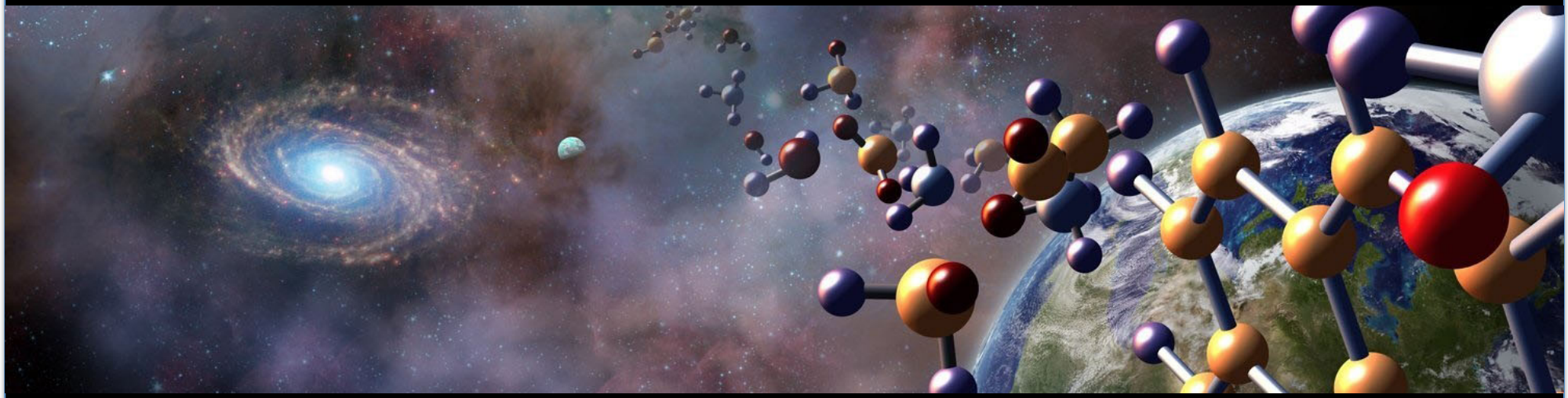
ORIGINS Space Telescope

From the Rise of Metals to Water for Habitable Worlds

NASA STDT: The Origins Space Telescope



Itsuki Sakon (University of Tokyo),

Origins Space Telescope (OST) STDT

Origins Space Telescope STDT

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

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Goddard Space Flight Center (GSFC): Ruth **Carter,** David **Leisawitz,** Johannes **Staguhn,** Michael **Dipirro**, Anel **Flores,** Joseph **Howard**, James **Corsetti**, Andrew **Jones**, James **Kellog**, Louis **Fantano**

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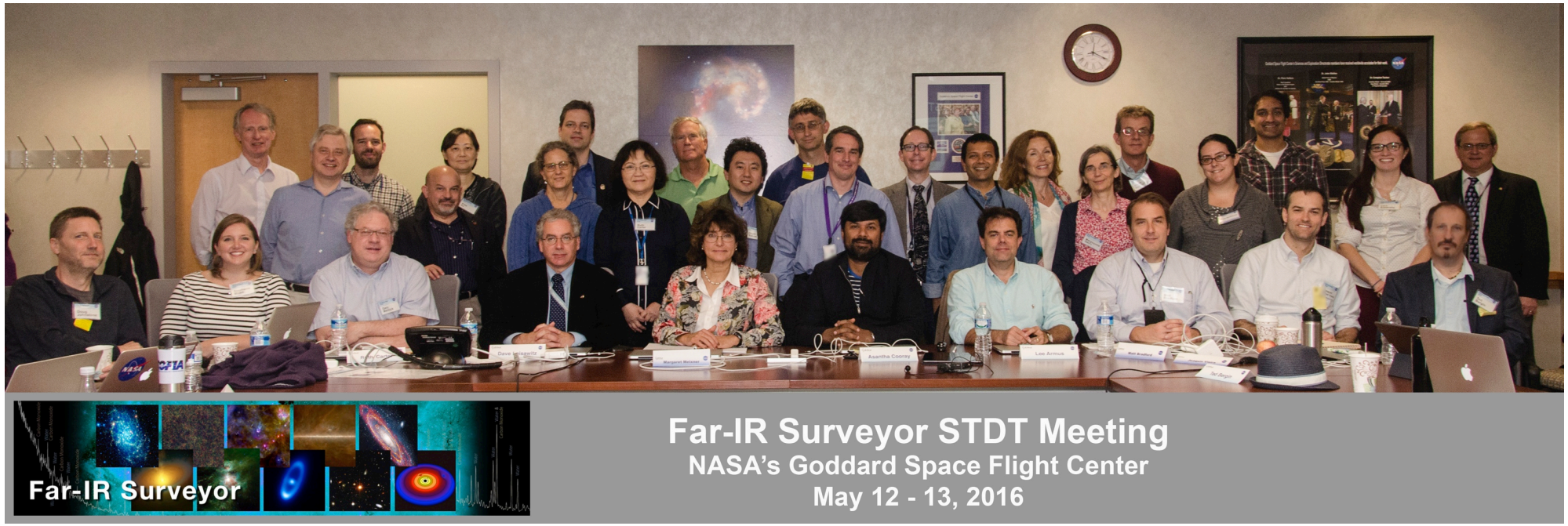
Ex officio non-voting representatives: Susan **Neff** & Deborah **Padgett**, NASA Cosmic Origins Program Office; Susanne **Alato**, SNSB; Douglas **Scott**, CAS; Maryvonne **Gerin**, CNES; Itsuki **Sakon**, JAXA; Frank **Helmich**, SRON; Roland **Vavrek**, ESA; Karl **Menten**, DLR; Sean **Carey**, IPAC

Members appointed by NASA (> 90 applications):

Lee **Armu**s, NASA IPAC; Cara **Battersby**, Harvard-Smithsonian CfA; Edwin **Bergin**, University of Michigan; Matt **Bradford**, NASA JPL; Kim **Ennico-Smith**, NASA Ames; Gary **Melnick**, Harvard-Smithsonian CfA; Stefanie **Milam**, NASA GSFC; Desika **Narayanan**, University of Florida; Klaus **Pontopiddan**, STSCI; Alexandra **Pope**, University of Massachusetts; Thomas **Roellig,** NASA Ames; Karin **Sandstrom**, UC, San Diego; Kate Y. L. **Su**, University of Arizona; Joaquin **Vieira,** University of Illinois, Urbana Champaign; Edward **Wright,** UC Los Angeles; Jonas **Zmuidzinas**, Caltech



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.

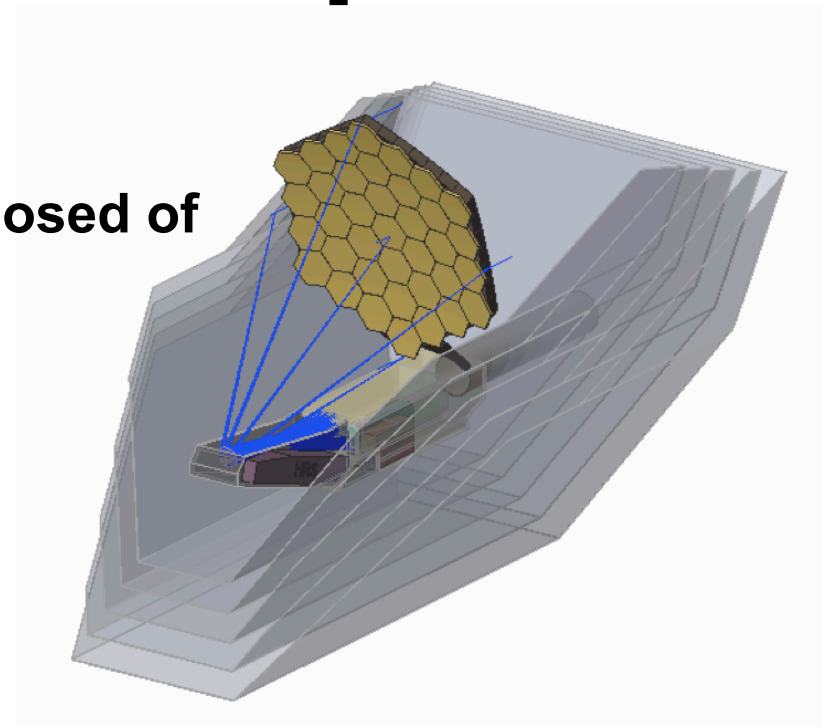
Charting the Rise of Metals, Dust, and the First Galaxies

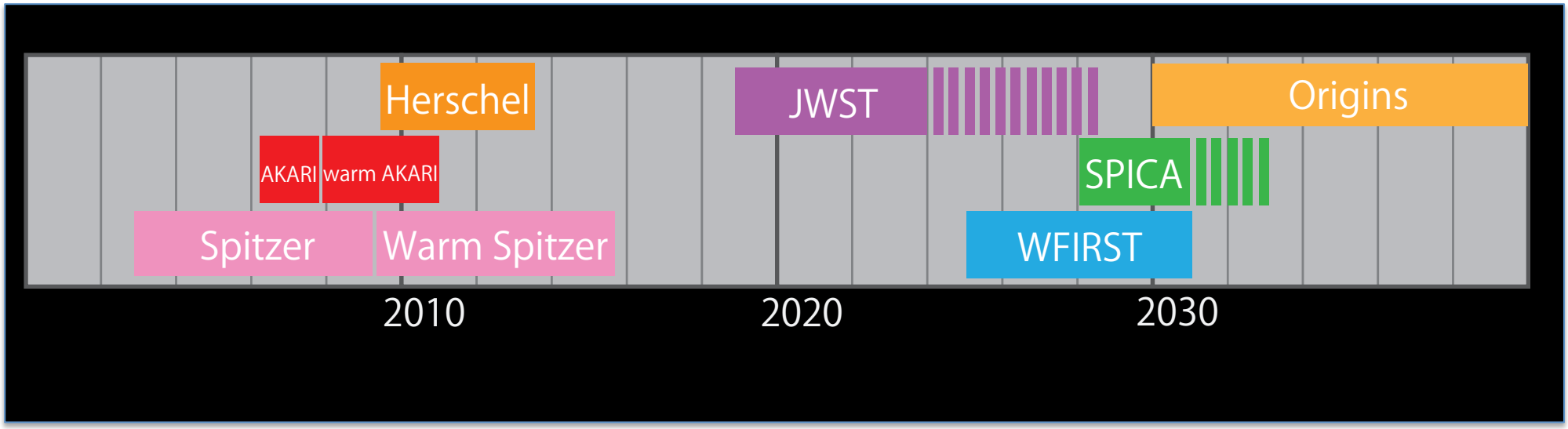
Origins will chart the role of comets in delivering water to the early Earth, and conduct a survey of thousands of ancient Trans Neptunian Objects (TNOs) in the outer reaches of the Solar System.

Characterizing Small Bodies in the Solar System

Origins Space Telescope

- 2020 Decadal
- 9.3m single aperture
- off-axis telescope with a primary composed of 37 lightweight hexagonal segments
- 5—600μm (TBD)
- Actively cooled to <6K
- Diffraction Limited at 20μm





Science Cases for OST

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

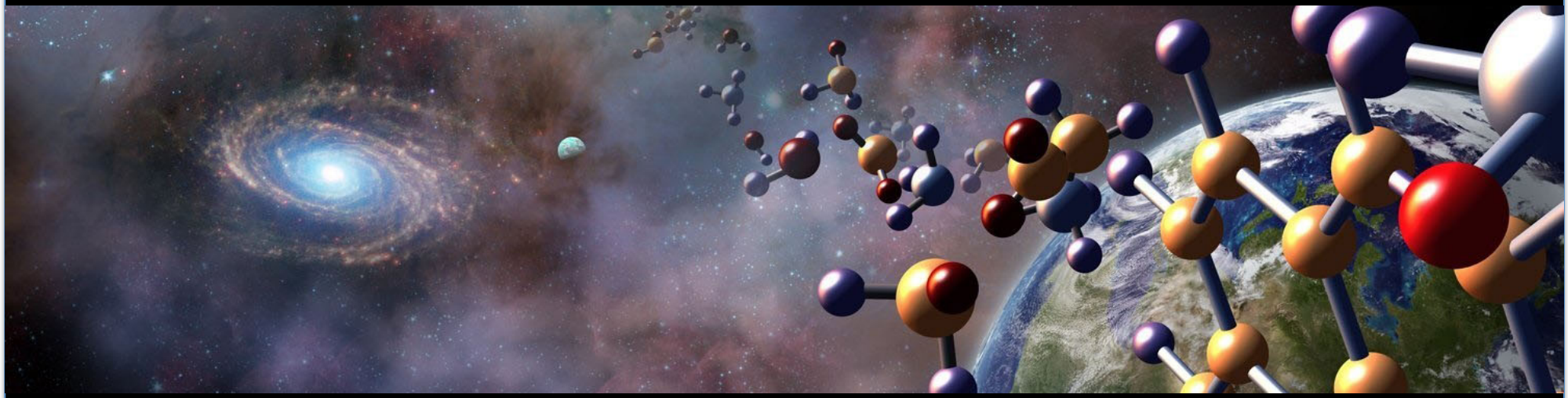
Instrument	Wavelength Coverage (μm)	Spectral Resolution ($\lambda/\Delta\lambda$)	Field of View # Spatial Pixels	Typical Required Sensitivity	Other
Low-Res Spectrometer	35 to 500	Low-res ~ 500 High-res ~ 10^4	100 per channel	10^{-21} W/m^2 (spectral line)	Multi-channel
High-Res Spectrometer	50 to 500	Low-res ~ 8×10^4 High-res ~ 5×10^5	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, 2×10^4	10^6	Photometric 1μJy@10μm	Coronagraph ~ 10^{-6} @ 0.5”, 10 μm Transit Spectroscopy

ORIGINS Space Telescope

From the Rise of Metals to Water for Habitable Worlds

Mission Concept Studies for the 2020 Decadal Survey ;

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



Itsuki Sakon (University of Tokyo), Thomas L. Reollig, Kimberly Ennico-Smith (NASA Ames)
Taro Matsuo (Osaka University), Yuji Ikeda (Photocoding), Tomoyasu Yamamuro (Optcraft), Naofumi Fujishiro (Teikyo University), Keigo Enya (ISAS/JAXA), Olivier Guyon (Univ. of Arizona/ NINS ABC), Takayuki Kotani (NAOJ), Jun Nishikawa (NAOJ)
OST/MISC Team, Origins Space Telescope (OST) STDT

Activity and Schedule

By Weekly OST STDT telecon (2016.4-)
By Weekly MISC Science Telecon (2017.3-)
Weekly MISC Instrument Telecon (2017.2-)

2016 May : 1st F2F STDT Meeting (@NASA GSFC)
2016 Aug. : 2nd F2F STDT Meeting (@NASA GSFC)
2016 Nov. : 3rd F2F STDT Meeting (@Ball Aerospace)
2017 Mar. : 4th F2F STDT Meeting (@Spitzer Science Center)
2017 Jun. : 5th F2F STDT Meeting (@S. Dillion Ripley Center)
2017 Sep. : 6th F2F STDT Meeting (@Space Telescope Science Institute)

2017. Sep.; Complete Concept 1 study
2017. Oct.; Independent Technical Review (ITR) at NASA GSFC
2017. Dec. ; Interim Report submitted to NASA HQ

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

(from JAXA and related Institutes)
-Taro Matsuo (Osaka University)
-Keigo Enya (JAXA)
-Jun Nishikawa (NAOJ)
-Takayuki Kotani (NAOJ)
-Olivier Guyon (Subaru Telescope/ Astrobiology Center, NINS/Steward Observatory, University of Arizona)
-Yuji Ikeda (Photocoding)
-Naofumi Fujishiro (Teikyou University)
-Tomoyasu Yamamuro (Optocraft)
-Naoshi Murakami (Hokkaido University)
-Yuki Sarugaku (University of Tokyo)
-Aoi Takahashi (ISAS/JAXA)
-Koji Tsumura (Tohoku University)
- And more

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)

OST MISC Instrument Requirements

Technical Parameter	Technical Requirement
Wavelength Range (microns)	6um-38um
Detector Bandwidth	Si:As : 6-16.3µm, Si:Sb: 15.4-38µm
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) (ver.20170613)

(1) Mid-Infrared Imager Spectrometer Module

- Wide Field Imager (WFI-S; 6-19um, WFI-L; 18-38um, R=3-10, R=100-300)
- Medium Resolution Spectrometer (MRS-S; 5-10um, MRS-M; 9.5-19µm, 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; wave front correction systems (DM + TTM), 6 Filter Wheels (2 for slit mirror changers, 4 for imagers and grisms for WFI)

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

(2) PIAACMC Coronagraph Module (COR)

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

Detectors; 1 2kx2k Si:As and 1 1kx1k Si:Sb

Mechanisms; wave front correction systems (DM + TTM), 4 Filter Wheels

(3) Transit Spectroscopy Module (TRA)

- densified pupil spectrometer (TRA-S; 5-8um, TRA-M; 8-14um, TRA-L; 14-26um, R~300)

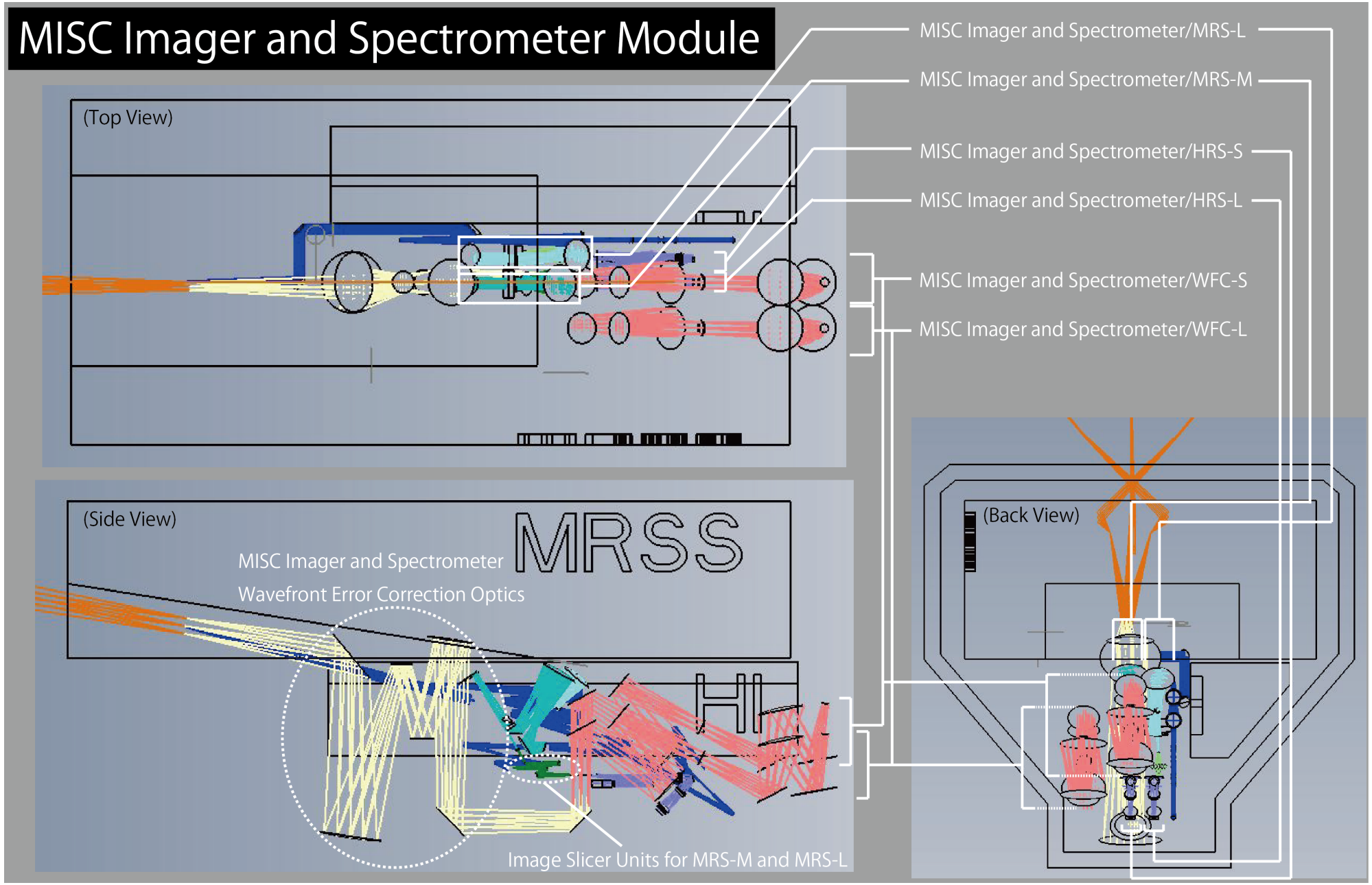
Detectors; 3 2kx2k Si:As

A Baseline design and specification of OST/MISC

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

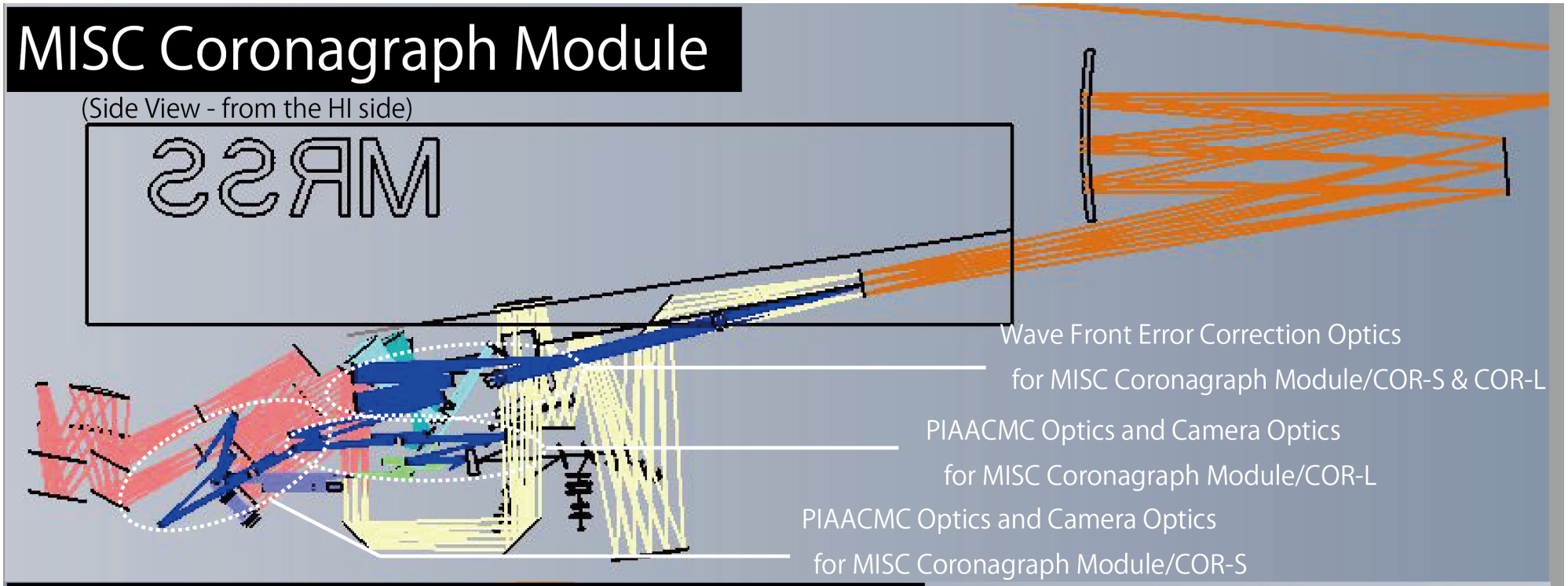
Module	Mid-IR Imager Spectrometer Channel			Transit Channel	Coronagraph Channel
	Imager/Low-Res Spec.	Medium-Res Spec.	High-Res Spec.	(Densified Pupil Spec.)	(PIAACMC)
	WFI-S/-L	MRS-S/-M/-L	HRS-S/-L	TRA-S/-M/-L	COR-S/-L
Bandpass (μm)	6-38	5-36	12-18, 25-38	5--26	6-38
Spectral Resolution	5-10 [Imager] 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

Mid-Infrared Imager, Spectrometer, Coronagraph (MISC)



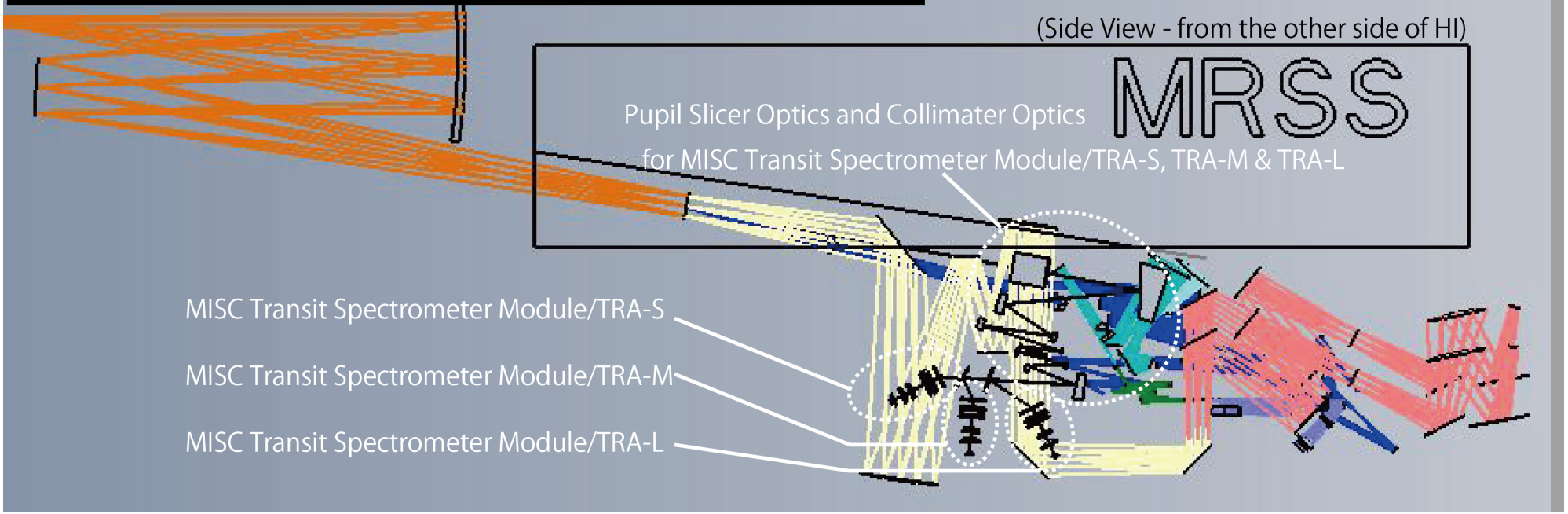
MISC Coronagraph Module

(Side View - from the HI side)



MISC Transit Spectrometer Module

(Side View - from the other side of HI)



Instrument TRL's and Heritage

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	SOFIA/FORCAST, TMT/MICHI, TAO/MIMIZUKU
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, TAO/MIMIZUKU
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	