Lunch Discussion:

Thoughts on Telescope for Far-IR Surveyor

13 May 2016

H. Philip Stahl, Ph.D.
NASA
h.philip.stahl@nasa.gov

Feasibility Question

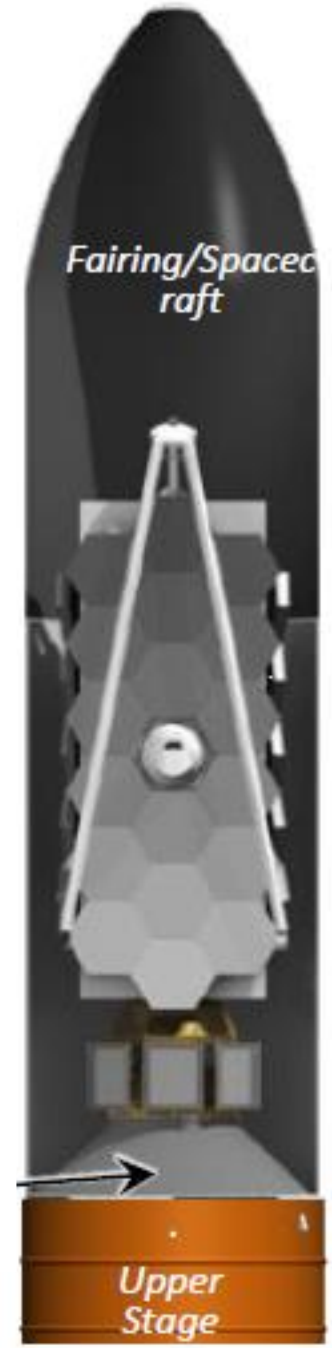
What is the largest feasible FIRS telescope that can be launched in on SLS and what is its estimated cost?

Angular Resolution	1 mas
Diameter	20 meters
Mass	15 mt
Diffraction Limit	100 µm
Cost	< $ 0.5 B

FIRS Requires SLS 8.4 m Long or 10 m Fairing.

8.4 m Fairing is 27 m tall

10 m Fairing is 31 m tall



Error Budget

Having a Telescope that is diffraction limited at 100 μm makes FIRS ~10X easier than JWST.

For Packaging analysis, I assume constant Structural Stiffness.

Mission	JWST	FIRS
Diffraction Limit	2 μm	100 μm
WFE	156 nm rms	7.8 μm
Science Instrument WFE	70 nm rms	3.5 μm rms
OTA WFE	140 nm rms	7.0 μm rms
Pointing Stability	70 nm rms	3.5 μm rms
Primary Mirror	50 nm rms	2.5 μm rms
PM Segments	25 nm rms	1 μm rms
PM Structure	40 nm rms	40 nm rms

Stiffness Drives Structure Design

JWST PM Structure first mode bending frequency is ~16 HZ with ~ 20 nm rms of wavefront error from back plane bending.

For 20-m FIRS to have the same performance it needs same frequency.

	JWST PMA	FIRS PMA	Factor
Diameter	6.5m	20 m	3X
Area	25 m^2	300 m^2	12X
Areal Mass	70 kg/m^2	50 kg/m^2	0.7X
Thickness	0.5 m	2 m	4X

$$\text{Frequency} \sim \text{Thickness}^{3/2} / \{\text{Diameter}^2 \times \text{Areal Density}^{0.5}\}$$

PMA Mass	1.75 mt	16 mt	9X
Mission Mass	6.5 mt	26 mt	4X
PMA Cost	$ 150 M	~ $60M	~0.4 X
Areal Cost	$ 6 M/m^2	~ $0.2M/$m^2$	~0.033 X
OTA Cost	$1.2B	~ $0.4B	~0.33 X

Launch Vehicle Constraint

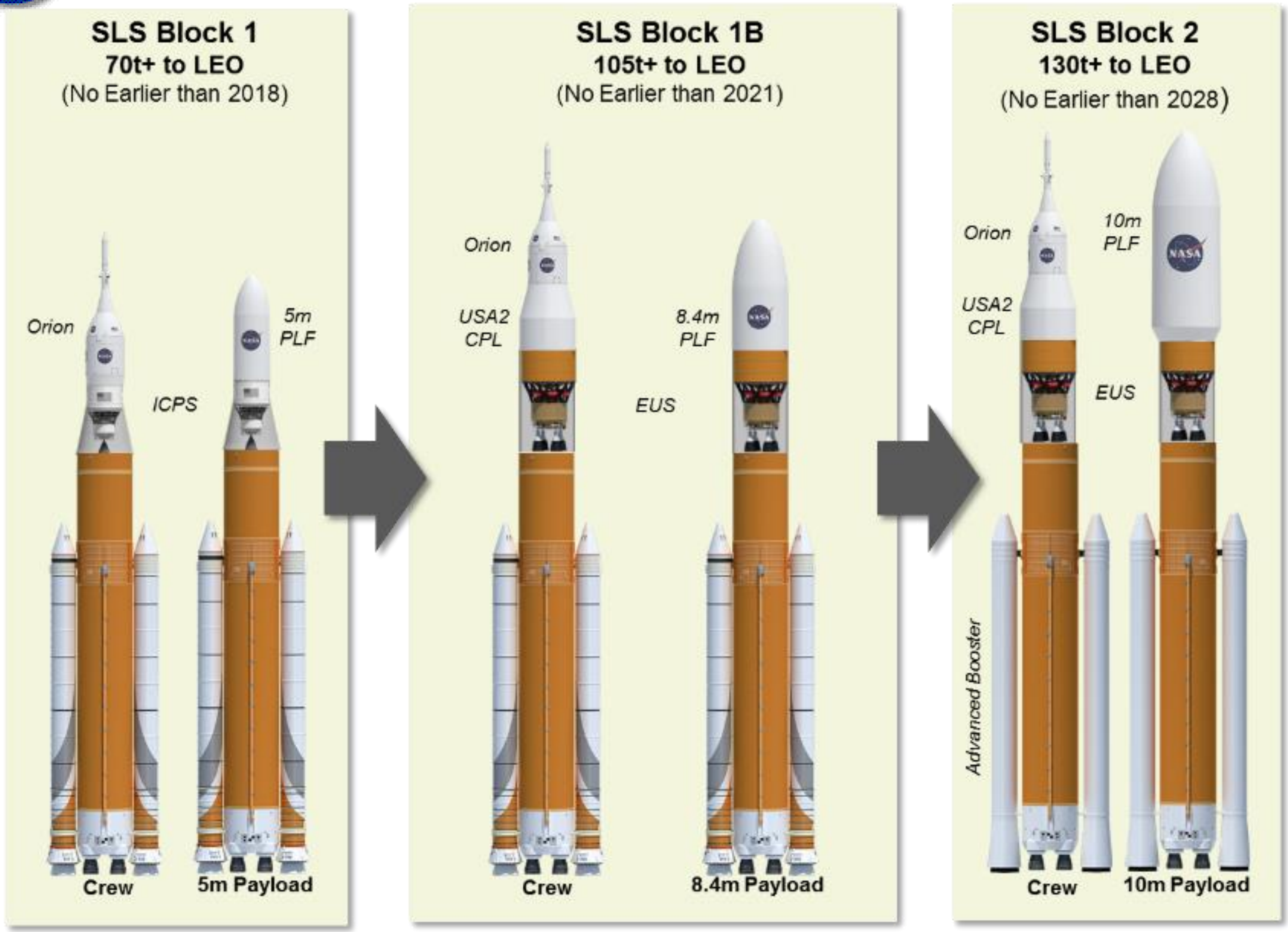
All Missions are constrained by their Launch Vehicle.

- HST and Chandra were designed for Shuttle
- JWST was designed for Ariane 5

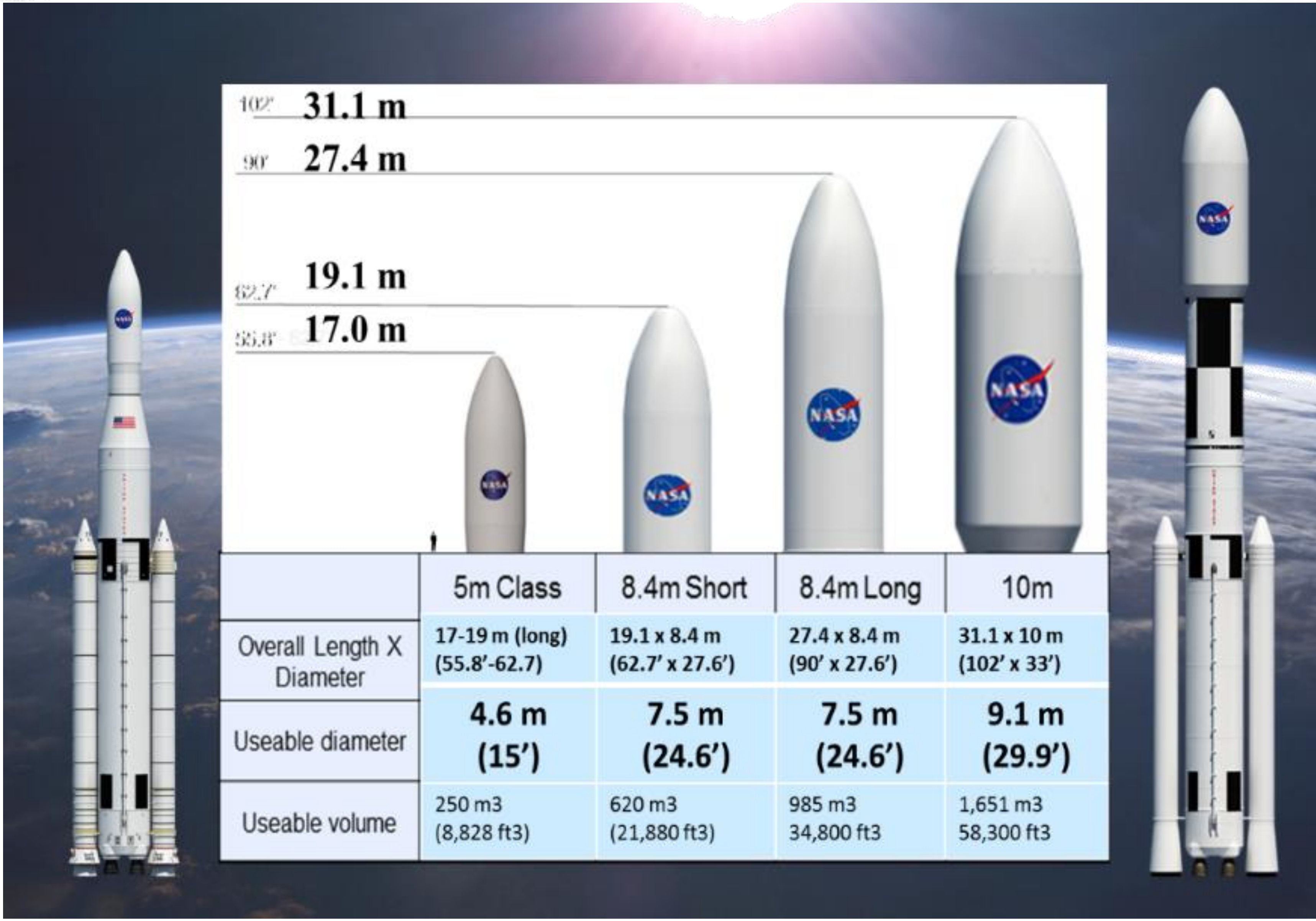
Space Shuttle Launch Capacities vs Science Mission Payload Requirements		
	Payload Mass	Payload Volume
Space Shuttle Capacities	25,061 kg (max at 185 km) 16,000 kg (max at 590 km)	4.6 m x 18.3 m
Hubble Space Telescope	11,110 kg (at 590 km)	4.3 m x 13.2 m
Chandra X-Ray Telescope (and Inertial Upper Stage)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

Ariane 5 Launch Capacities vs JWST Requirements		
	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

SLS Block Development Schedule



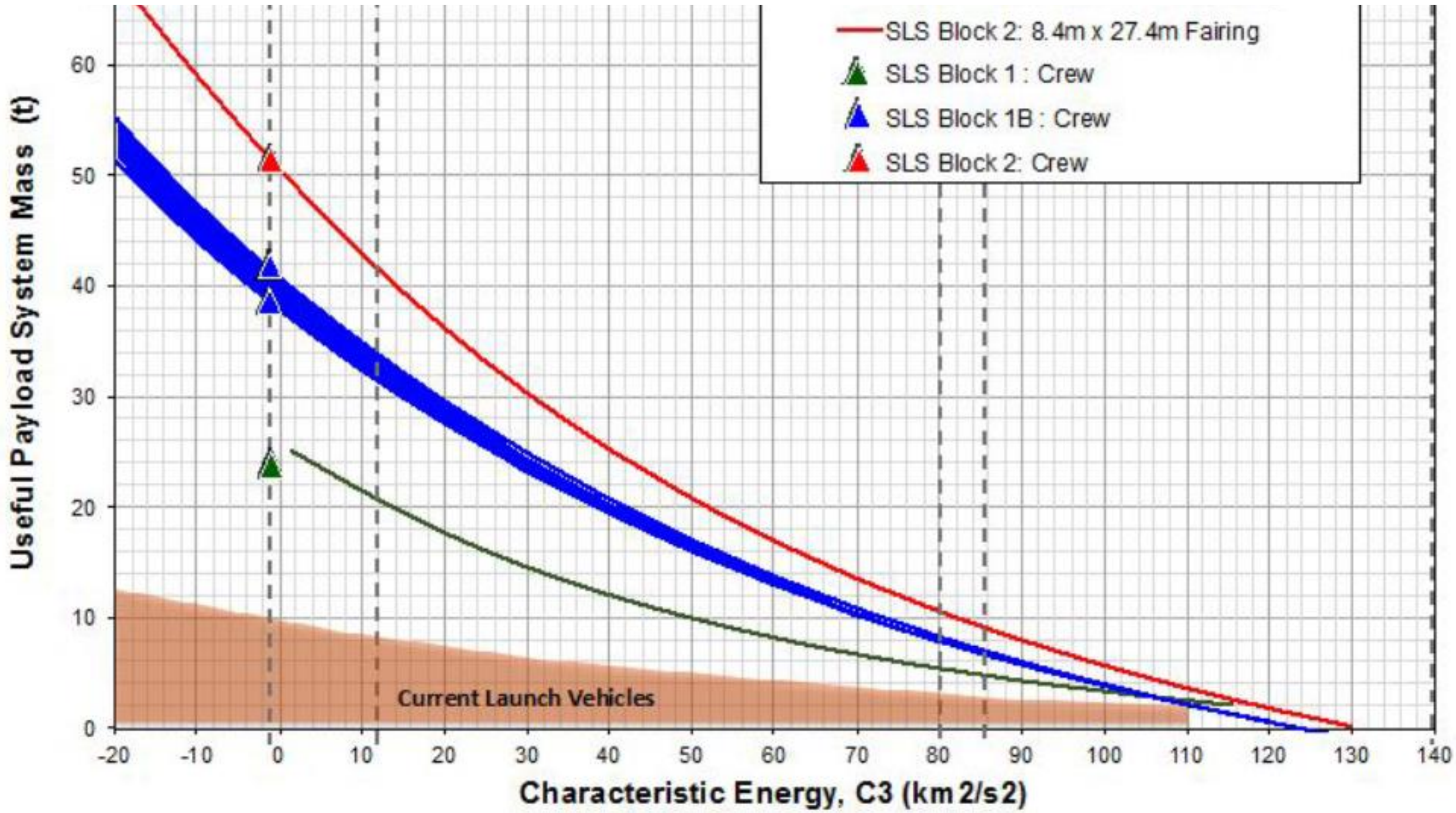
SLS Fairing Capacity



	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

SLS Mass Capacity

Available Maximum Payload Mass after Margin for Select SLS Vehicles				
SLS	Block-1B min	Block-1B max	Block-2 (10m)	Block-2 (8.4m)
Projected Mass to SE-L2	35,000 kg	40,000 kg	45,000 kg	50,000 kg
Max Payload with 30% Margin	26,900 kg	30,800 kg	34,600 kg	38,500 kg
Max Payload with 43% Margin	24,500 kg	28,000 kg	31,500 kg	35,000 kg



Primary Mirror Areal Mass

Assuming a range of maximum masses for the payload.
Assuming 80% of the payload mass is in the OTA
Assuming 50% of the OTA mass is in the PMA
What is the required PMA Areal Mass for various Diameters.

Flow-down from allowable SLS Payload Mass to Primary Mirror Areal Mass			
SLS	Block-1B	Block-2 min	Block-2 max
Max Payload Mass with 43% Margin	24,500 kg	31,500 kg	38,500 kg
80% Observatory Allocation	20,00 kg	25,000 kg	30,000 kg
50% Primary Mirror Assembly Allocation	9,800 kg	12,500 kg	15,000 kg
Primary Mirror Assembly Areal Mass	[kg/m^2]	[kg/m^2]	[kg/m^2]
4 meter diameter	800	1000	1200
8 meter diameter	200	250	300
12 meter diameter	100	125	150
16 meter diameter	50	62.5	75
20 meter diameter	30	40	50
30 meter diameter	14	18	20

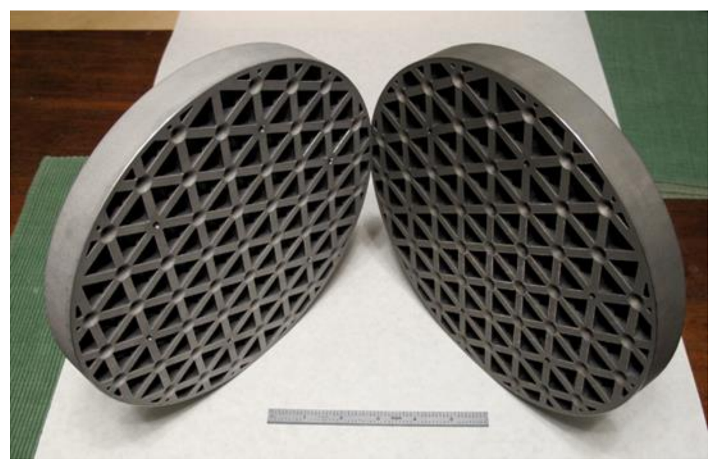
State of Art

20 meter FIRS Telescope is consistent with the SOA.

Mission	FIRS	JWST	BLAST	SBIR AL
PM Areal Mass	25 kg/m^2	30 kg/m^2	15 kg/m^2	9 kg/m^2
PMA AM	50 kg/m^2	70 kg/m^2	30 kg/m^2	
PMA Areal Cost	\$ 0.2 M/m^2	\$ 6 M/m^2	\$ 0.15 M/m^2	\$ 0.05 M/m^2
PMA Total Cost	\$ 60M	\$ 150M	\$ 0.75M	\$ 0.0025M
WFE	2.5 μm rms	0.02 μm rms	5 μm rms	---

Technology Development will reduce Areal Mass and Areal Cost

Use SBIR SubTopic to make 1m class FIR Segement



Stahl Published Cost Model

Cost modeling is an inexact science, it is very difficult to predict an exact cost. But, it is useful for extrapolating cost of one mission relative to another.

For a comparison of JWST with FIRS, I suggest:

$$\textbf{OTA Cost} \sim \mathbf{D}^{\,1.7}\, \lambda^{-0.5}\ e^{-0.04(\Delta \mathrm{YOD})}$$

Mission	JWST	FIRS	Factor	$ Facor
Diameter	6.5 m	20 m	3X	6.5X
Wavelength	2 μm	100 μm	50X	.14X
YOD	2003	2023	20	.45X
Predicted OTA Cost	$1.2B	$0.5B		.4X

Additional Cost Savings can be anticipated via Technology Development and Segmentation Architecture.

Any Question?