HabEx Mirror Accommodation Considerations

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Agenda

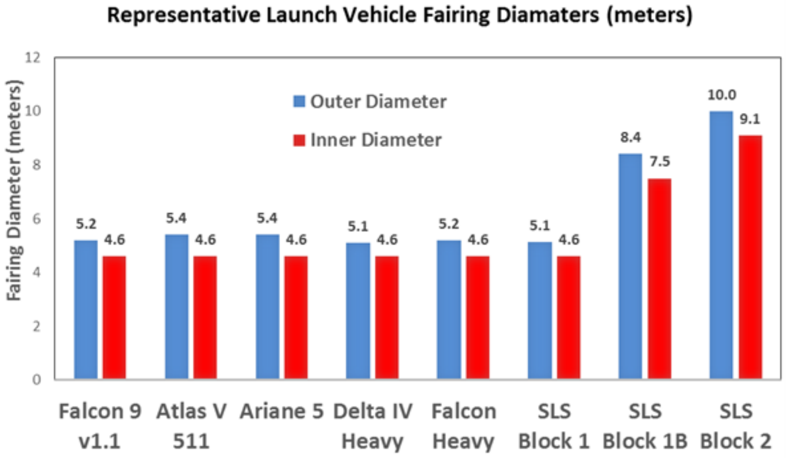
- Impact of Fairing on Telescope Diameter
- Impact of Fairing on Telescope F/#
- Impact of Fairing on Primary Mirror Mass
- Pros/Cons of a more massive Primary Mirror - Stability
- 4-meter Primary Mirror Point Designs for SLS
- Mirror Manufacturability

Question #1

How does launch vehicle fairing impact Aperture Diameter?

Answer - It depends on:

- Fairing Dynamic Envelope
- On-Axis versus Off-Axis
- Straylight Tube or Flat Baffle
- Monolithic or Segmented
- Circular or Elliptical Mirror



Monolithic 4-m 'class' (or larger) without Fairing. (3.5m may be limit for EELV.)

4m monoliths with deployments and planar sunshield may be possible in Delta IVH but needs study

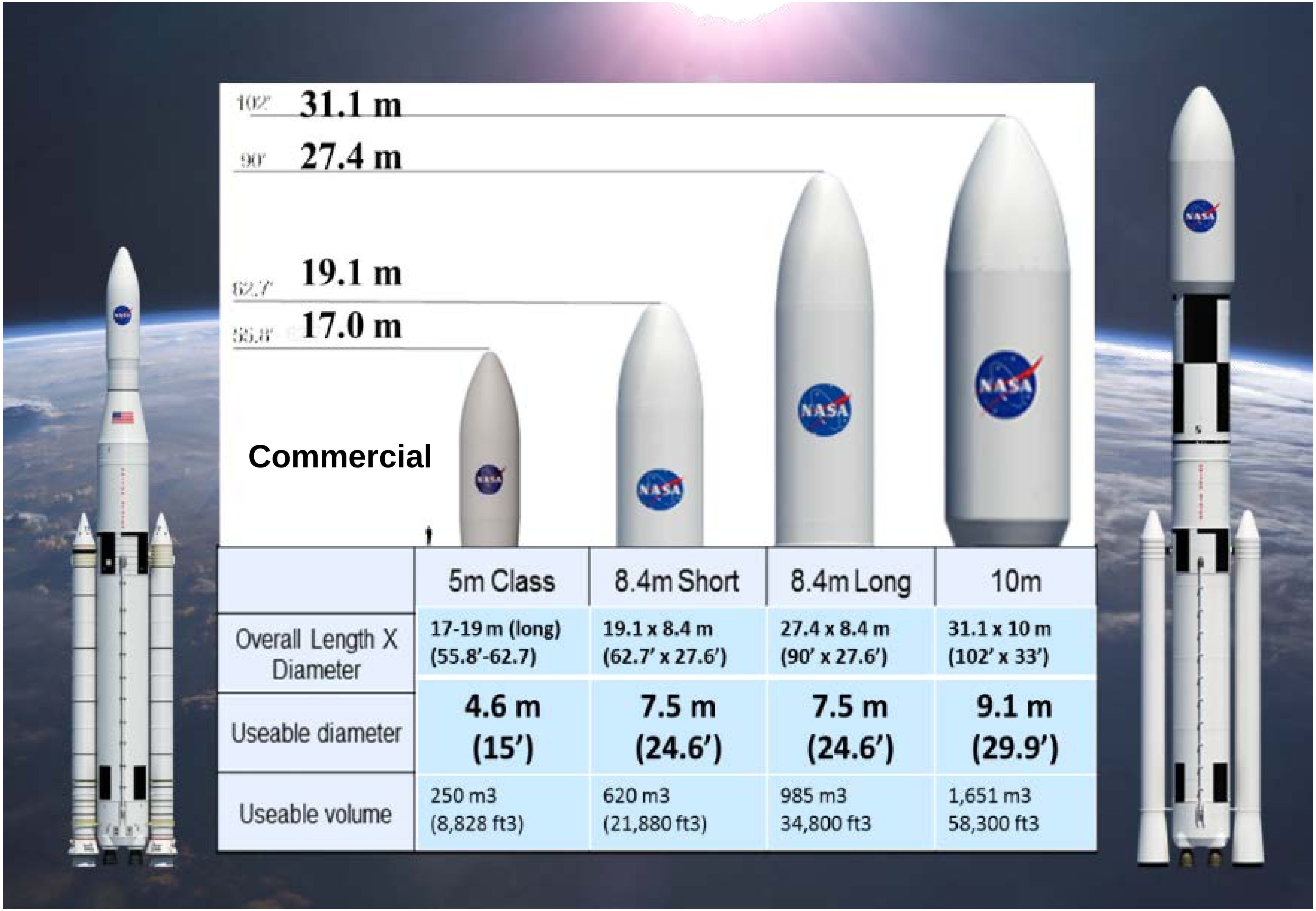
Segmented with deployments are needed for larger apertures.

Estimated Monolithic Aperture Diameter with No Deployments				
Fairing	Dynamic Envelope	On-Axis	Off-Axis	Notes
EELV-5	4.6 m	3.5	2.0	Herschel is 3.5 m; smaller if in a tube.
SLS-8.4	7.5 m	6.5	4.0	On-Axis: ATLAST Design Studies Off-Axis: HabEx Design Studies
SLS-10	9.1 m	8.0	6.0	

BACKUP for Question #1:

How does fairing impact Aperture Diameter?

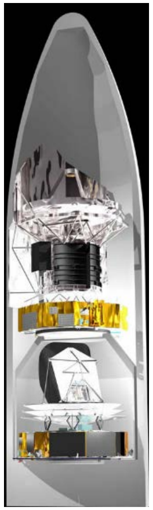
Fairing Volume Capacity



	5m Class	8.4m Short	8.4m Long	10m
Overall Length X Diameter	17-19 m (long) (55.8'-62.7)	19.1 x 8.4 m (62.7' x 27.6')	27.4 x 8.4 m (90' x 27.6')	31.1 x 10 m (102' x 33')
Useable diameter	**4.6 m (15')**	**7.5 m (24.6')**	**7.5 m (24.6')**	**9.1 m (29.9')**
Useable volume	250 m3 (8,828 ft3)	620 m3 (21,880 ft3)	985 m3 34,800 ft3	1,651 m3 58,300 ft3

Fairing Volume Payload Accommodation

EELV 5-m fairing



Herschel

Webb

ATLAST-9

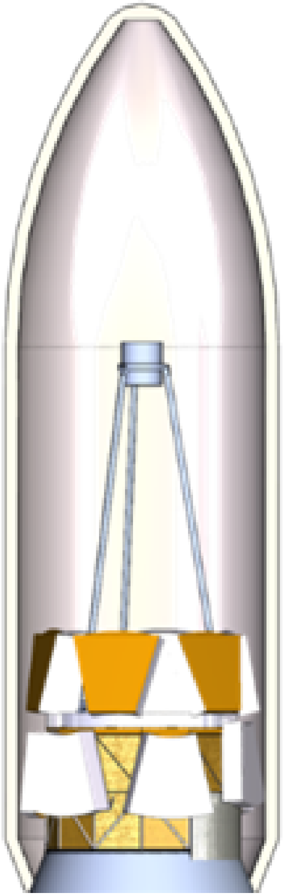
SLS 8.4-m x
27.4-m fairing

HabEx-4

ATLAST-16

SLS 10-m x
31.1-m fairing

ATLAST-8



ATLAST-12

END BACKUP #1

Question #2

How does launch vehicle fairing impact Telescope F/#?

Discussion:

- Coronagraphs desire ‘slower’ F/# telescopes for Polarization.
    - ‘Faster’ F/# telescopes may require separate polarization channels.
- F/2.5 off-axis mirror has same Polarization as F/1.25 on-axis.

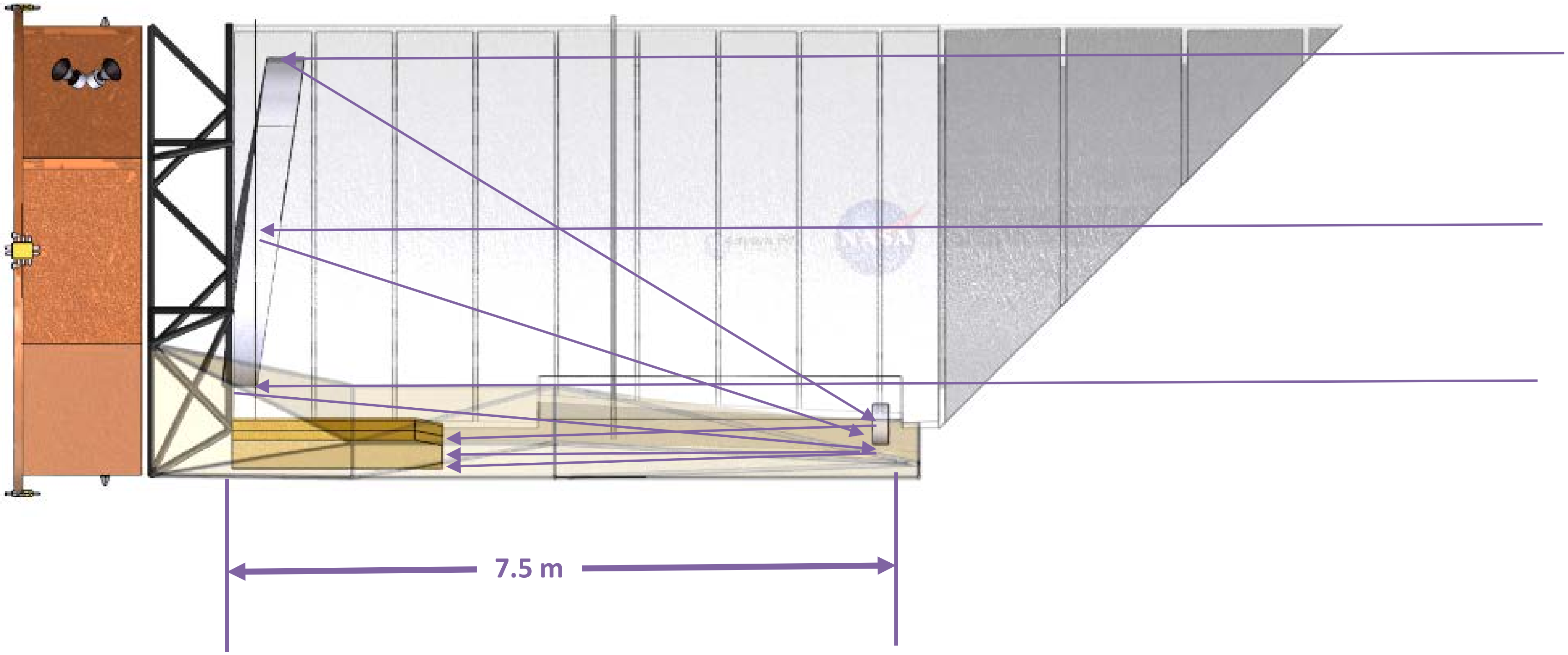
Answer:

- EELV Fairing requires either deployed Secondary or ‘fast’ F/#
- SLS Fairing height does not require deployment.
- Can package single F/2.5 HabEx in SLS-8.4 fairing.
- Can package F/2 HabEx AND a Starshade in SLS-8.4 fairing.

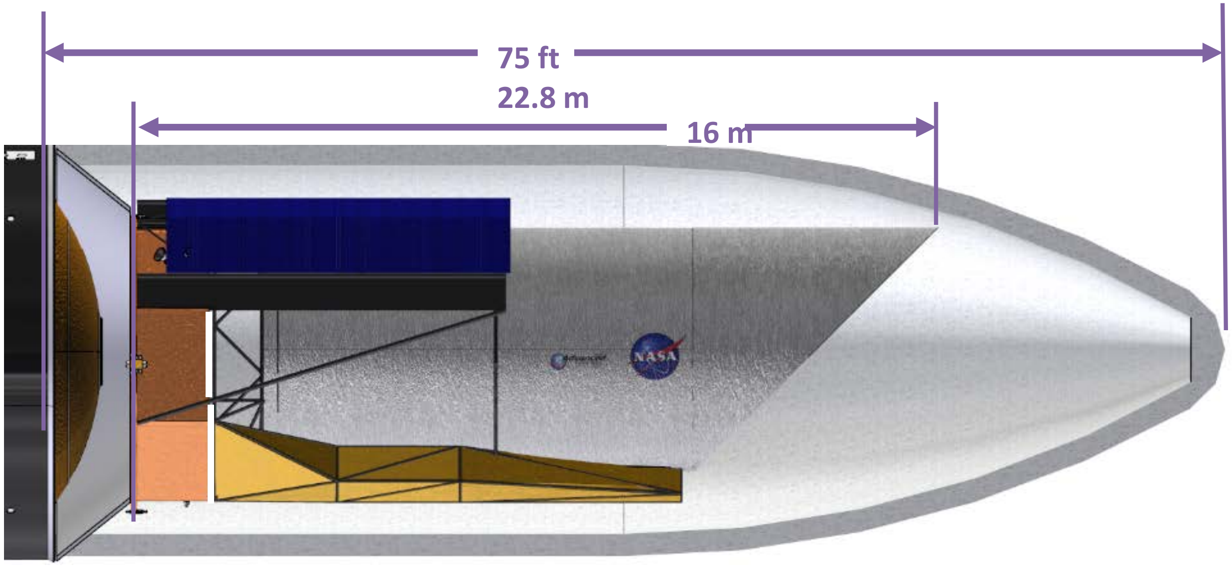
BACKUP for Question #2:

How does fairing impact Telescope F/#?

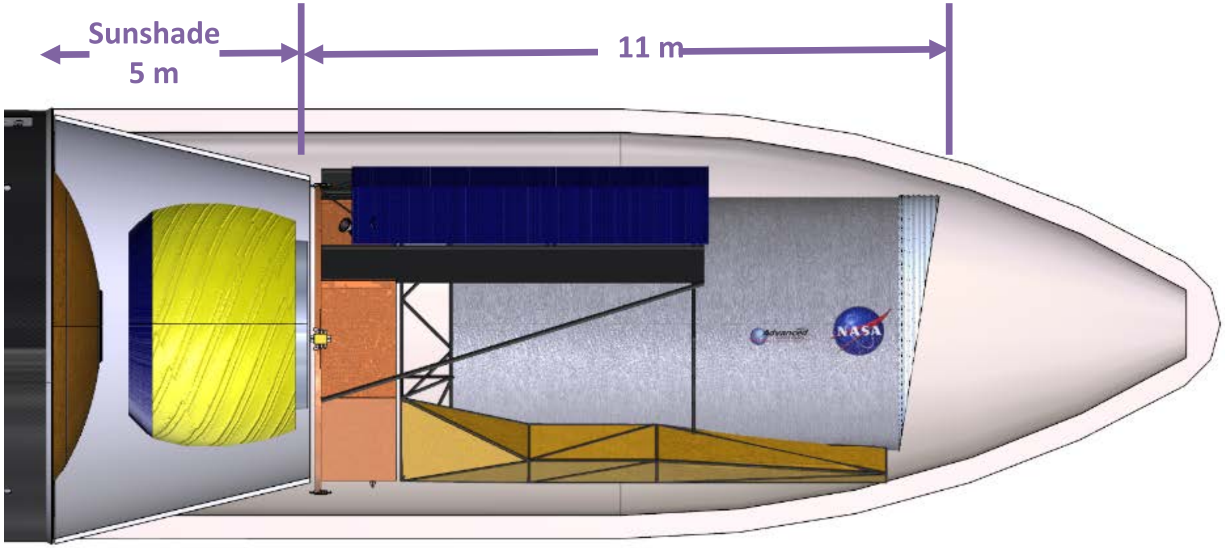
HabEx-4 F/2.5 Optical Design



Configuration



HabEx-4 F/2.5 fits in SLS-8.4 fairing without deployment



To add Starshade: deploy Forward Scarf Baffle & change to F/2.0 (reduce PM/SM spacing)

F# Considerations

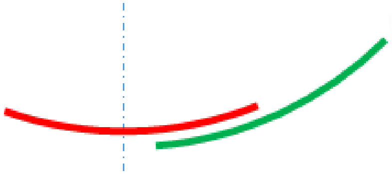
Off Axis Primary Mirror

- Retain angle of incidence on the primary as a F/#2.5 on-axis primary
- Resulting RoC is very long with an effective child F/#5

Secondary location at 90% of the focal length

	PM-SM Spacing	
Diameter (m)	On-Axis F#2.5 (m)	Off-Axis F#5.0 (m)
2.4	5.4	10.8
4	9	18
6	13.5	27
8	18	36

Ref JWST ~7m PM-SM Spacing



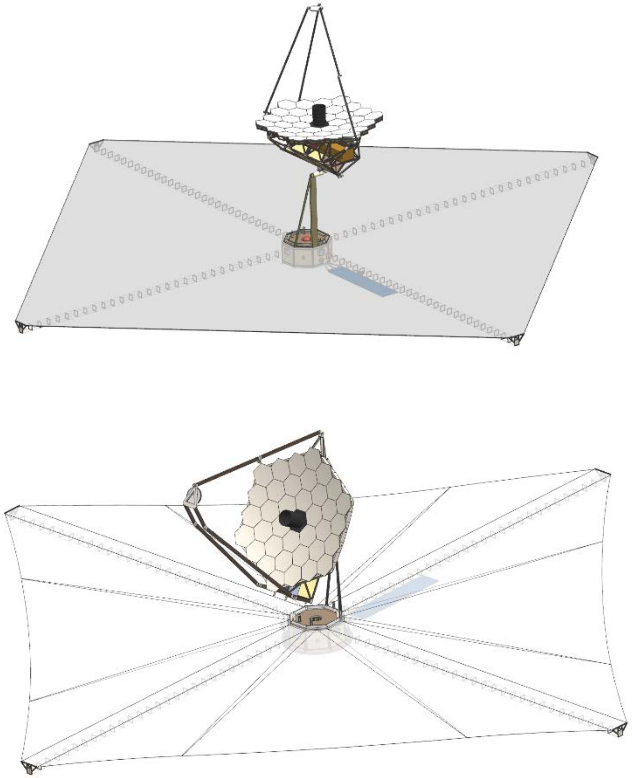
Angle of Incidence

On-axis/Off-axis with same parent

Very simplified concept of off-axis concept shown

Can adapt planar sunshield and deployment concepts for monoliths (or segmented systems)

9.2m in Delta IVH:
Circular Geometry
JWST SM deployment,
3 JWST-wings per side



Planar sunshield type architectures are more mass and volume efficient, use of an articulating gimbal allows full hemisphere Field of Regard, can work at sun angles consistent with starshades

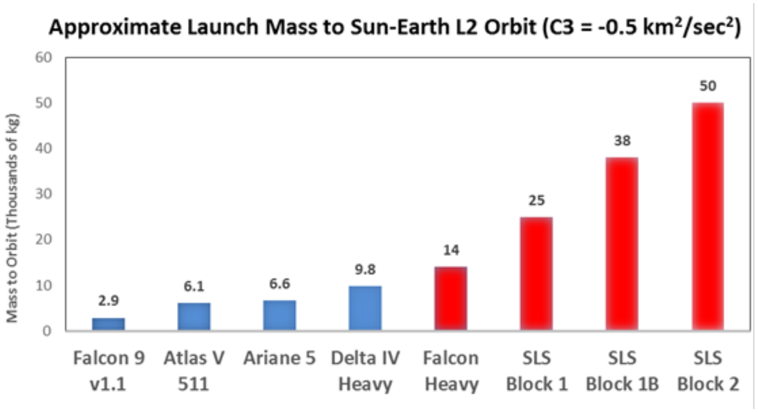
END BACKUP #2

Question #3

How does launch vehicle fairing impact Primary Mirror Mass?

PM Mass is Independent of:

- Monolithic or Segmented.
- On vs Off-axis



Approximate Launch Mass to Sun-Earth L2 Orbit (C3 = -0.5 km^2/sec^2)

With Circular Baffle, Delta IV-H can launch

- PM with mass 1000 kg (Webb PM mass is ~900 kg
- PMA with mass < 2000 kg (Webb PMA mass is ~1800 kg.)
- For 4-meter, this hard engineering – not new technology.

A planar sunshield deployment scheme like Webb would allow more mass for the mirror (whether monolith or segmented)

SLSs can launch PMA with mass up to 15,000 kg.

- Robust 4-meter point designs have mass of less than 3000 kg.

BACKUP for Question #3:

How does fairing impact Primary Mirror Mass?

Launch Vehicle Constraint

All Missions are constrained by their Launch Vehicle.

- HST and Chandra were designed for Shuttle

	Payload Mass	Payload Volume
Space Shuttle Capacities	25,061 kg (max at 185 km) 16,000 kg (max at 590 km)	4.6 m x 18.3 m
Hubble Space Telescope	11,110 kg (at 590 km)	4.3 m x 13.2 m
Chandra X-Ray Telescope (and Inertial Upper Stage)	22,800 kg (at 185 km)	4.3 m x 17.4 m

- JWST was designed for Ariane 5

	Payload Mass	Payload Volume
Ariane 5 Capacities	6600 kg (at SE L2)	4.5 m x 15.5 m
James Webb Space Telescope	6530 kg (at SE L2)	4.47 m x 10.66 m

Mass Flow Down w/Circular Baffle

Mission architecture is driven by mass and volume.

Launch Vehicle	Delta-IVH	Block-1B	Block-2 min	Block-2 max
Payload Mass with 43% Margin	7,000 kg	24,500 kg	31,500 kg	38,500 kg
Spacecraft Allocation	2400 kg	4,500 kg	6,500 kg	8,500 kg
Observatory Allocation	4600 kg	20,000 kg	25,000 kg	30,000 kg
Science Instruments	1600 kg	2,000 kg	2,500 kg	3,000 kg
Telescope (PMA, SMA, & Structure)	3000 kg	18,000 kg	22,500 kg	27,000 kg
SMA and Structure	1500 kg	8,000 kg	10,000 kg	12,000 kg
PMA Allocation	1500 kg	10,000 kg	12,500 kg	15,000 kg
Primary Mirror Allocation	1000 kg	6,000 kg	8,000 kg	10,000 kg
Primary Mirror Areal Mass	[kg/m^2]	[kg/m^2]	[kg/m^2]	[kg/m^2]
4 meter diameter (12.5 m^2)	80	480	640	800
8 meter diameter (50 m^2)	20	120	160	200
12 meter diameter (100 m^2)	10	60	80	100
16 meter diameter (200 m^2)	5	30	40	50

	Diameter	Primary Mirror		Primary Mirror Assembly	
Telescope	[m]	[kg]	[kg/m^2]	[kg]	[kg/m^2]
Hubble	2.4	760	170	1860	460
WFIRST	2.4	200	45	---	---
Webb	6.5	~875	~35	~1750	~70
TMT	30	---	---	~100,000	150

END BACKUP #3

Question #4

What are Pros/Cons of more massive Primary Mirror?

Pro:

- More Mass makes the mirror more Thermally Stable.
- Appropriate more Mass lowers mirror fabrication risk/cost.
- Mass associated with making the mirror thicker, makes the mirror stiffer and more Mechanically Stable.

Con:

- Mass that does not increase Stiffness, decreases Mechanical Stability.

Substrate design (mass & structure) is complex System Engineering problem that requires integrated modeling and extensive trade analysis that evaluates interaction between mirror and coronagraph.

BACKUP for Question #4:

Can it meet stability and does mass help?

Stability

- Dynamic Stability is complicated because it is system architecture dependent, but…
  - Recommendation from SCDA team was first mode 5x higher than highest wheel speed based on JWST modeling experience which showed 3-4x harmonics. JWST takes science up to 70hz
    - Can consider alternatives to reaction wheels, although it could be complex
  - JWST segment testing shows that mirror tilting may cause bending due to inertia and mounts, this is a consideration when doing LOS correction and indication of what could happen at picometer levels
  - JWST segment first mode is 220hz, WFIRST primary first mode is 221hz, HST is around 300hz
  - Gravity sag and associated uncertainty in dealing with it can also be impacted by mirror stiffness
- Thermal Stability
  - For continuous milli-Kelvin architectures, mainly driven by CTE and thermal intertia
    - Thermal conductance exhibited by SiC can be an advantage for settling times if milli-Kelvin control is not maintained
  - ULE modeling showed that front to back facesheet changes sensitive to <1 ppB, driven by CTE uniformity (spatial distribution and matching is key)
  - More mass helps thermal inertia, too much may be hard to control
  - For larger mirrors, need to model with realistic (measured?) CTE distributions. Best solution is likely ULE that has been carefully matched front to back and key question is thermal control needed.
- Assumption of linearity for joints, bonds etc at picometer level is under investigate and another important consideration that needs to be understood
  - How does one mount a mirror? Are bonds, flexures, joints a concern? Can one scale dynamic models to picometer level?
  - A monolith that is fully dynamically decoupled and stiff will likely be the most stable

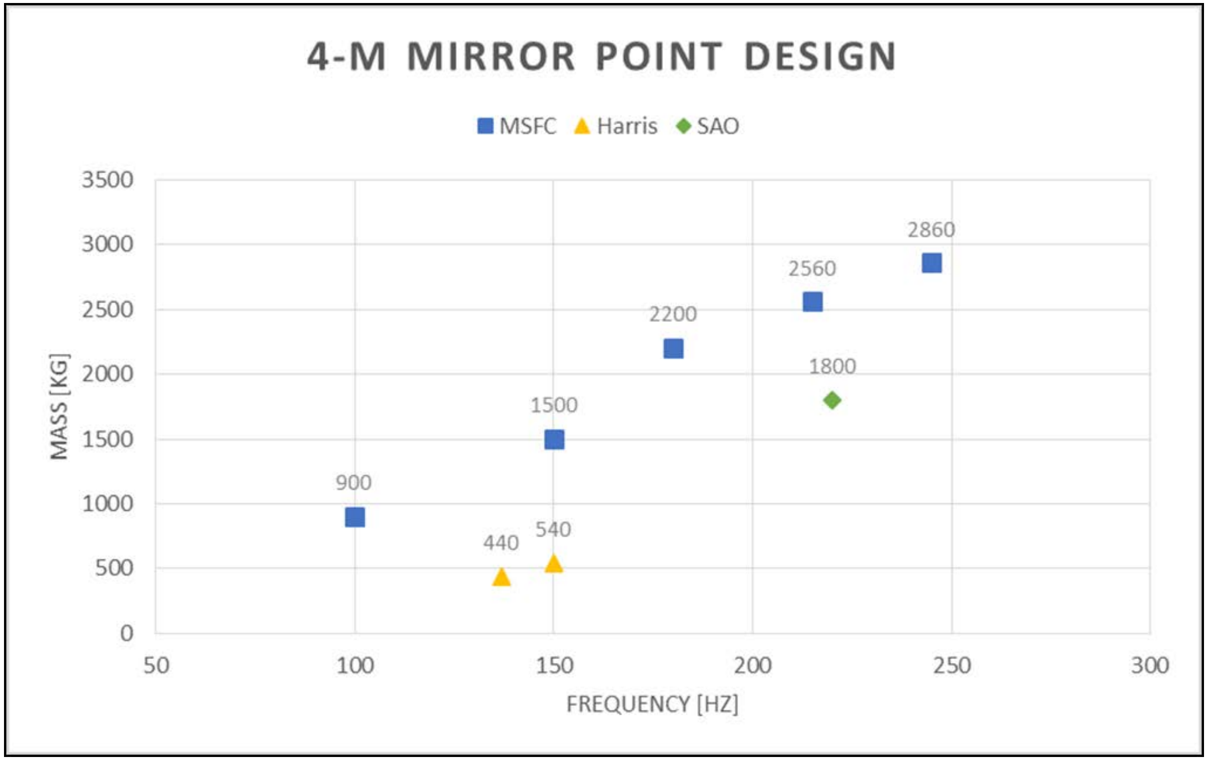
END BACKUP #4

Question #5

Can > 200 Hz 4-meter class mirrors meet mass budget?

Answer: AMTD has produced multiple 4-m Point Designs

- Harris Corporation explored lower limit of mass.
- MSFC explored range of higher mass, more robust designs.

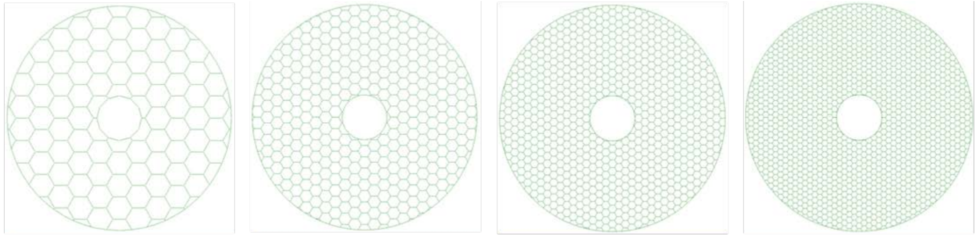


BACKUP for Question #5:

Can >200 Hz 4-meter mirror meet mass budget?

Point Design Trade Studies

Trade assuming constant 40 cm thickness & core cell size.



CRITERIA	2 meter		4 meter		6 meter		8 meter	
	kg	hz	kg	hz	kg	hz	kg	hz
100 hertz	88	100	911	106	14908	106	(2)	(2)
200 hertz	130	231	5727	204	(1)	(1)	(2)	(2)

(1) Doubling facesheet thickness (24010 kg) still only increased f=109 hz.

(2) Upper limits of feasible design (32,312 kg) only produced f=66 hz. at 8 meter OD

Trade assuming constant face/back-sheet & core wall thicknesses

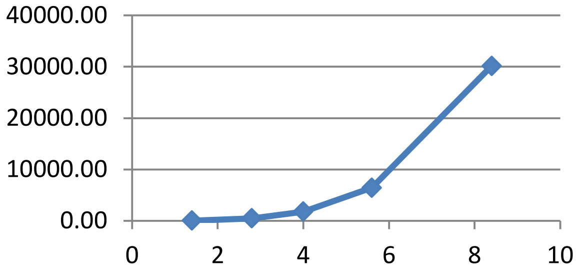
4-meter Mirror Point Designs			
Thickness [m]	0.45	0.6	0.75
Mass [kg]	2200	2560	2860
First Mode [Hz]	180	215	245

SAO Constant Frequency Scaling

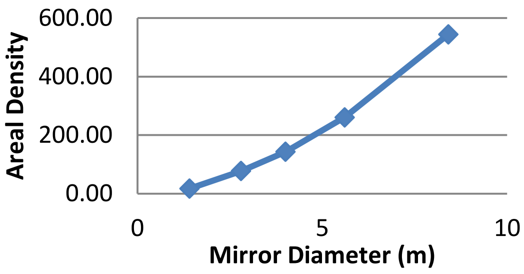
SAO performed a simple parametric scaling exercise for a closed back ULE mirror with 220 Hz first mode frequency.

- All design elements of the mirror (face/back sheets, mirror thickness, rib thickness, core sizes, etc.) were scaled linearly with diameter.

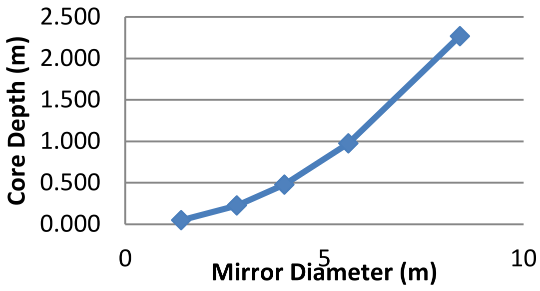
Total Mass (kg)



Areal Density (kg/m^2)



Depth (m)



Findings:

- Mass increases with Diameter
- But, even at 8 meters, mass is with-in capacity of SLS
- To maintain constant Frequency, must increase thickness

Question #6

Can these mirrors be manufactured?

Answer:

- AMTD demonstrated ability to manufacture 40 cm deep mirror.
- AMTD is demonstrating lateral scalability of stacked core technology to a 1/3rd subscale (1.5 meter) of a 4-meter mirror.

AMTD assesses that there are viable paths for producing 4 to 6-meter (and maybe even 8-m) mirrors, but stiffness/mass becomes an issue at 6m

BUT, a lot more analysis is needed.

Courtesy of Harris Corp

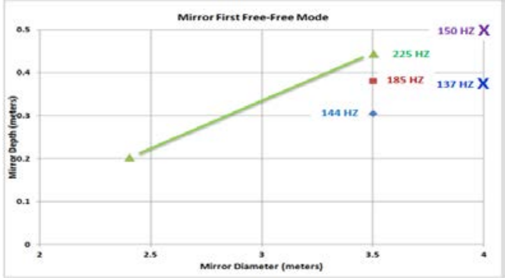
BACKUP for Question #6:

Can these mirrors be manufactured?

Large Substrate: Technical Challenge

Future large-aperture space telescopes (regardless of monolithic or segmented) need ultra-stable mechanical and thermal performance for high-contrast imaging.

This requires larger, thicker, and stiffer substrates.



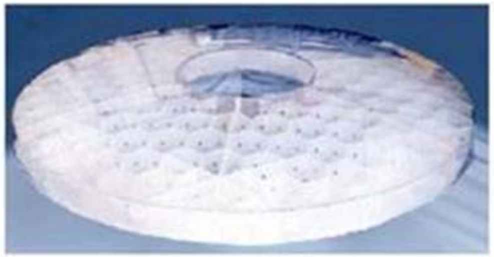
Current launch vehicle capacity limits requires low areal density.

State of the Art is

ATT Mirror: 2.4 m, 3-layer, 0.3 m deep, 24 kg/m2; LTF as sphere

AMSD ULE©: 1.4 m, 3 layer, 0.06m deep, 13 kg/m2; LTF & LTS

Kepler: 1 m, frit bonded



Harris 2.4 m ATT Mirror

Large Substrate: Achievements

Successfully demonstrated a new fabrication process (stacked core low-temperature fusion).

Process offers significant cost and risk reduction. It is difficult (and expensive) to cut a deep-core substrate to exacting rib thickness requirements. Current SOA is ~300 mm on an expensive custom machine; commercial machines can cut < 130 mm cores.

Extended state of the art for deep core mirrors from less than 300 mm to greater than 400 mm.

Successfully 're-slumped' a ULE© fused substrate.

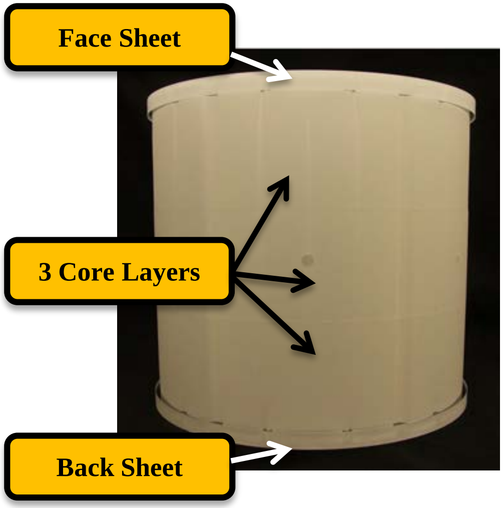
This allows generic substrates to be assembled and placed in inventory for re-slumping to a final radius of curvature.

Quantified Strength of Stack-Core LTF process components.

43 cm Deep Core Mirror

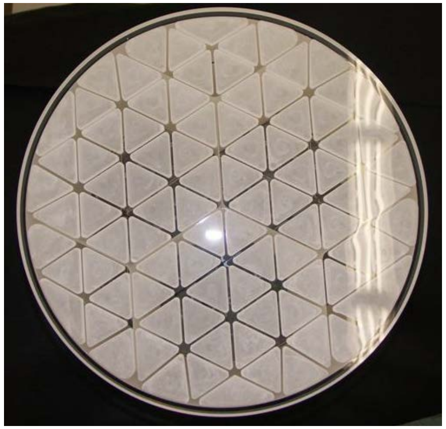
Harris successfully demonstrated 5-layer ‘stack & fuse’ technique which fuses 3 core structural element layers to front & back faceplates.

Made 43 cm ‘cut-out’ of a 4 m dia, > 0.4 m deep, 60 kg/m^2 mirror substrate.



Post-Fusion Side View

3 Core Layers and Vent Hole Visible



Post-Fusion Top View

Pocket Milled Faceplate

Post Slump:

2.5 meter Radius of Curvature

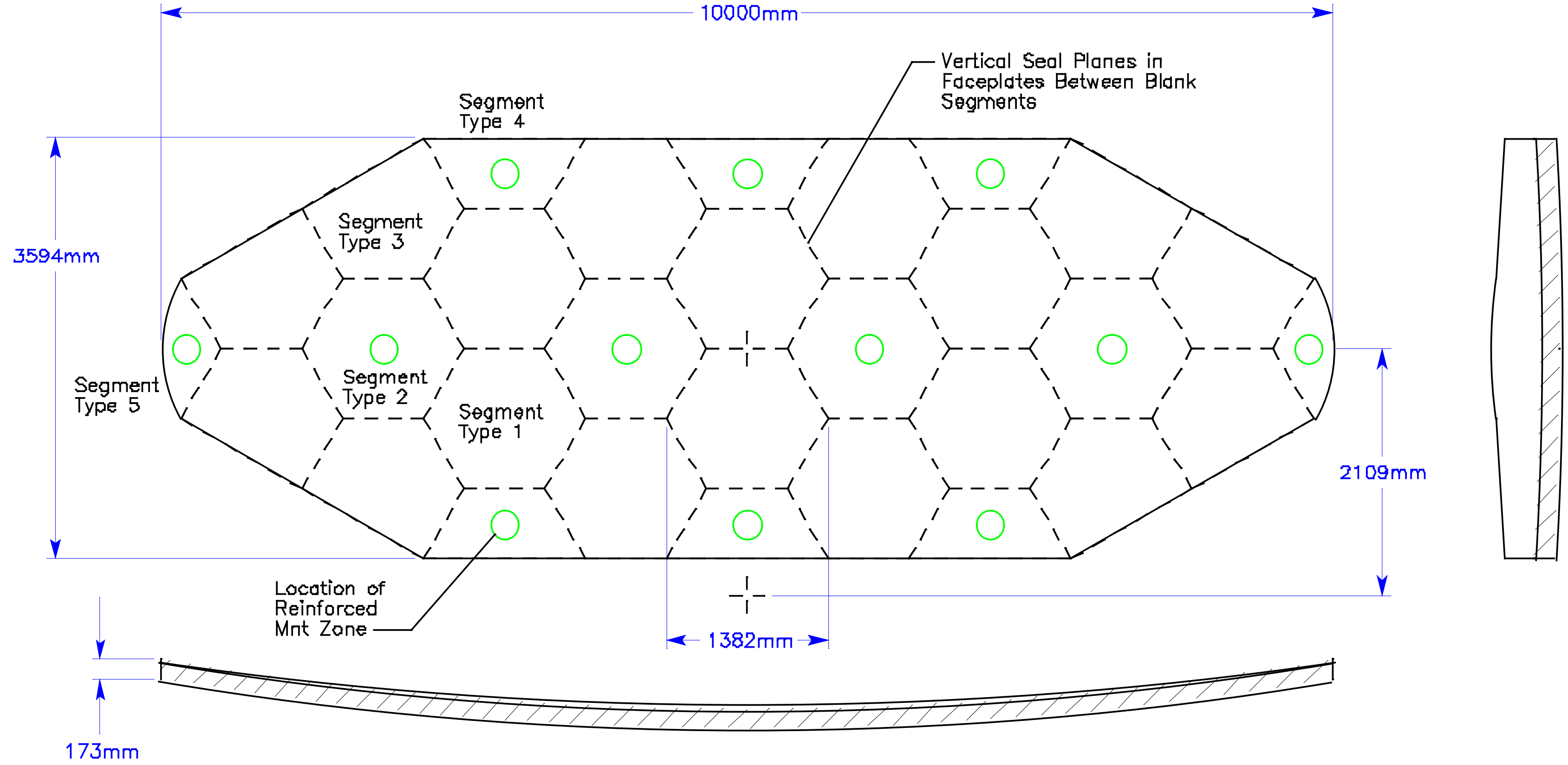
This technology advance leads to stiffer 2 to 4 (to ?) meter class substrates at lower cost and risk for monolithic or segmented mirrors.

Matthews, Gary, et al, *Development of stacked core technology for the fabrication of deep lightweight UV quality space mirrors*, SPIE Conference on Optical Manufacturing and Testing X, 2013.

Mirror Concept

Mirror assembled from 30 smaller lightweight blanks constructed from Corning ULE™[1] glass

Blanks are joined by edge welding of faceplates before processing.



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