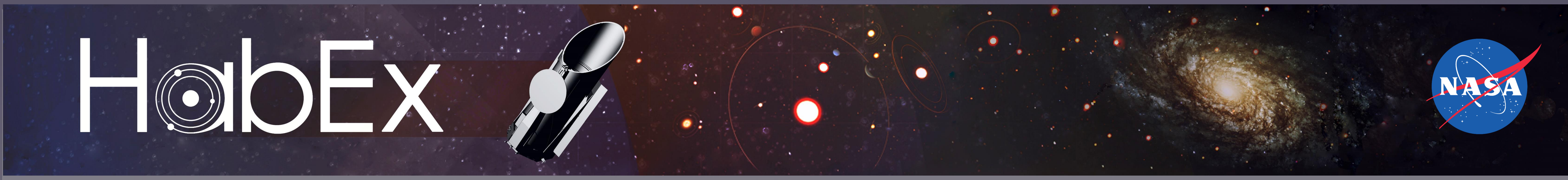

HABEX BASELINE OPTICAL TELESCOPE ASSEMBLY

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With MSFC HabEx Telescope Design Team, JPL HabEx Study Team and HabEx Science and Technology Definition Team

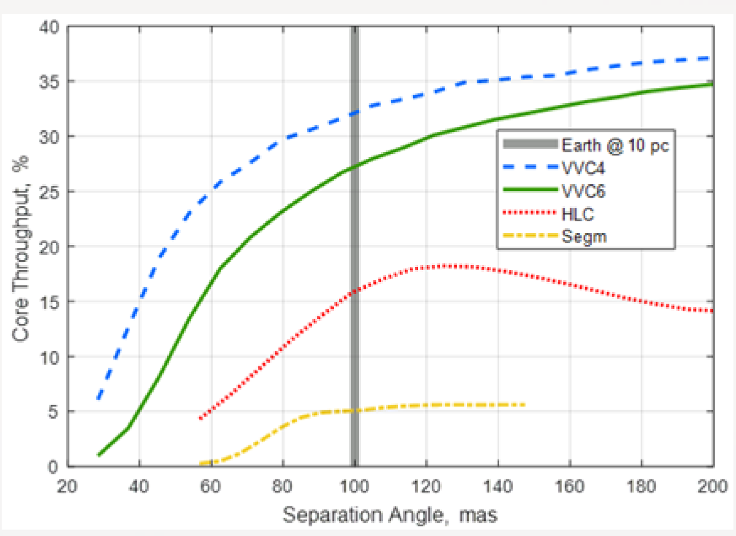
INTRODUCTION

The Habitable Exoplanet Observatory Mission (HabEx) will image and spectroscopically characterize planetary systems in the habitable zone around nearby sun-like stars. Additionally, HabEx will perform a broad range of general astrophysics science enabled by 100 to 2500 nm spectral range and 3 x 3 arc-minute FOV. Critical to achieving the HabEx science goals is a large, ultra-stable telescope. The baseline HabEx telescope is a 4-m off-axis unobscured three-mirror-anastigmatic design with diffraction limited performance at 400 nm and wavefront stability of picometers per mK. These specifications are driven by science requirements. STOP (structural thermal optical performance) analysis predicts that the baseline telescope's opto-mechanical design meets its specified performance tolerances.

DESIGN ENABLES EXOPLANET IMAGING

Exoplanet science drives the choice of an off-axis architecture, aperture diameter and primary mirror F/#. General astrophysics' desire for a 3 x 3 arcminute field of view (FOV) drives the choice of a three mirror anastigmatic (TMA) optical design and spectral range. Both exoplanet and general astrophysics science need 400 nm diffraction limited. Coronagraphy drives the wavefront stability specification.

The baseline HabEx off-axis aperture telescope with vector-vortex coronagraph enables imaging of habitable zone exoplanets by producing a dark hole with a small inner working angle and a large core throughput.

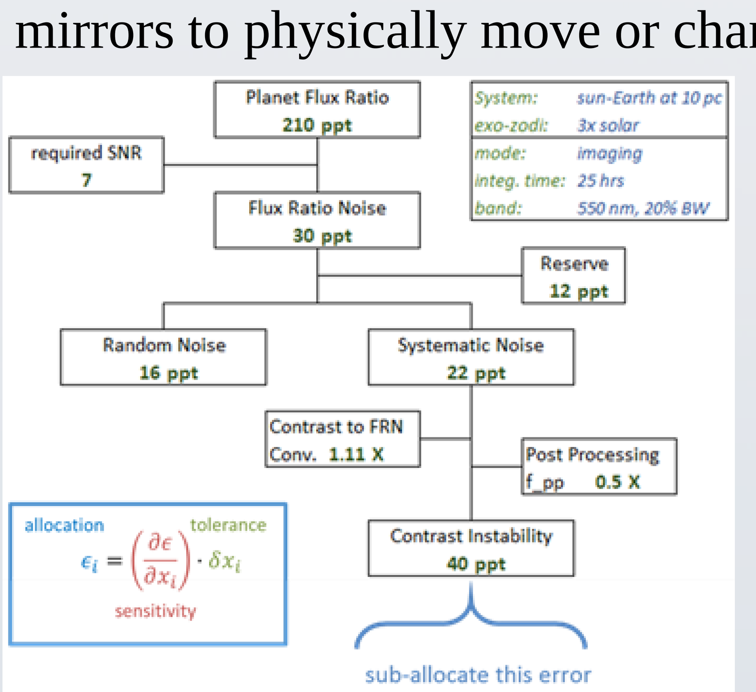


Left: Core throughput for 4 different coronagraphs: vector-vortex charge 4 (VVC4), VVC6 and hybrid Lyot (HLC) with the HabEx baseline 4-meter off-axis unobscured telescope; and, for a 6-m on-axis segmented primary mirror telescope (i.e. JWST) with an apodized pupil Lyot coronagraph (APLC)

WAVEFRONT (WFE) STABILITY

Imaging habitable zone exoplanets using a coronagraph requires an ultra-stable wavefront. Temporal or dynamic change in WFE can result in dark-hole speckles that produce a false exoplanet measurement or mask a true signal.

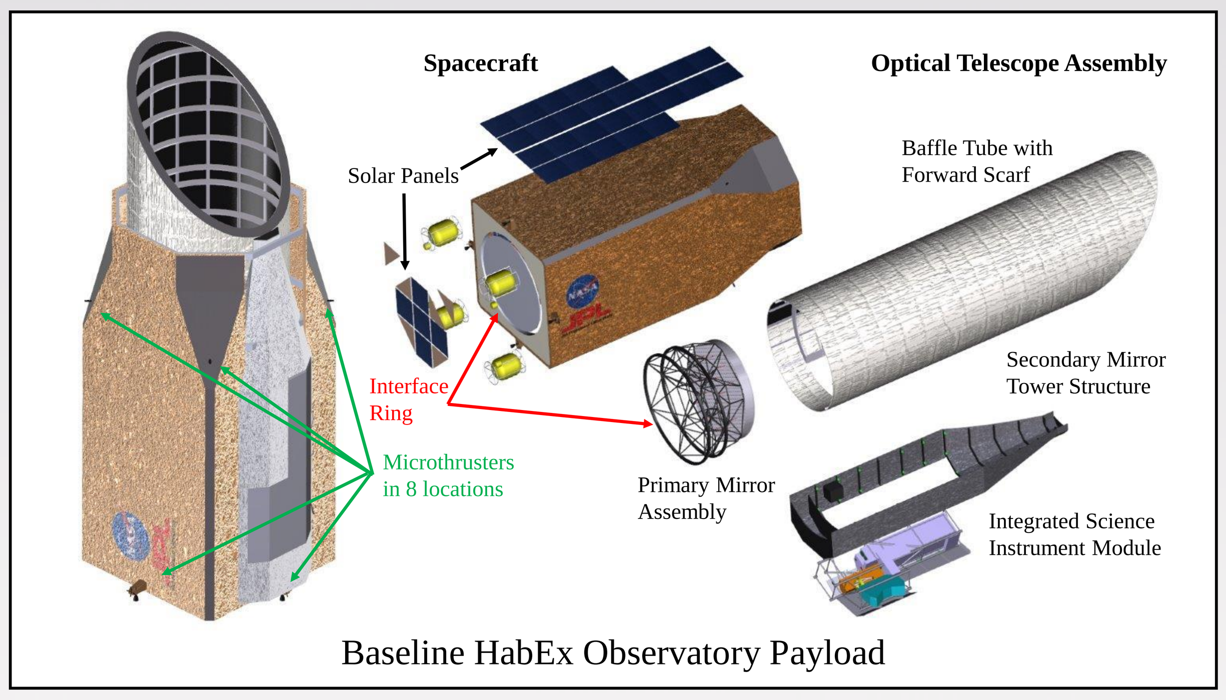
WFE instability come from many sources – mechanical and thermal. Line of sight (LOS) WFE occurs when LOS drift or jitter moves the wavefront laterally on the secondary or tertiary mirror. Because the mirrors are conics, beam-shear produces low-order astigmatism and coma WFE (shear of spherical is coma and sub-aperture coma appears to be astigmatism). Inertial WFE occurs when the primary mirror is accelerated by mechanical disturbances causing it to react (i.e. bend) against its mounts. Thermal WFE occurs when the temperature of the structure or mirrors changes, causing the mirrors to physically move or change shape due to CTE homogeneity.



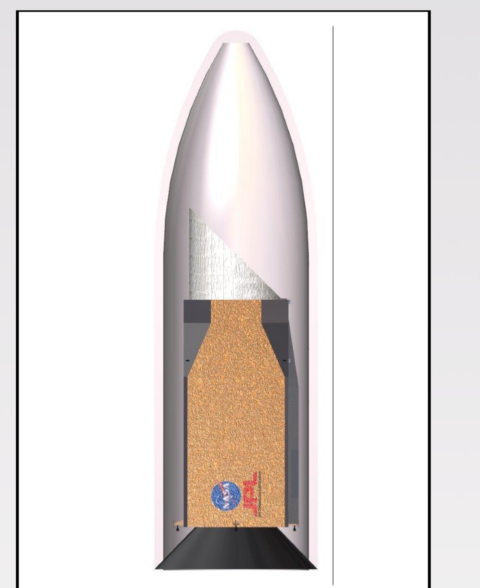
Left: WFE stability error budget was derived from the total allowable coronagraph leakage which enables the detection, at a defined signal to noise ratio, of an exoplanet with a given flux ratio relative to its host star by a coronagraph with specific noise properties. To bound the telescope design, performance specifications were defined for a Vector Vortex Charge 4 Coronagraph.

BASELINE TELESCOPE

WFE stability requires an ultra-stable opto-mechanical telescope. The baseline architecture achieves this level of performance because of the mass and volume capacities of the planned Space Launch System (SLS). SLS mass capacity enables the design of an extremely stiff opto-mechanical structure that can align the primary, secondary and tertiary mirrors to each other and maintain that alignment. And, SLS volume capacity enables a monolithic aperture off-axis primary mirror with no deployments. A fundamental rule for the telescope design was that every proposed system, subsystem or component should be at TRL-6 or higher except for the primary mirror assembly and science instruments. The resulting design is extremely robust.



Baseline HabEx Observatory Payload



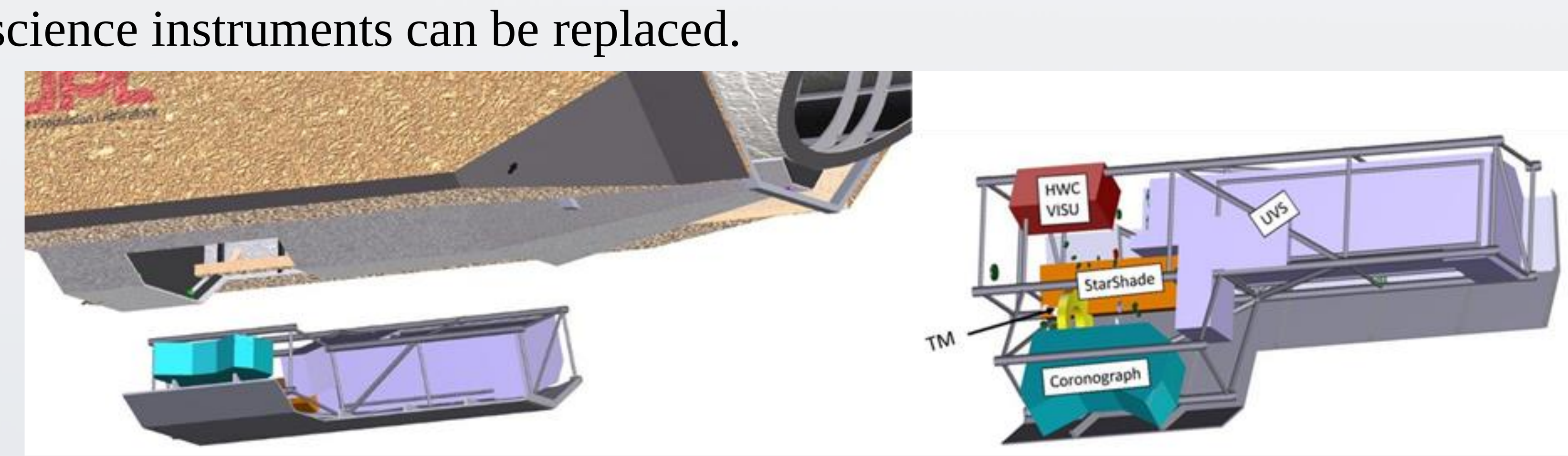
Payload fits in SLS 8.4m fairing.

Two design elements critical to achieving ultra-stable performance are stable structure and low disturbance noise. The telescope secondary mirror structure is designed with a first mode above 25 Hz and the primary mirror structure is above 40 Hz. To minimize noise, the baseline HabEx observatory does not use reaction wheels. Instead thrusters are used to slew and point the telescope. After only a 5-minute ring-down period, the WFE is sufficiently stable for coronagraphy. Micro-thrusters are used to maintain pointing during the science exposure. Because the micro-thruster noise spectrum is less than 0.1 micro-Newton and the telescope structure is very stiff, any WFE excited is smaller than the required performance specification.

The other key challenge is thermal stability. The baseline architecture achieves the required thermal stability via the combination of large thermal mass (enabled by the SLS) and TRL-9 active thermal control technology.

ISIM IS SERVICABLE

Integrated science instrument module (ISIM) maintains optical alignment of the science instruments relative to the tertiary mirror. The ISIM is removable from the observatory for servicing as a whole. Or, once removed, individual science instruments can be replaced.



PREDICTED PERFORMANCE

STOP analysis predicts that the baseline telescope will meet all performance specifications with margin: LOS jitter, LOS WFE stability, inertial WFE stability caused by micro-thruster noise; thermal LOS and WFE drift caused by thermal slews; and impulse ring-down.

K	N	M	Aberration	VVC-4 Tolerance [pm rms]	LOS [pm rms]	Inertial [pm rms]	Thermal [pm rms]	Reserve [pm rms]	Predicted Performance Margin: LOS	Predicted Performance Margin: Inertial [uG]	Predicted Performance Margin: Thermal [mK]
			Allocation	100%	30%	30%	30%	10%		0.04	
			TOTAL RMS	1628.4	892	892	892	515			
1	1	1	Tilt	1192.8	653.32	653.32	653.32	377.19	1081.68	11575.61	36663.98
2	2	0	Power (Defocus)	1108.6	607.19	607.19	607.19	350.56	376.46	1027.69	227.99
3	2	2	Pri Astigmatism	3.8	2.09	2.09	2.09	1.21	2.22	2.88	3.80
4	3	1	Pri Coma	3.3	1.81	1.81	1.81	1.05	8.53	81.26	17.41
5	3	3	Pri Trefoil	3.3	1.81	1.81	1.81	1.05	178.07	3.48	2.98
6	4	0	Pri Spherical	3.1	1.69	1.69	1.69	0.97	326.00	16.93	19.31
7	4	2	Sec Astigmatism	3.1	1.69	1.69	1.69	0.97	433.18	48.13	22.61
8	4	4	Pri Tetrafoil	3.0	1.62	1.62	1.62	0.94	13803.12	34.02	7.51
9	5	1	Sec Coma	2.7	1.48	1.48	1.48	0.85	2440.84	1140.46	22.17
10	5	3	Sec Trefoil	2.7	1.48	1.48	1.48	0.85	27891.87	20.87	15.39
11	5	5	Pri Pentafoil	2.7	1.48	1.48	1.48	0.85	1096474.81	47.56	15.53
12	6	0	Sec Spherical	2.7	1.48	1.48	1.48	0.85	97981.90	182.33	40.86
13	6	2	Ter Astigmatism	2.1	1.13	1.13	1.13	0.65	82614.13	307.45	15.32
14	6	4	Sec Tetrafoil	2.5	1.37	1.37	1.37	0.79	1960641.38	300.30	19.58
15	6	6	Pri Hexafoil	2.5	1.37	1.37	1.37	0.79	10000643.10	0.00	9.59
16	7	1	Ter Coma	1.4	0.77	0.77	0.77	0.45	514728.84	2956.10	11.05
17	7	3	Ter Trefoil	1.6	0.90	0.90	0.90	0.52	3046202.86	190.20	14.80
18	7	5	Sec Pentafoil	1.6	0.87	0.87	0.87	0.50	6920068.80	0.00	9.20
19	7	7	Pri Septafoil	1.8	0.98	0.98	0.98	0.56	6926970.63	0.00	0.00
20	8	0	Ter Spherical	0.7	0.37	0.37	0.37	0.22	4936563.16	1435.49	6.36
21	8	2	Qua Astigmatism	1.0	0.55	0.55	0.55	0.32	0.00	2453.60	9.62
22	8	4	Ter Tetrafoil	1.2	0.67	0.67	0.67	0.38	0.00	0.00	16.24
23	8	6	Sec Hexafoil	1.4	0.79	0.79	0.79	0.45	0.00	0.00	12.02
24	8	8	Pri Octafoil	1.4	0.75	0.75	0.75	0.43	0.00	0.00	0.00
25	9	1	Qua Coma	0.9	0.50	0.50	0.50	0.29	0.00	2819.93	0.00
26	10	0	Qua Spherical	1.1	0.63	0.63	0.63	0.36	0.00	877.23	0.00
27	12	0	Qin Spherical	2.0	1.07	1.07	1.07	0.62	0.00	7039.21	0.00

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