国際超大型観測衛星計画の検討

左近 樹 (東京大学), 住 貴宏 (大阪大学), 田村 元秀 (東京大学), 田代 信 (埼玉大学),
山田　亨 (東北大学), 国際超大型計画検討RG

概要
2016 年度より、米国 NASA が宇宙物理分野の Decadal Survey 2020 における評価を念頭に、JWST、WFIRST に続くフラッグシップとなる計画の検討を進めている。NASA は当初より JAXAなど海外機関に呼びかけ、検討への参加を要請した。巨大化する宇宙物理の最先端計画は、国際協力が必須であり、また、日本自身の将来計画の検討においても、国際大型計画に参加することは究めて有益である。これまでに、米国 NASA が中心となり、Lynx（大型X 線望遠鏡）、LUVOIR（紫外～近赤外大型望遠鏡）、HabEx （太陽系外惑星）、OST （赤外線大型冷却望遠鏡）の4つのミッションについて、Science and Technology Definition Teamが設置され、JAXAではコミュニティからの公募を経て、4ミッションに合計4人の研究者が国際メンバーとして検討に参画し、日本の研究者とのリエゾンの役割を担い活動を進めている。本講演では、これらの活動を中心に、本リサーチグループ活動の概要と進捗を報告する。

関連ポスター:　P-158　”The Mid-Infrared Imager/Spectrometer/Coronagraph (MISC) for the Origins Space Telescope”

P-165　“光赤外天文連絡会の20年後までのスペースミッションを考えるWGの活動・検討報告”

LYNX

Revealing the Invisible Universe

www.astro.msfc.nasa.gov/lynx/

Mission Concept: 各Science Working Groupでの検討を踏まえ「３本柱」を決定
搭載装置検討：各装置のコンセプトをもとに設計パラメータの検討を深めている
1/25-26 にヒューストンでface-to-face meeting。Configuration, concept, costなどの議論。

Chairs of the STDT: Feryal Oezel (U of Arizona), Alexey Vikhlinin (Harvard CfA),

Study Scientist: Jessica Gaskin (NASA/MSFC)

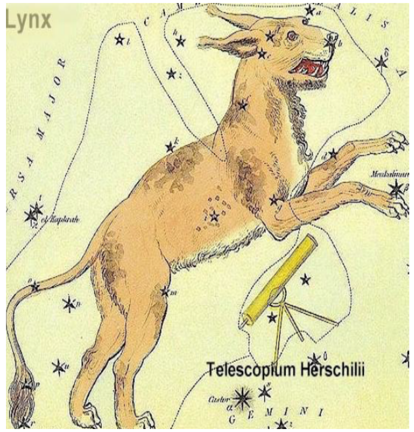
STDT member: S. Allen, M. Bautz, W. N. Brandt, J. Bregman, M. Donahue, Z. Haiman, R. Hickox, T. Jeltema, J. Kollmeier, A. Kravtsov, L. Lopez, P. Madau, R. Osten, F. Paerels, D. Pooley, A. Ptak, E. Quantaert, C. Reynolds, D. Stern,

Ex-Officio observer of STDT: T. Brandt, D. Evans, R. Petre, R. Smith

International Ex-Officio: P. Jonker (SRON), B. McNamara (CSA), K. Nandra (DLR), G. Pareschi (ASI), G. Pratt (CEA), M. Tashiro (JAXA)

https://wwwastro.msfc.nasa.gov/lynx/

Lynx --- Revealing the invisible Universe



Lynx: a sympol of great insight with the ability to see through solid objects to **reveal the true nature of things**.

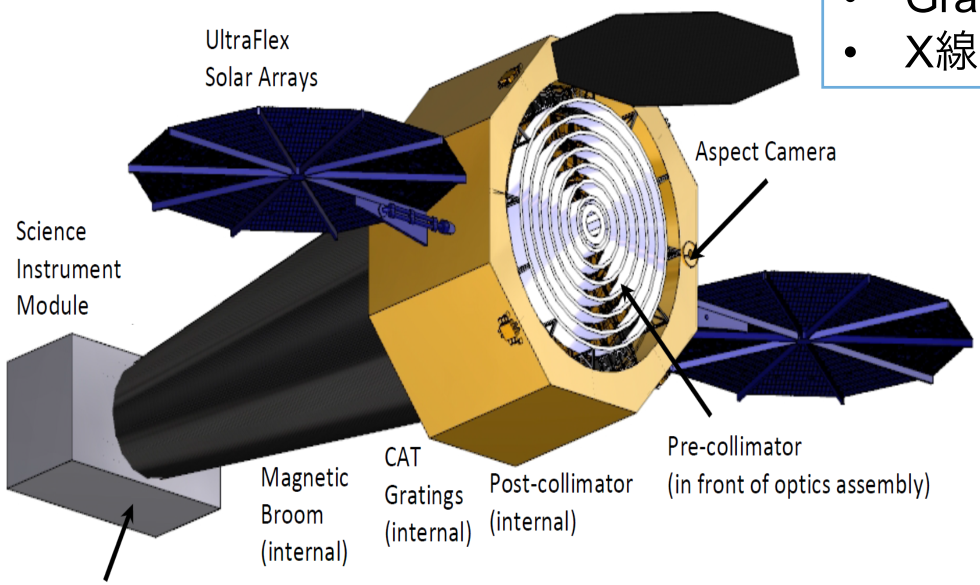
- Scientific Objectives

1. **The Dawn of Black Holes**: *Lynx*は、~10^{-19} erg cm^{-2} s^{-1}に至る感度で、宇宙の最初期の銀河に付随する巨大質量ブラックホールを観測し、その進化と銀河との共進化を明らかにする。
2. **The Invisible Drivers of Galaxy Formation and Evolution**: *Lynx*は秒角を超える空間分解能と、R~5000の分光能力で、背景活動銀河核X線をつかった銀河間ガスの分光および、銀河をとりまく高温ガスやCosmic Webの直接撮像分光を行い、銀河形成におよぼす影響を解明。
3. **The Energetic Side of Stellar Evolution and Stellar Ecosystems**: *Lynx*は、卓越した空間分解・分光能力によって、天の川銀河や近傍銀河の星を観測し、星の誕生と死、X線紫外線放射や星風が惑星の生命存在可能性に及ぼす影響を調べる。

https://wwwastro.msfc.nasa.gov/lynx/

Lynx: 観測装置

- Chandraと同じ空間分解能で 50倍のthroughput
- Chandraの16倍の視野
- Grating 分光計搭載
- X線マイクロカロリメータによる高分解能撮像分光



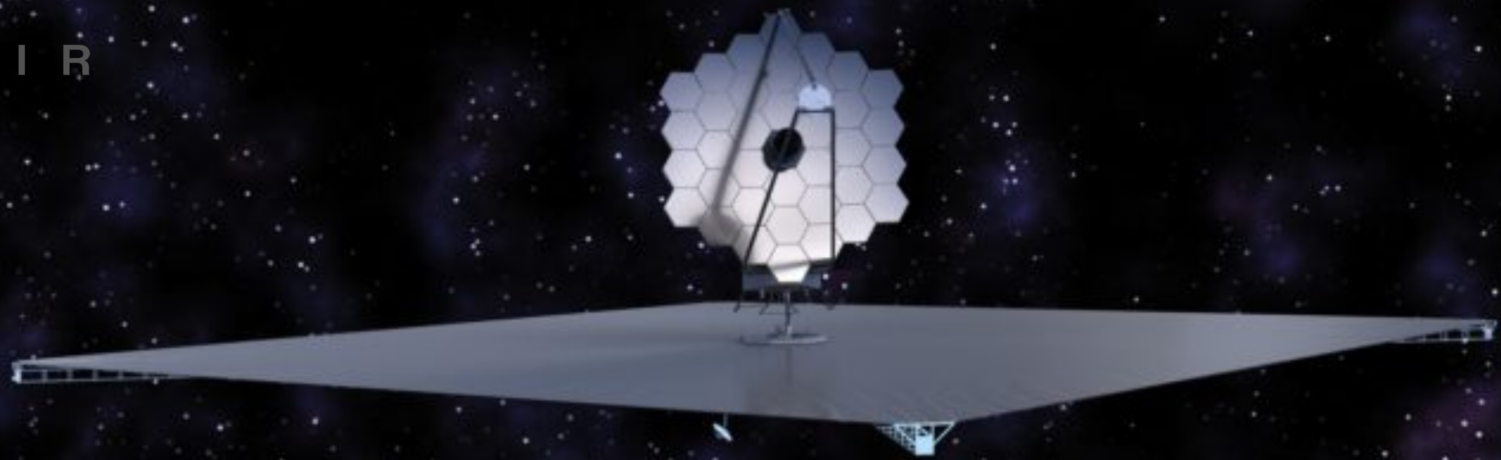
Lynx Optical Assembly	
角分解能	< 0.5 arcsec HPD
有効面積 @ 1 keV	2 m^2
視野 (秒角撮像領域)	10 arcmin radius

	High Definition X-ray Imager	X-ray Microcalorimter Imaging Spectrometer
帯域	0.2 – 10 keV	
視野	22’ x 22’	> 5’ x 5’
ピクセルサイズ	< 16 um (< 0.33”)	50 um (1”)
エネルギー分解能	120 eV @ 6 keV	< 5 eV (FWHM)

	X-ray Grating Spectrometer
有効面積	~ 4000 cm2 @ 0.3 keV
波長分解能	R > 5000

LUVOIR

https://asd.gsfc.nasa.gov/luvoir/



Chairs of the STDT: Debra Fischer (Yale), Bradley Peterson (Ohio State)

STDT members: J. Bean, D. Calzetti, R. Dawson, C. Dressing, L. Feinberg, K. France, O. Guyon, W. Harris, M. Marley, V. Meadows, L. Moustakas, J. O'Meara, I. Pascucci, M. Postman, L. Pueyo, D. Redding, J. Rigby, A. Robergem, D. Schiminovich, B. Schmidt, K. Stapelfeldt, J. Tumlinson

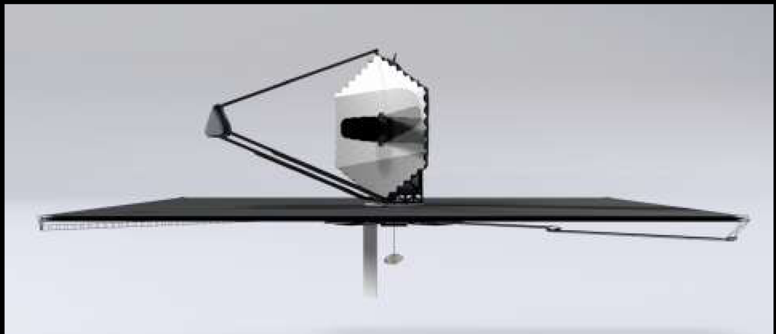
International Ex-Officio Non-Voting Members: M. Barstow, L. Buchhave, N. Cowan, J. D. do Nascimento Jr., M. Ferrari, A. G. de Castro, K. Heng, T. Henning, A. Nota, T. Sumi

Ex-Officio Non-Voting Members: S. Domagal-Goldman, M. Perez, M. Garcia, S. Neff, E. Smith

Study Office: J. Crooke, M. Bolcar, J. Hylan, G. Arney, T. Fauchez, T. Groff, R. J. Parramon, R. Kopparappu, E. Lopez, A. Mandell, Geronimo Villanueva, Neil Zimmerman

Telescope

- Segmented, deployable UV/optical/ near-IR telescope
- Ultra-stable to enable high performance coronagraphy
- Serviceable and upgradable (25 year lifetime goal for non-serviceable components)
- Earth-Sun L2 orbit
- Two sizes to be studied :
  - LUVOIR-A : 15 m diameter, for launch in an SLS or equivalent
  - LUVOIR-B : 9 m diameter, for launch in a Delta IV Heavy or equivalent



Candidate Instruments

ECLIPS: Coronagraph with imaging spectroscopy

- Total bandpass: 200 – 2200 nm
- 10^{-10} contrast
- IWA - OWA: ~ 4 - 64 λ/D

LUMOS: Multi-object spectrograph and imager

- Total bandpass: 100 – 400 nm
- Resolution: 500 < R < 65,000

HDI: High resolution wide-field camera

- Total bandpass: 200 – 2500 nm
- Field-of-view: 2' x 3'

POLLUX: Spectropolarimeter (European instrument)

- Total bandpass: 100 – 400 nm
- R = 120,000
- Circular + linear polarization

LUVOIR has multiple primary science goals

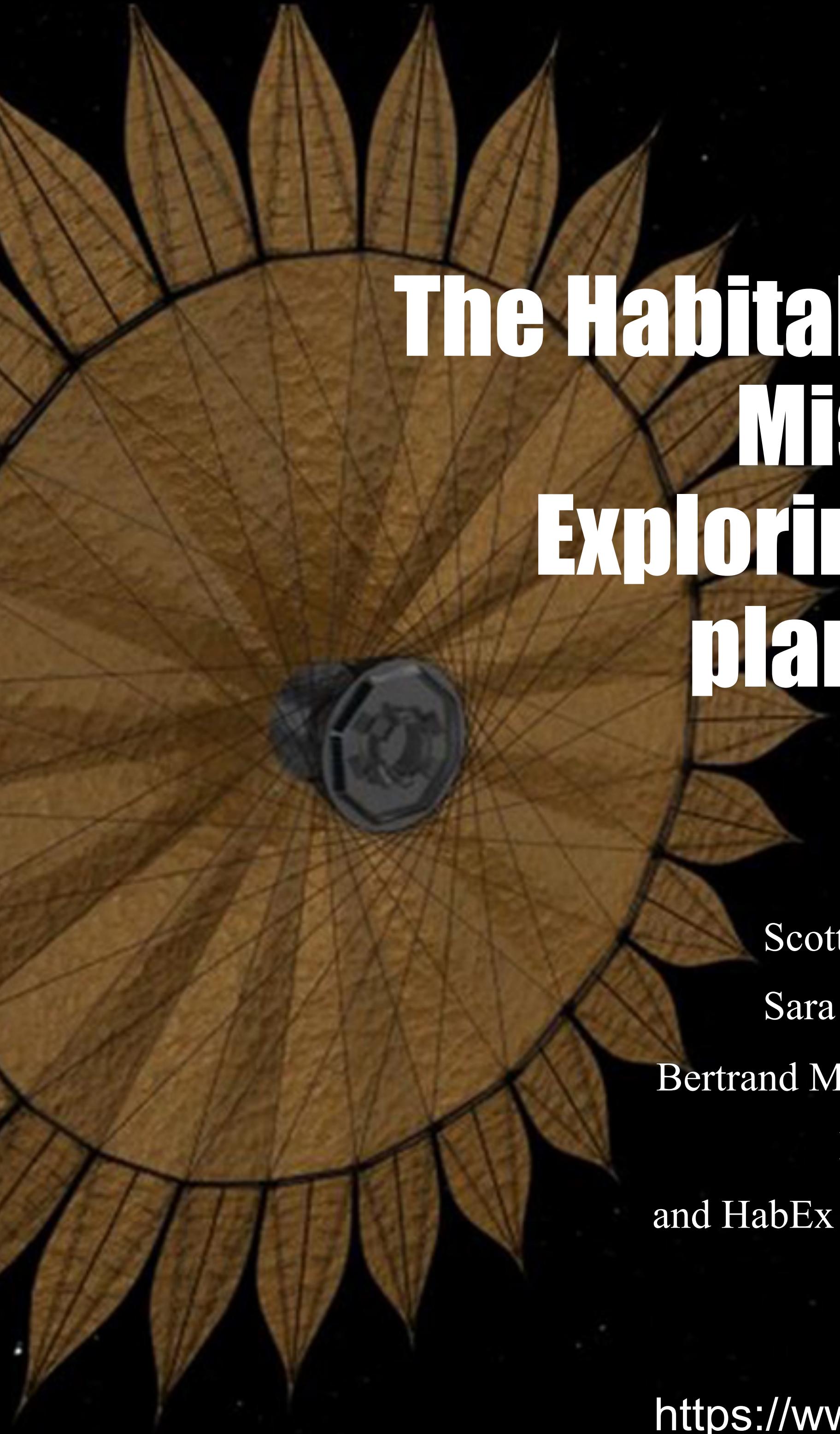
① Habitable exoplanets & biosignatures

② Broad range of general astrophysics and Solar System observations

Challenge is to blend goals into single powerful mission

LUVOIR will provide a statistical study of Goal 1, factors of ~ 100 increased science grasp over Hubble for Goal 2

Wide range of capabilities to enable decades of future investigations and unexpected discoveries



The Habitable Exoplanet Imaging Mission (HabEx): Exploring our neighboring planetary systems

Scott Gaudi (Community Chair)

Sara Seager (Community Chair)

Bertrand Mennesson (Center Study Scientist)

Keith Warfield (Study)

and HabEx team including Motohide Tamura

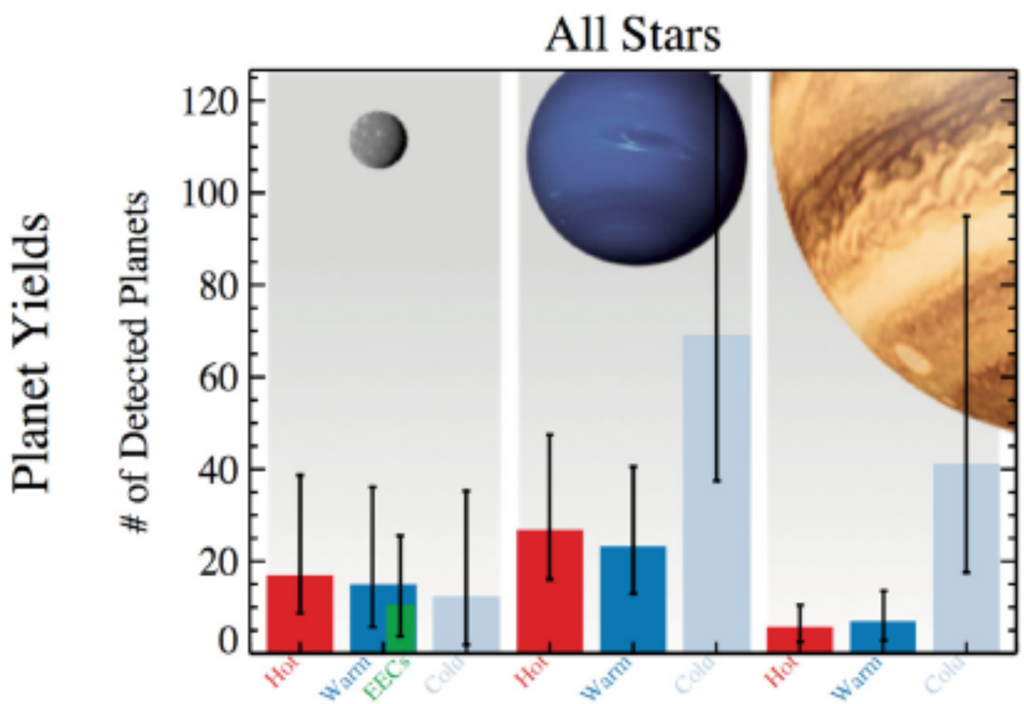
https://www.jpl.nasa.gov/habex/

HabEx Science Goal

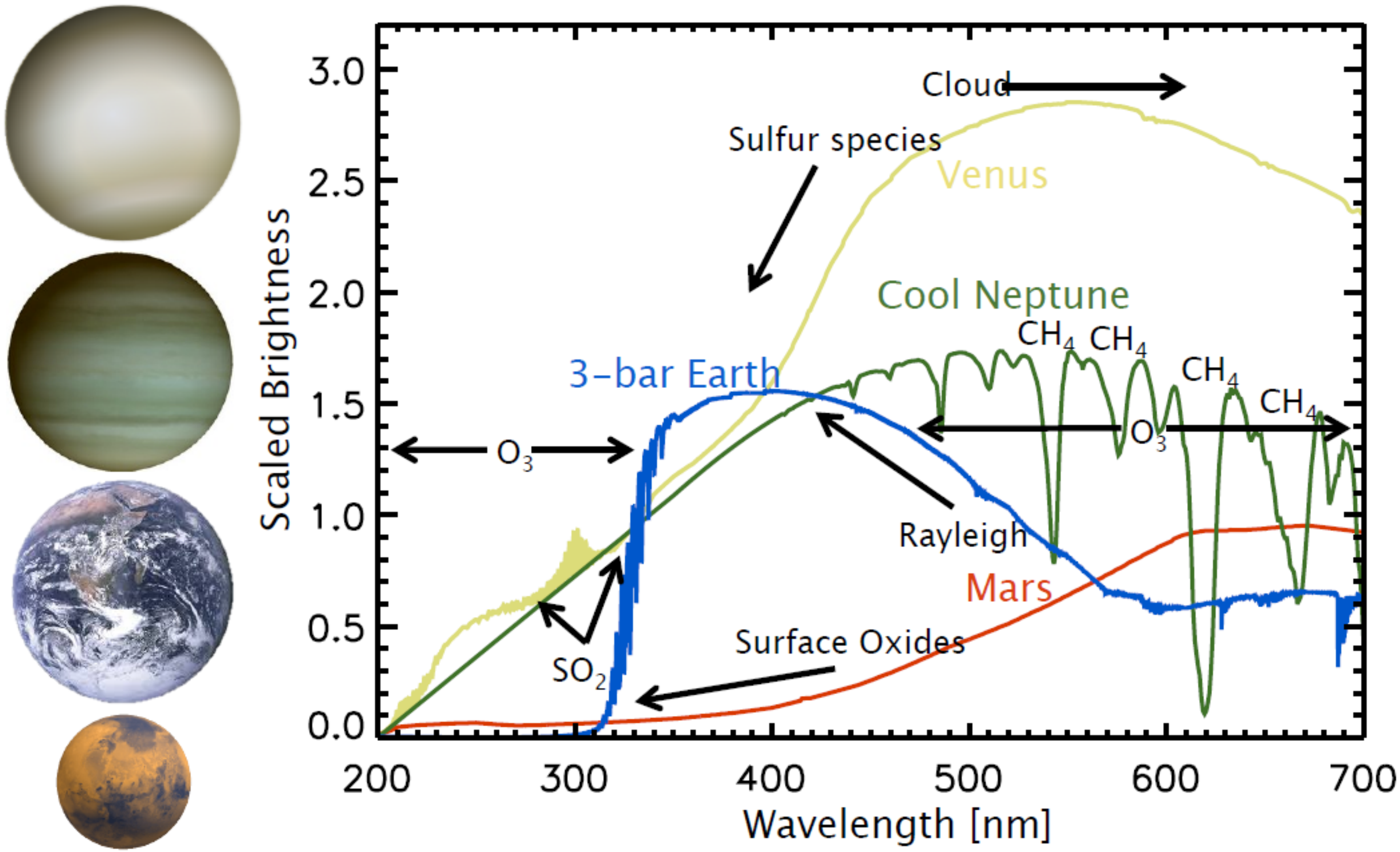
- Goal 1: To determine how unique the Earth is compared with small planets in nearby planetary systems.
- Goal 2: To determine how unique the solar system is compared with nearby stellar systems.
- Plus: To enables a broad range of general astrophysics (solar system, galactic, and extragalactic science) through two instruments: an Ultraviolet Spectrograph (UVS) & the HabEx Workhorse Camera (HWC), with a broad UV, optical, and near-IR wavelength coverage.

HabEx Architecture and Observations

- An ultra-stable 4-m diameter aperture, **off-axis space telescope** that is diffraction-limited at 400 nm and has both an internal coronagraph and a 72m starshade at a distance of roughly 124,000 km.
- A nominal survey of ~100 sunlike stars (3.75 yr) & a deep dive study of ~10 nearby stars (1.25 yr).



Expected yields of exoplanets of multiple types. The green bar indicates the expected yield of exo-Earth candidates. Yields of cold planets are likely overestimated (HabEx team).



Courtesy of Ty Robinson

Spectra of different planet types at ultraviolet and visible wavelengths. Spectra for Mars (red) and Venus (yellow) are based on models validated with real data, and spectra for an Earth-like planet with a 3 bar atmosphere (blue) and a cool Neptune-like planet (green) are simulated.

HabEx vs. LUVOIR

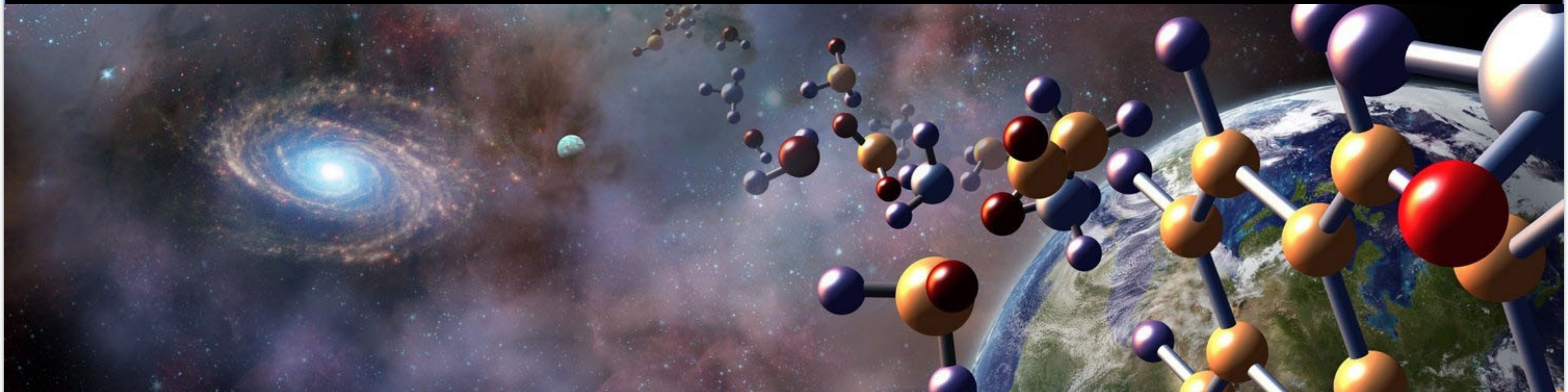
- LUVOIR and HabEx share two primary science goals:

Studying habitability and biosignatures in the atmospheres of exoplanets around sunlike stars and (2) Executing a broad range of general astrophysics studies.

- The two missions differ in their quantitative levels of ambition. HabEx will explore the nearest stars to "search for" signs of habitability and biosignatures via direct detection of reflected light. LUVOIR will survey more stars to "constrain the frequency" of habitability and biosignatures and produce a statistically meaningful sample of temperate terrestrial planets.
- The two studies will provide a continuum of options for a range of futures.

From the first stars to life

The Origins Space Telescope (OST)



OST STDT web site
https://asd.gsfc.nasa.gov/firs/
https://www.ipac.caltech.edu/future/project/origins
OST/MISC team web site
http://exoplanets.astron.s.u-tokyo.ac.jp/OST/MISC/index_misc_case_A.html

Origins Space Telescope STDT

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

NASA Study Center:

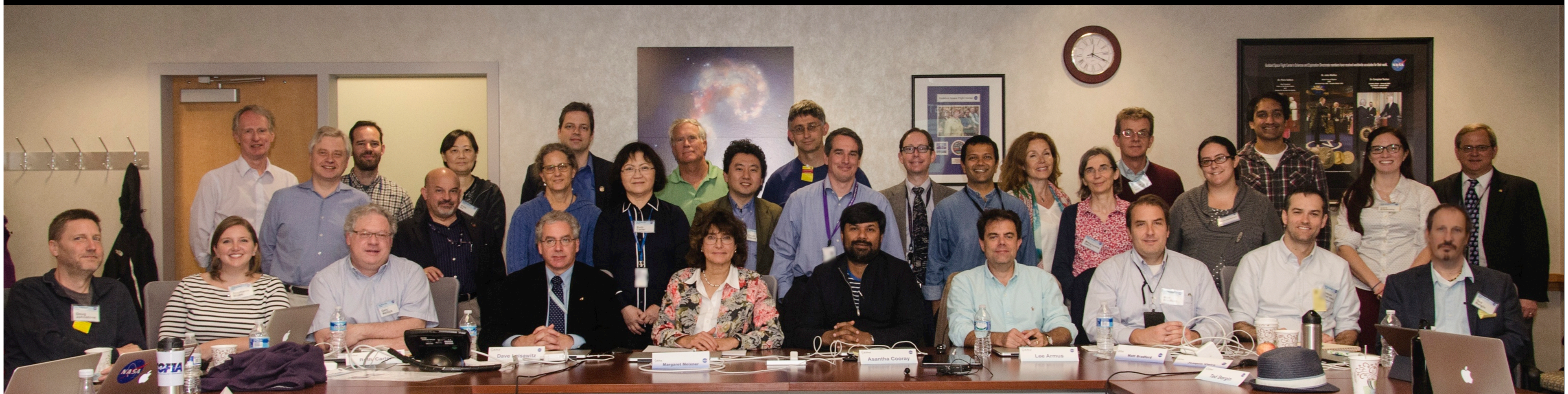
Goddard Space Flight Center (GSFC): Ruth **Carter,** David **Leisawitz,** Johannes **Staguhn,** Michael **Dipirro**, Anel **Flores,** Joseph **Howard**, James **Corsetti**, Andrew **Jones**, James **Kellog**, Louis **Fantano**

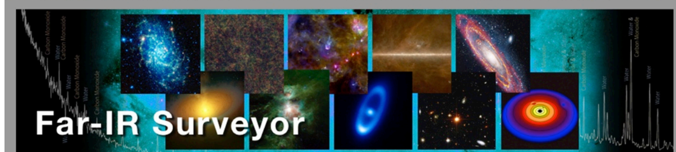
NASA Head Quarters Program Scientists (non-voting): Kartik **Sheth** and Dominic **Benford**

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:

Lee **Armus**, 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





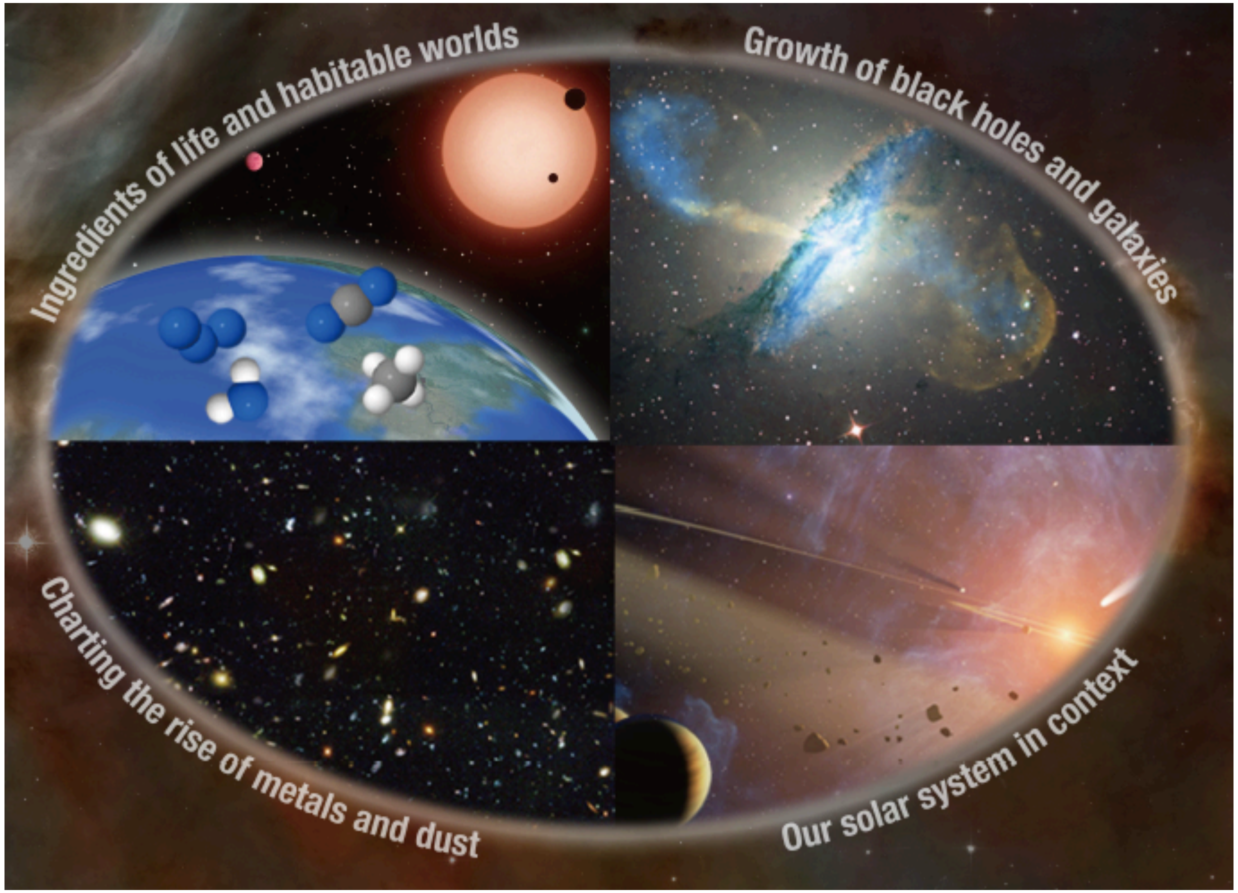
Far-IR Surveyor STDT Meeting
NASA's Goddard Space Flight Center
May 12 - 13, 2016

Key Scientific Goals

• To characterize exoplanet atmospheres looking for bio-signatures in transiting planets and directly imaging thermal emission in Jupiter- and Saturn- exoplanet analogs.

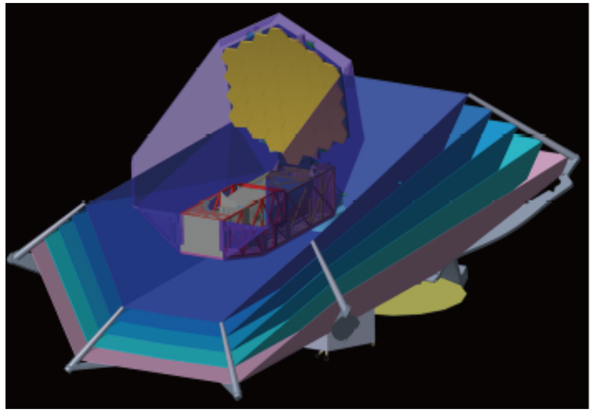
• To measure water across cosmic time from the first galaxies to proto-planetary disks to hundreds of comets in the solar system to solve the mystery of the origin of water on Earth.

• To study proto-galaxies before the epoch of re-ionization in the cosmic dark ages and map the evolution of metals and chemistry over all cosmic time.



Origins Space Telescope (OST): Mission Concept 1

Primary mirror	9.1m off axis
Temperature	4 K
Wavelengths	5—660μm
Instruments	MISC, FIP, MRSS, HRS, HERO
Lunch date	2030s
Orbit	Sun-Earth L2
Lifetime	5 years, 10+ year goal



OST Instruments: Mission Concept 1

Instrument	Wavelength	R(Δλ/λ)	Observing Modes
MISC: Mid-Infrared Imager, Spectrometer, Coronagraph	5μm—38μm	15, 300, 1200, 2.5×10^{4}	Imaging, Spectroscopy Coronagraphy (10^{-6} contrast) Transit spectrometer (<10ppm stability)
MRSS: Medium Resolution Survey Spectrometer	30μm—660μm	500, 4×10^{4}	Multi-band Spectroscopy Survey, Pointed
FIP: Far-Infrared Imager and Polarimeter	40μm, 80μm, 120μm, 240μm	15	Broad band imaging Field of view: 2'.5x2'.5, 7'.5x7'.5 Differential polarimetric imaging
HERO: Heterodyne Receiver for OST	63μm—66μm, 111μm—610μm	10^{7}	Multi-beam spectroscopy
HRS: High Resolution Spectrometer	25μm—200μm	5×10^{4}, 5×10^{5}	spectroscopy

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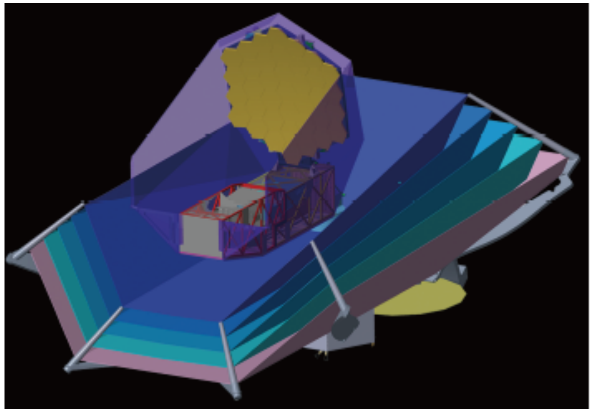

OST Instruments: Mission Concept 1

JAXAがNASA AmesとともにMISCの装置検討をリード
(詳細はポスターP-158へ)

Instrument	Wavelength	R(Δλ/λ)	Observing Modes
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HRS: High Resolution Spectrometer	25μm—200μm	5×10^4, 5×10^5	spectroscopy

Discussions toward Future International Large Flagship Mission

International Astronomy Union（国際天文学連合）;
Working Group on Global Coordination of Ground and Space Astrophysics directly to the IAU Executive Committee

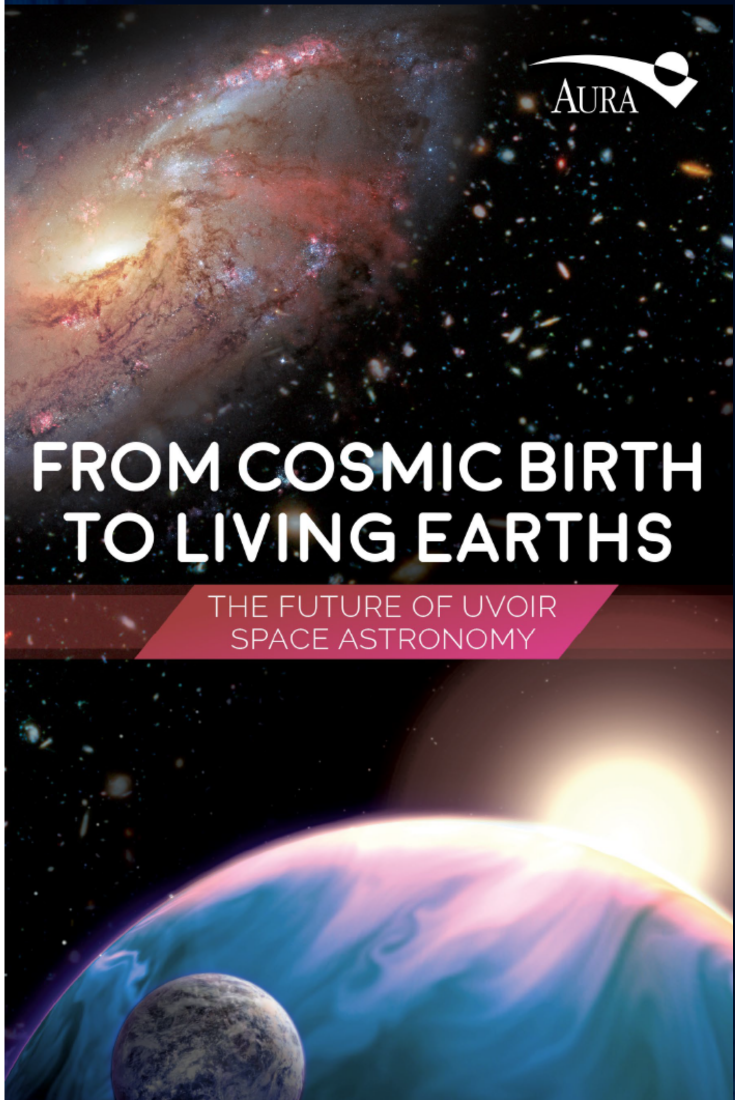
2017.7.17-19
Kavli IAU workshop on global coordination of ground and space astrophysics: Future space based optical/UV/IR telescopes
Report: Debra Elmegreen, Ewine van Dishoeck, David Spergel, and Roger Davies (2017)
https://arxiv.org/ftp/arxiv/papers/1709/1709.06992.pdf

~50名、米、欧、日、中、露、豪、南ア、ブラジル、イスラエルから参加

今回の Workshop
- Focusing UV-Optical IR telescope
- Central Science Driver in 2030's
  地球型系外惑星大気のキャラクタリゼーション
  地球型系外惑星大気のバイオシグニチャー

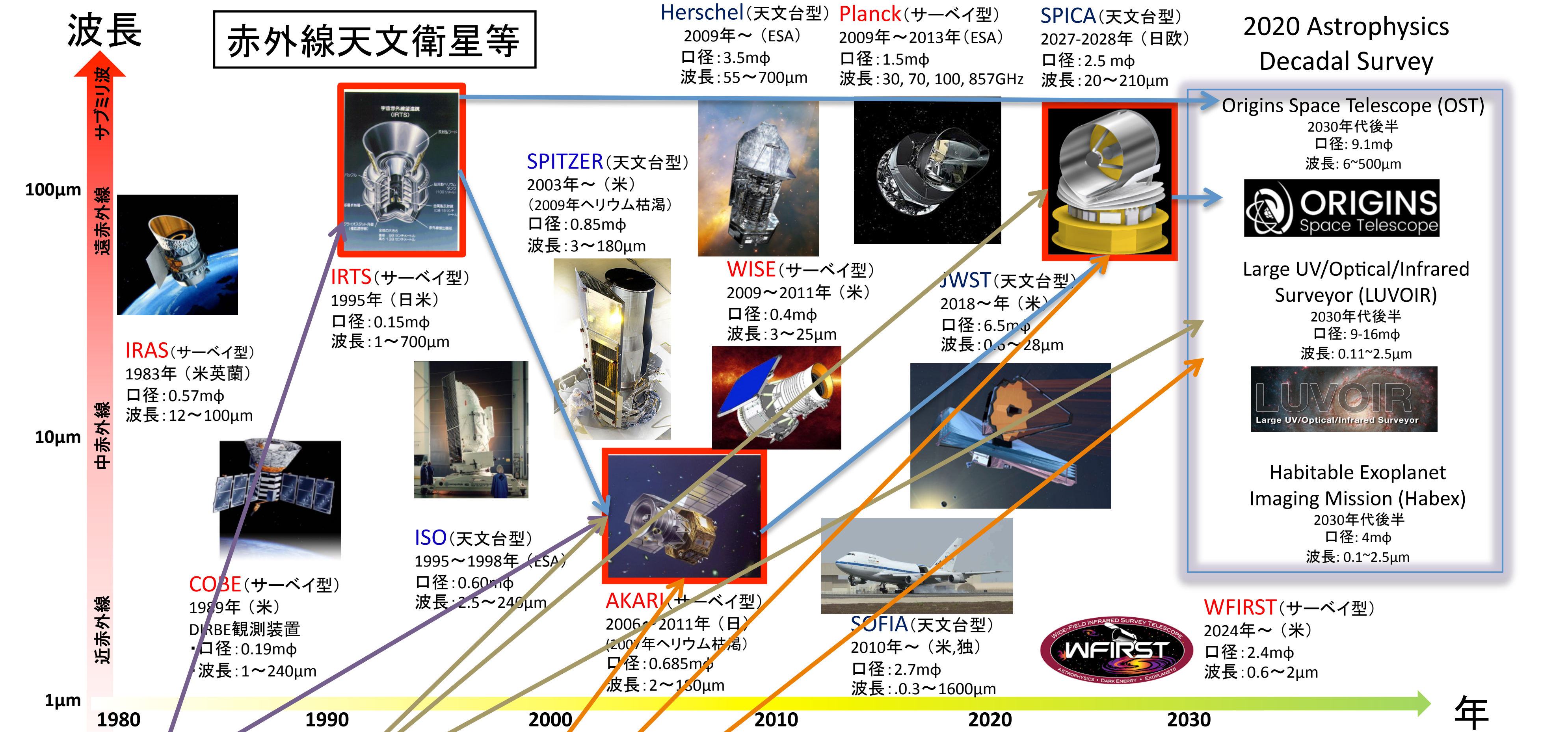
IAU 総会毎に Focused Meeting の開催

AURA (The Association of Universities for Research in Astronomy）による将来計画検討： High Definition Space Telescope



AURA HDST Report
(Dalcanton+ 2015)
http://www.hdstvision.org/report/
口径12m級の大型宇宙望遠鏡

HDST **folded within an EELV or SLS-1 shroud**



（出典: http://www.ir.isas.jaxa.jp/SPICA/SPICA_HP/History.html#satellites を改変）

気球実験

航空機実験

ロケット実験

ISS利用実験 (~2024)： 簡易曝露実験装置(ExHAM)
[http://iss.jaxa.jp/kiboexp/equipment/ef/exham/]
：中型曝露実験アダプター(i-SEEP)
[http://iss.jaxa.jp/kiboexp/equipment/ef/i-seep/]
：小型衛星放出(J-SSOD)
[http://iss.jaxa.jp/user/pdf/j-ssod_20150303.pdf]

- 低コスト、短期間での実現性
  → 次世代メガミッションで利用可能な新規技術の挑戦的開発
  → 大学院教育を通じたサイエンスコミュニティの拡充
- 比較的リスクの高い最先端の技術課題、サイエンステーマへの挑戦可能性
  → 国際的な次世代メガミッションに参画する上での技術的責任分担への萌芽的寄与
- End-to-endのプロジェクト遂行経験の機会提供
  →大学・研究機関における人材育成
- 実験天文学を通じた多角的見知の提供
  → 惑星探査ミッションと観測系ミッションのコミュニティ間連携に寄与

地上赤外線観測:
すばる望遠鏡等
東京大学アタカマ天文台、国内中小望遠鏡、他
TMT計画等

- 継続的、安定的な長期運用
  → 大学・研究機関における安定的な人材育成、サイエンスコミュニティ維持への寄与
- マルチフェーズでの観測装置の供給可能性
  → 装置開発の技術継承に好都合、赤外技術コミュニティの維持、
  → 産業界への技術力向上／維持の働きかけ

Appendix

OST/MISC Study team

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	U Tokyo	Instrument Lead
Joaquin Vieira	Illinois, Urbana Champaign	
Margaret Meixner	STScI	
Kimberly Ennico Smith	NASA/Ames	Science Lead
Thomas L. Roellig	NASA/Ames	Instrument Lead
Klaus Pontoppidan	STScI	
from NASA Ames Research Center		
Tom Greene	NASA/Ames	MISC Transit Spectrograph Module
Mark McKelvey	NASA/Ames	MISC Transit Spectrograph Module
from Laboratoire d'Astrophysique de Marseille (LAM) and related Institute		
Denis Burgarella	Laboratoire d'Astrophysique de Marseille	
David Le Miqnant	Laboratoire d'Astrophysique de Marseille	Deformable Mirror, IFU, Micro Mirror Shutter
Frederic Zamkotsian	Laboratoire d'Astrophysique de Marseille	Deformable Mirror, IFU, Micro Mirror Shutter

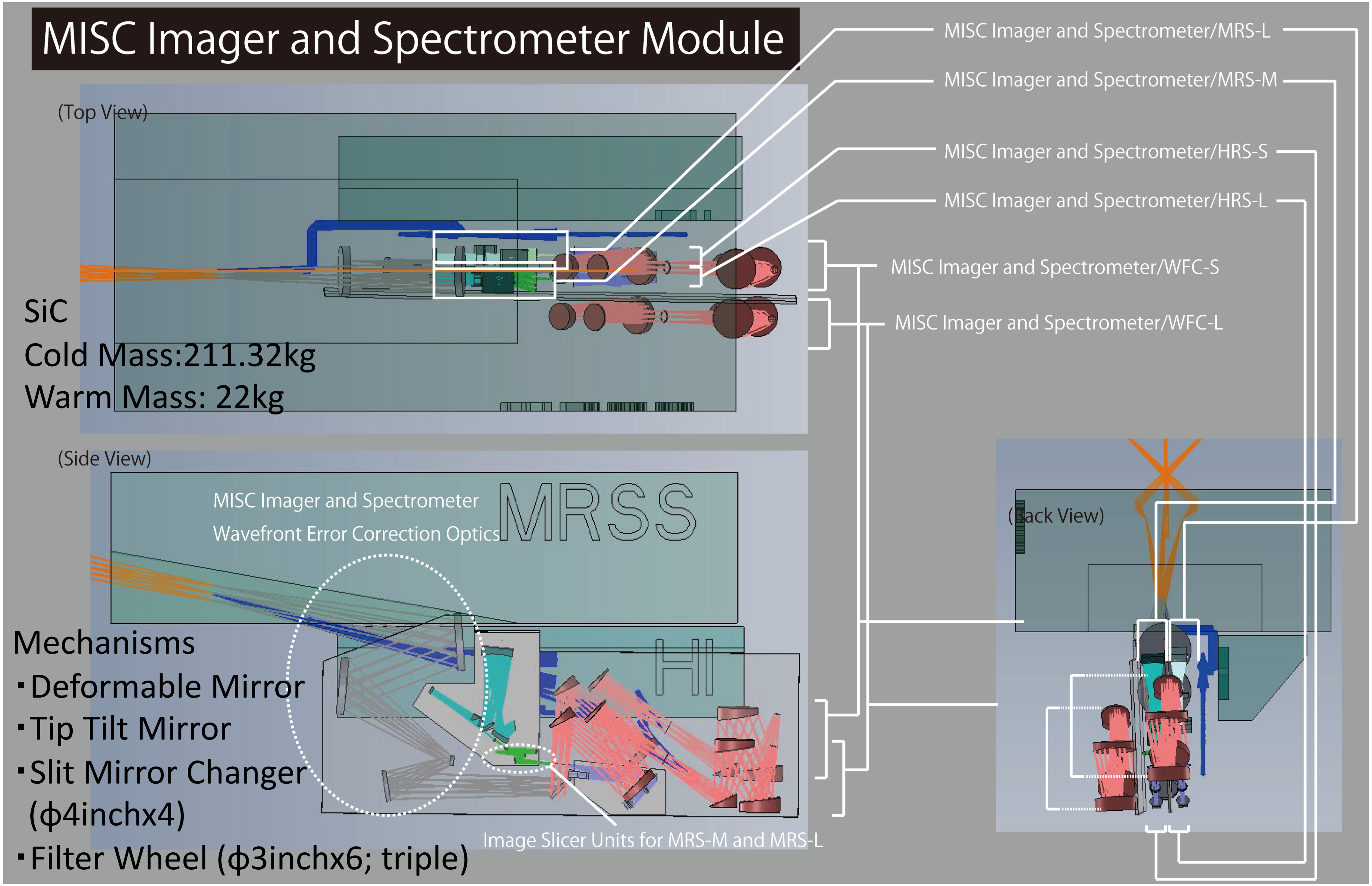
OST/MISC Study team

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

Optical and Mechanical Design of OST/MISC

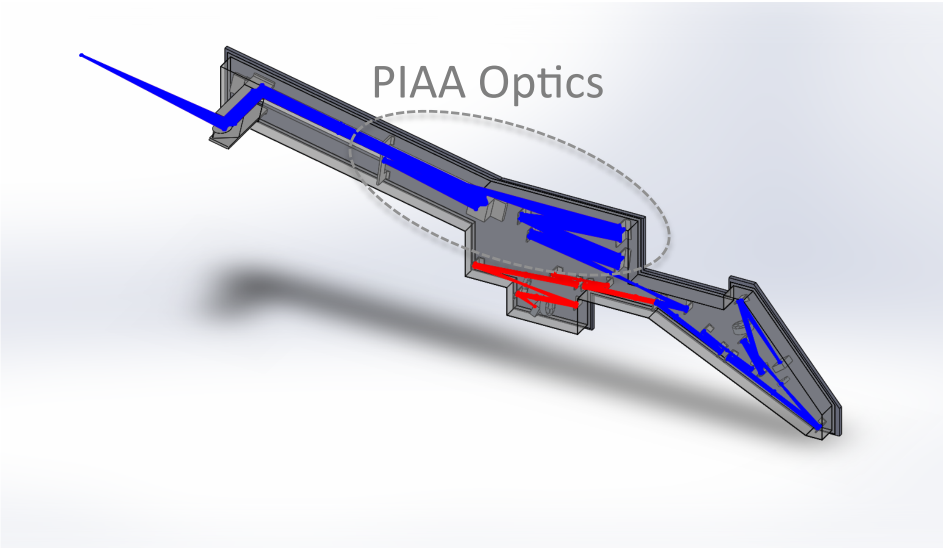
(1) MISC Imager and Spectrometer Module



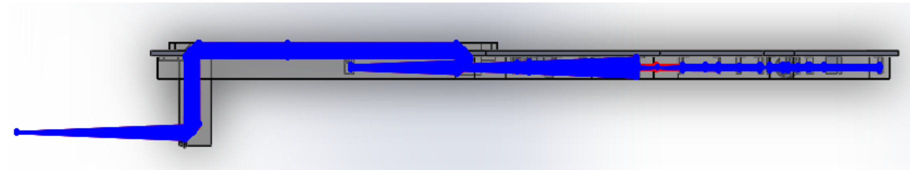
Optical and Mechanical Design of OST/MISC

(2) MISC Coronagraph Module

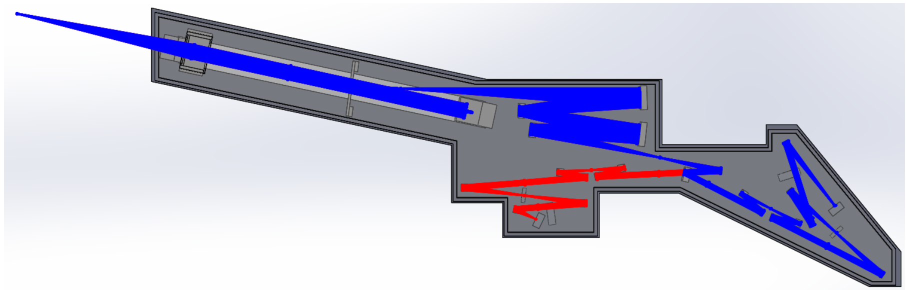
<u>Bird's eye view</u>



<u>Top view</u>



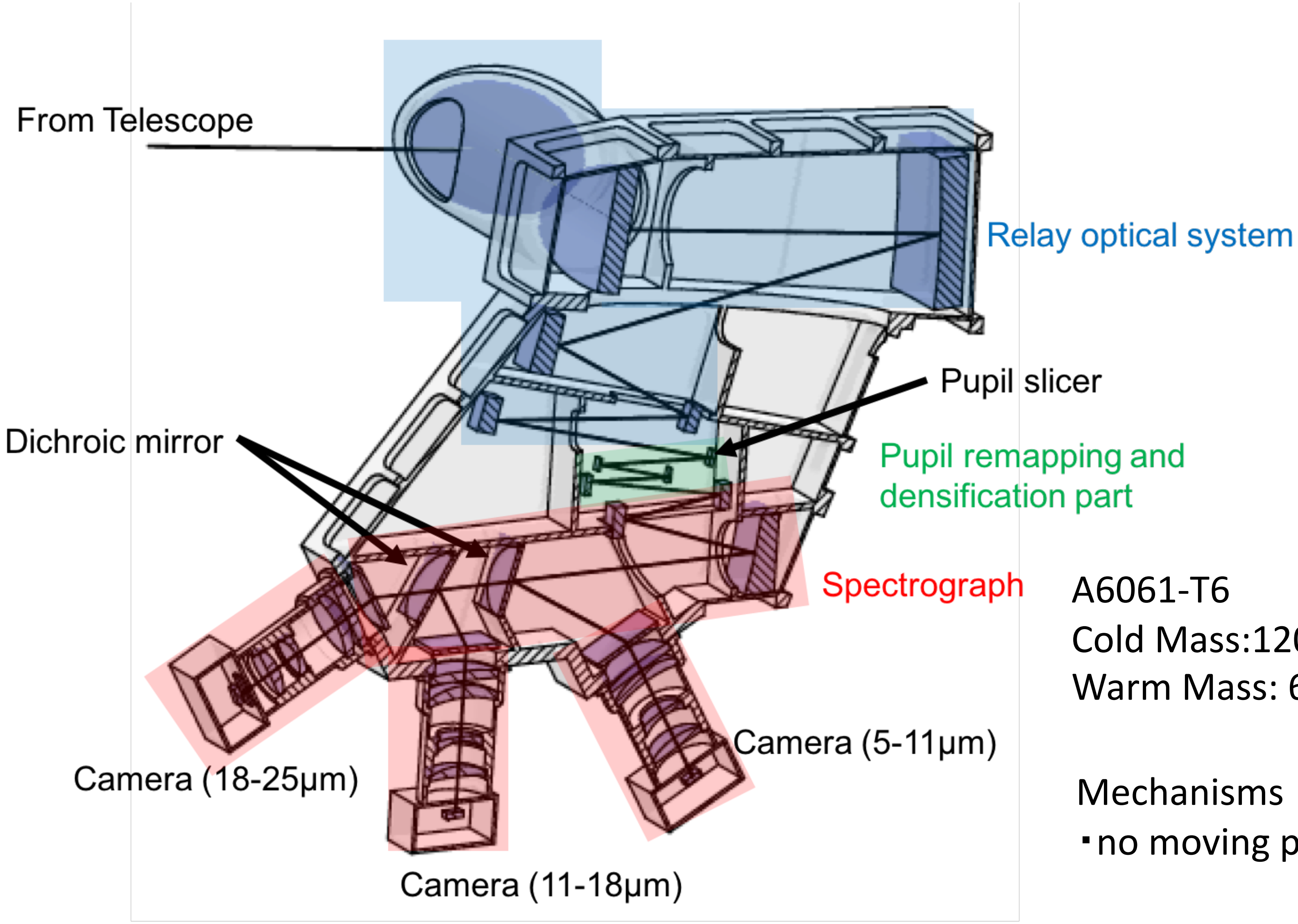
<u>Side view</u>



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

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

Optical and Mechanical Design of OST/MISC
(3) MISC Transit Spectrometer Module



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

Mechanisms
- no moving part

The Mid-Infrared Imager, Spectrometer, Coronagraph (MISC) Fact Sheet: Mission Concept 1

Module	MISC Imager & Spectrometer			MISC Transit Spectrometer	MISC Coronagraph
	Imager/Low-Res Spec. WFI-S/-L	Medium-Res Spec. MRS-S/-M/-L*	High-Res Spec. HRS-S/-L	(Densified Pupil Spec.) TRA-S/-M/-L	(PIAA) COR-S/-L
Bandpass (μm)	6--38	10--36 (goal: 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) ＃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* 0.031μJy@5μm, 0.18μJy@10μm, 0.29μJy@15μm, 0.41μJy@20μm, 0.61μJy@25μm, 0.70μJy@30μm, 0.78μJy@35μm **Sensitivity [Low-Res Spec.];** *1-hour 5s Continuum Sens.* *for a Point Source* (R=300) 0.68μJy@5μm, 1.5μJy@10μm, 4.5μJy@15μm, 5.6μJy@20μm, 9.9μJy@25μm, 13.8μJy@30μm, 43μJy@35μm	**Sensitivity;** *1-hour 5s Continuum Sens.* *for a Point Source (R~1200)* 3.4μJy@7μm, 11μJy@15μm, 34μJy@24μm,114μJy@32μm *1-hour 5s Line Sens.* *for a Point Source* 1.1×10^{-21} W/m^2 @7μm, 2.3×10^{-21} W/m^2 @15μm, 3.4×10^{-21} W/m^2 @24μm, 1.1×10^{-20} W/m^2 @32μm	**Sensitivity;** *1-hour 5s Line Sens.* *for a Point Source* 1.2×10^{-21} W/m^2 @15μm, 3.6×10^{-21} W/m^2 @30μm	**Photometric stability;** 3-5 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

＊ MRS-S is an optional function