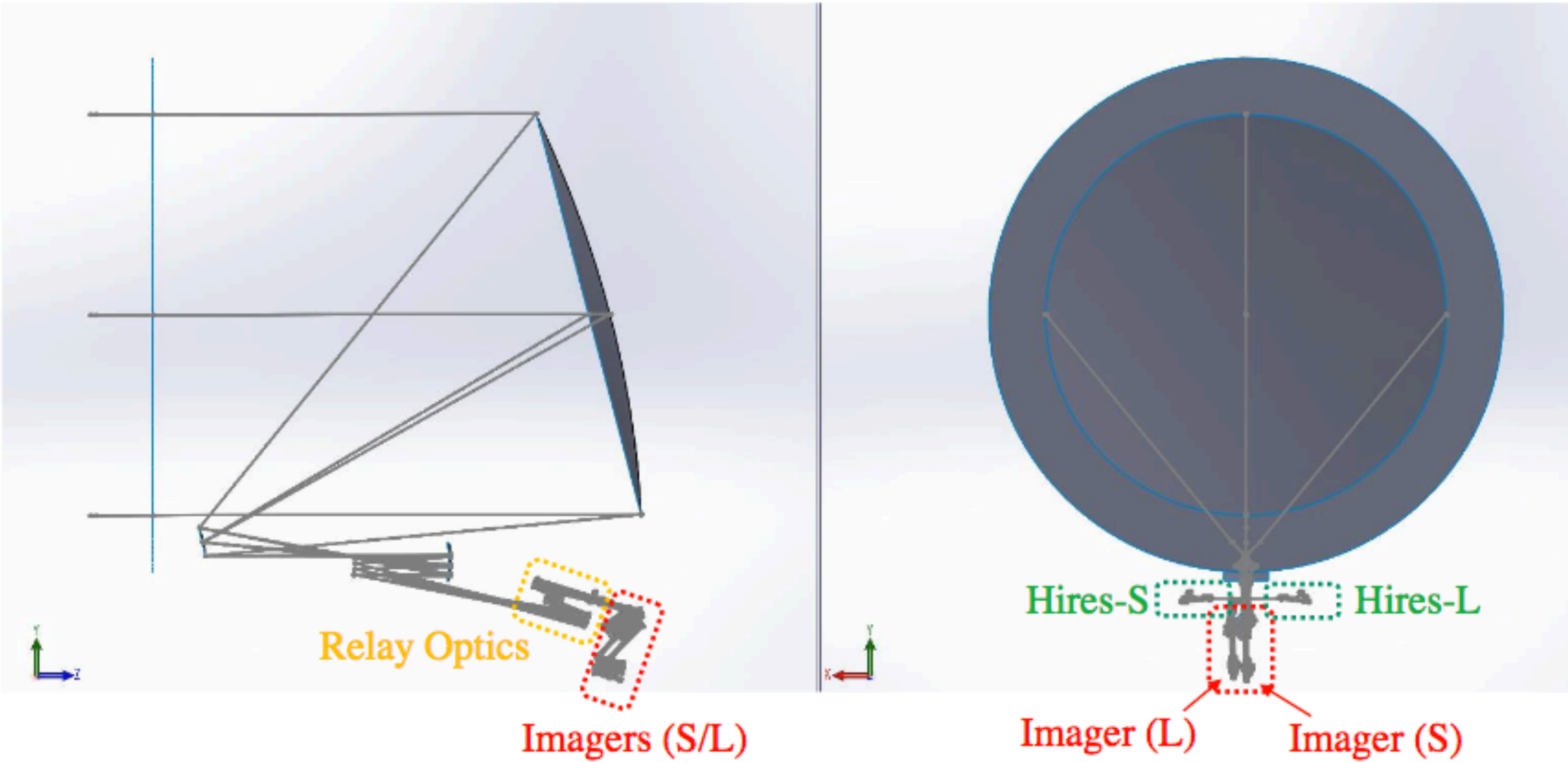


MISC Instrument Diagram or sketch

(MIR Imager and Spectrometer Channel)

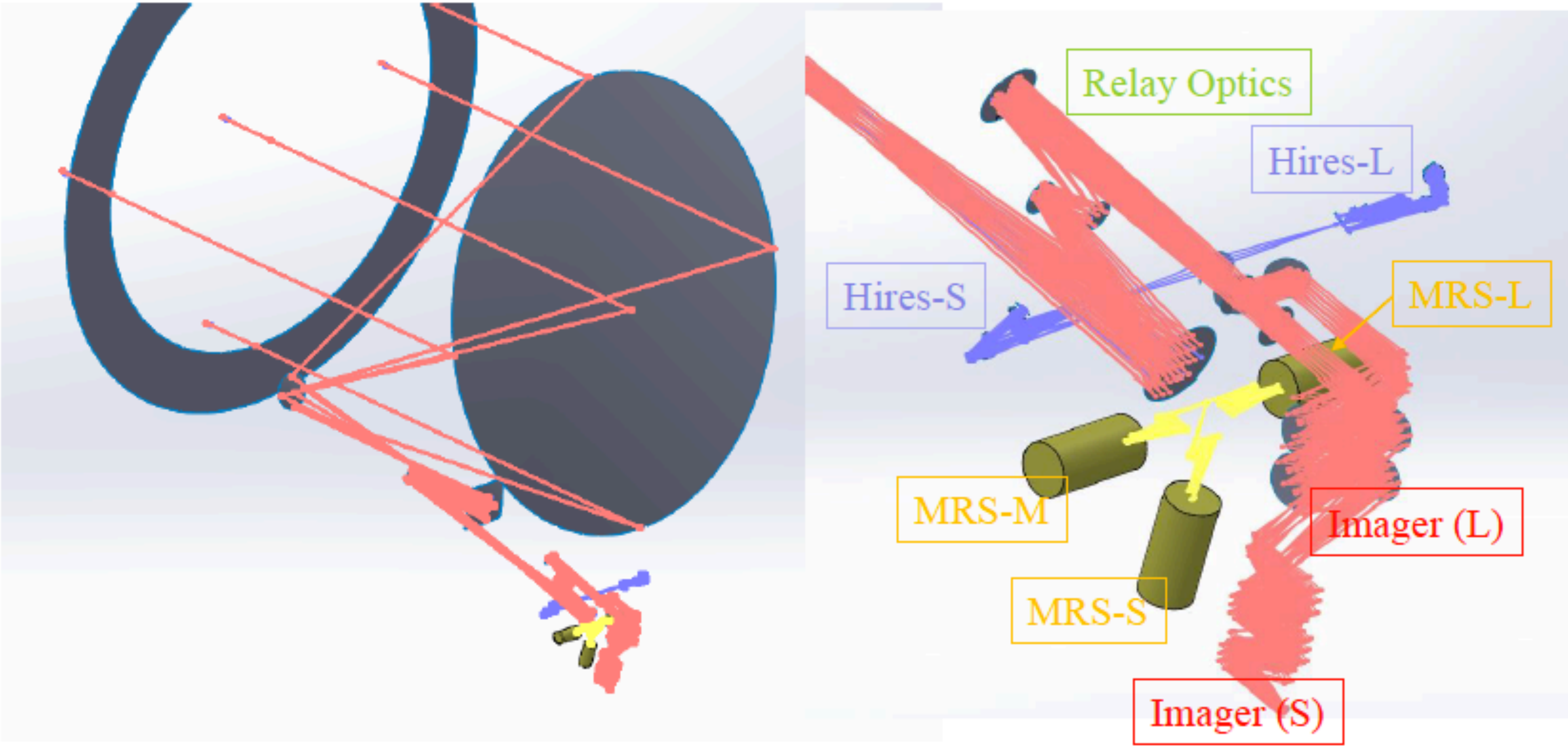


Optical Design of MISC Normal Imager and Spectrometer Channel



(note.) Optical design of Medium resolution Spectrometers are not ready

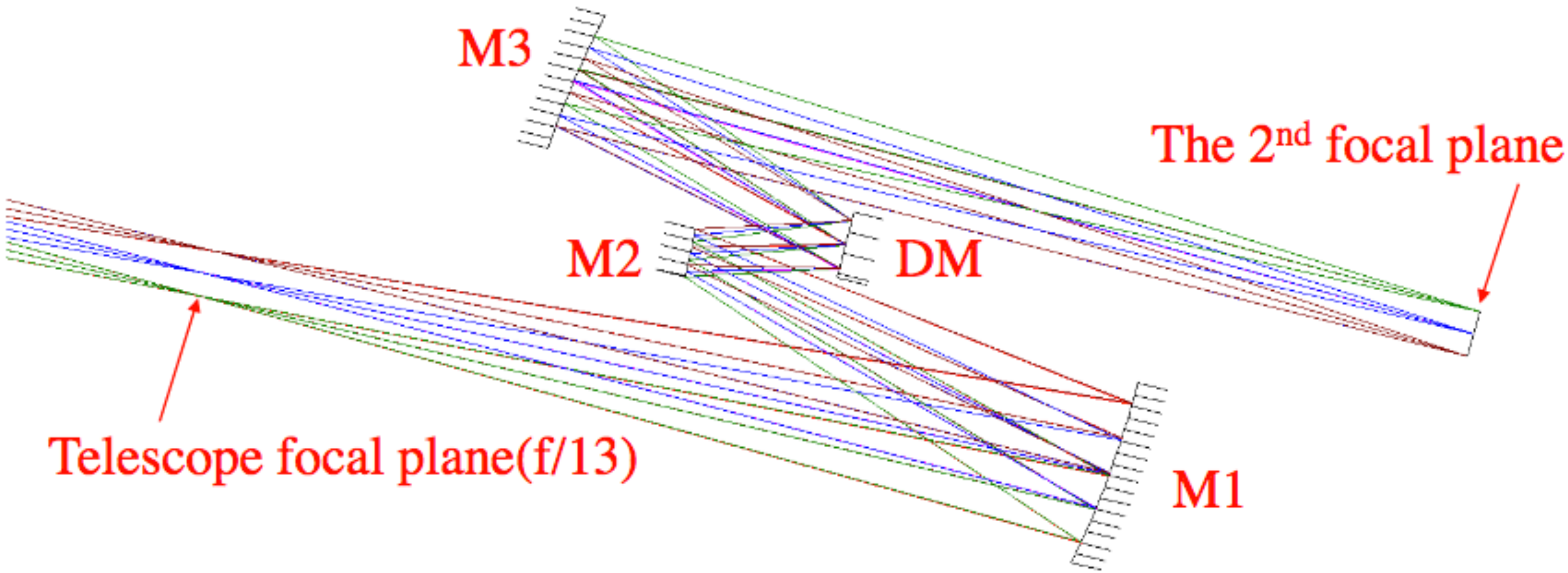
Optical Design of MISC Normal Imager and Spectrometer Channel



(note.) Optical design of Medium resolution Spectrometers are not ready

Wave Front Error Control System

Optical layout of the relay optics including the DM



Wide Field Imager

Optical layout of the Wide Field Imager

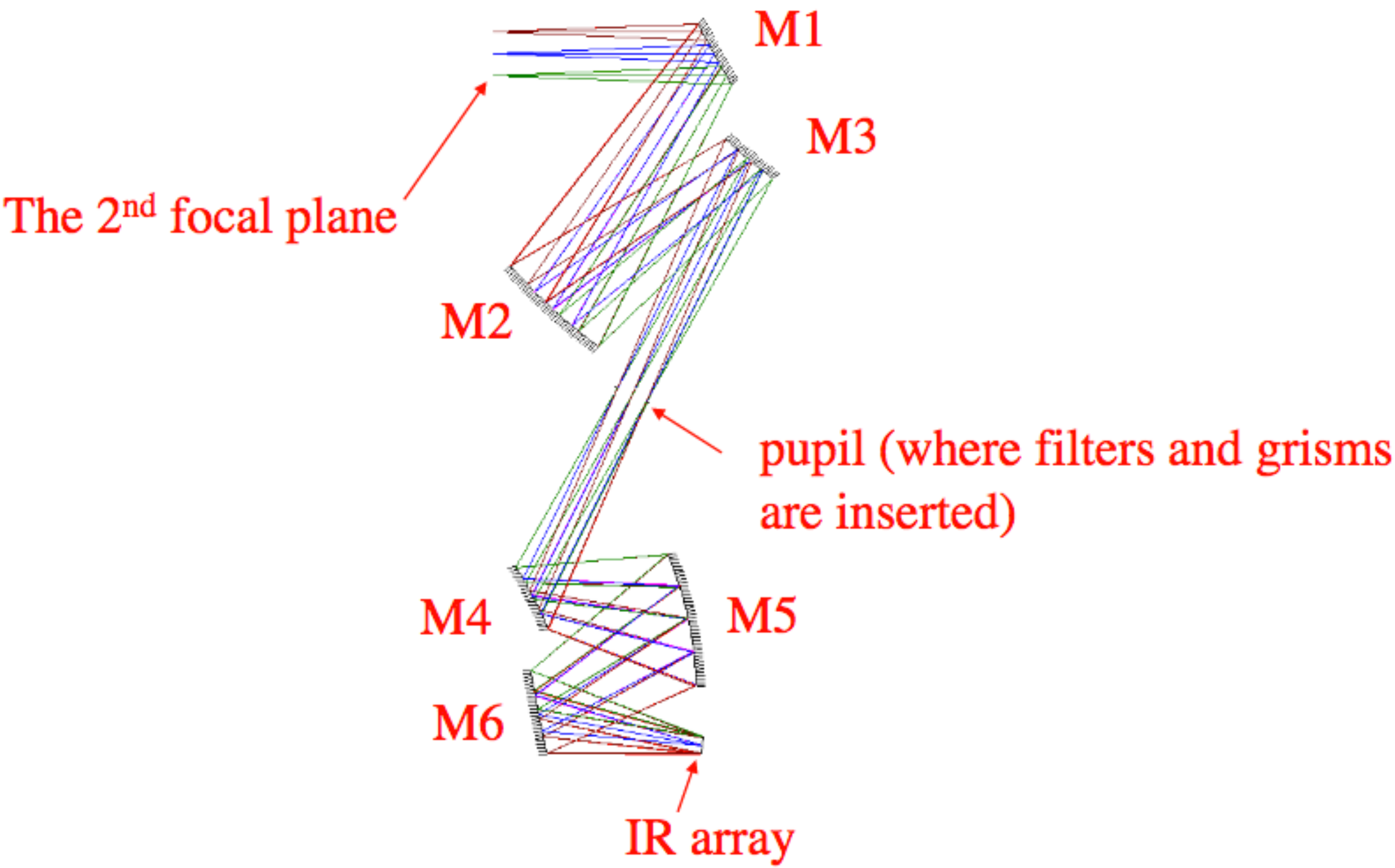
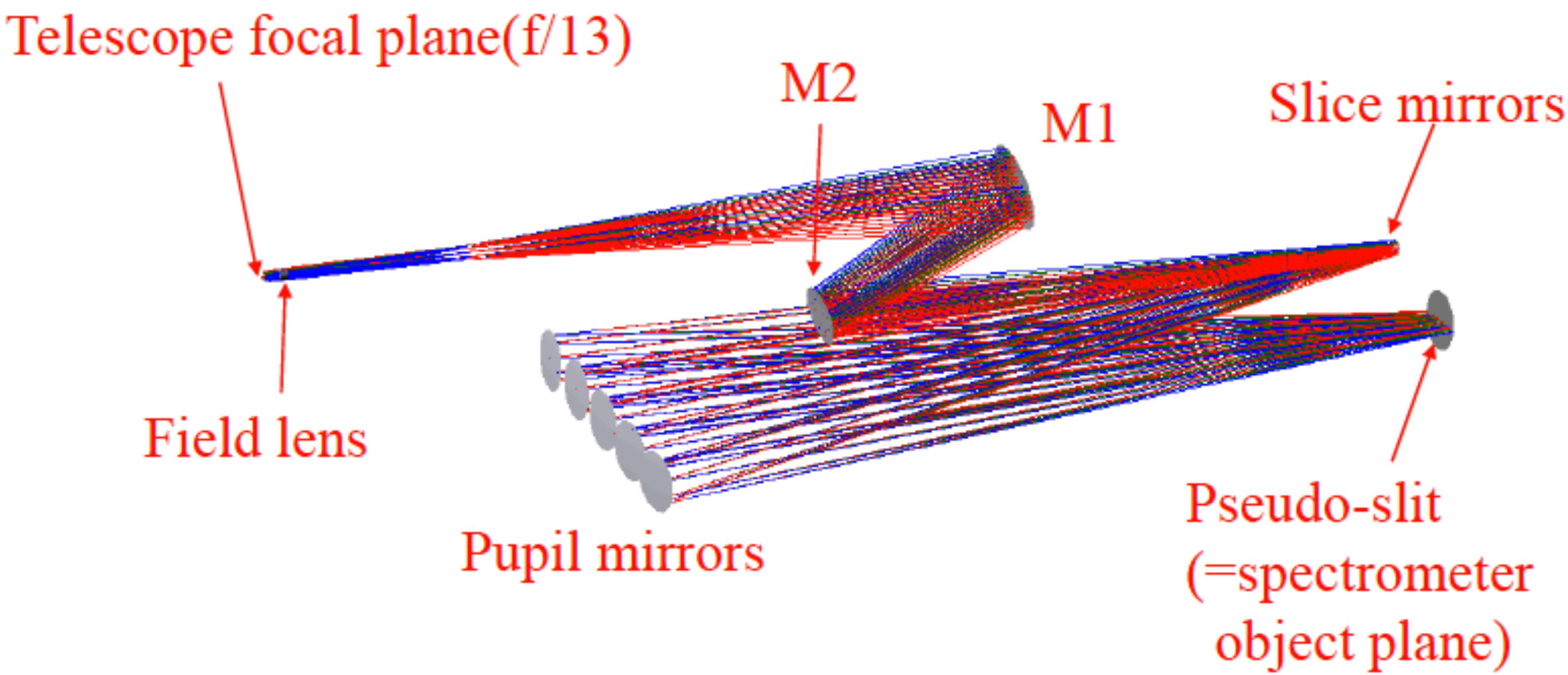


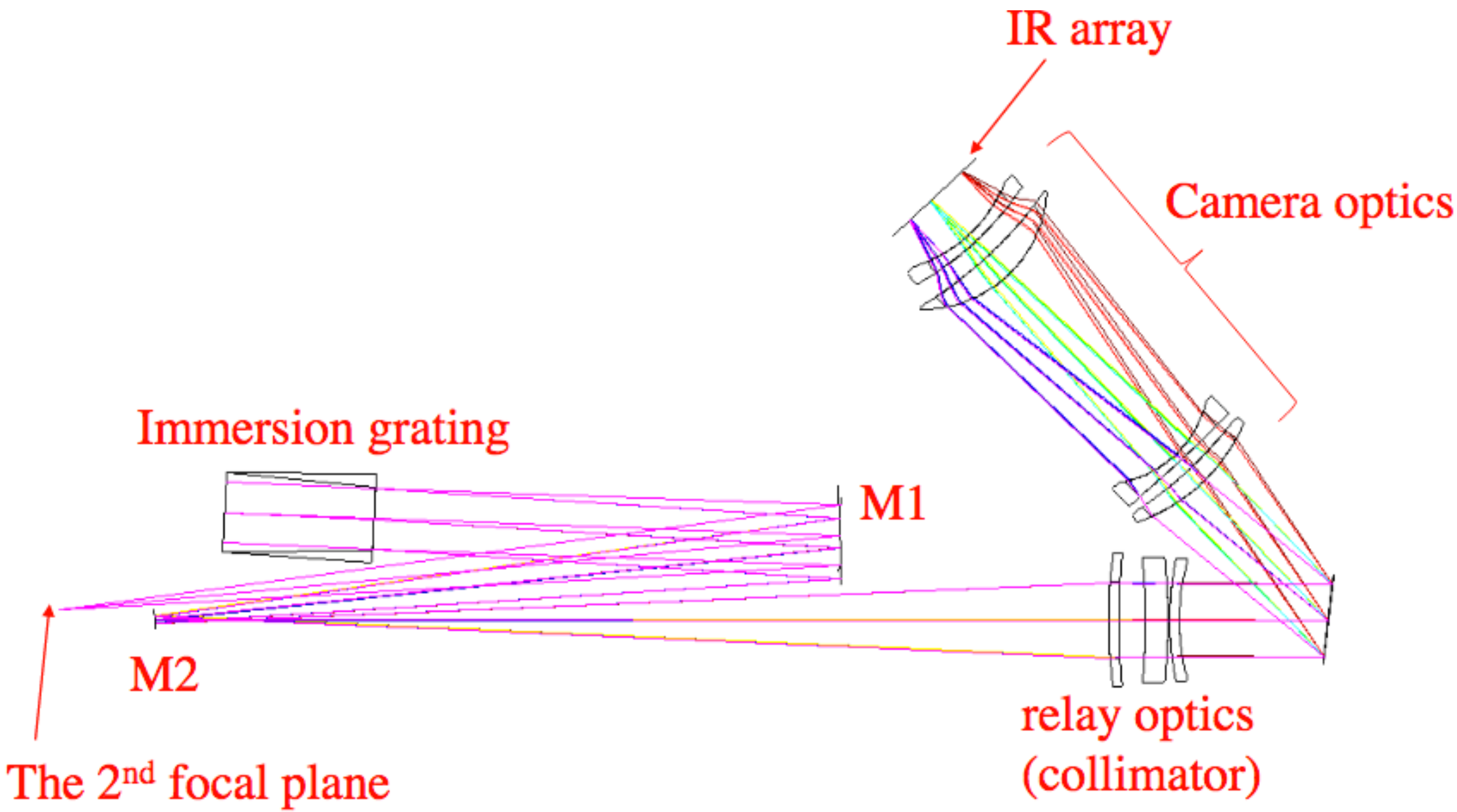
Image Slicer Unit

Optical layout of the Image Slicer Unit in Medium Resolution Spectrometer



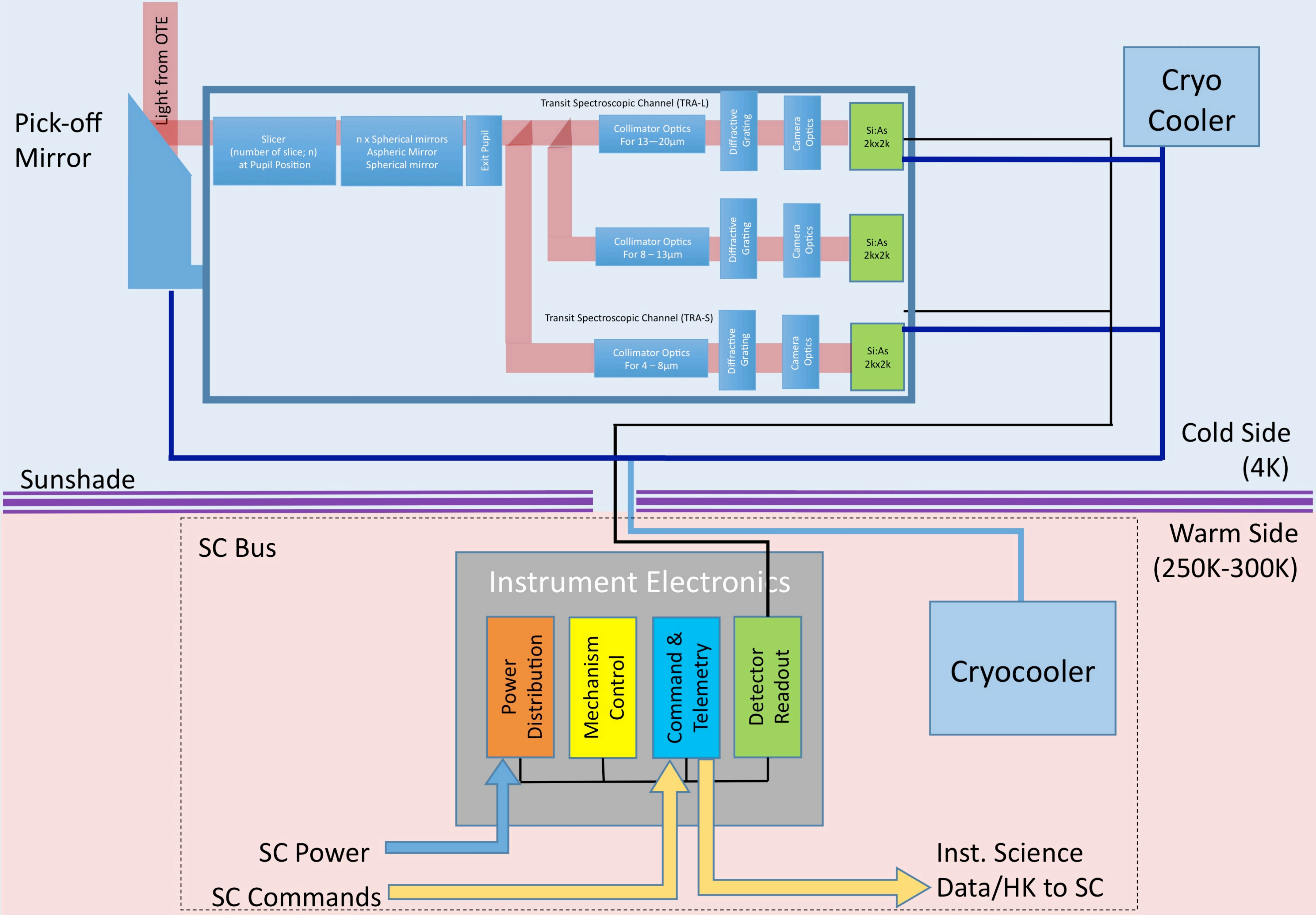
High Resolution Spectrometer

Optical layout of the High Resolution Spectrometer-short



[3] OST/MISC Transit Channel

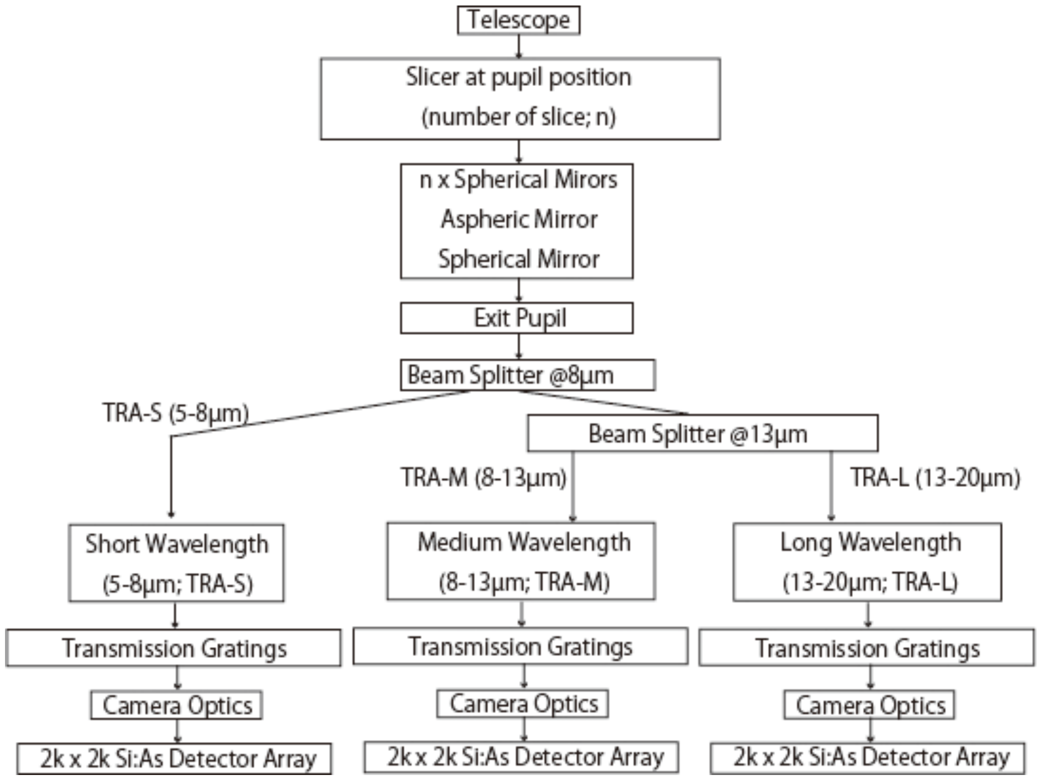
(A-3) MISC/Transit Spectroscopic Channel Instrument Block Diagram



Goal of Transit spectrophotometer (from Exoplanet SWG)

・Characterization of Earth-size planets around early M-type stars
-> extremely high stability down to 1ppm
・Separation of transit signal from stellar activity
-> higher spectral resolution

MISC Instrument Diagram or sketch
(MISC Transit Spectrometer Channel)

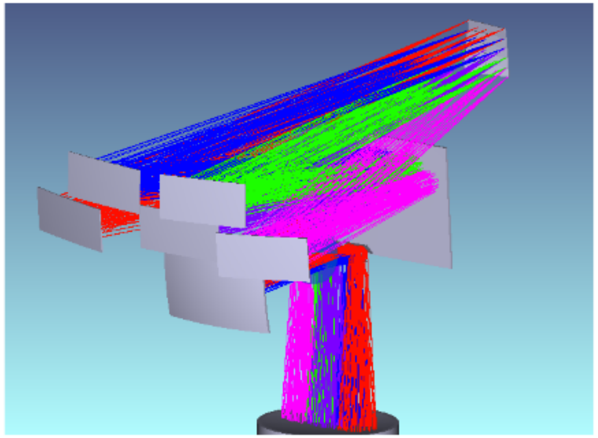


Expected performance achieved by densified pupil spectrometer; ~ a few 10^{-6}

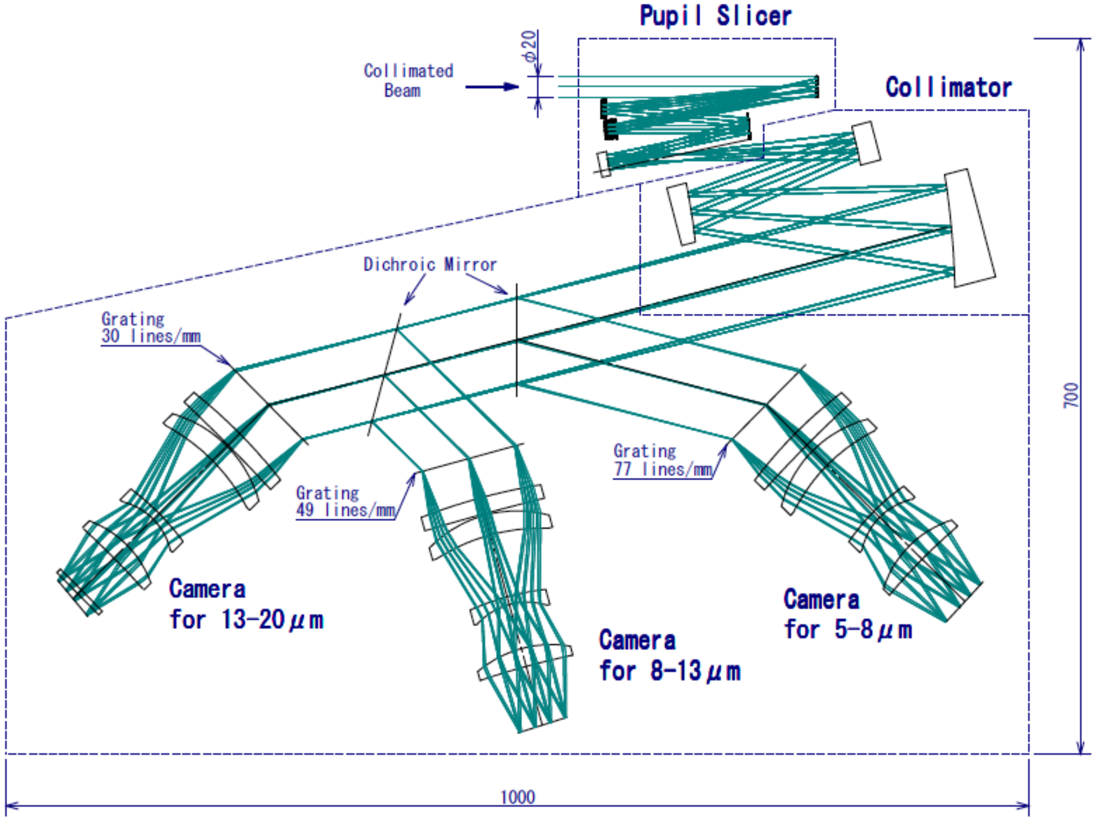
Systematic noise	Value
Movement of PSF on detector intra- and inter-pixel sensitivity variation by pointing jitter	4×10^{-7}
Movement of PSF on Field stop by pointing jitter	1×10^{-6}
Change of PSF width on detector intra- and inter-pixel sensitivity variation by deformation of primary mirror	5×10^{-7}
Fluctuation of detector gain	??

Optical Design of MISC Transit Spectrometer Channel

Pupil slicer



Pupil slicer/densification (colored by slice mirror)



- Size: 1350 x 950 mm (-> can be reduced by plane mirrors and lenses to 1000 x 700 mm)
- Pupil slicer/densification + Spectrometer
- 5-20μm is broken into three channels (5-8, 8-13, 13-20μm).

-> absorption features of H2O, CH4, O3, and CO2 are NOT separated.

- Pupil slicer and collimator lens in the spectrometer are commonly used. (collimator lens will be replaced by Casegren-based mirrors.)
- R~300 is achieved over 5-20um.
- Transmission gratings/grismsare required

Initial Concept of Operations (ConOps)

Operational Modes, for example:

	COR-S	COR-L	WFI-S	WFI-L	MRS-S	MRS-L	HRS-S	HRS-L	TRA-S	TRA-L
	6-16um	15-38um	6-16um	15-38um	17-26um	25-38um	12-18um	25-38um	6-16um	25-38um
Coronagraph Imaging	**ON**		**Standby**		**Standby**		**Standby**		**Standby**	
Coronagraph Imaging (option 1)	ON		ON		ON		ON	Standby	Standby	
Coronagraph Imaging (option 2)	ON		ON		Standby		Standby	ON	Standby	
Coronagraph Spectroscopy	**ON**		**Standby**		**Standby**		**Standby**		**Standby**	
Coronagraph Spectroscopy (option 1)	ON		ON		ON		ON	Standby	Standby	
Coronagraph Spectroscopy (option 2)	ON		ON		Stanby		Standby	ON	Standby	
MIR imaging	**Standby**		**ON**		**Standby**		**Standby**		**Standby**	
MIR imaging (option 1)	Standby		ON		ON		ON	Standby	Standby	
MIR imaging (option 2)	Standby		ON		Standby		Standby	ON	Standby	
MIR low res spectroscopy	**Standby**		**ON**		**Standby**		**Standby**		**Standby**	
MIR low res spectroscopy (option 1)	Standby		ON		ON		ON	Standby	Standby	
MIR low res spectroscopy (option 2)	Standby		ON		Standby		Standby	ON	Standby	
MIR med res spectroscopy	**Standby**		**ON**		**ON**		**Standby**		**Standby**	
MIR med res spectroscopy (option 1)	Standby		ON		ON		ON	Standby	Standby	
MIR high res spectroscopy	**Standby**		**ON**		**Standby**		**ON**		**Standby**	
Transit spectroscopy	**Standby**		**Standby**		**Standby**		**Standby**		**ON**	
Transit Spectroscopy (option 1)	Standby		ON		ON		ON	Standby	ON	
Transit Spectroscopy (option 2)	Standby		ON		Standby		Standby	ON	ON	

Instrument TRL's and Heritage

Description	Subsystem/ Component	TRL	Heritage
Deformable Mirror	Component	4	SPICA/SCI
Tip Tilt Mirror	Component	4	SPICA/SCI, JWST/NIRCAM
2K x 2K Si:As, 2K x 2K Si:Sb	Component	2	
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
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	