Mission Concept Studies for the 2020 Decadal Survey

ORIGINS Space Telescope

Origins Space Telescopeの科学推進とハードウェア貢献

Itsuki Sakon (U Tokyo)
Origins/MISC Team
Origins Science and Technology Definition Team

http://origins.ipac.caltech.edu

Origins STDT

Origins Space Telescope (*Origins*) Science and Technology Definition Team (STDT) members

Margaret Meixner (*meixner@stsci.edu*) STScI/JHU, Baltimore, MD (*Origins* Study Chair)
Asantha Cooray (*acooray@uci.edu*) University of California at Irvine, Irvine, CA (*Origins* Study Chair)
Dave Leisawitz (*david.t.leisawitz@nasa.gov*) NASA GSFC, Greenbelt, MD (*Origins* Study Scientist)
Johannes Staguhn (*jstaguhn@jhu.edu*) JHU/GSFC, Greenbelt, MD (*Origins* Deputy Study Scientist)
Lee Armus (*lee@ipac.caltech.edu*) California Institute of Technology/IPAC , Pasadena, CA
Cara Batterysby (*cara.battersby@uconn.edu*) University of Connecticut, Storrs, CT
James "Gerbs" Bauer (*gerbsbauer@gmail.com*) University of Maryland, College Park MD
Edwin "Ted" Bergin (*ebergin@umich.edu*) University of Michigan, Ann Arbor, MI
Charles "Matt" Bradford (*bradford@caltech.edu*) California Institute of Technology/JPL, Pasadena, CA
Kimberly Ennico-Smith (*kimberly.ennico@nasa.gov*) NASA Ames Research Center, Moffett Field, CA
Jonathan Fortney (*jfortney@ucsc.edu*) University of California, Santa Cruz, CA
Tiffany Kataria (*tiffany.kataria@jpl.nasa.gov*) JPL/NASA, Pasadena, CA
Gary Melnick (*gmelnick@cfa.harvard.edu*) Harvard Smithsonian, Boston, MA
Stefanie Milam (*stefanie.n.milam@nasa.gov*) NASA GSFC, Greenbelt, MD
Desika Narayanan (*desika.narayanan@gmail.com*) University of Florida, Gainesville, FL
Deborah Padgett (*Deborah.L.Padgett@jpl.nasa.gov*) JPL/NASA, Pasadena, CA
Klaus Pontoppidan (*pontoppi@stsci.edu*) STScI, Baltimore, MD
Alexandra Pope (*pope@astro.umass.edu*) University of Mass, Amherst, MA
Thomas Roellig (*thomas.l.roellig@nasa.gov*) NASA Ames Research Center, Moffett Field, CA
Karin Sandstrom (*kmsandstrom@ucsd.edu*) University of California at San Diego, in La Jolla, CA
Kevin Stevenson (*kbs@stsci.edu*) STScI, Baltimore, MD
Kate Su (*ksu@as.arizona.edu*) University of Arizona, Tucson, AZ
Joaquin Vieira (*jvieira@illinois.edu*) University of Illinois, Urbana-Champaign, Illinois
Edward L. "Ned" Wright (*wright@astro.ucla.edu*) UCLA, Los Angeles, CA
Jonas Zmuidzinas (*jonas@caltech.edu*) California Institute of Technology/JPL, Pasadena, CA

Ex-Officio (non-voting) members of *Origins* Science and Technology Definition Team

Kartik Sheth, NASA HQ, Program Scientist
Dominic Benford, NASA HQ, Deputy Program Scientist
Eric E. Mamajek, NASA JPL/Caltech, ExEP Deputy Program Scientist
Susan Neff, NASA/GSFC, COR Chief Scientist
Elvire De Beck, Chalmers Institute of Technology, SNSB Liaison
Maryvonne Gerin, LERMA, Obs. De Paris, CNES Liason
Frank Helmich, SRON, Netherlands Institute for Space Research Liaison
Itsuki Sakon, University of Tokyo, JAXA Liaison, MISC instrument lead
Douglas Scott, University of British Columbia, CAS Liaison
Roland Vavrek, ESA/ESAC, ESA Liaison
Martina Wiedner, LERMA, Obs. De Paris, HERO nstrument lead
Sean Carey, Caltech/IPAC, Communications Scientist
Denis Burgarella, Laboratoire d'Astrophysique de Marseille, collaborator
Samuel Harvey Moseley, NASA/GSFC, instrument scientist

Origins/MISC team

Mid-Infrared Spectrometer and Camera (MISC) Team

Itsuki Sakon (University of Tokyo, JAXA) MISC Co-Instrument Lead
Thomas Roellig (NASA Ames) MISC Co-Instrument Lead
Kimberly Ennico-Smith (NASA Ames) MISC Science Lead
Keigo Enya (ISAS/JAXA)
Naofumi Fujishiro (Teikyo University)
Shohei Goda (Osaka Univ.)
Thomas Greene (NASA Ames)
Bernard's Helvensteijn (NASA Ames)
Lynn Hofland (NASA Ames)
Masayuki Ido (Osaka University)
Naoto Iida (Kyocera)
Yuji Ikeda (Photocoding) MISC Imager optical and structural design
Satoshi Itoh (Osaka University)
Roy Johnson (NASA Ames)
Masatsugu Kamiura (Kyocera)
Ali Kashani (NASA Ames)
Mitsunobu Kawada (ISAS/JAXA)
Takayuki Kotani (NAOJ)
Takeo Manome (Kyocera)
Taro Matsuo (Osaka University) MISC densified spectrometer design
Naoshi Murakami (Hokkaido University)
Bob McMurray (NASA Ames)
Jun Nishikawa (NAOJ)
Emmett Quigley (NASA Ames)
Yuki Sarugaku (Kyoto Sangyo University)
Hiroshi Shibai (Osaka University)
Takahiro Sumi (Osaka University)
Aoi Takahashi (ISAS/JAXA)
Masayuki Tsuboi (Osaka University)
Takehiko Wada (ISAS/JAXA)
Tomoyasu Yamamuro (OptoCraft)MISC TRA optical and structural design
Kentaro Yanagibashi (Kyocera)

参考文献

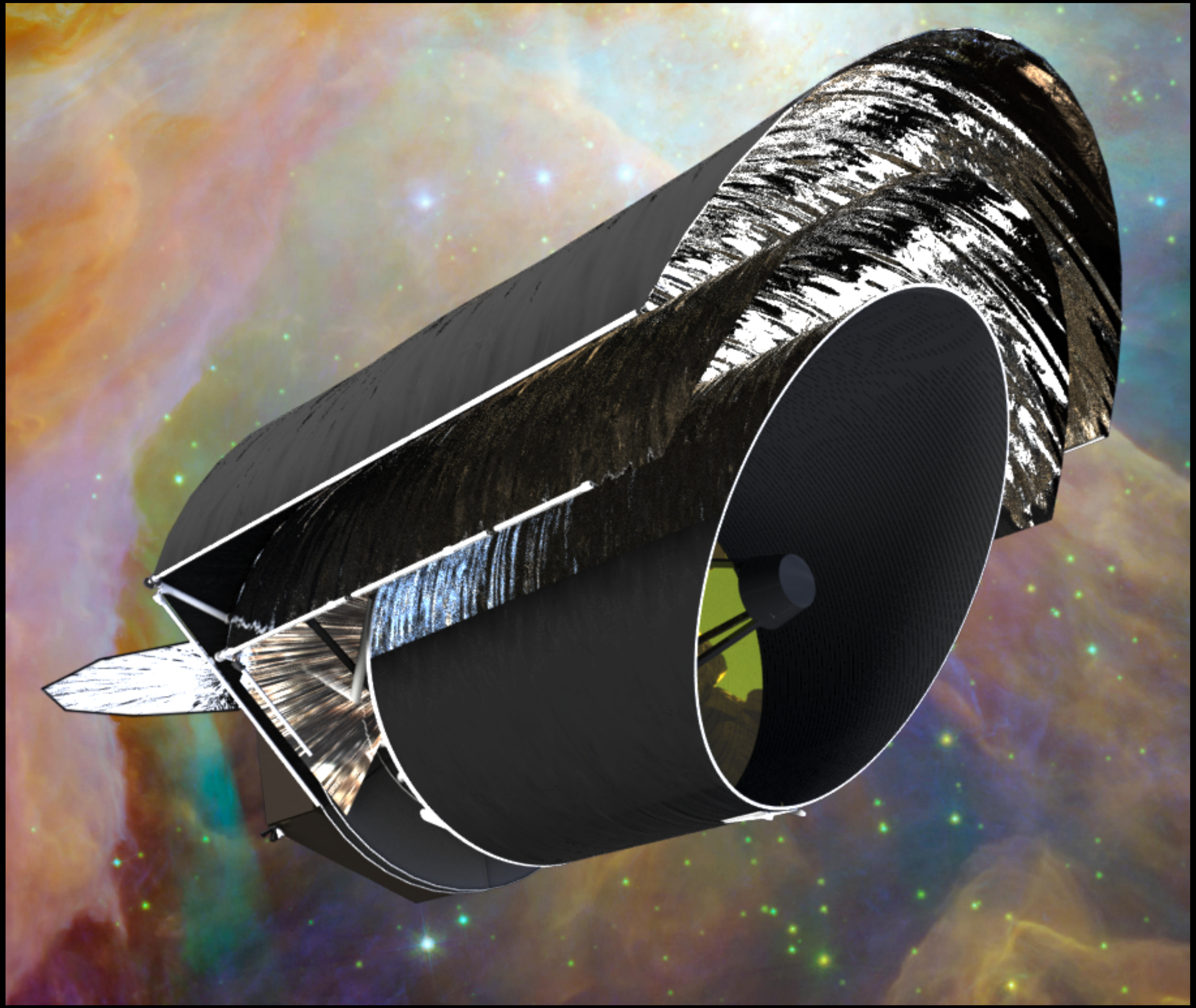
Origins Space Telescope Mission Concept Study Report

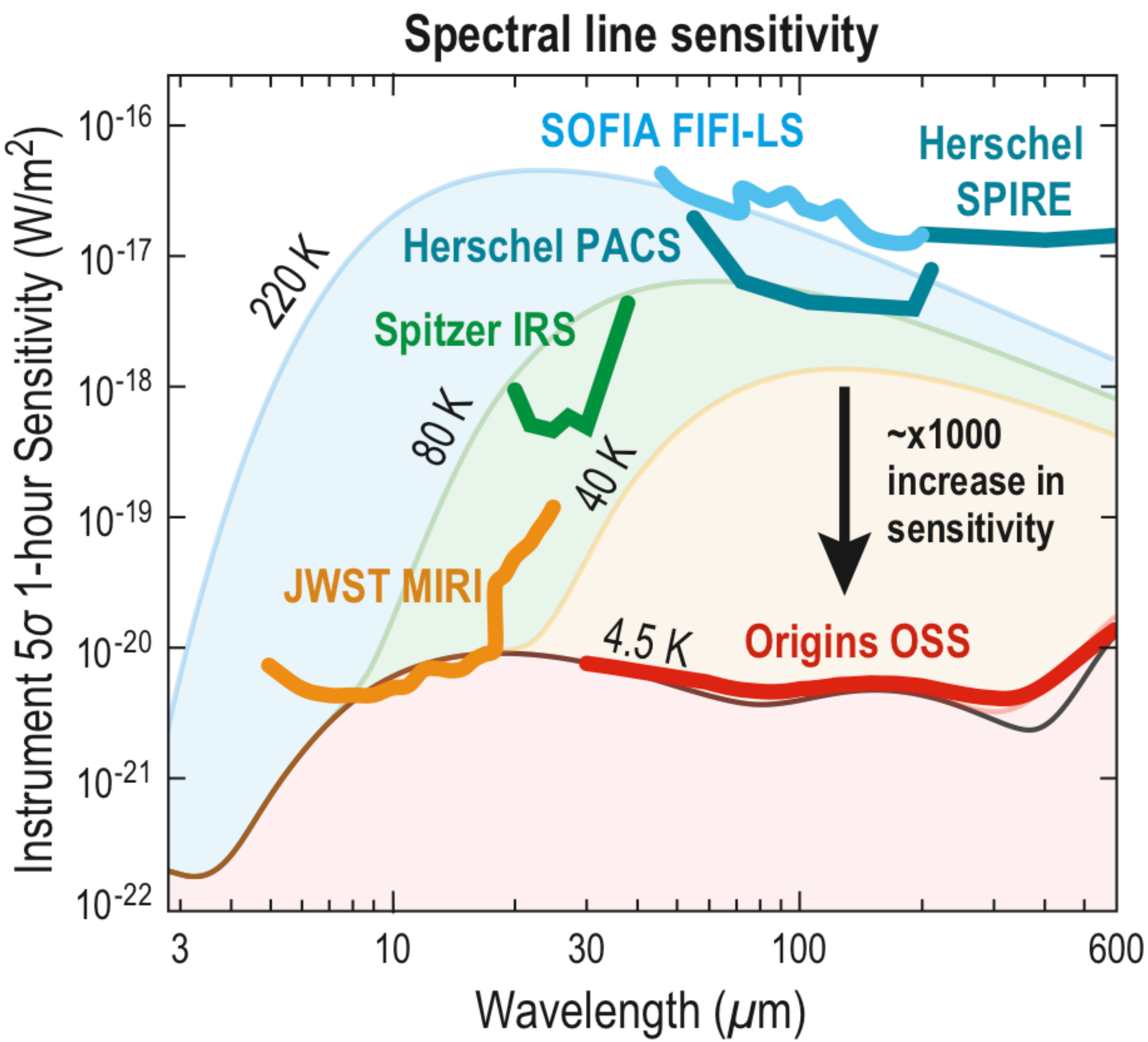
https://asd.gsfc.nasa.gov/firs/docs/OriginsVolume1MissionConceptStudyReport25Aug2020.pdf

Mid-Infrared Spectrometer and Camera (MISC) for Origins Space Telescope

Sakon, I., Roellig, T. L., Ennico-Smith, K., et al. “Mid-infrared spectrometer and camera for Origins SpaceTelescope”, JATIS,7,011013(2021)https://doi.org/10.1117/1.JATIS.7.1.011013

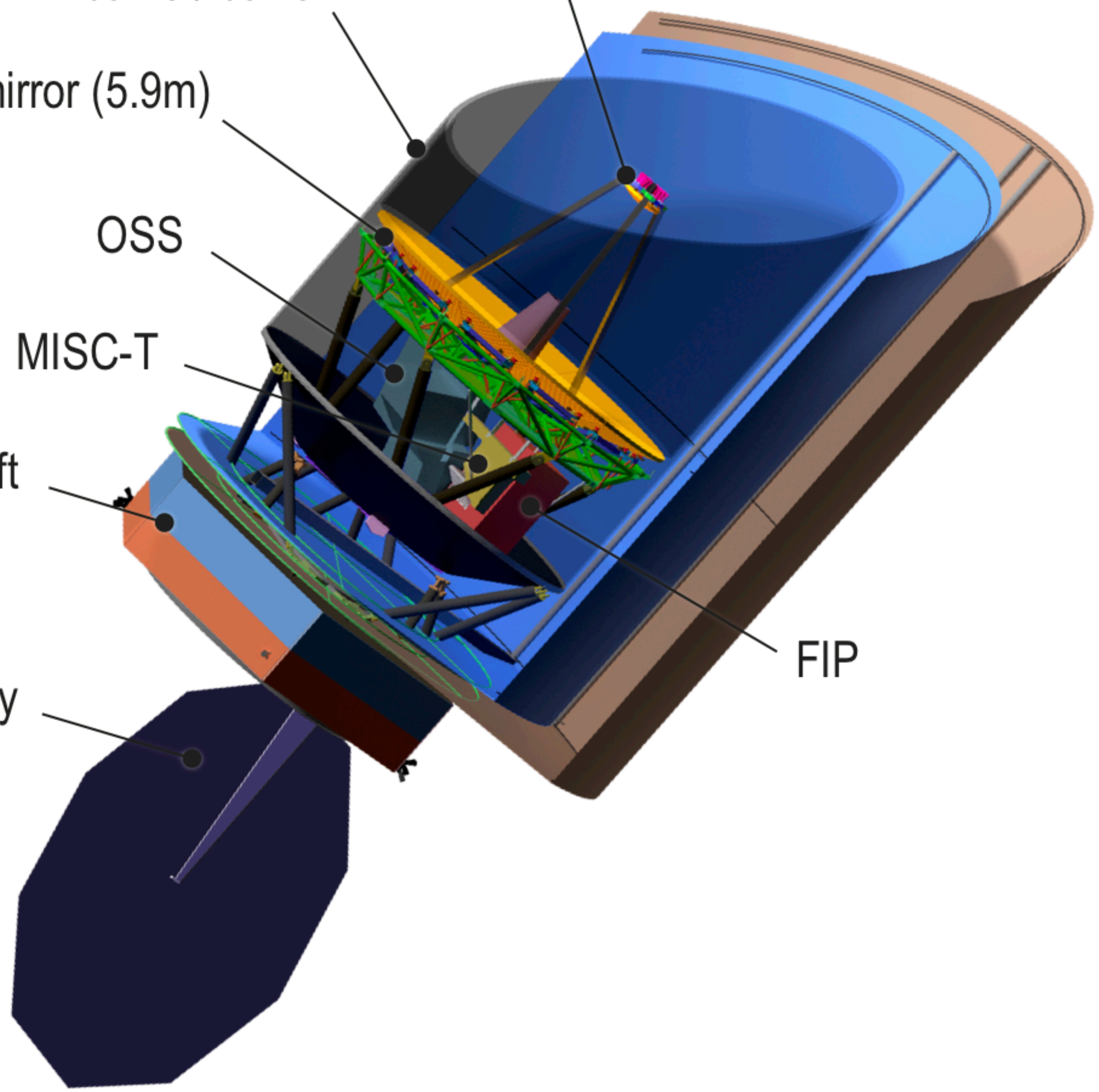
- ★ x1000 more sensitive than anything before
- ★ 5.9m aperture non-deployed cold aperture (4.5K)
- ★ Low-risk development, testing, and deployment
- ★ 3 orders of magnitude in wavelength coverage: 2.8-588 μm





Spectral line sensitivity
Instrument 5σ 1-hour Sensitivity (W/m²)
10⁻¹⁶
10⁻¹⁷
10⁻¹⁸
10⁻¹⁹
10⁻²⁰
10⁻²¹
10⁻²²
3
10
30
100
600
Wavelength (μm)
SOFIA FIFI-LS
Herschel SPIRE
Herschel PACS
Spitzer IRS
JWST MIRI
Origins OSS
220 K
80 K
40 K
4.5 K
~x1000 increase in sensitivity

Origins: Spitzer-like minimal deployable design



wavelength coverage: 2.8-588 μm

Telescope:

- diameter: 5.9 m
- area: 25 m^2 (=JWST area)
- diffraction-limit: 30 μm
- temperature: 4.5 K

Cooling: long life cryro-coolers

Agile Observatory for surveys: 60” per second

Launch Vehicle:

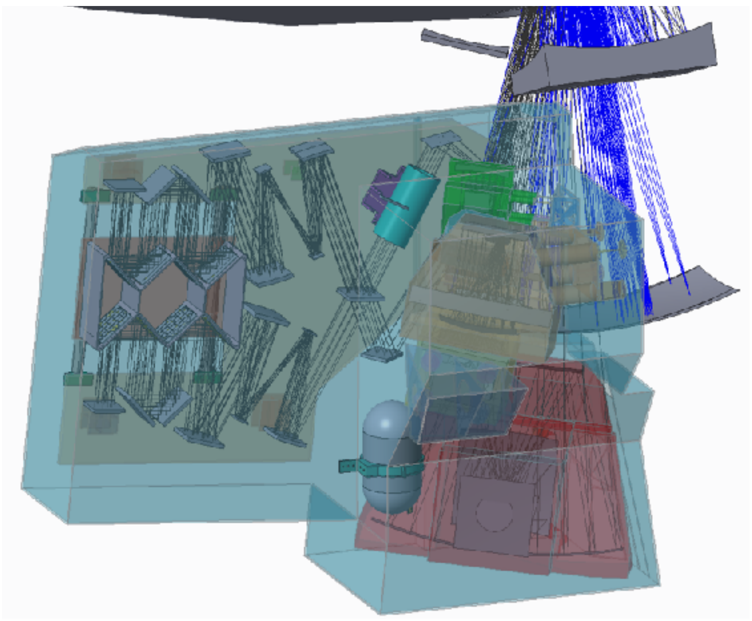
- Large, SLS Block 1, Space-X BFR

Mission: 10 year propellant, serviceable

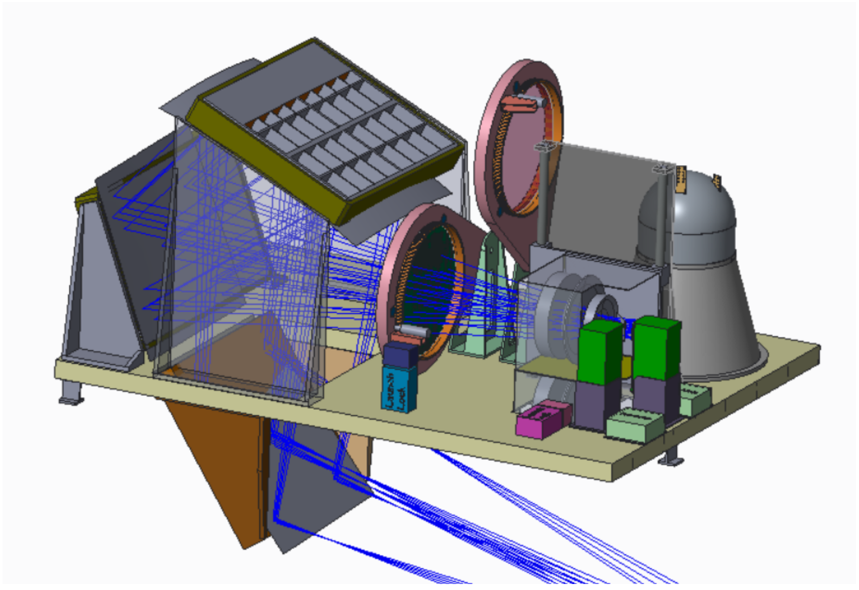
Orbit: Sun-Earth L2

Three Baseline Instruments

OSS: Origins Survey Spectrometer



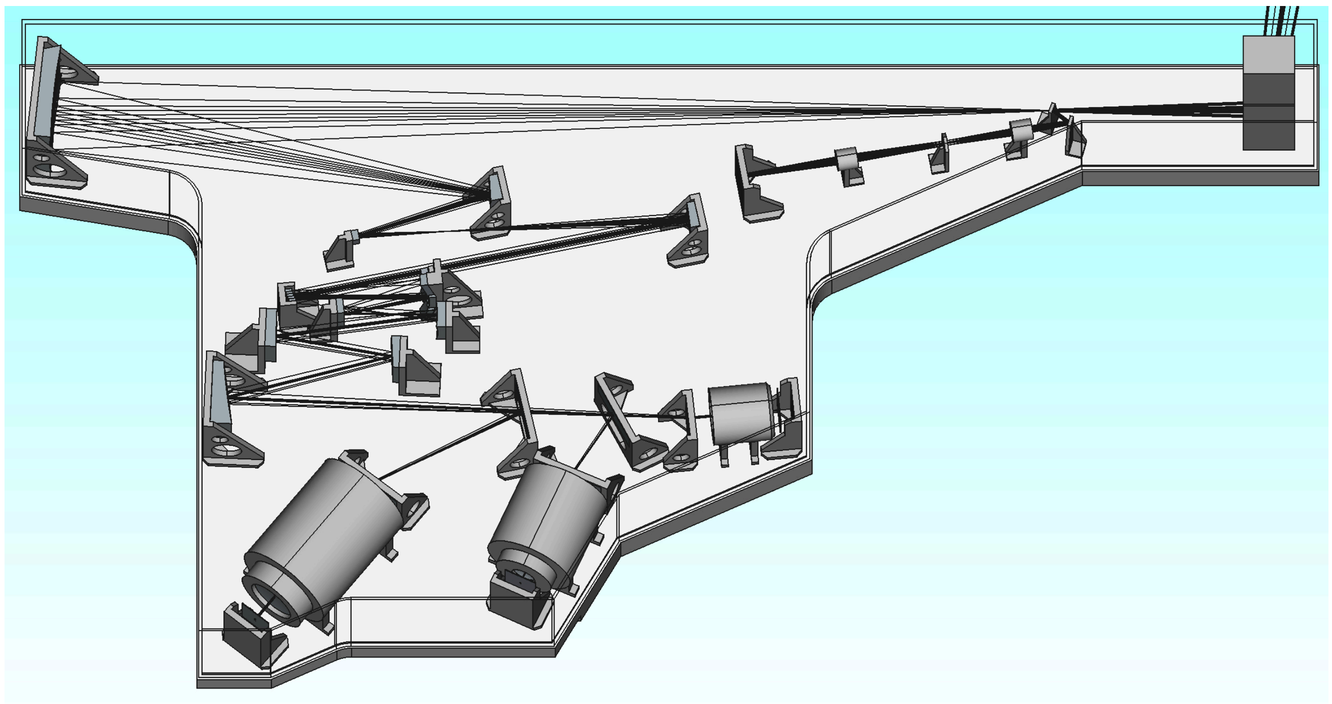
-25-588 μm R~300, survey mapping
-25-588 μm R~43,000, spectral surveys
-100-200 μm R~325,000, kinematics



FIP: Far-infrared Imager Polarimeter

- 50 or 250 μm, Large area survey mapping
- 50 or 250 μm, polarimetry

MISC-T: Mid-Infrared Spectrometer **Camera Transit**
(Sakon et al. 2021, JATIS, 7, 011013)



-Ultra-Stable Transit Spectroscopy
achieved by Densified Pupil Spectroscopy (Matsuo et al. 2016, 2018)
-2.8-20 μm R~50-295

Origins Instrument Performance

Instrument/ Observing Mode	Wavelength Coverage (µm)	Field of View (FOV)	Spectral Resolving Power ($R=\lambda/\Delta\lambda$)	Saturation Limits	Representative Sensitivity 5σ in 1 hr
***Origins* Survey Spectrometer (OSS)**					
Grating	25–588 µm simultaneously	6 slits for 6 bands: 2.7′ x 1.4″ to 14′ x 20″	300	5 Jy @ 128 µm	3.7 x 10^{-21} W m^{-2} @ 200 µm
High Resolution	25–588 µm with FTS	Slit: 20″ [2.7″ to 20″]	43,000 x [112 µm/λ]	5 Jy @ 128 µm	7.4 x 10^{-21} W m^{-2} @ 200 µm
Ultra-High Resolution	100–200 µm	One beam: 6.7″	325,000 x [112 µm/λ]	100 Jy @ 180 µm	2.8 x 10^{-19} W m^{-2} @ 200 µm
Far-IR Imager Polarimeter (FIP)					
Pointed	50 or 250 µm (selectable)	50 µm: 3.6′ x 2.5′ 250 µm: 13.5′ x 9′ (109 x 73 pixels)	3.3	50 µm: 1 Jy 250 µm: 5 Jy	50/250 µm: 0.9/2.5 µJy Confusion limit: 50/250 µm: 120 nJy/1.1 mJy
Survey mapping	50 or 250 µm (selectable)	60″ per second scan rate, with above FOVs	3.3	50 µm: 1 Jy 250 µm: 5 Jy	Same as above, confusion limit reached in 50/250 µm: 1.9 hours/2 msec
Polarimetry	50 or 250 µm (selectable)	50 µm: 3.6′ x 2.5′ 250 µm: 13.5′ x 9′	3.3	50 µm: 2 Jy 250 µm: 10 Jy	0.1% in linear and circular polarization, ±1° in pol. Angle
Mid-Infrared Spectrometer Camera Transit Spectrometer (MISC-T)					
Ultra-Stable Transit Spectroscopy	2.8–20 µm in 3 simultaneous bands	2.8–10.5 µm: 2.5″ radius 10.5–20 µm: 1.7″ radius	2.8-10.5 µm: 50–100 10.5-20 µm: 165–295	K~3.0 mag 30 Jy @ 3.3µm	Assume K~9.85 mag M-type star, R=50 SNR/sqrt(hr)>12,900 @ 3.3 µm in 60 transits with stability ~5 ppm < 10.5 µm, ~20 ppm ≥ 10.5 µm

ORIGINS
Space Telescope

How does the universe work?

How did we get here?

Are we alone?

Discovery of new phenomena

学術的価値

Originsは4.5Kに冷却された主鏡直径5.9mでJWSTとほぼ同じ集光面積（25m²）をもつ冷却赤外線宇宙望遠鏡で、３つの baseline 観測装置（OSS, FIP, MISC-T）で波長2.8μmから588μmの分光、偏光撮像観測を行う。

これにより、(1) 宇宙再電離から現在まで、銀河がいかに星形成を行い、金属量を増やし、中心の超巨大質量ブラックホールを形成したか、(2) 惑星形成の間にいかにハビタビリティの条件が育まれたか、(3) M型矮星の惑星に生命がもたらされるか、の解決に挑む。

深宇宙探査でのconfusionを克服し、十分な空間分解能で従来の遠赤外線の凡ゆる観測手段と比べて1000倍深い感度を達成(NASAの宇宙物理学ロードマップで定義)

<u>2016.5-2019.8のSTDT活動で実施したこと</u>

サイエンスの定義と優先順位の決定
Concept 1の創出
(上位のscience cases達成に必要不可欠な装置の概念設計)

サイエンスの再定義と優先順位の決定
Concept 2の創出
(上位のscience cases達成に必要不可欠な装置の概念設計)

Baseline Conceptの創出
Upscope Conceptの創出

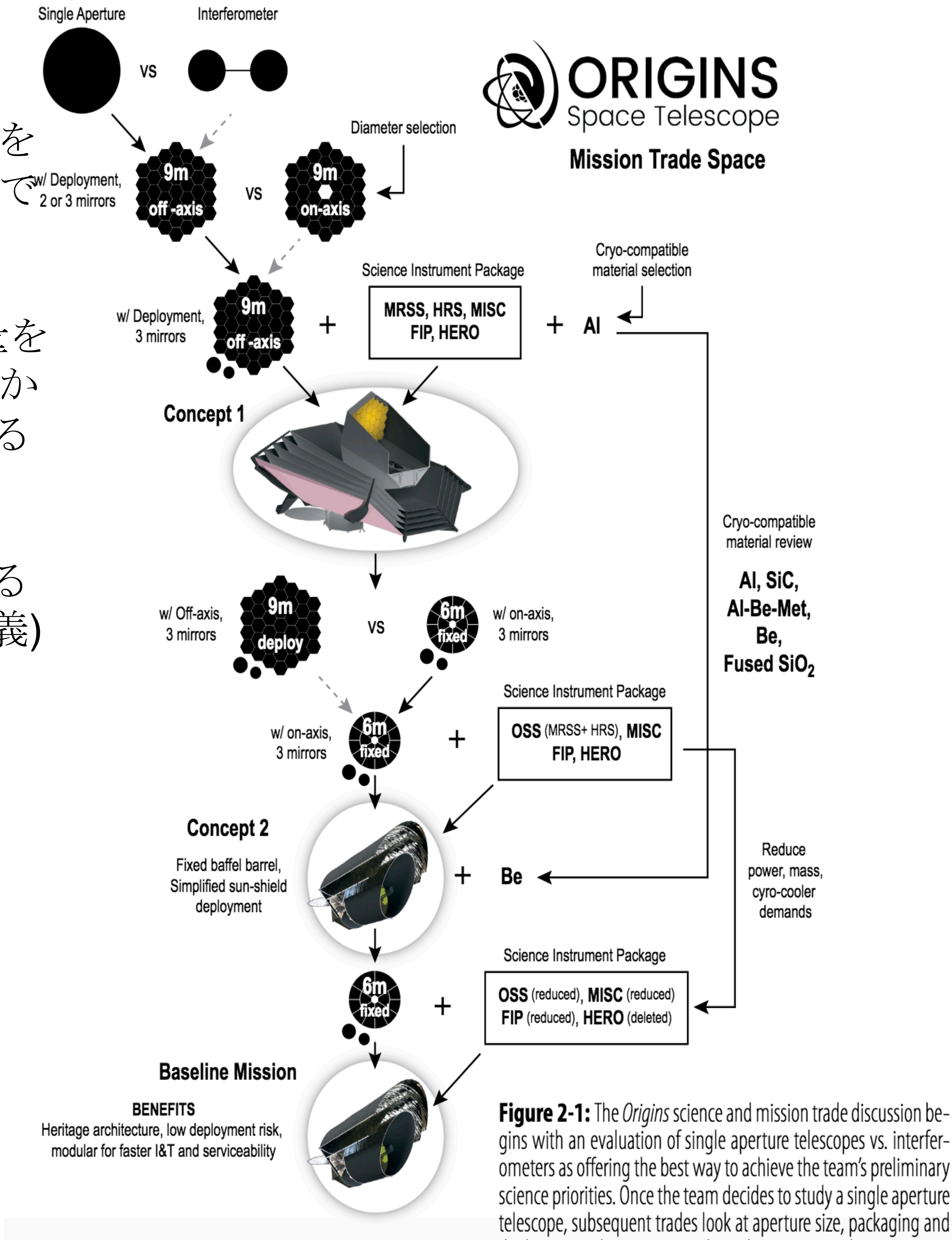


Figure 2-1: The *Origins* science and mission trade discussion begins with an evaluation of single aperture telescopes vs. interferometers as offering the best way to achieve the team's preliminary science priorities. Once the team decides to study a single aperture telescope, subsequent trades look at aperture size, packaging and deployment schemes, materials, and instrument selection.

2016-2019のSTDT活動で実現できたこと

人類のミッションとして、利用可能な技術を米国、欧州、日本から集積し比較
- 日本のスペース赤外ミッションの過去の実績と要素技術開発実績のの国際的可視化
・IRTS, あかり/近中間赤外線カメラ(IRC), SPICA Coronagraph Instrument (SCI), SCPIA/MCS
- 技術開発ロードマップのスケジュールと照らして利用可能な新規技術の開発
・densified pupil spectrometer (Matsuo et al. 2016) をMISCのベースラインに採用

・Concept 1 検討ではMid-Infrared Imager, Spectrometer and Coronagraph (MISC)の概念設計検討を担当
中間赤外線コロナグラフ装置
中間赤外線撮像・低分散分光・中分散分光・高分散分光装置 (5-38)
中間赤外線系外惑星トランジット分光装置
・Concept 2 検討ではMid-Infrared Spectrometer and Camera (MISC)の概念設計を担当
中間赤外線撮像・低分散分光装置 (5-28μm)
中間赤外線系外惑星トランジット分光装置
(Sakon et al. 2018, SPIE, 10698, 1069817)

・Baseline Concept に MISC Transit Spectrometer が残り、Originsの最終検討報告書を分担執筆
・Upscope Concept に MISC Wide Field Imager を維持し、Originsの最終検討報告書を分担執筆
(Sakon et al. 2021, JATIS, 7, 011013)

Pre-phase Aスタート時に日本がハードウェア貢献を行うための道筋を確保できた

2020 Decadal SurveyでOriginsが選定されたら

「20年後のサイエンス」を担うフラッグシップミッションをデザインする
→ 従来の日本の宇宙科学ミッション遂行のやり方とは異なる部分がある

STDT活動においてサイエンス検討は、
- Origins Galaxy Evolution and Cosmology Science Working Group
- Origins Milky Way, ISM, and Nearby Galaxies Science Working Group
- Origins Solar System Working Group
- Origins Disks Working Group
- Origins Exoplanets Working Group

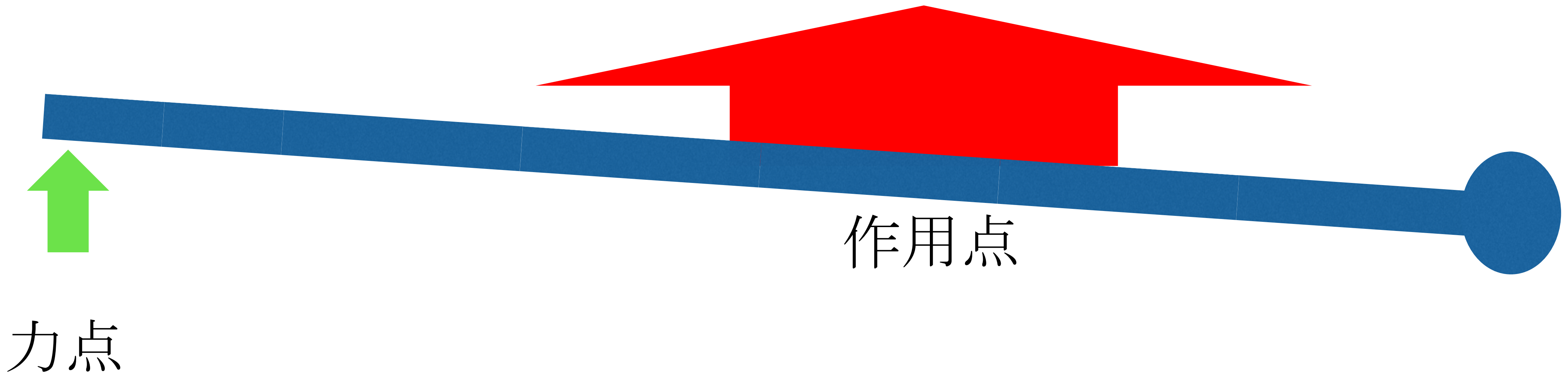
で実行されてきた。

→ 各ワーキンググループがpre-phase A(2021-2025)にサイエンスの再定義を行う過程で日本の各分野の研究者が加わること
(→ SPICAミッションのヘリテージはこのサイエンス検討に最も生かされる)

フラッグシップミッションにハードウェア貢献を行うことの意味
- 技術のフロンティア、競争・競合の場に「居る」こと
- コロナ後、技術の機密・戦略的取り扱いの厳格化が一層進むと考えられる。
  国際的な最先端を競う場所に、日本が拠点を持たない限り取り残される。

国際フラッグシップミッションへのハードウェアを通じた貢献の意義

- バス部、ミッション部(望遠鏡、観測装置)全体でチームを構成
- MISCと望遠鏡、他の観測装置(OSS, FIP)との間で、常にインターフェースを設けながらミッションを推進
- コンポーネントレベルでの日本技術のインプットの機会に適時手を挙げられる (日本の技術の売り込み)
- あらゆる点で国際的に最先端の技術の土俵に身をおかざるを得ない (最先端の技術の可視化)
- 全ての観測装置に対して、適切なコンタクト先を持ち、最新の情報共有が可能
- MISCだけでなく、OSS, FIPを用いた、サイエンス検討に、ゲストオブザーバーではなくチームとして参加可能
- 日本の国際プロジェクトにおける実績 (→ 他の日本の独自ミッションへの重要なリターンとなる)



装置MISCを通じた貢献

・日本の独創的装置デザイン(Densified Pupil Spectrometer; baselineに採用)
コスト：437MUSD*注 x (1-α) [α; NASA/Amesの担当割合。特に検出器開発を想定。]
注：Total cost 6.7BUSDの6.5%に相当。現時点でOriginsミッションのコスト見積もりに含有された上でDecadal Committeeに提出