HabEx

Habitable Exoplanet Observatory - HabEx -

Exploring New Worlds, Understanding Our Universe

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

HabEx概要

- 口径4m 1枚鏡 宇宙望遠鏡
- 0.4 μ m 回折限界
- 4つの観測装置
- 50%の系外惑星研究
- 50%の宇宙物理学研究
- 現在Astrophysics 2020 Decadal Surveyに提案中

近傍の地球類似惑星の探査とそのハビタビリティの調査

- （主に）太陽型星
- 生命居住可能惑星の発見と直接撮像分光
- 生命の兆候の探査

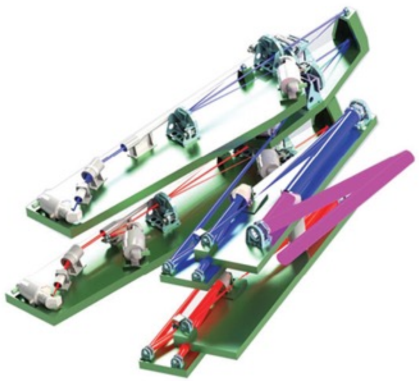
近傍の惑星系の姿を描き出しその多様性を理解する

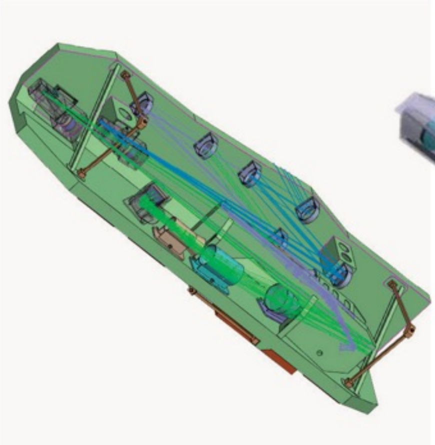
- 惑星系の家族写真
- 内側から外側の惑星たちを発見し特徴付ける
- 残骸円盤やダスト

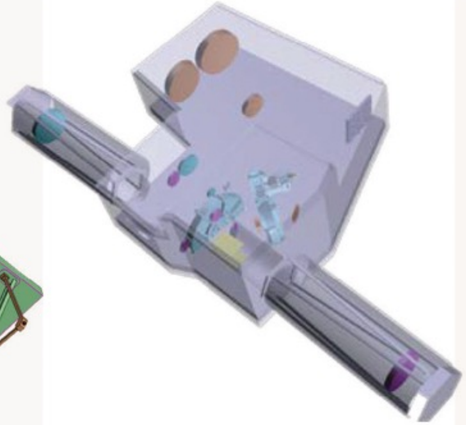
太陽系から系外銀河までのさまざまな観測対象に対し、紫外線から近赤外線での新たな探査を可能にする

- Guest Observer program (GO)で多様な宇宙物理学研究を実現する

HabExの観測装置







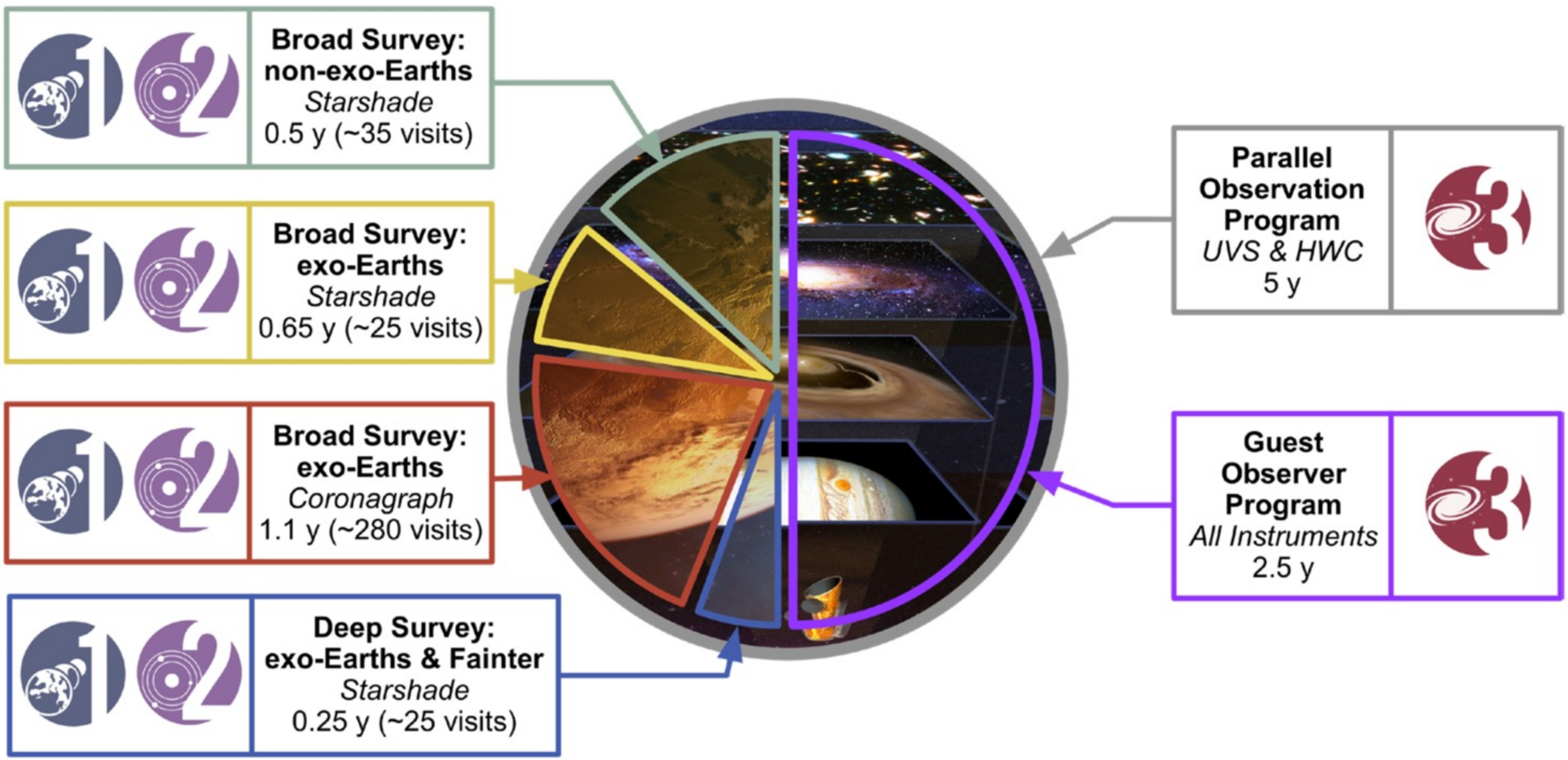
	Coronagraph (HCG)	Starshade (SSI)	Workhorse Camera (HWC)	UV Spectograph (UVS)
Purpose	Exoplanet imaging and characterization	Exoplanet imaging and characterization	Multipurpose, wide-field imaging camera and spectograph for observatory science	High-resolution, UV imaging and spectroscopy for observatory science
Instrument Type	Vector Vortex charge 6 coronagraph with: - Raw contrast: 2.5×10^{-10} at the IWA - Δ mag limit = 26.5 - 20% instantaneous bandwidth - Imager and spectograph	52 m diameter starshade occulter with: - 76,600 km separation (Visible) - Raw contrast: 1×10^{-10} at the IWA - Δ mag limit = 26.5 - 107% instantaneous bandwidth - Imager and spectograph	Imager and spectograph	High-resolution imager and spectrograph
Channels	Visible: 0.45–0.975 μm - Imager + IFS with $R = 140$ Near-IR: 0.975–1.8 μm - Imager + IFS with $R = 40$	UV: 0.2–0.45 μm - Imager + grism with $R = 7$ Visible: 0.45–0.975 μm - Imager + IFS with $R = 140$ Near-IR: 0.975–1.8 μm - Imager + IFS with $R = 40$	Visible: 0.37–0.975 μm - Imager + grism with $R = 1{,}000$ Near-IR: 0.95–1.8 μm - Imager + grism with $R = 1{,}000$	UV: 115–320 nm (with 115–370 nm available at $R \leq 1{,}000$) R = 60,000; 25,000; 12,000; 6,000; 3,000; 1,000; 500; imaging
Field of View	IWA: 2.4 λ/D = 62 mas at 0.5 μm OWA: 32 λ/D = 830 mas at 0.5 μm	IWA: 58 mas at 0.3–1.0 μm OWA: 6 arcsec (Vis. broadband imaging) OWA: 1 arcsec (Visible IFS)	3 x 3 arcmin^2	3 x 3 arcmin^2
Features	64 x 64 deformable mirrors (2) Low-order wavefront sensing and control	Formation flying, sensing, and control	Microshutter array for multi-object spectroscopy - 2 x 2 array, 171 x 365 apertures	Microshutter array for multi-object spectroscopy - 2 x 2 array, 171 x 365 apertures

系外惑星の直接撮像+分光

紫外～近赤外の撮像・分光(多目的)

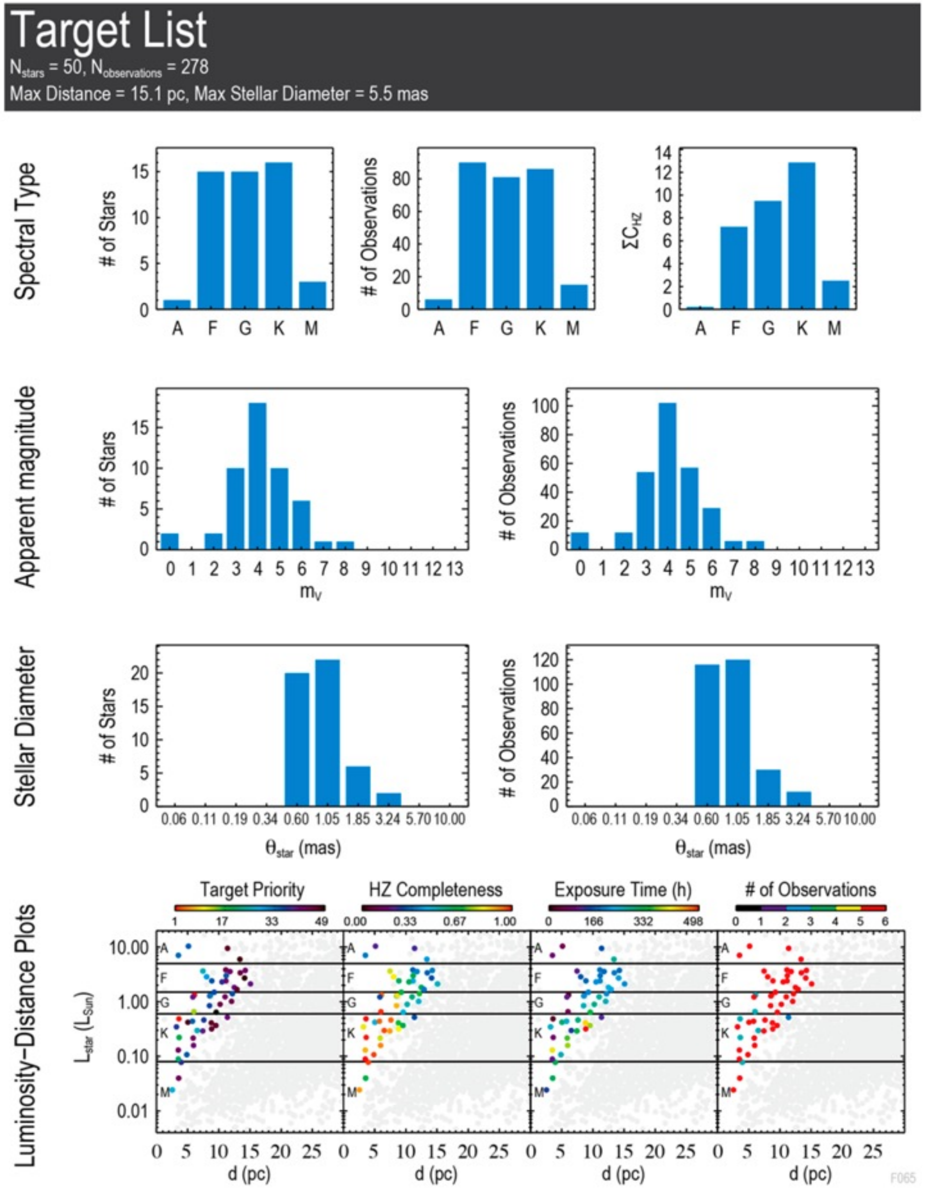
HabExの時間配分(当初5年間)

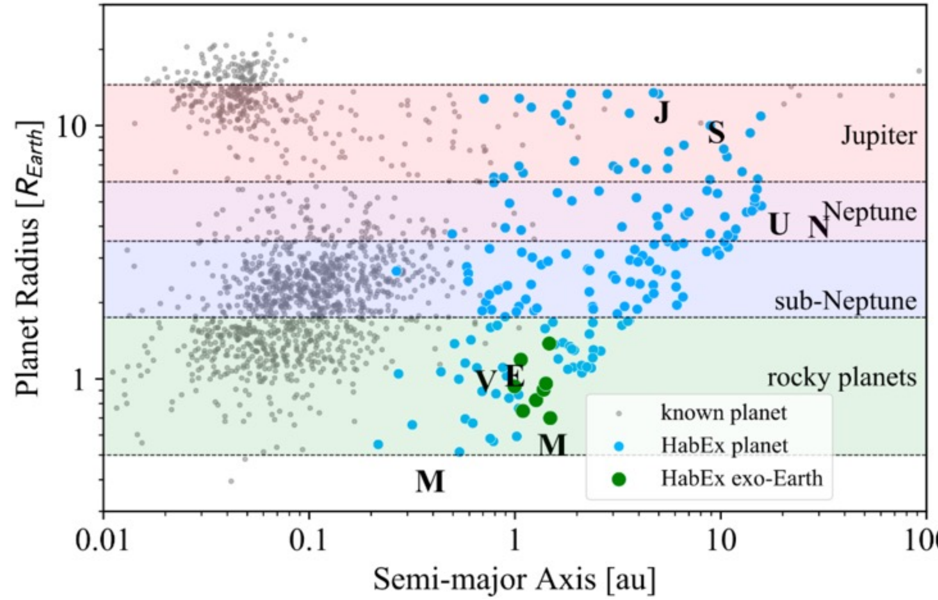
50%はミッションとしての系外惑星探査、50%がGOによる全分野の研究

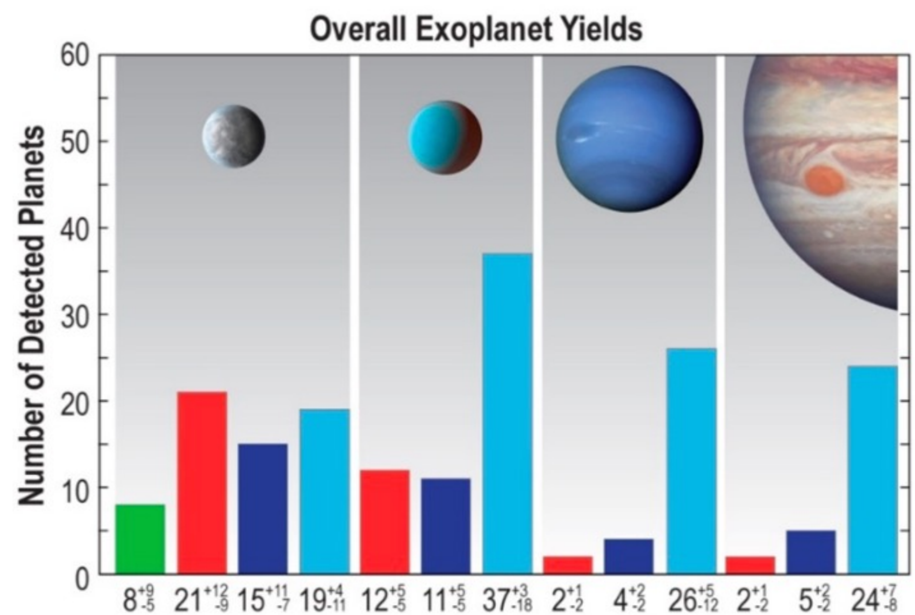


延長ミッション(5年)は100%がGOの観測となる

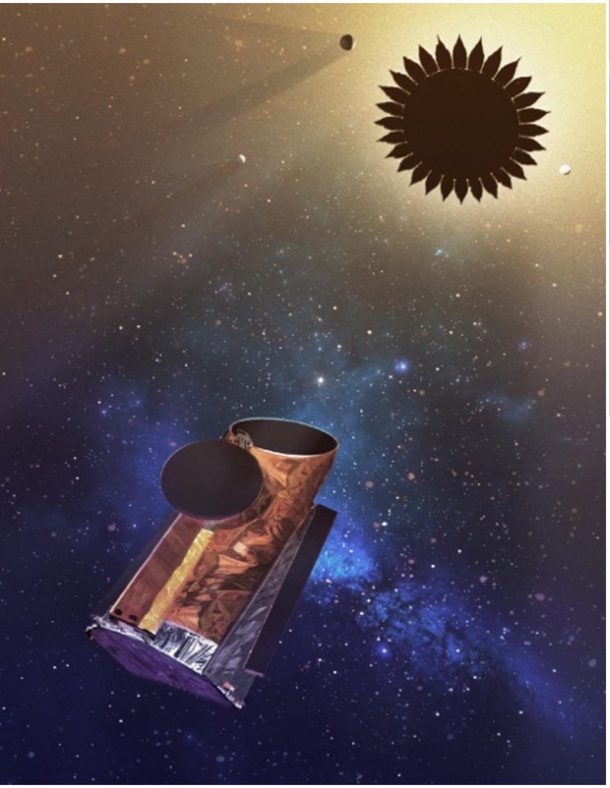
コロナグラフ(HCG)による近傍星の探査

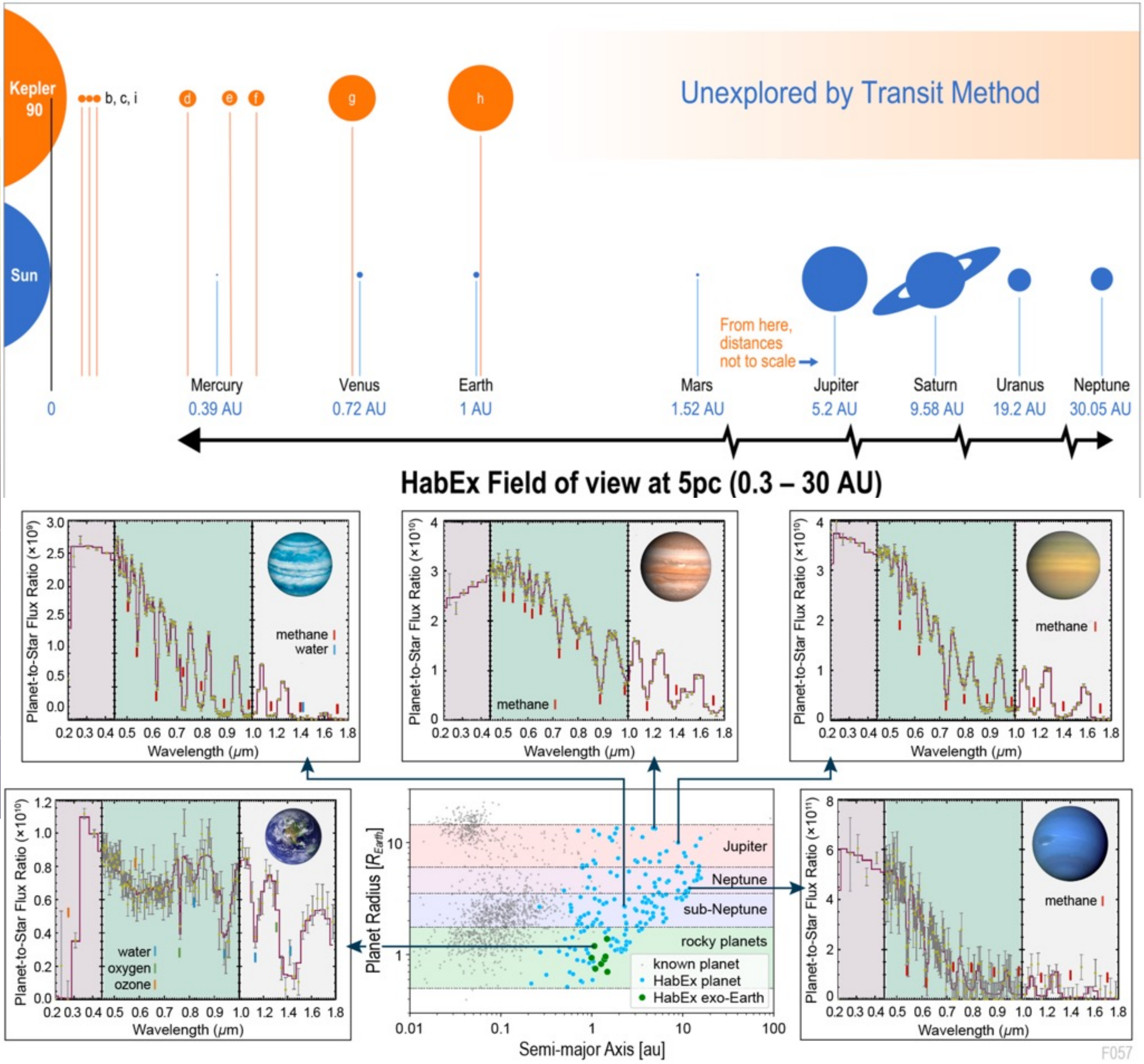




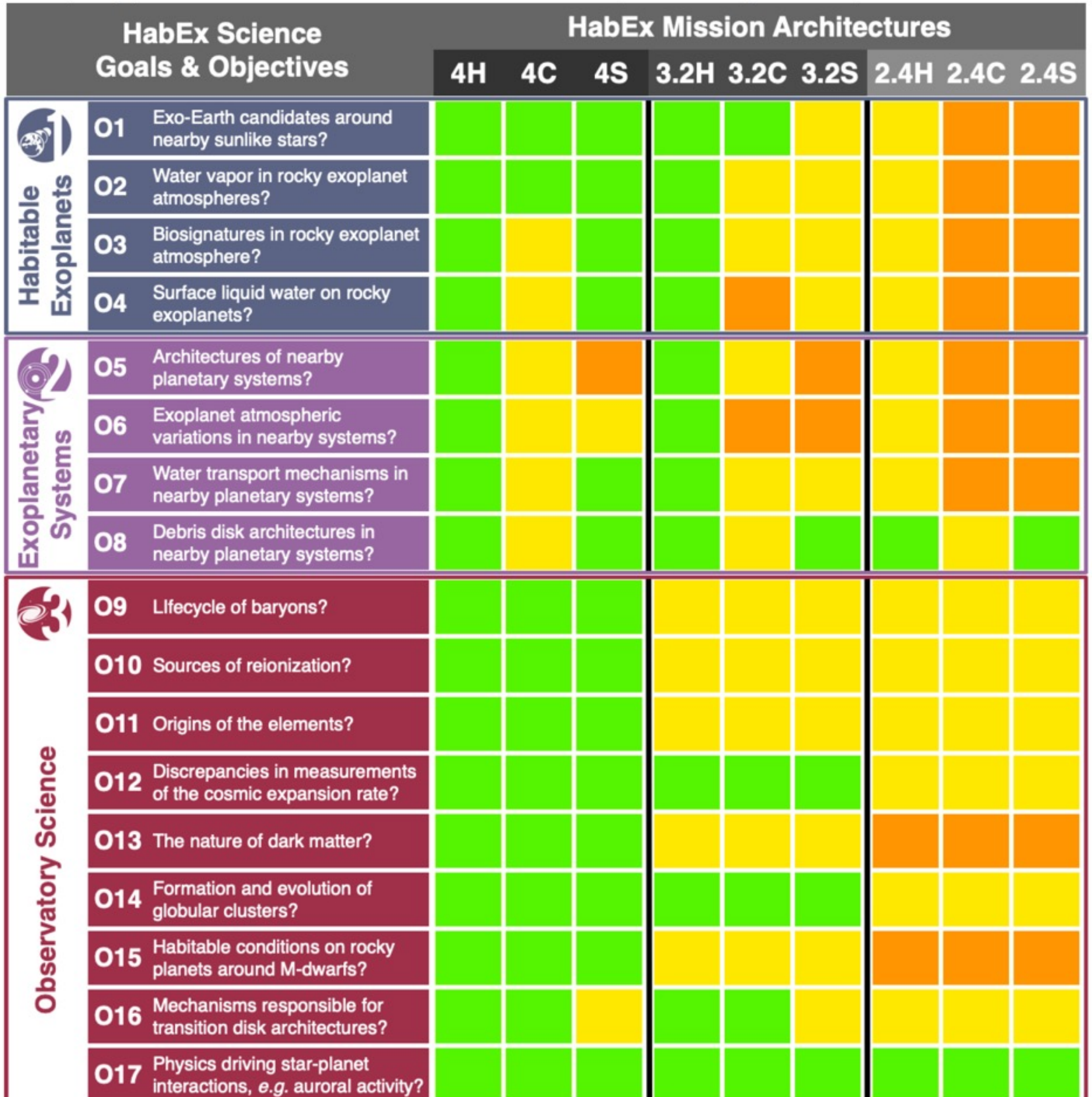


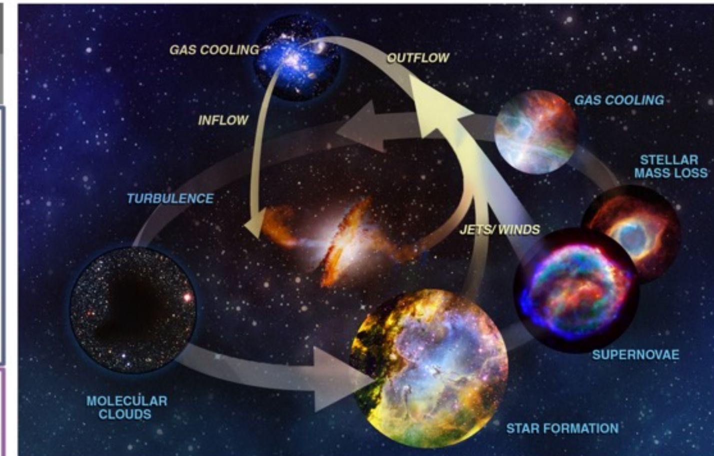
スターシェード(SSI)による特徴付け

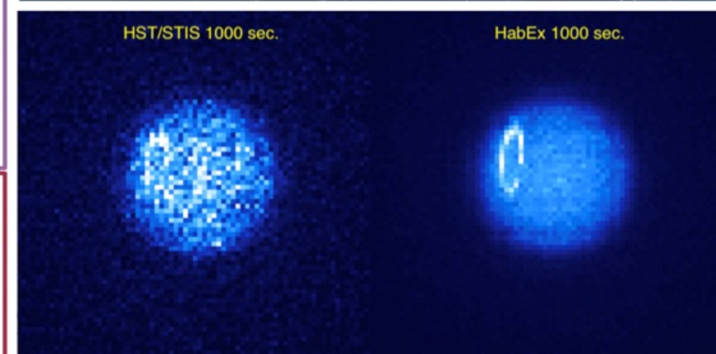




GOによる多様な宇宙物理学研究



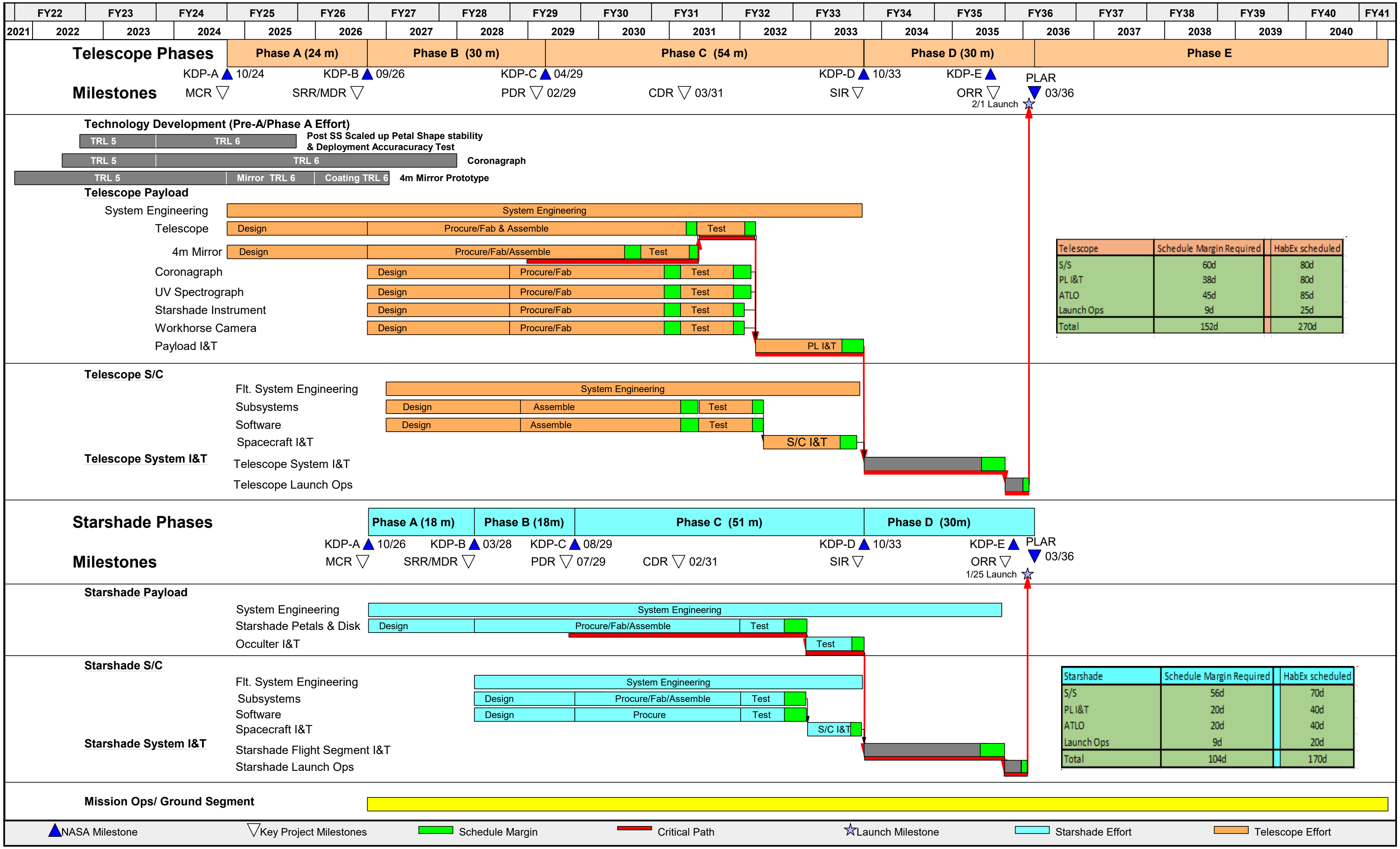




Observing Program	Estimated Time Required
O9. Baryon lifecycle	~6 weeks
O10. Metagalactic ionizing radiation	~4 weeks
O11. Massive stars	~3 weeks
O12. Hubble constant	~3 weeks
O13. Dark matter in dwarf galaxies	~2 weeks
O14. Globular clusters	~2 weeks
O15. Exoplanet transit spectroscopy	~1 week
O16. Transition disks	~1 week
O17. Solar system auroral activity	~1 week

タイムラインと緊急性(Astro2020の結果による)

2024年Phase A、2026年Phase B、2029年Phase C開始、2036年打ち上げ予定



Telescope	Schedule Margin Required	HabEx scheduled
S/S	60d	80d
PL I&T	38d	80d
ATLO	45d	85d
Launch Ops	9d	25d
Total	152d	270d

Starshade	Schedule Margin Required	HabEx scheduled
S/S	56d	70d
PL I&T	20d	40d
ATLO	20d	40d
Launch Ops	9d	20d
Total	104d	170d

Figure 9.3-1. The HabEx baseline schedule has been well-bounded by historical analogs. The critical path flows through the 4 m monolith telescope development.

HabExへの参加状況と各分野との連携

- HabExには日本から田村元秀(東大/ABC)がSTDTの議論に参加

International Ex-Officio Non-Voting Members
Christian Marois, NRC Canada (Canadian Space Agency, CSA, Observer)
David Mouillet, IPAG Grenoble (Centre National d'Etudes Spatiales, CNES, Observer)
Timo Prusti, ESA (European Space Agency, ESA, Observer)
Andreas Quirrenbach, Heidelberg University (Deutschen Zentrums für Luft- und Raumfahrt, DLR, Observer)
Motohide Tamura, University of Tokyo (Japanese Aerospace Exploration Agency, JAXA, Observer)
Pieter de Visser, Netherlands Institute for Space Research (SRON)

- 2019年10月にHabExのDeputy Study ScientistのAlina KiesslingがABCを訪問し、田村・成田らで対応
  - 日本からの貢献の意思と新UV検出器やコロナグラフ関連技術の紹介
- gopiraでの議論
  - 2019年にgopiraにLoIを提出
  - 2020年にLUVOIRと合同でWhite paperを提出、gopiraシンポジウムで紹介
  - Hubble, JWST後の汎用大型宇宙望遠鏡であり、系外惑星に限らず、広い宇宙物理学分野および太陽系科学分野と連携が期待される

実現性：技術リスクとその緩和策

現在全ての要素技術はTRL4以上、リスク緩和策によって技術的な実現性は問題ない見通し

Table 9.2-2. Highest impact HabEx risks and their mitigations.

Risk ID	if	due to	then	Consequence (Pre-Mitigation)	Likelihood (Pre-Mitigation)	Mitigation	Consequence (Post-Mitigation)	Likelihood (Post-Mitigation)
1. G-Release Error	The G-release error exceeds specifications	Inadequate characterization of gravity sag during fabrication	Static wavefront error degrades observations	3	3	Demonstrate ability to achieve 0 G surface during testing, corrective actuators during operations	3	1
2. Starshade Integration & Test	Delivery of the starshade is delayed	Complications during integration and test	Late completion of baseline mission	4	2	Starshade can be launched after the telescope and still meet science requirements	4	1
3. Starshade to TRL 5	Late demonstration of Starshade to TRL 5	Multiple development activities	The starshade spacecraft is delayed	4	2	Use slack in schedule, or delay the starshade development and launch	4	1
4. EMCCD Development	Late demonstration of EMCCD to TRL 6	Problems in development	direct imaging spectral band performance will be reduced	3	2	EMCCD not on the critical path – release technology development schedule slack	3	1
5. Microthruster Lifetime	The telescope microthrusters are not qualified to expected lifetime	Problems in lifetime testing	The telescope cannot launch	5	3	Use schedule slack to resolve the problems, or manifest additional microthrusters	5	1
6. SLS Launch Vehicle	The SLS Block 1B not available for HabEx	Unexpected development problems	The baseline telescope cannot be launched	5	2	Launch the telescope on an alternate launch vehicle	5	1
7. Foreign Contribution	The ESA contribution does not materialize	Formal agreement not in place	The HabEx total cost increases	3	2	Release cost reserve equivalent to contribution	3	1

Category \ # of Enabling Tech.	2019		2020 (estimated)		2023 (estimated)		
	TRL 4	TRL 5	TRL 4	TRL 5	TRL 4	TRL 5	TRL 6
Starshade	3	2	2	3	0	4	1
Large Mirror	2	0	2	0	1	1	0
Metrology	0	1	0	1	0	0	1
Coronagraph	3	0	2	1	0	3	0
Detectors	4	0	4	0	1	3	0
Microthrusters	1	0	0	1	0	1	0
Total	**13**	**3**	**10**	**6**	**2**	**12**	**2**

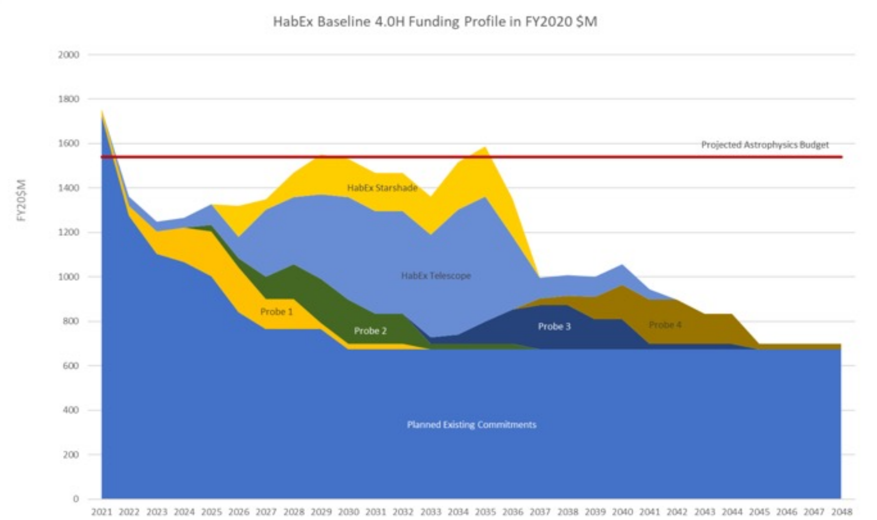
Rating	Consequence	Likelihood
1	Minimal	Remote
2	Small	Unlikely
3	Moderate	Possible
4	Significant	Likely
5	Complete Loss	Very Likely

実現性：総コストとコストプロファイルの見通し

予備費を含めて総額 ~$7.4B (インフレと海外からの貢献分を含まず)

Table 9.4-1. HabEx cost summary.

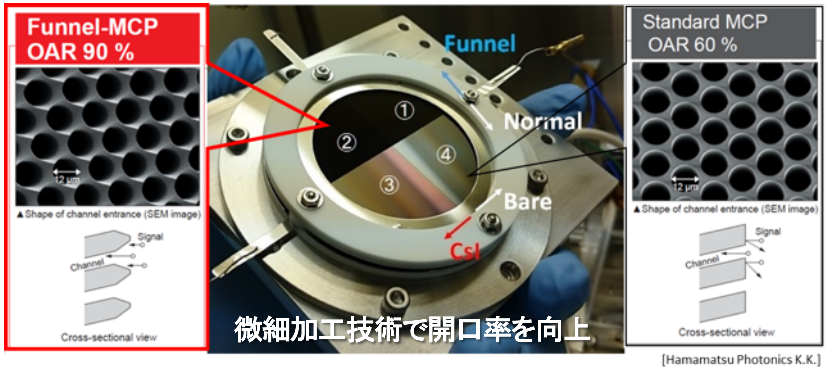
WBS Element	FY20$M	RY$M	Cost Basis
Pre-Phase A	**59**	**64**	Based on cost needed to advance technologies to TRL 5
Phase A	**211**	**253**	Based on cost needed to advance technologies to TRL 6
WBS 01–03 Proj Mgmt/Sys Eng (incl Mssn Design)/SMA	444	589	Percentage based on Flagship-class missions
WBS 04 Science	113	150	Percentage based on Flagship-class missions
WBS 05 Payload System	1996	2643	
P/L Mgmt/Sys Eng	136	180	Percentage based on Flagship-class missions
Coronagraph	447	591	NICM VIII System Model
Starshade Camera	119	158	NICM VIII System Model
UV Spectrograph	257	340	NICM VIII Subsystem Model
Telescope (OTA)	659	872	Average of Phil Stahl 2019 Multivariable and 2013 Single Variable equation
Fine Guider	29	38	NICM VIII System Model
Workhorse Camera	180	238	NICM VIII System Model
Starshade Petals and Disk	170	227	SEER-H Modeled Cost
WBS 06 Flight System + 10 ATLO	1724	2291	
Telescope Bus	1045	1382	Team X Study, includes Mgmt, SE and ATLO for Telescope Bus
Starshade Bus	680	908	Team X Study estimate for 72 m starshade bus, includes Mgmt, SE and ATLO for Telescope Bus
WBS 07/09 MOS/GDS	85	113	Team X Study
Phase B-D Subtotal	**4363**	**5785**	
Reserves (B–D)	1309	1736	30% reserves
Phase B-D w/ reserves	**5672**	**7521**	
LV (Telescope)	650	925	Costs provided by NASA
LV (Starshade)	300	429	Costs provided by NASA
Phase B-D w/ LV	**6622**	**8875**	
ESA Contribution	-565	-747	
Total Phase B-D w/ contribution	**6057**	**8128**	
Operations (Phase E–F)	400	609	Based on average operations cost for HST and WFIRST
Phase E–F Reserves	60	91	15% reserves
Total Phase E-F	**460**	**701**	
Total Pre-Phase A-F	**6786**	**9145**	



NASA Astrophysics cost profileにほぼ収まる予算規模と年次計画となっており、既存の計画や今後のProbe-class missionを妨げることがない

日本からの貢献

- 2025年頃打ち上げ予定のNASAのRoman宇宙望遠鏡と、ロシアの紫外線宇宙望遠鏡WSO-UVへの参加により国際スペース計画への参加の実経験を積み、それを2030年代の大型計画に活かす
- 具体的なハードウェア貢献の可能性（以下で合計100億円程度）
  - Romanのヘリテージ
    - 偏光器・偏光補償光学系
    - コロナグラフマスク光学系
      - Roman用の基盤・レンズ製作中。独自コロナグラフ構想は20年前のJTPFから
  - WSO-UVのヘリテージ
    - 紫外線観測装置
    - 紫外線新型検出器
    - 紫外線高効率グレーティング
      - ひさき、WSO-UVの実績。Funnel MCPなど日本独自技術の貢献が可能



[Hamamatsu Photonics K.K.]

まとめ

- HabExは2030年代のNASAの旗艦宇宙望遠鏡計画のひとつ
  - 近傍の太陽型星周りの地球類似惑星の直接撮像分光
  - 近傍の惑星系の多様性と全体像の理解
  - GOによる多様な宇宙物理学研究
  - gopiraおよび太陽系科学にまたがる多様なサイエンスを実現
  - 技術的な実現可能性は高く、費用的にもNASAのcost profileと整合的

- 日本単独では不可能な計画で、日本の参加が強く望まれる
  - Astro2020で推薦を受けた場合、2024年にPhase A開始を予定
  - 日本の正式参加に向けて早期のマスタープラン掲載が望ましい