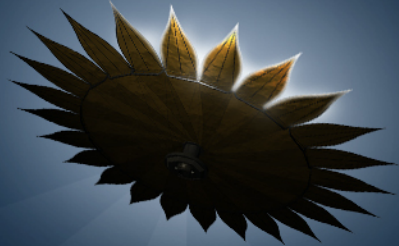
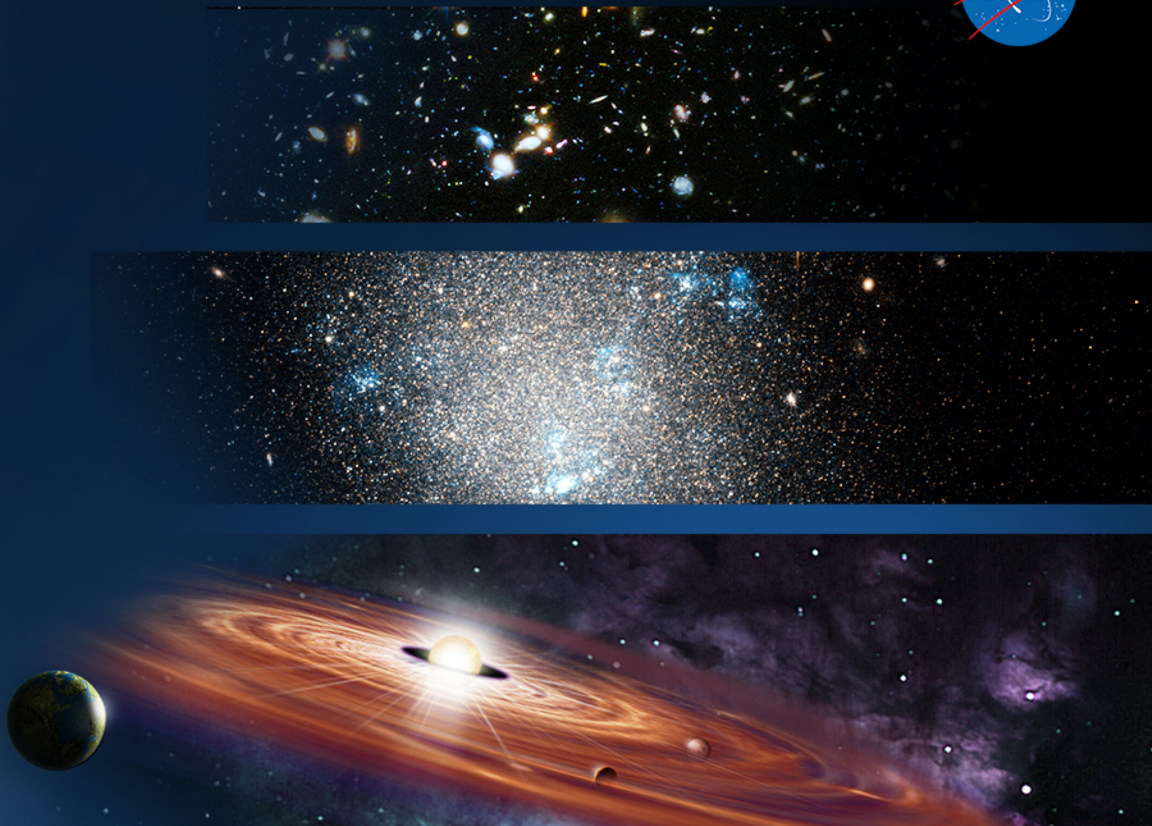


HabEx

Habitable Exoplanet Observatory



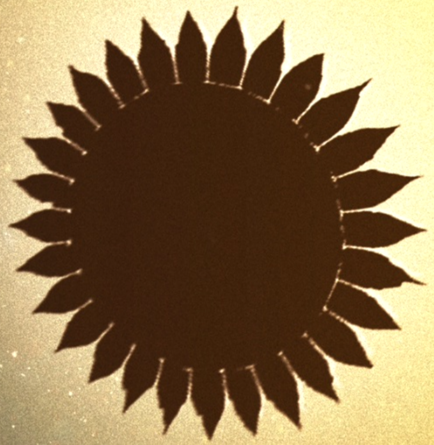
HabEx Cost Development and Risk Management

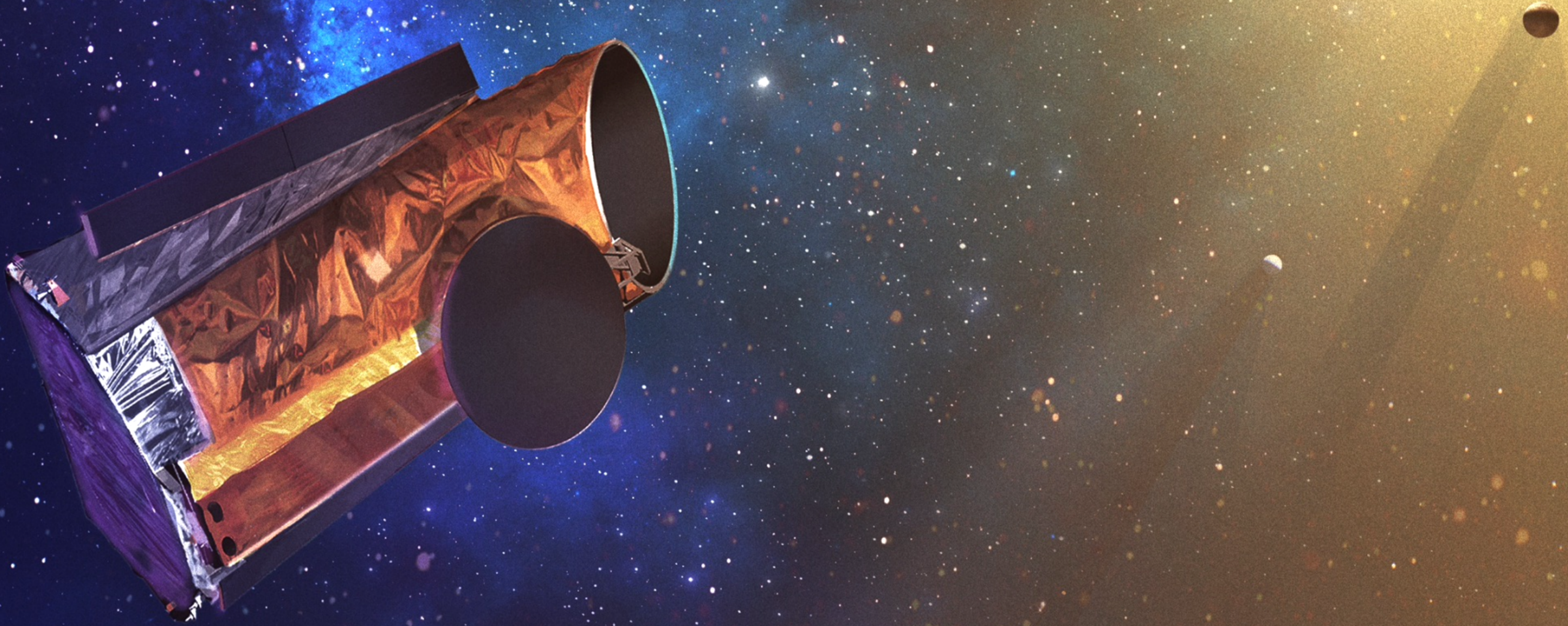
Keith Warfield, HabEx Study Manager
Jet Propulsion Laboratory, California Institute of Technology

HabEx

Is HabEx's Revolutionary Science Reachable Now?

- Will the technologies be ready in time for the mission?
- Does the technical design meet requirements?
- Are the risks manageable?
- Are the costs realistic and affordable?





Study Flexibility

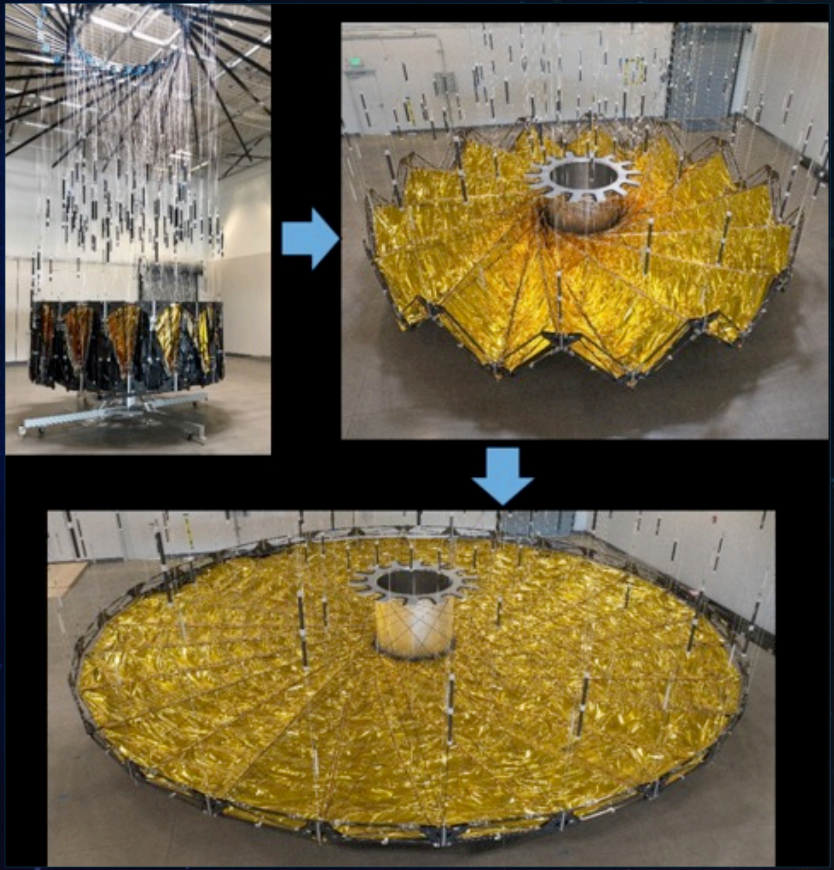
The trade between performance, cost and risk gives HabEx flexibility for the future.

HabEx Science Goals & Objectives		HabEx Mission Architectures								
		4H	4C	4S	3.2H	3.2C	3.2S	2.4H	2.4C	2.4S
1 Habitable Exoplanets	O1 Exo-Earth candidates around nearby sunlike stars?	green	green	green	green	green	yellow	yellow	red	red
	O2 Water vapor in rocky exoplanet atmospheres?	green	green	green	green	yellow	yellow	yellow	red	red
	O3 Biosignatures in rocky exoplanet atmosphere?	green	yellow	green	green	yellow	yellow	yellow	red	red
	O4 Surface liquid water on rocky exoplanets?	green	yellow	green	green	red	yellow	yellow	red	red
2 Exoplanetary Systems	O5 Architectures of nearby planetary systems?	green	yellow	red	green	yellow	red	yellow	red	red
	O6 Exoplanet atmospheric variations in nearby systems?	green	yellow	yellow	green	red	red	yellow	red	red
	O7 Water transport mechanisms in nearby planetary systems?	green	yellow	green	green	yellow	yellow	yellow	red	red
	O8 Debris disk architectures in nearby planetary systems?	green	yellow	green	green	yellow	green	green	yellow	green
3 Observatory Science	O9 Lifecycle of baryons?	green	green	green	yellow	yellow	yellow	yellow	yellow	yellow
	O10 Sources of reionization?	green	green	green	yellow	yellow	yellow	yellow	yellow	yellow
	O11 Origins of the elements?	green	green	green	yellow	yellow	yellow	yellow	yellow	yellow
	O12 Discrepancies in measurements of the cosmic expansion rate?	green	green	green	green	green	green	yellow	yellow	yellow
	O13 The nature of dark matter?	green	green	green	yellow	yellow	yellow	red	red	red
	O14 Formation and evolution of globular clusters?	green	green	green	green	green	green	yellow	yellow	yellow
	O15 Habitable conditions on rocky planets around M-dwarfs?	green	green	green	yellow	yellow	yellow	red	red	red
	O16 Mechanisms responsible for transition disk architectures?	green	green	yellow	green	green	yellow	yellow	yellow	yellow
	O17 Physics driving star-planet interactions, *e.g.* auroral activity?	green	green	green	green	green	green	green	green	green
Estimated Cost ($B FY20)		6.8	4.8	5.7	5.7	3.7	5.0	4.8	3.1	4.0
Number of TRL4 technologies		13	10	9	12	9	9	11	8	8

Risks

Risks: Starshade Development

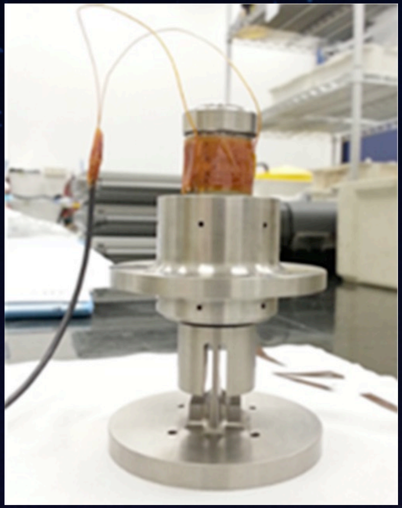
- Risk: Starshade TRL-5 development could run into a problem
- Consequence: Could delay HabEx mission
- Mitigations:
  - The starshade TRL 5 schedule carries nearly 3 years of slack
  - TRL 5 schedule could be accelerated with additional funding
  - The starshade could be launched later than the telescope if slack is insufficient
- Risk: Starshade I&T could run into scale-related problems
- Consequence: Could delay HabEx mission and cause cost overruns
- Mitigation: Debug I&T problems with a full-scale TRL 6 prototype before PDR

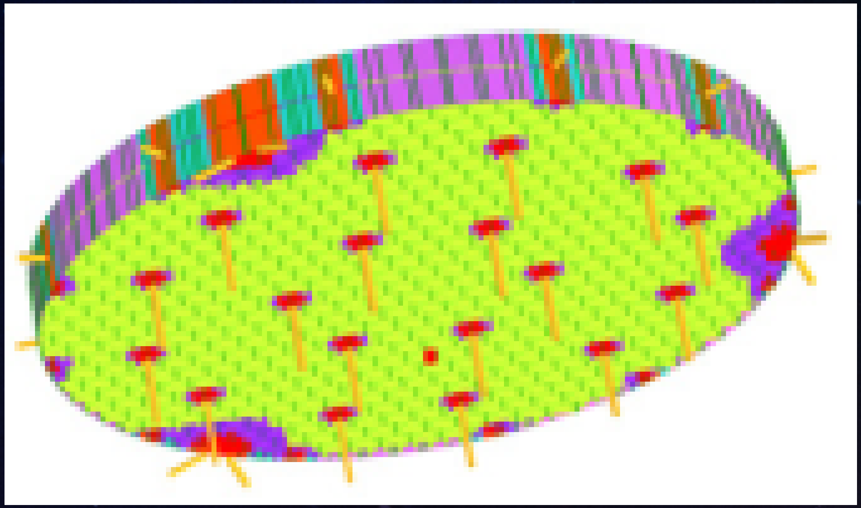


Starshade ½ scale prototype truss and inner disk deployment test

Risk: Gravity-Release

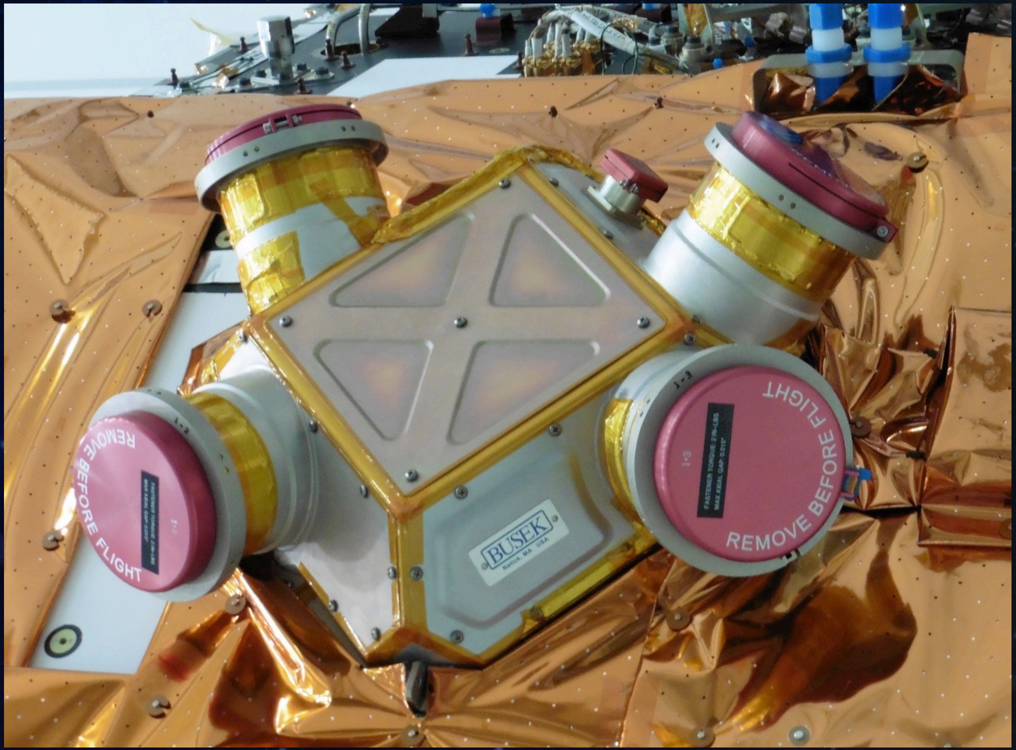
- Risk: The 4 m mirror’s on-orbit gravity-release error may be greater than modeled
- Consequence: Coronagraph DMs will not have enough stroke to compensate and contrast performance will be degraded
- Mitigations:
  - Full scale prototyping with ground-based testing
  - Piezo-actuators behind primary mirror as a back-up safeguard


AMTD fine stage actuator


18-axial primary mirror launch constraint/actuation points

Risk: Microthruster Lifetime

- Risk: Microthrusters cannot reliably operate through the end of the mission due to throughput performance
- Consequence: The Habex mission will not be able to observe for the entire 10-year design life
- Mitigations:
  - Ground-based throughput testing
  - Add more microthrusters to the baseline design
- Note: Microthrusters have flown in space. They are at TRL 4 only because of HabEx's 10 year lifetime



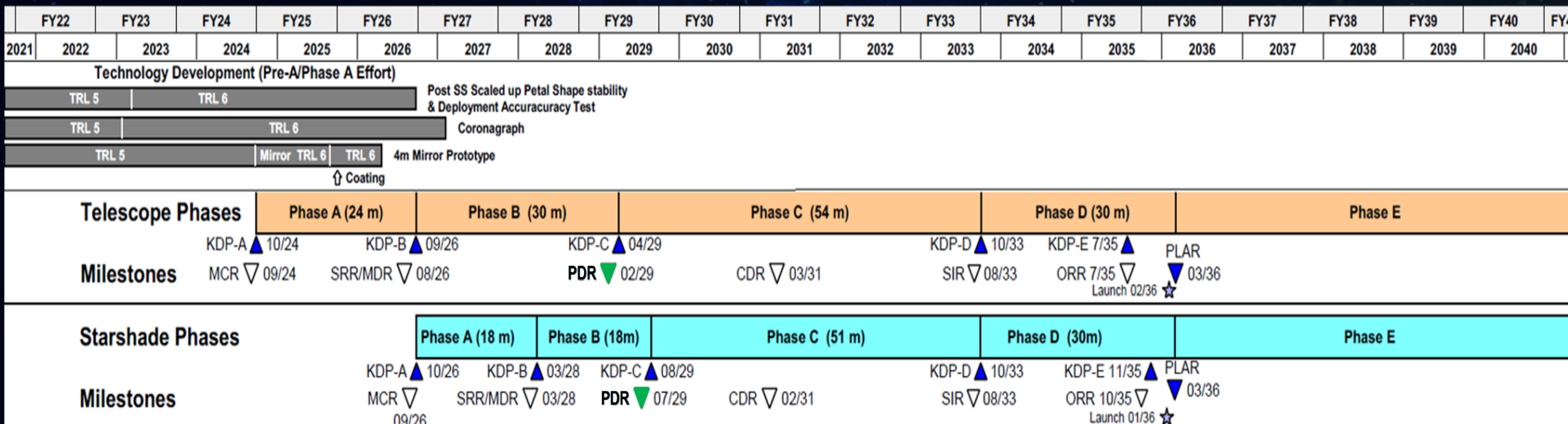
LISA-Pathfinder colloidal microthrusters

Cost and Schedule

Cost and Schedule Estimation Process

- Design
  - A cost engineer and scheduler were part of the HabEx design team
  - Cost and schedule were used in the design trade process
- Estimation
  - Schedule developed using historical analogies
  - Costs were largely developed parametrically
- Review
  - Crosscheck estimate results with analogues and actual costs were possible
  - Held internal reviews with JPL management
  - Independent assessment team evaluated the reasonableness of the cost and schedule

Schedule



Missions	Phase A	Phase B	Phase C	Phase D[1]	Total Start–LRD
HabEx	24	30	54	29	**137**
Average	**21**	**23**	**32**	**48**	**123**
WFIRST	24	23	46	28	**121**
JWST	21	20	25	132	**198**
Spitzer	4	18	42	23	**87**
Chandra	19	36	13	42	**110**
HST	4	17	32	98	**151**

Cost Estimate and Basis

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 (inc 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 Bus
Starshade Bus	680	908	Team X Study, includes Mgmt, SE and ATLO for 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**	

- Total cost: $6.8B FY20$
- Includes an assumed $565M ESA contribution
- Parametric models used to estimate scientific instruments and starshade occulter
- Percentage wrap factors based on JPL flagship missions (Cassini, Spitzer, MSL, Juno) used to estimate level of effort (LOE) tasks
- Team X used to estimate Spacecraft Buses, ATLO, and MOS GDS

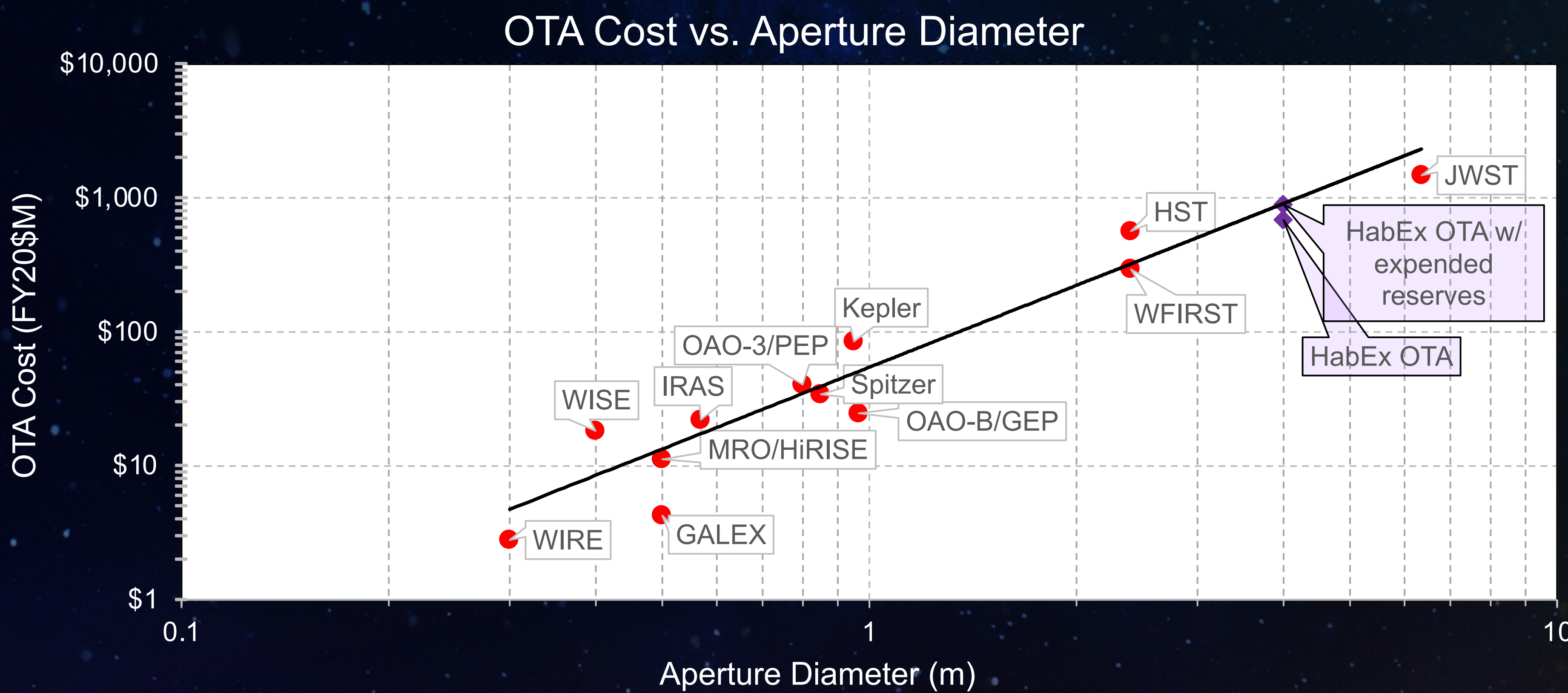
Validation—LOE Percentages

HabEx LOE WBS percentages for Phases B–D are in family with other JPL large projects.

WBS	WBS Element	HabEx	MSL	SMAP	Cassini	Juno
01, 02, 03, 12	PM, SE, MA, MD	10.2%	10.8%	9.4%	9.2%	11.1%
04	Science	2.6%	1.0%	3.3%	2.6%	3.3%
05.01, 05.02	PL Mgmt, SE*	6.8%	7.1%	5.8%	5.8%	7.7%

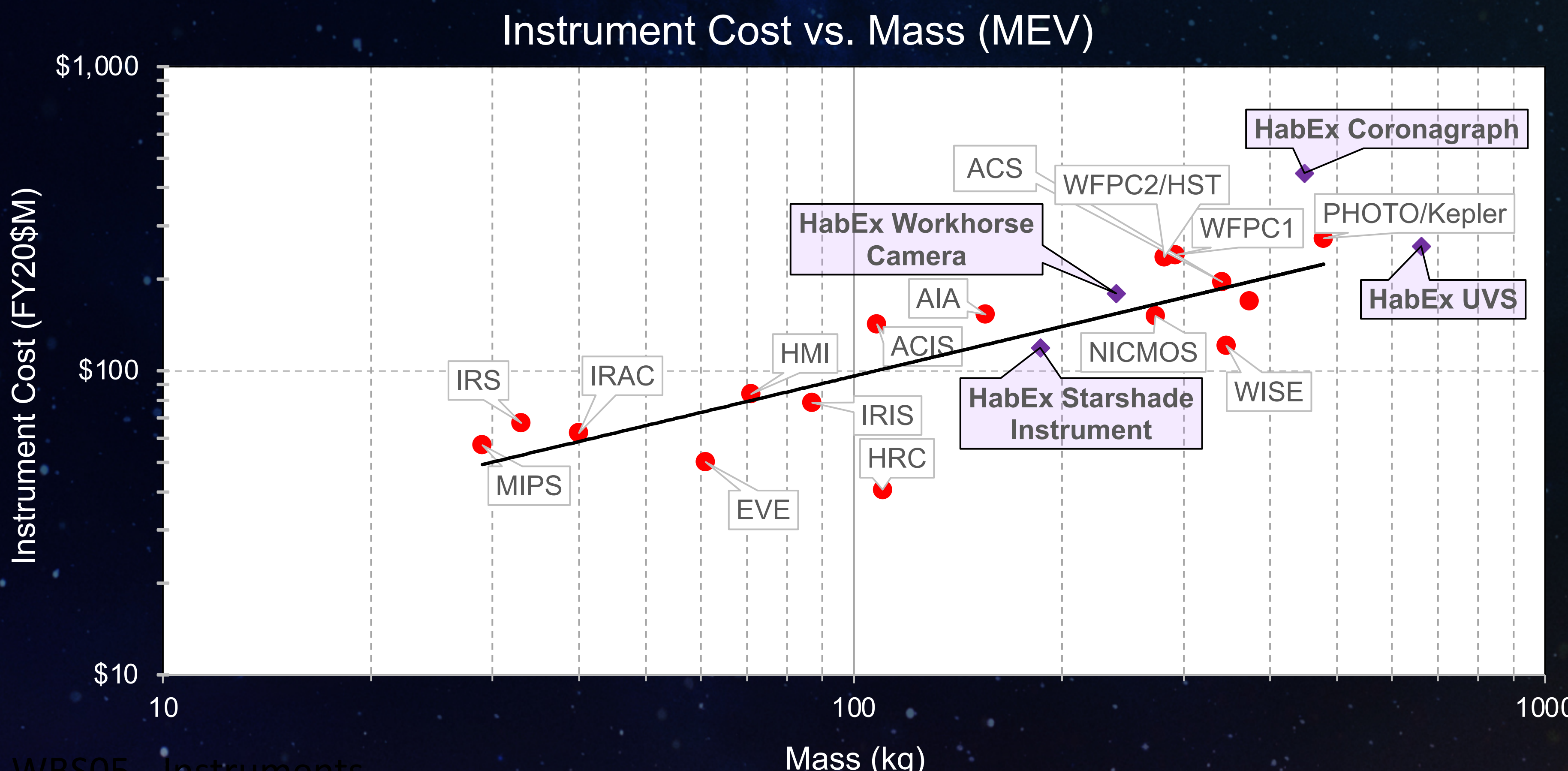
*PL Mgmt and SE are calculated as a cost ratio to the payload total cost

Validation—Telescope



WBS05 - Telescope

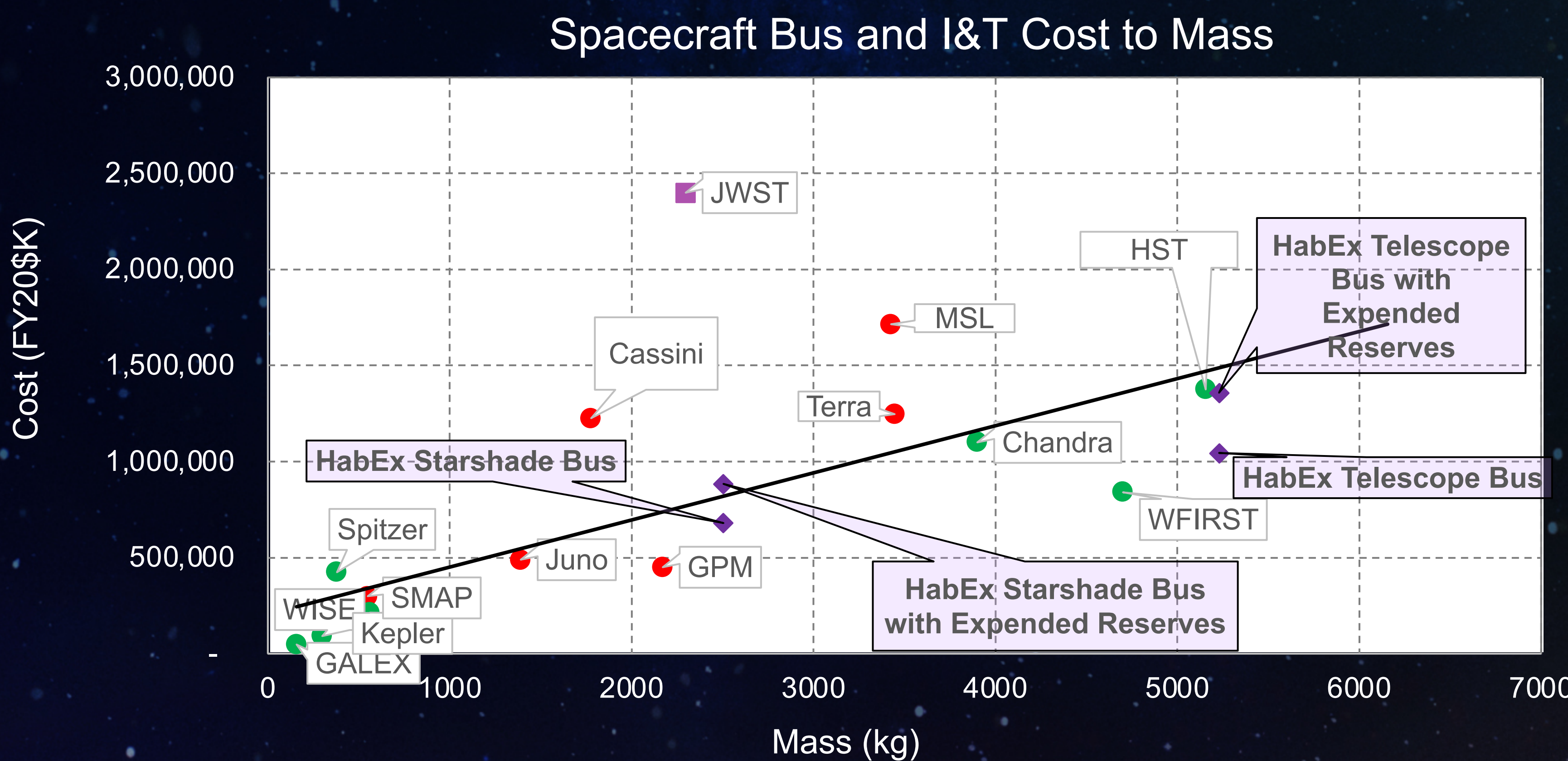
Validation—Instruments



WBS05 - Instruments

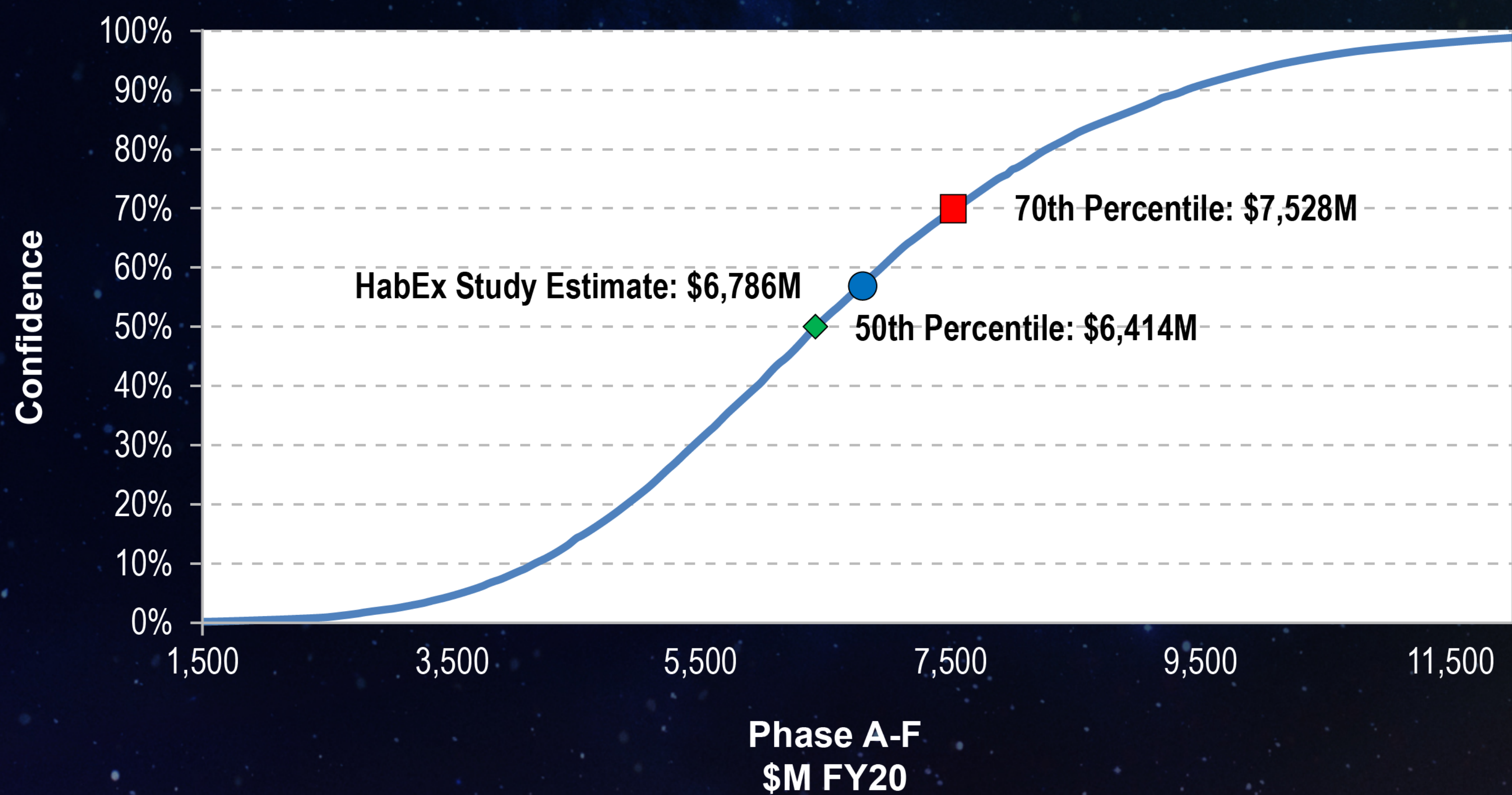
WBS05 - Instruments

Validation—Spacecraft Bus and I&T



WBS06 + WBS10

Independent Assessment Supports the HabEx Study Cost Estimate

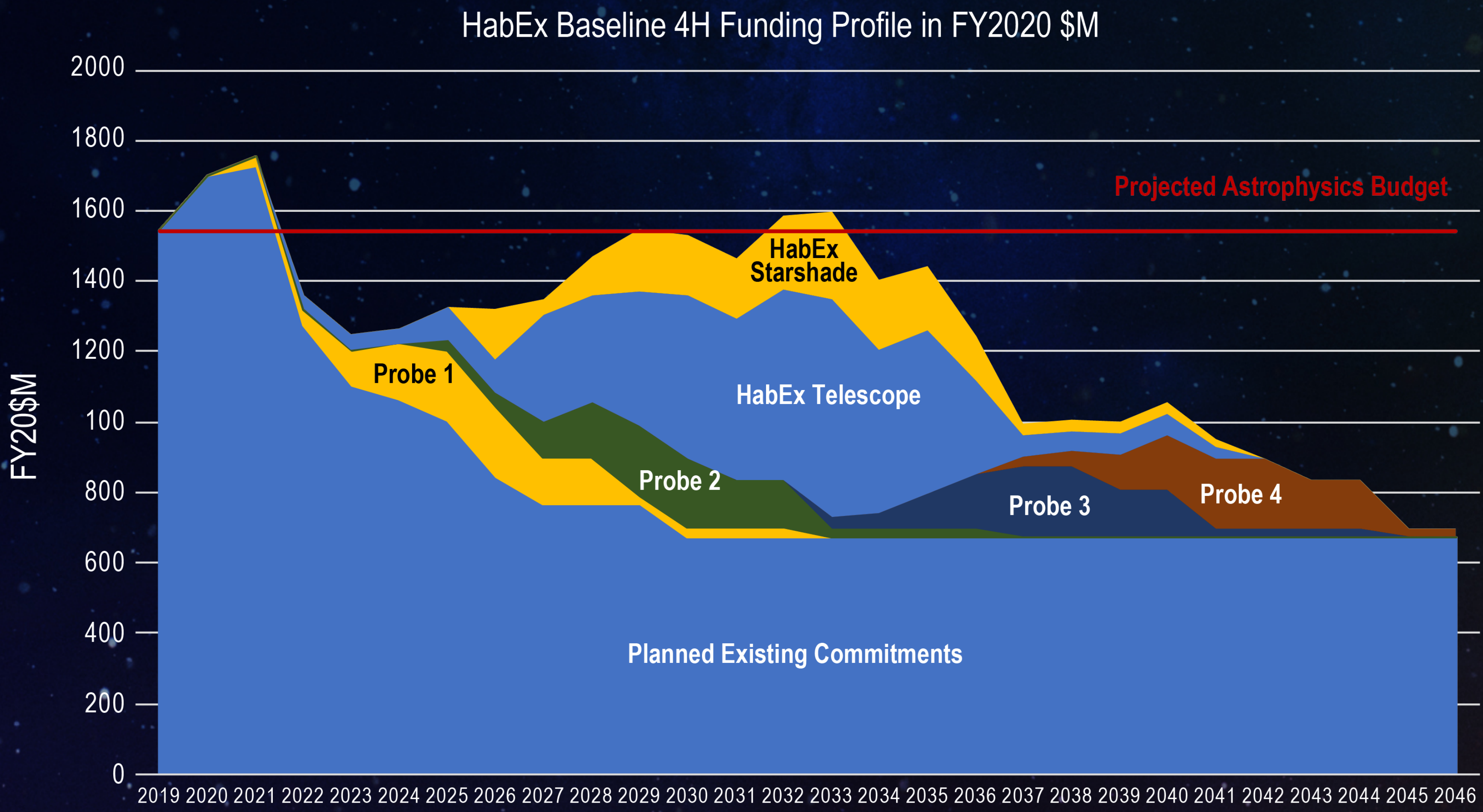


HabEx

Affordable Costs

NASA

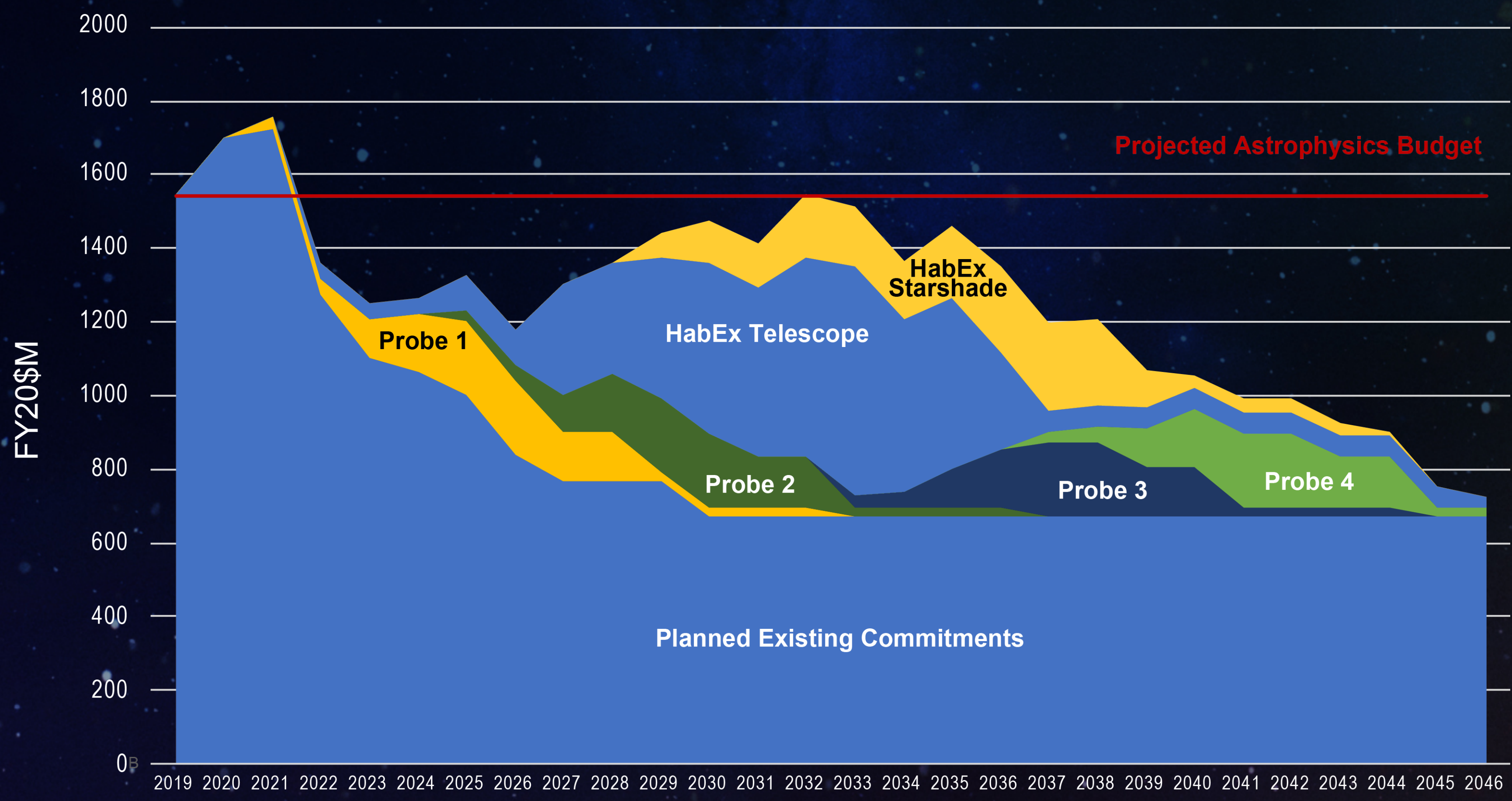
HabEx is affordable at current funding levels with 2 new Probes per decade.



Flexible Costs

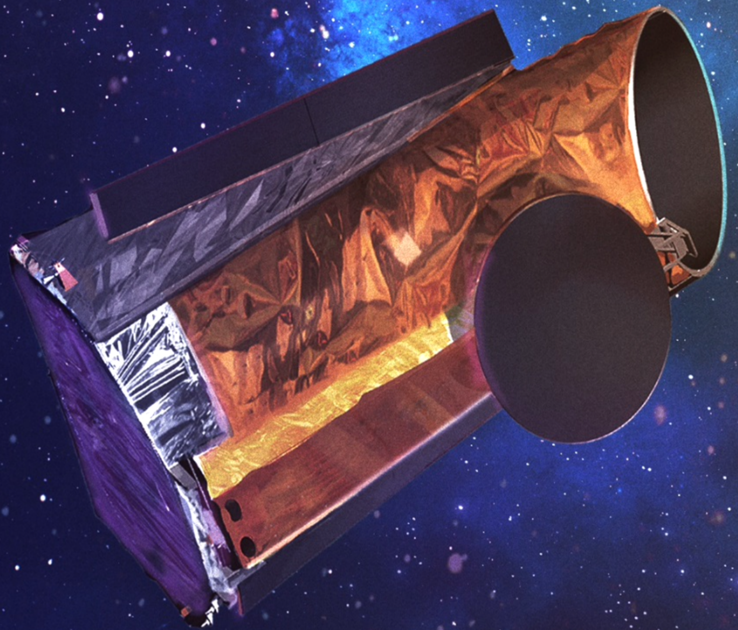
HabEx can accommodate unexpected cost growth with a starshade launch delay…

HabEx Delayed Launch 4H Funding Profile FY20$M



Is HabEx's Revolutionary Science Reachable Now?

- Technologies are maturing quickly and will be at TRL 6 two years before the start of mission development
- Technical design is meeting requirements as shown in simulations and analyses
- Major risks have been identified and can be mitigated
- Costs are consistent with historic analogs and affordable at current funding levels



Backup

Risk: SLS Availability

Baseline requires the SLS-1B or the Falcon Starship for mass and volume reasons

- Mitigations:
  – Both vehicles now in development; due to launch in 2021
  – Only the HabEx 4H and 4C architectures need the SLS or the Starship

Does a 26 m S5 Starshade Qualify a 52 m to TRL 5?

- Subscale article testing is permitted for TRL 5
- A 52 m HabEx starshade prototype will be constructed to reach TRL 6
- Commercial perimeter-trusses up to 22 m are currently available—HabEx needs a 20 m truss
  - At least 10 perimeter trusses on orbit. No failures.

Starshade 10 m perimeter truss with four 3.5 m petals