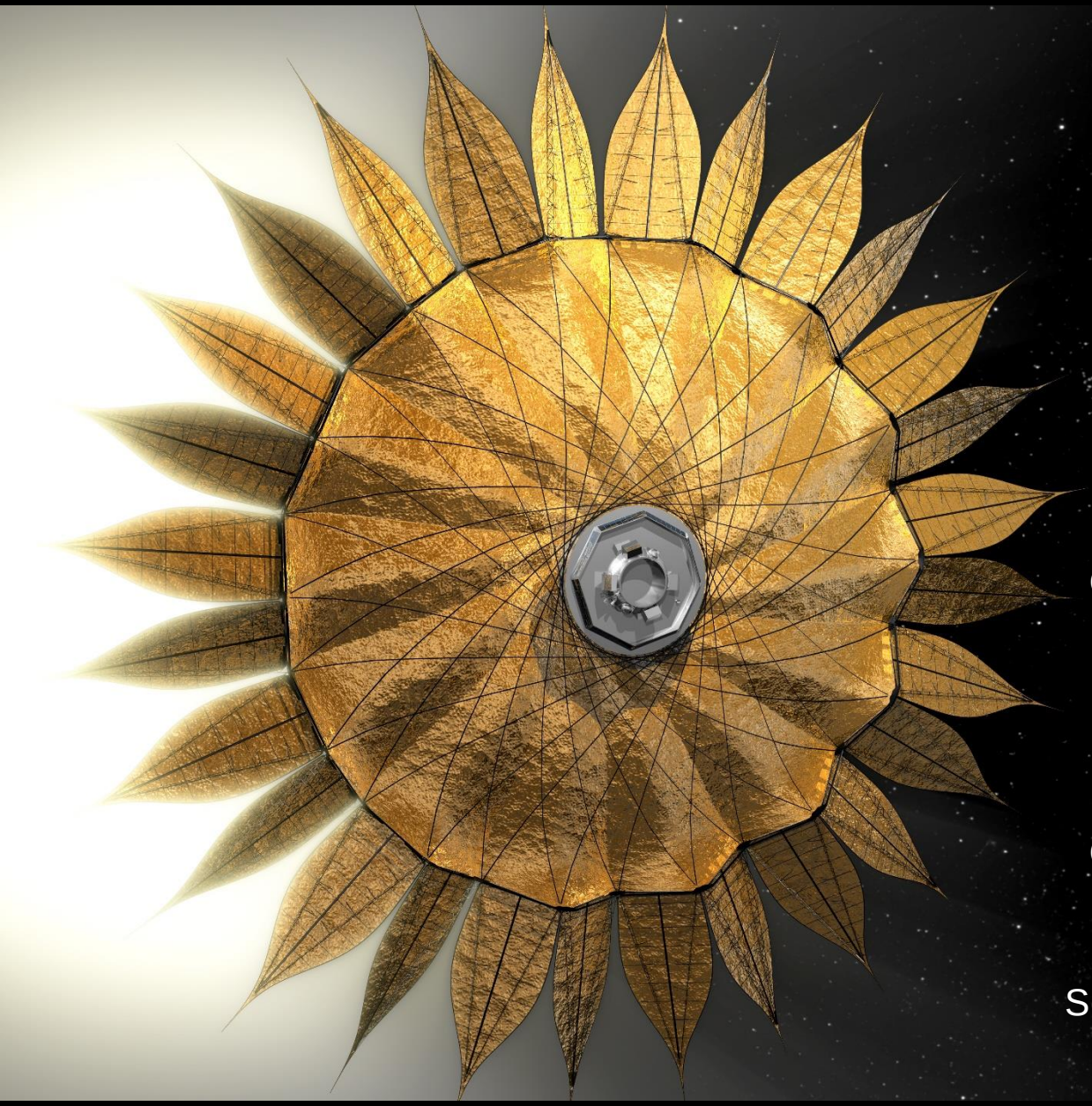

An Initial Candidate In-Space Assembly Mission: The Starshade

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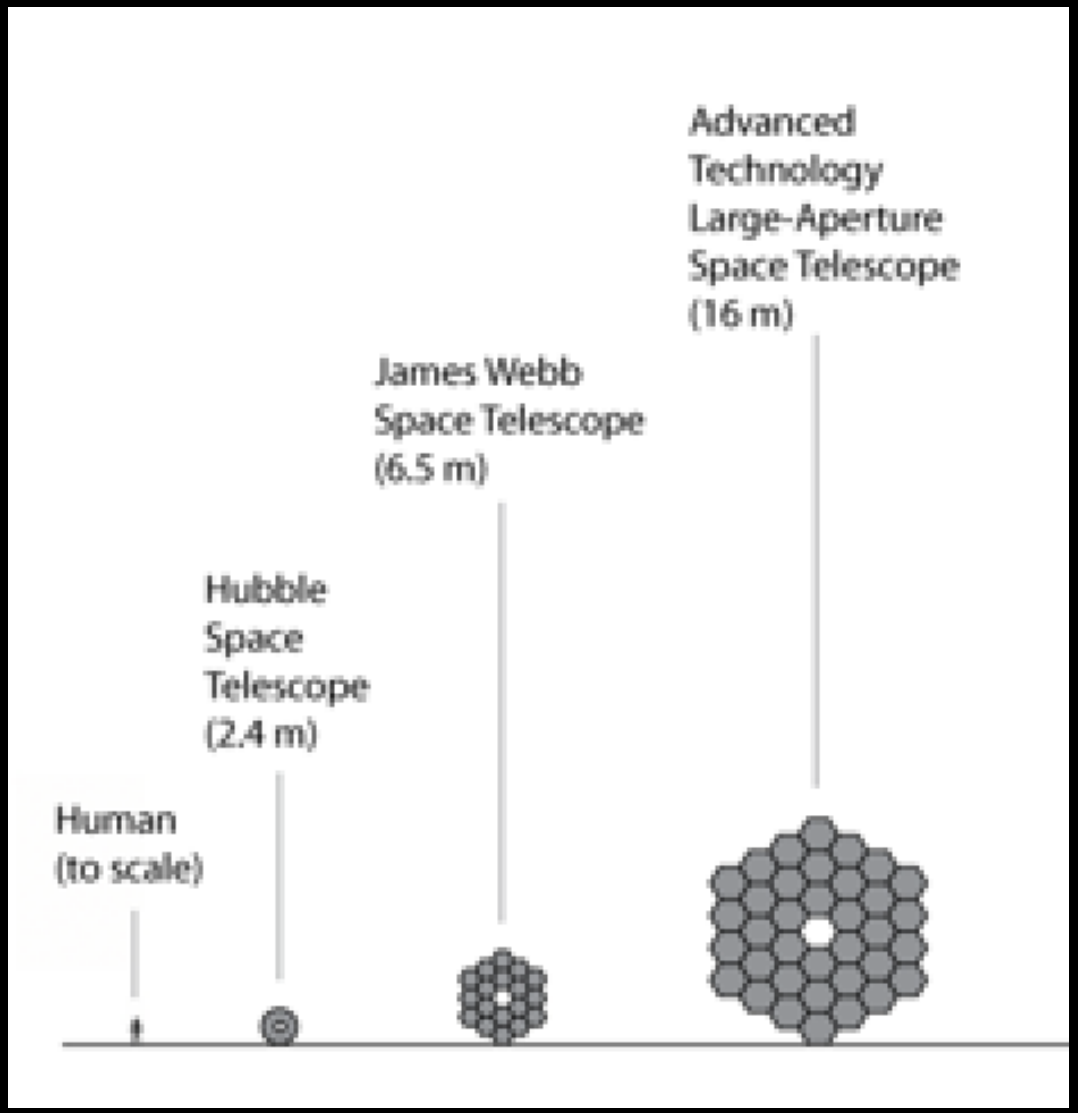
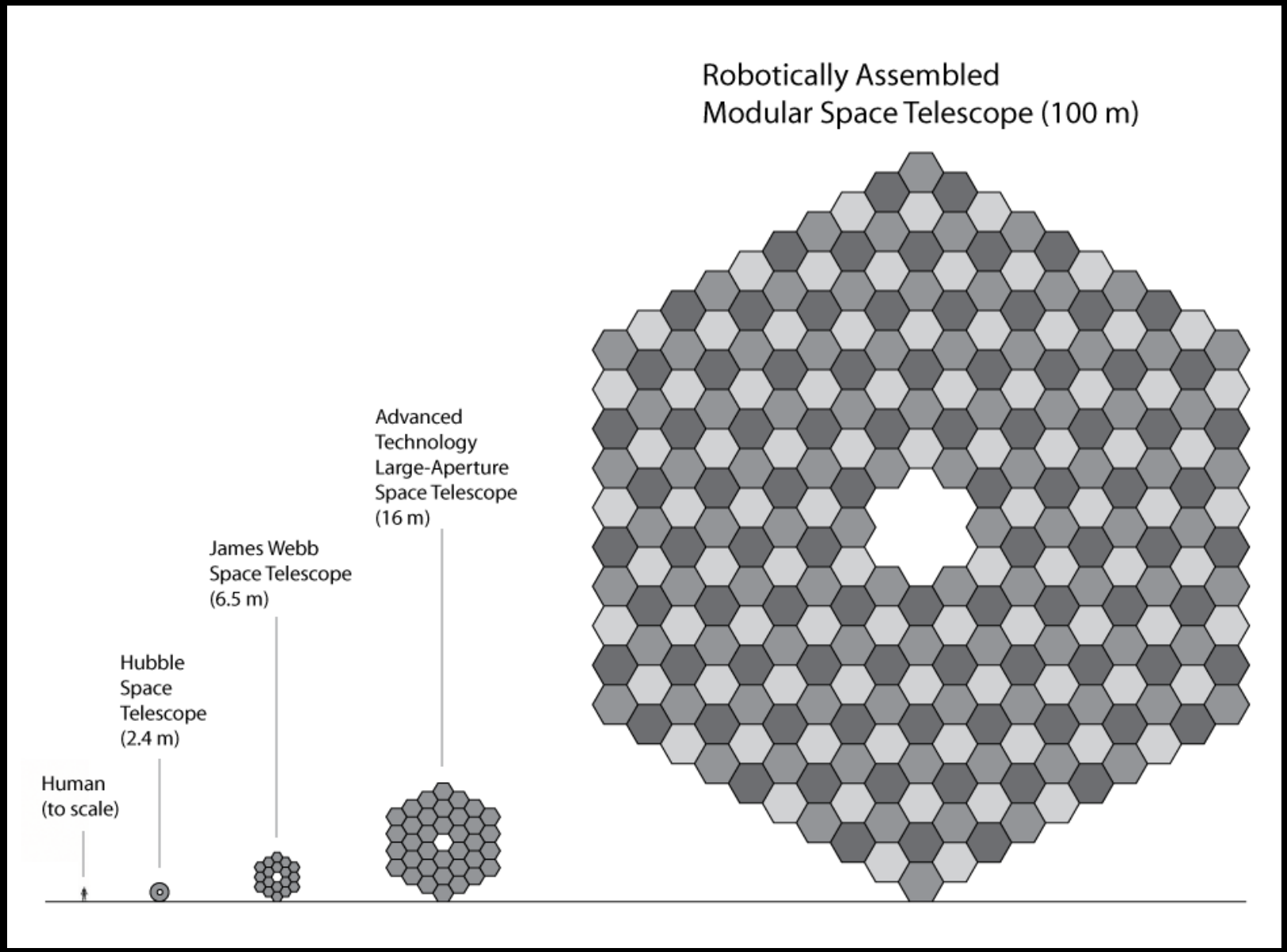
Dr. Rudra Mukherjee,
Lewis Jones
Robotics Group
Jet Propulsion Laboratory,
California Institute of Technology

Dr. Matt Greenhouse
Science & Exploration Directorate
(NASA-GSFC)

August 7, 2017 **SPIE San Diego**

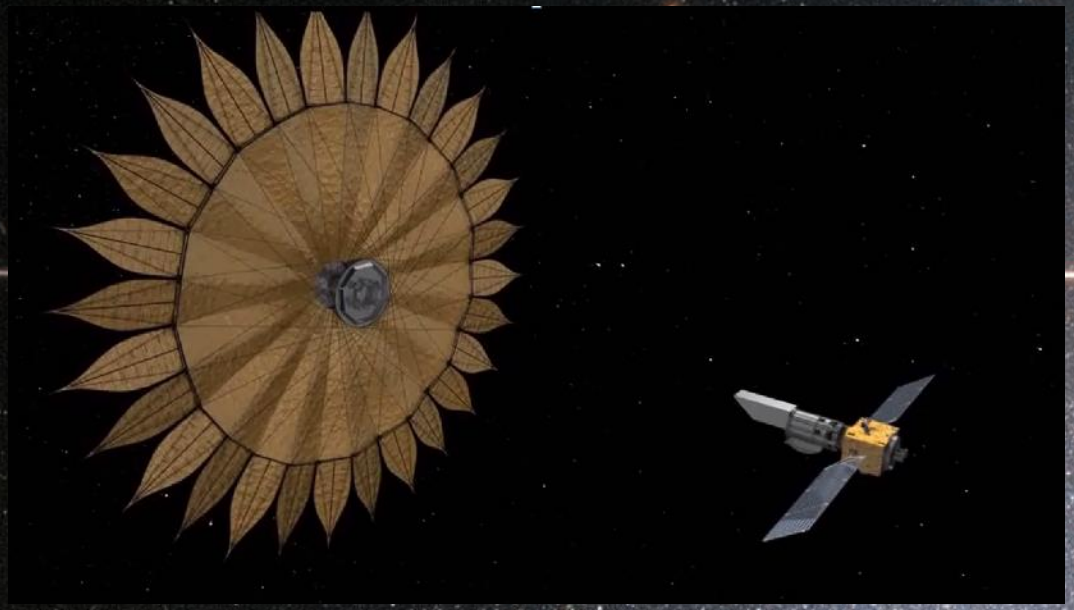


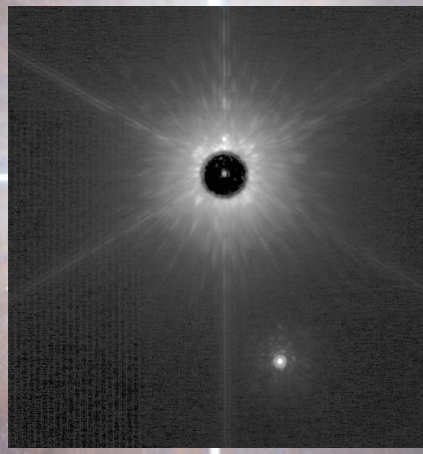
Lee et al (2016)



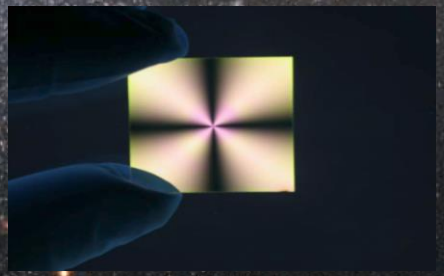
Lee et al (2016)

External Occulter (Starshade)

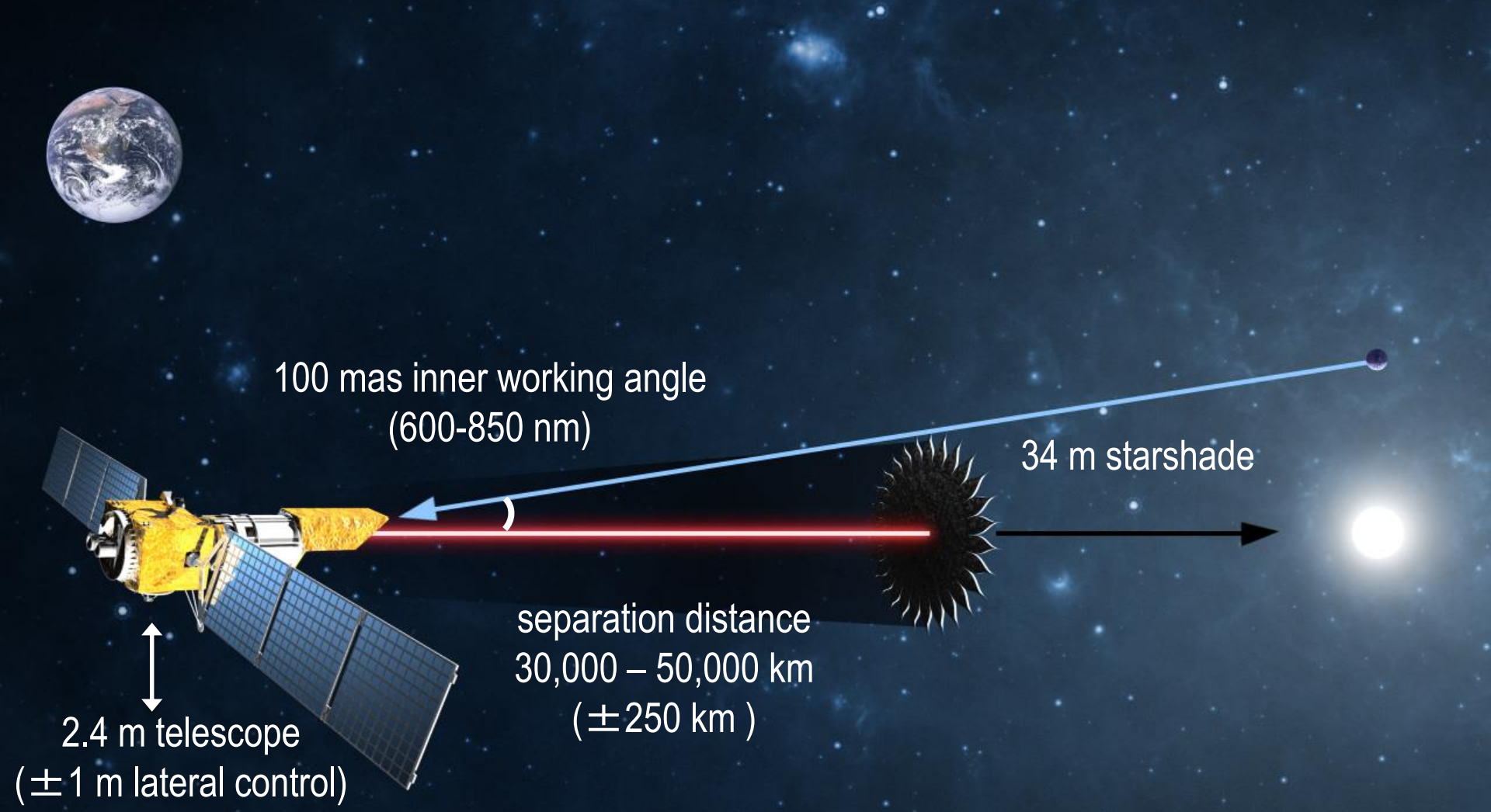




Internal Occulter (Coronagraph)



A Starshade Mission Concept Animation Video



- **As telescopes get larger, their starshades get larger and farther away.**
- **As starshades get larger, their inner working angles get smaller.**
- **As inner working angles get smaller, telescopes can probe for more Earth-sized planets in the habitable zones of their stars and observe in the NIR**
- **High throughput allows for higher spectral resolution**

There must be a Limit to How Big a Starshade can be Autonomously Deployed

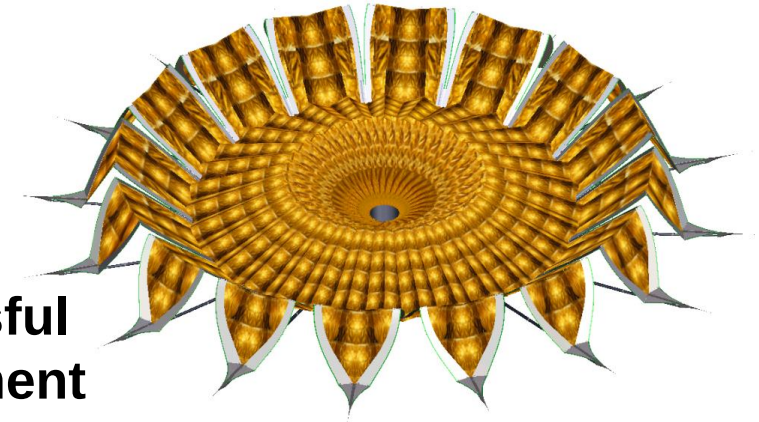
10 m,
1800 m^3
fairing

SLS Block II

stowed

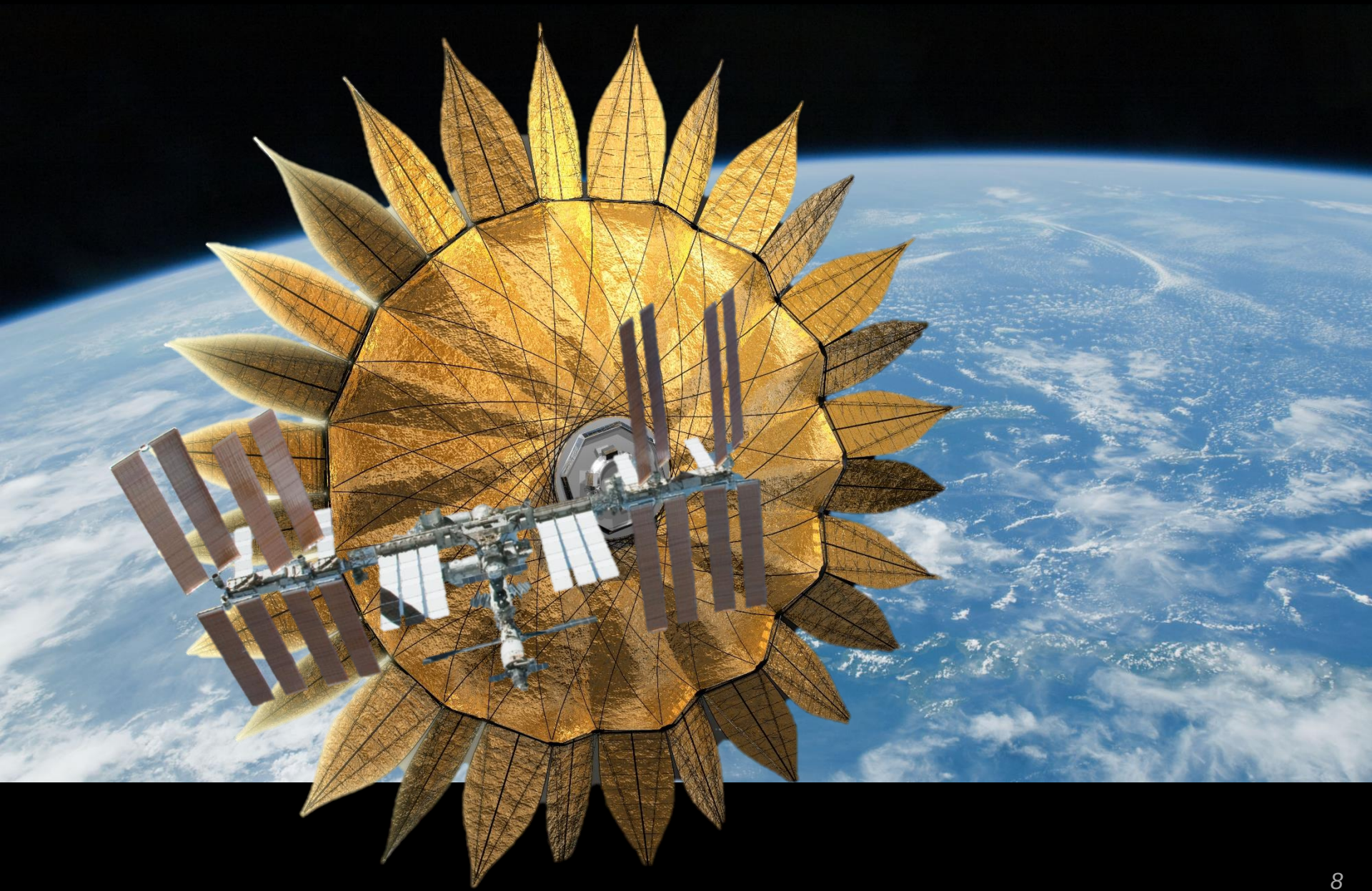
NGAS
starshade

Successful
deployment

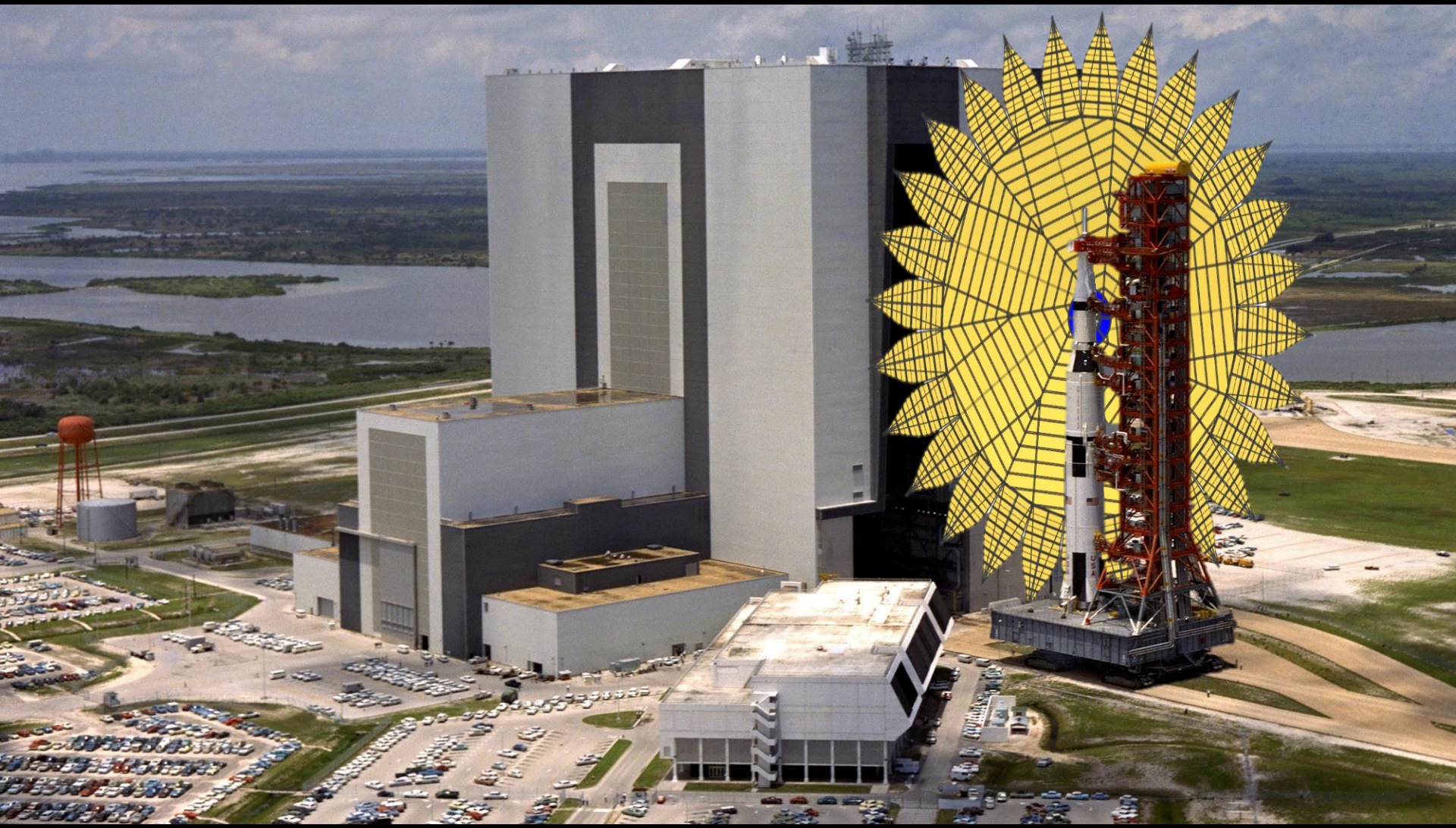


- We don't yet know what the upper size limits of autonomously-deployable starshades are.
- 72 m starshade for the HabEx mission concept is planned to be autonomously deployable.

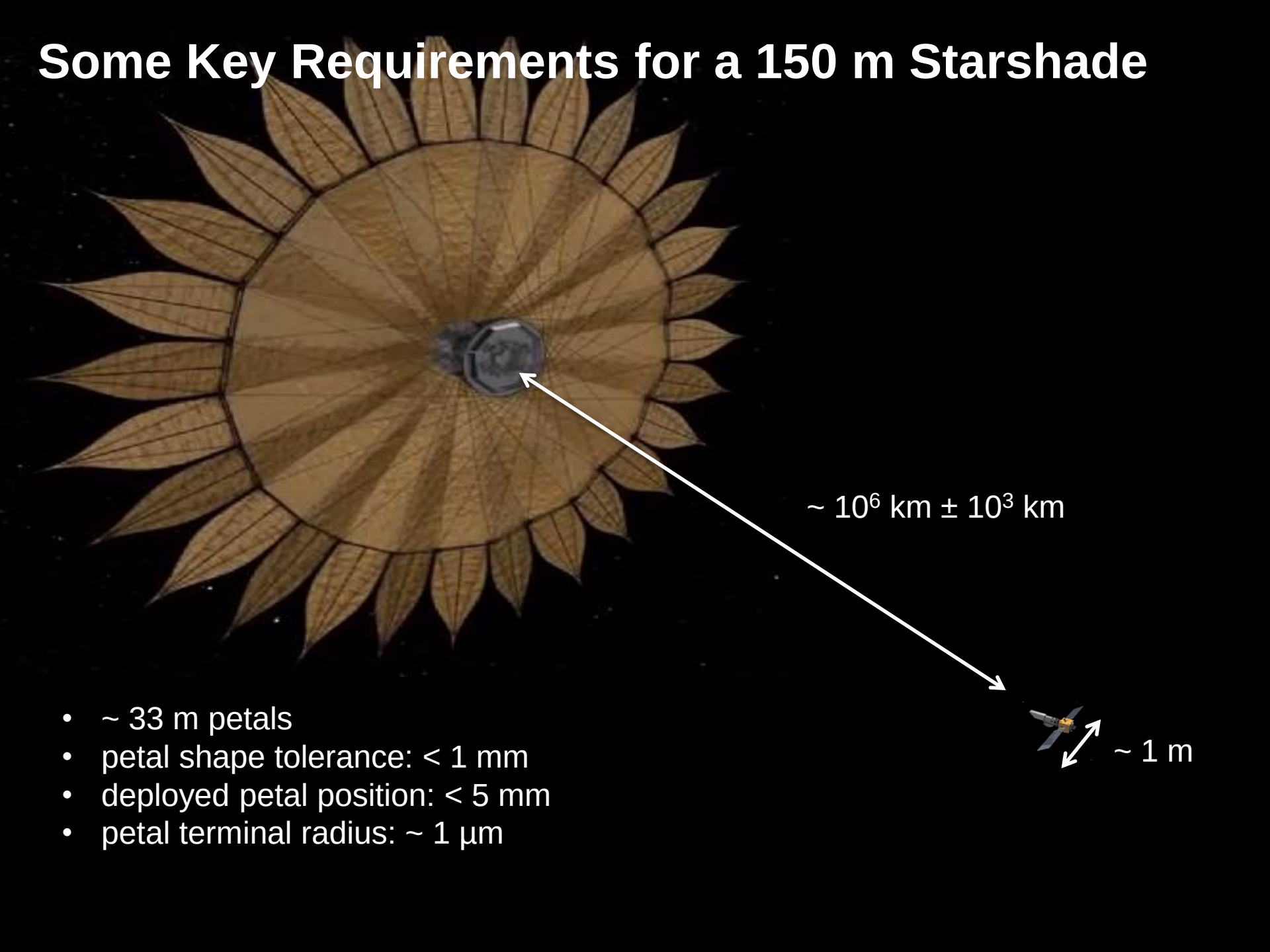
A 150 m Starshade



A 150 m Starshade



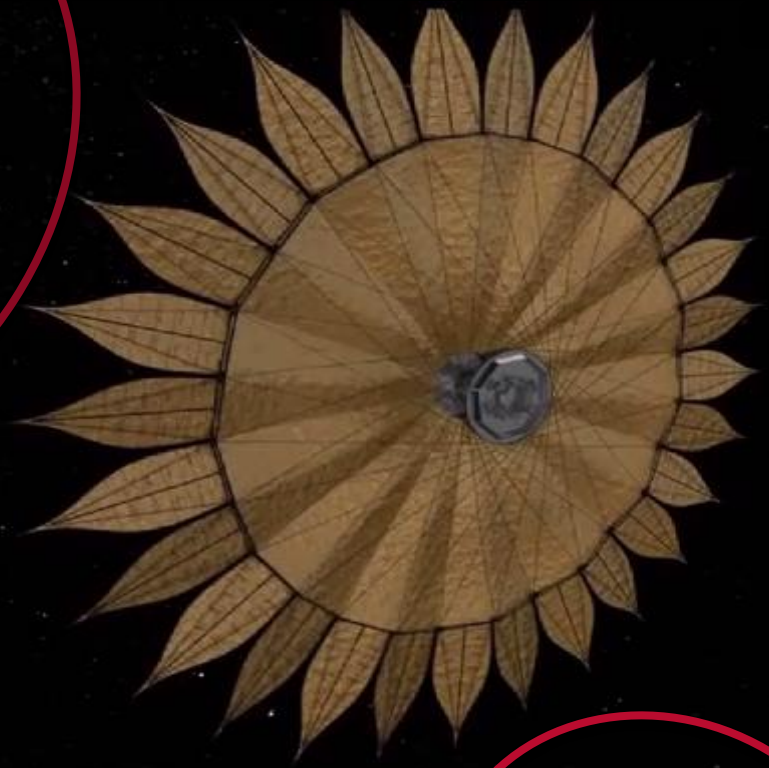
Some Key Requirements for a 150 m Starshade

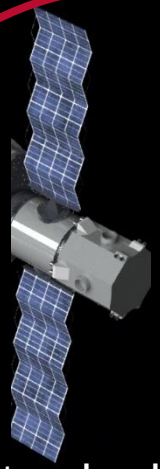


- ~ 33 m petals
- petal shape tolerance: < 1 mm
- deployed petal position: < 5 mm
- petal terminal radius: ~ 1 µm

Large Solution Space for In-Space Assembly

Cis-lunar station





Starshade spacecraft bus

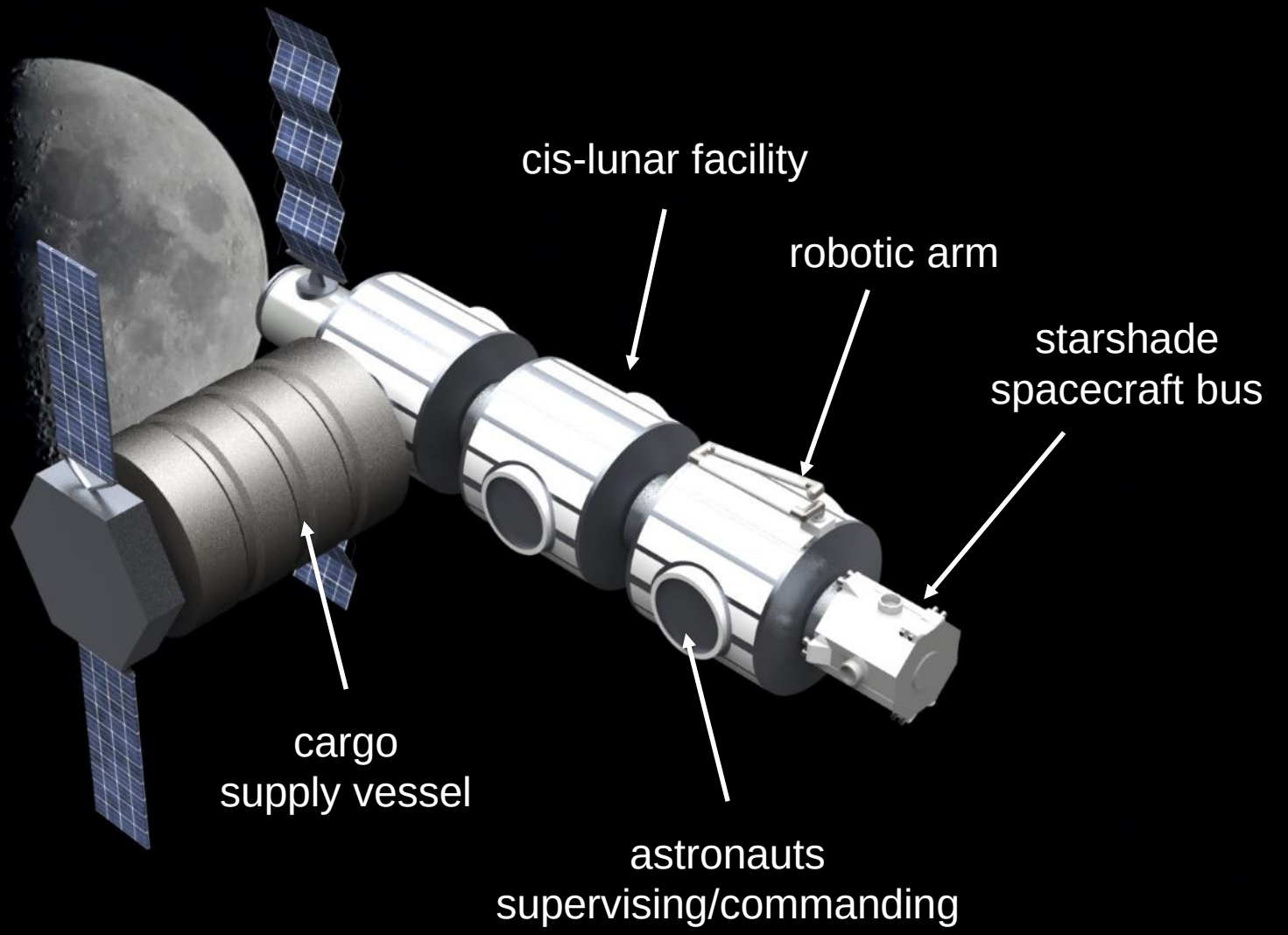
In-space manufacturing

Free-flying servicer

Mobile assembly robot

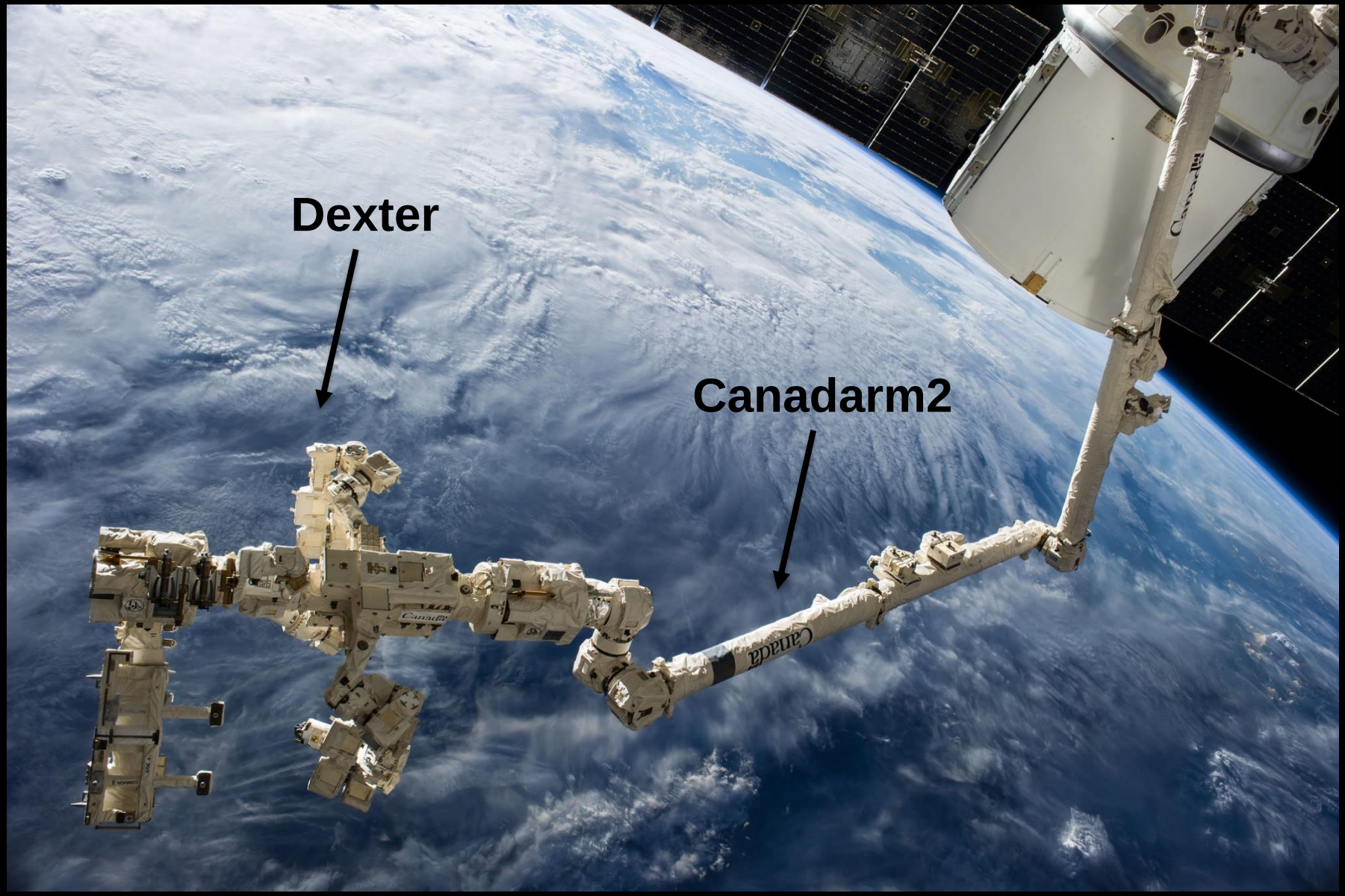
Fixed assembly robot

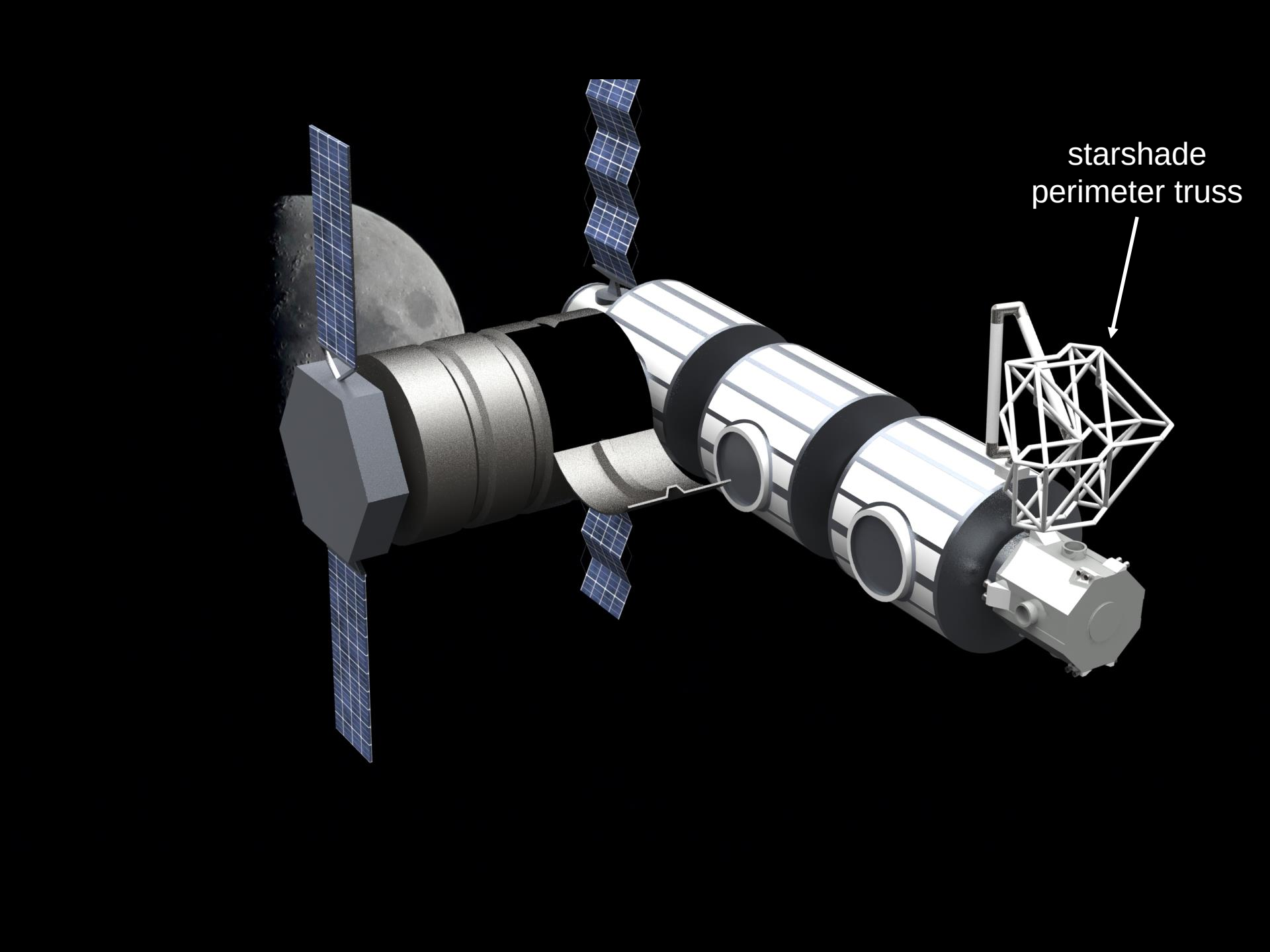
Astronaut support

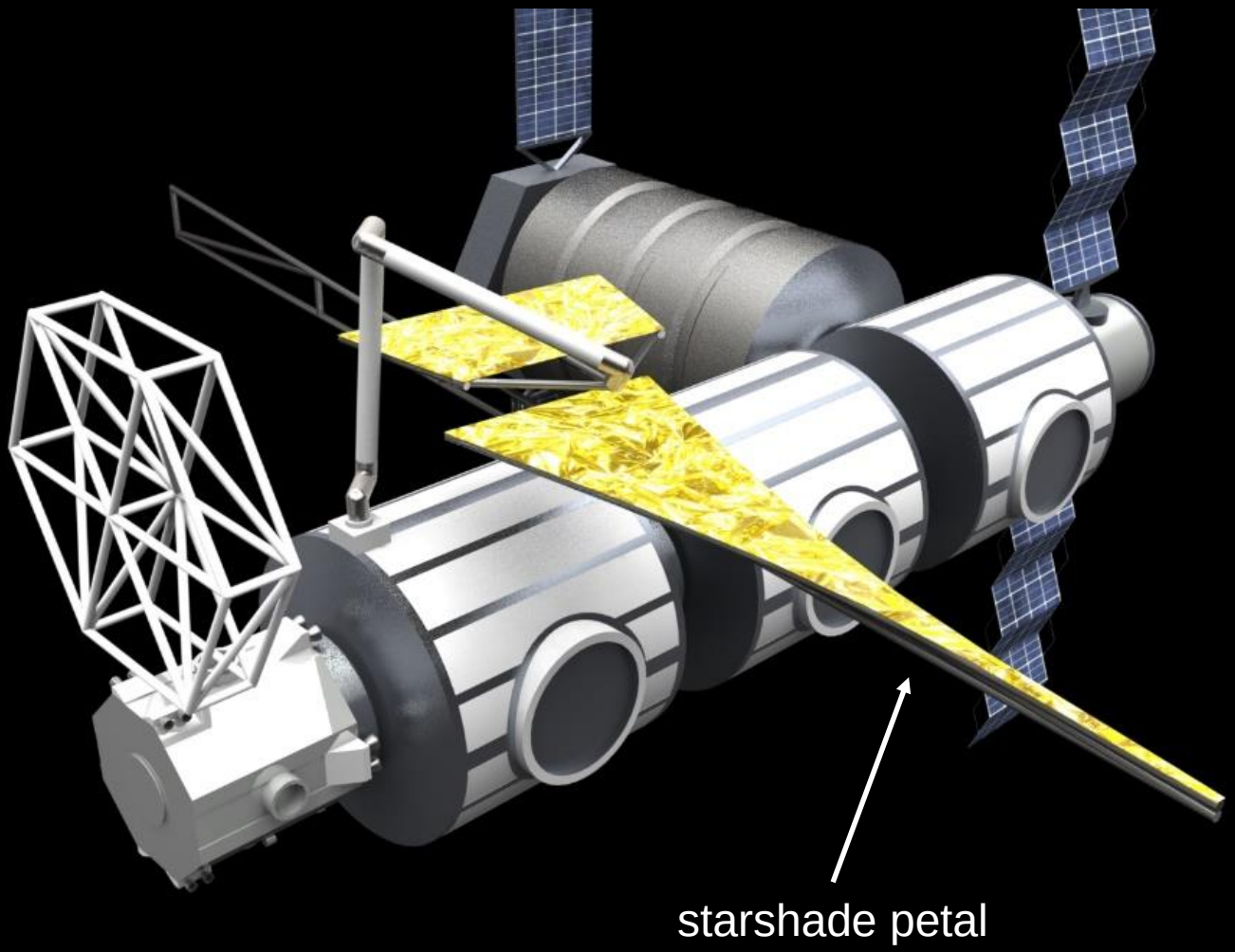

cis-lunar facility
robotic arm
starshade
spacecraft bus
cargo
supply vessel
astronauts
supervising/commanding

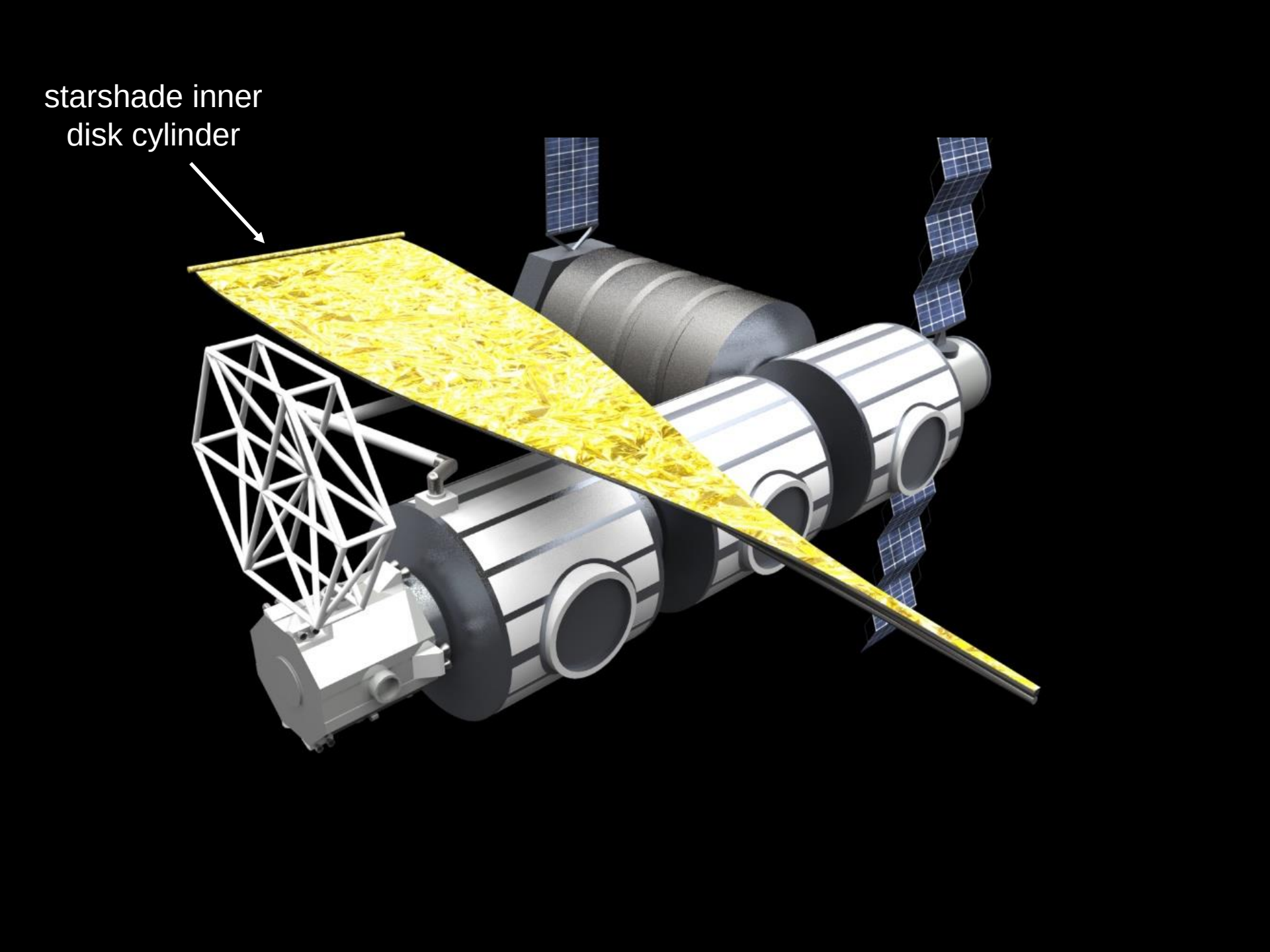
Special Purpose Dexterous Manipulator

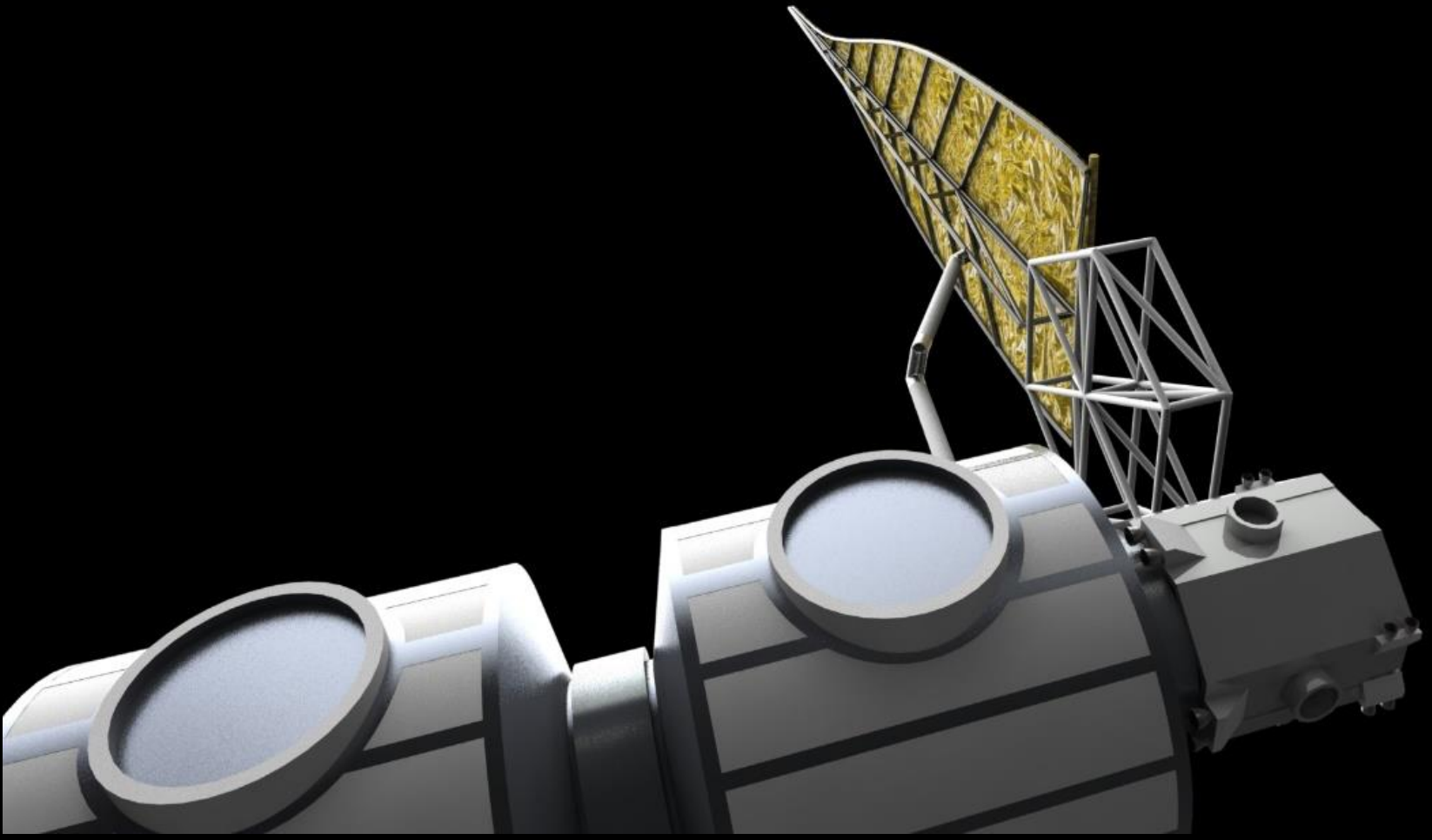
Two armed robot working with Canadarm

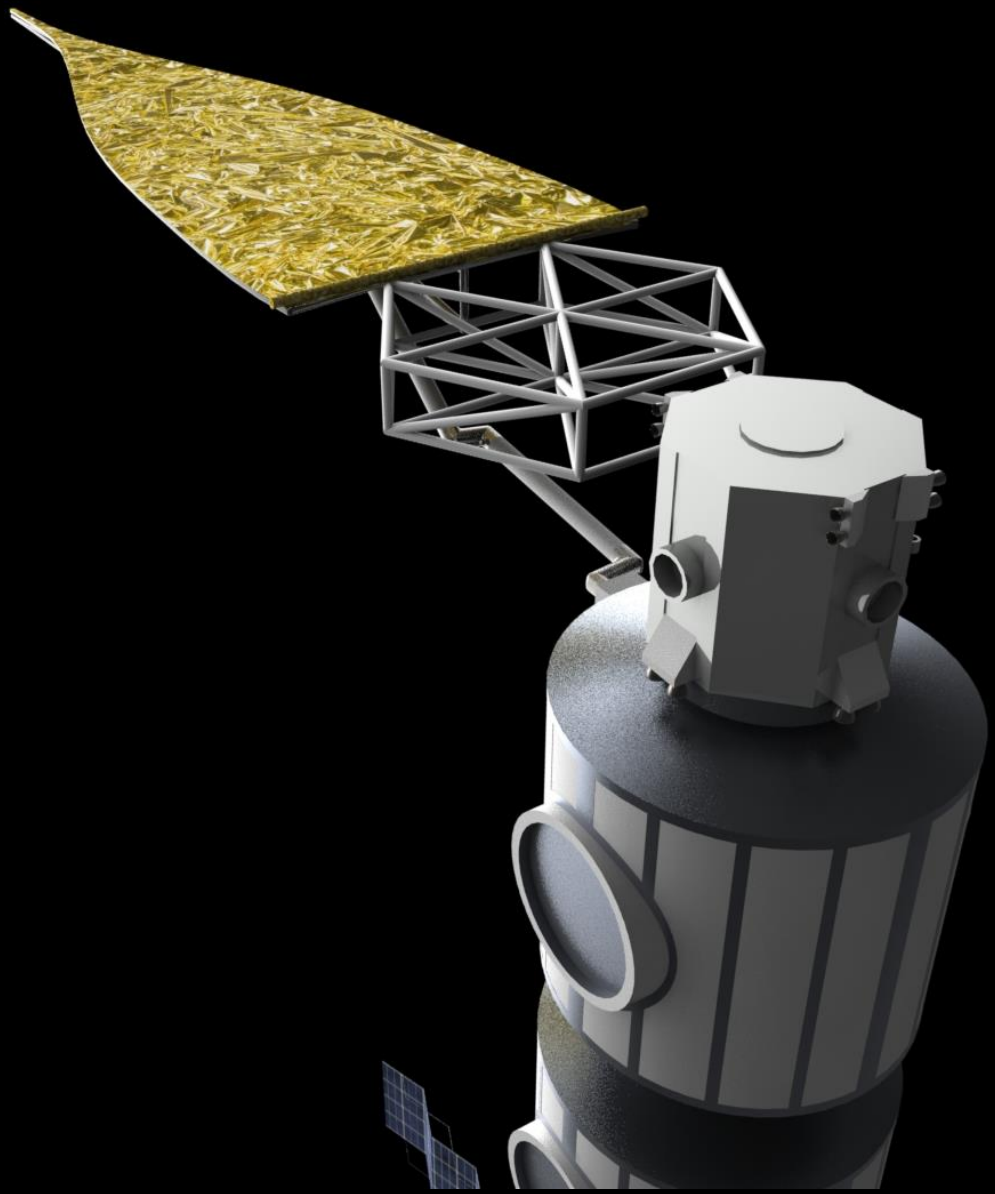


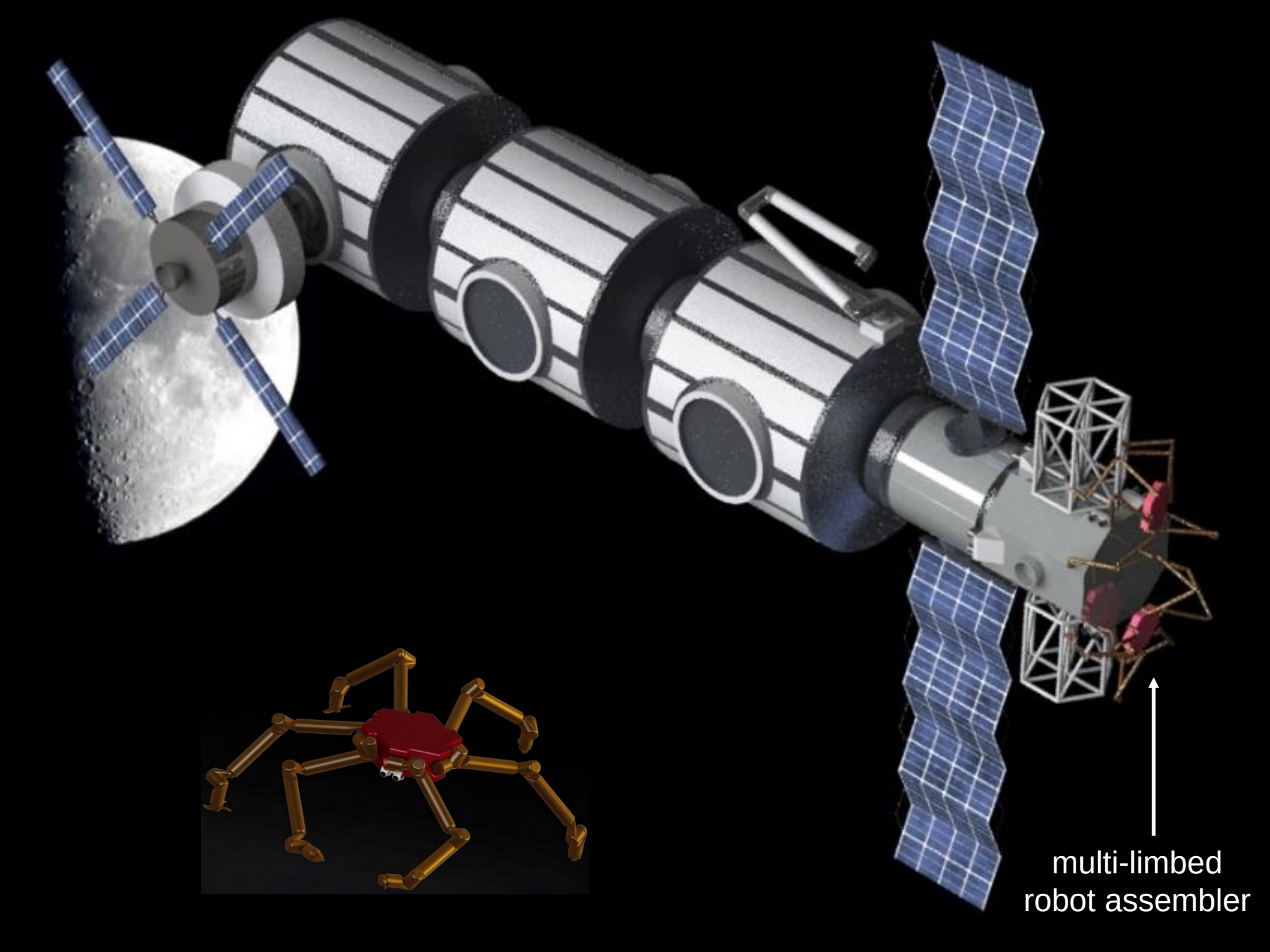

starshade
perimeter truss

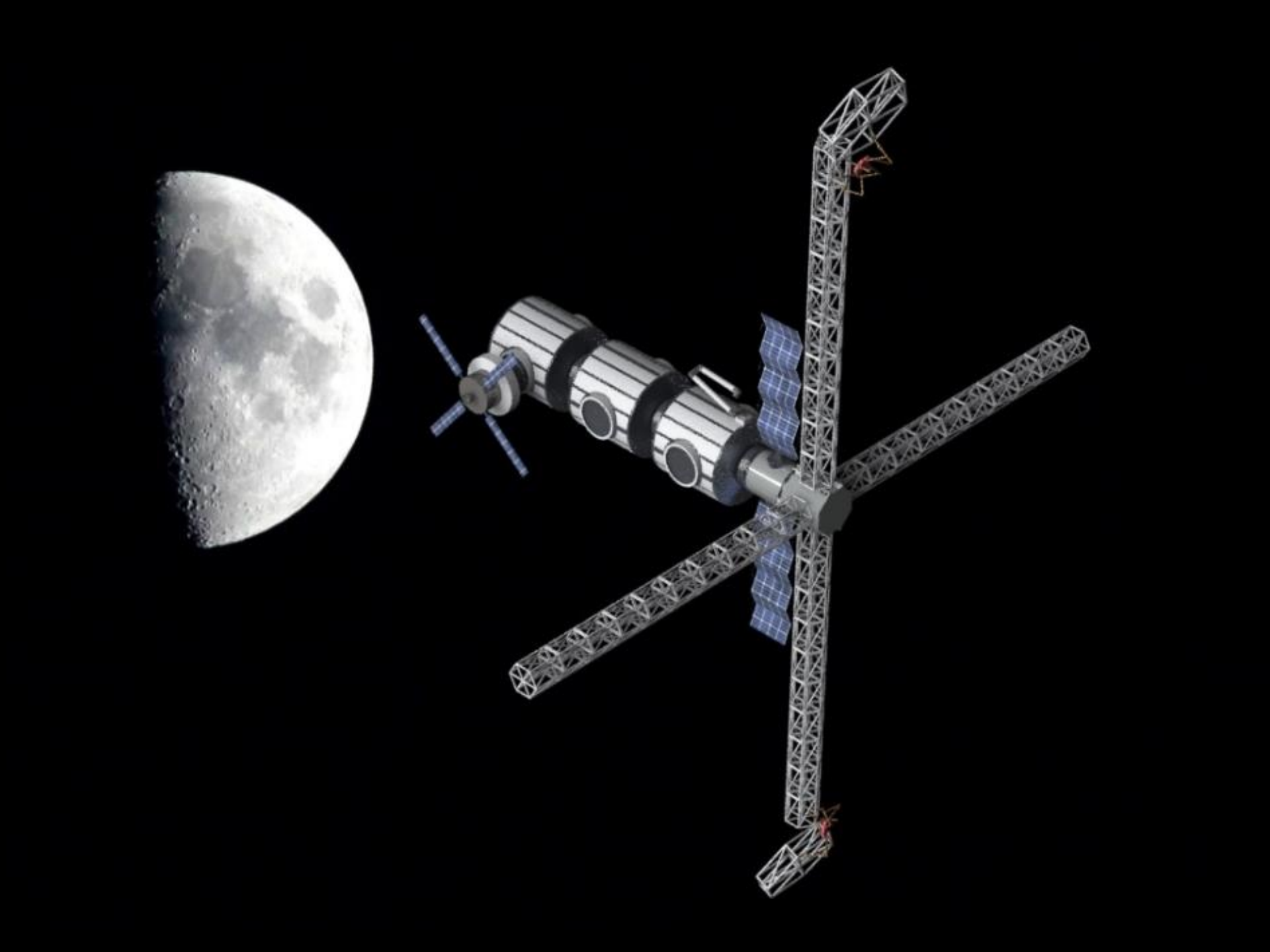

starshade petal

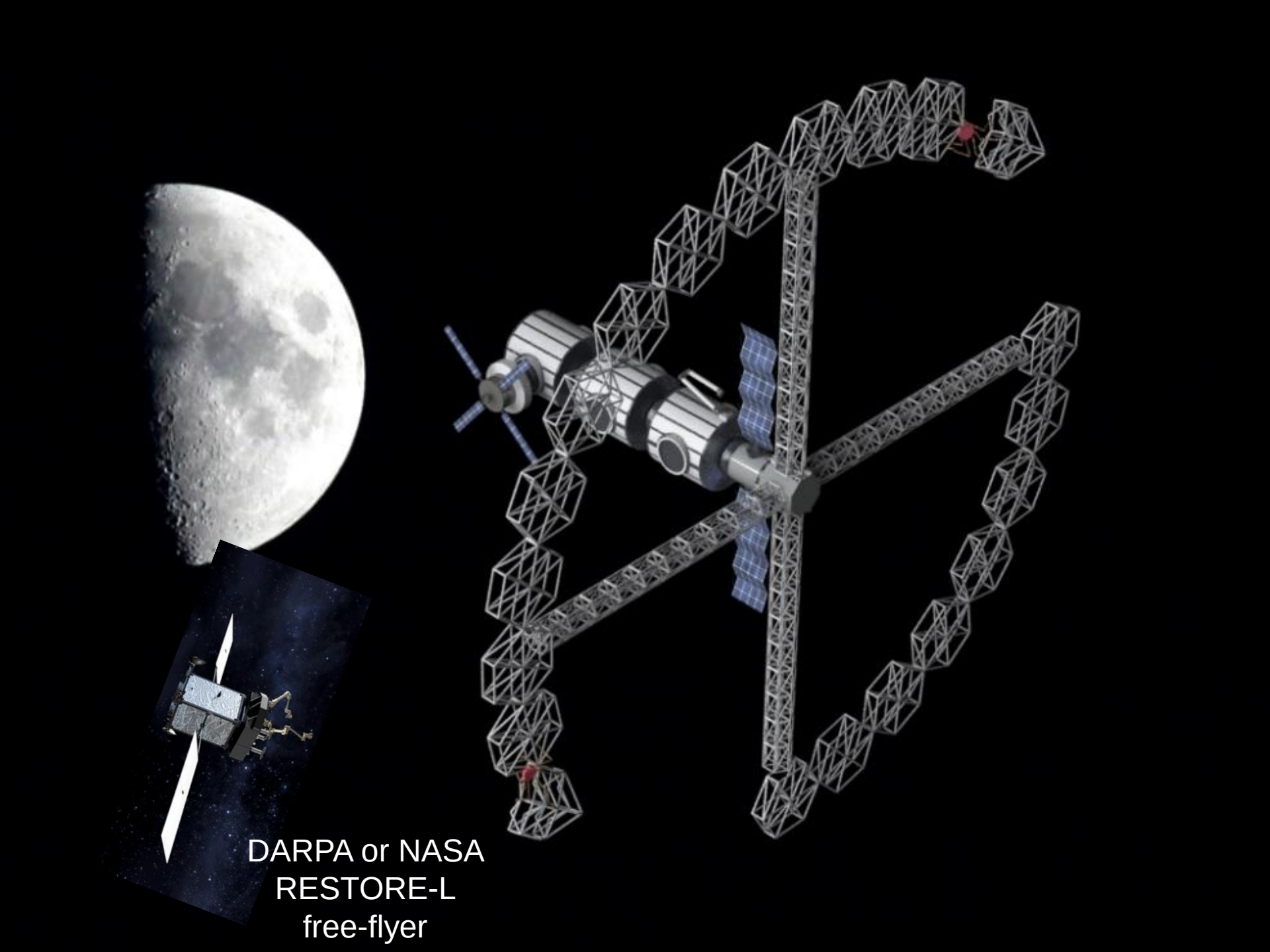

starshade inner
disk cylinder





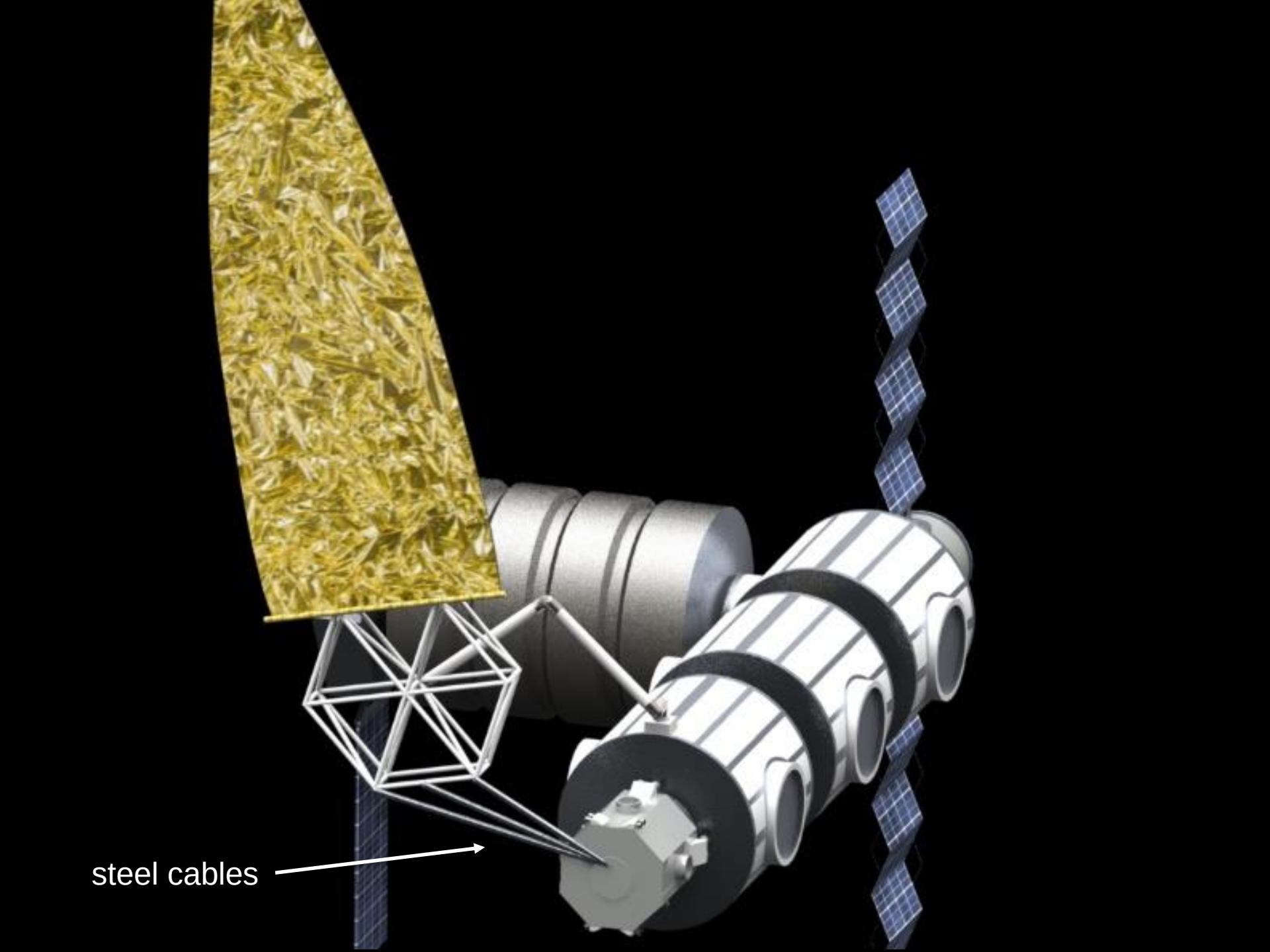

multi-limbed
robot assembler

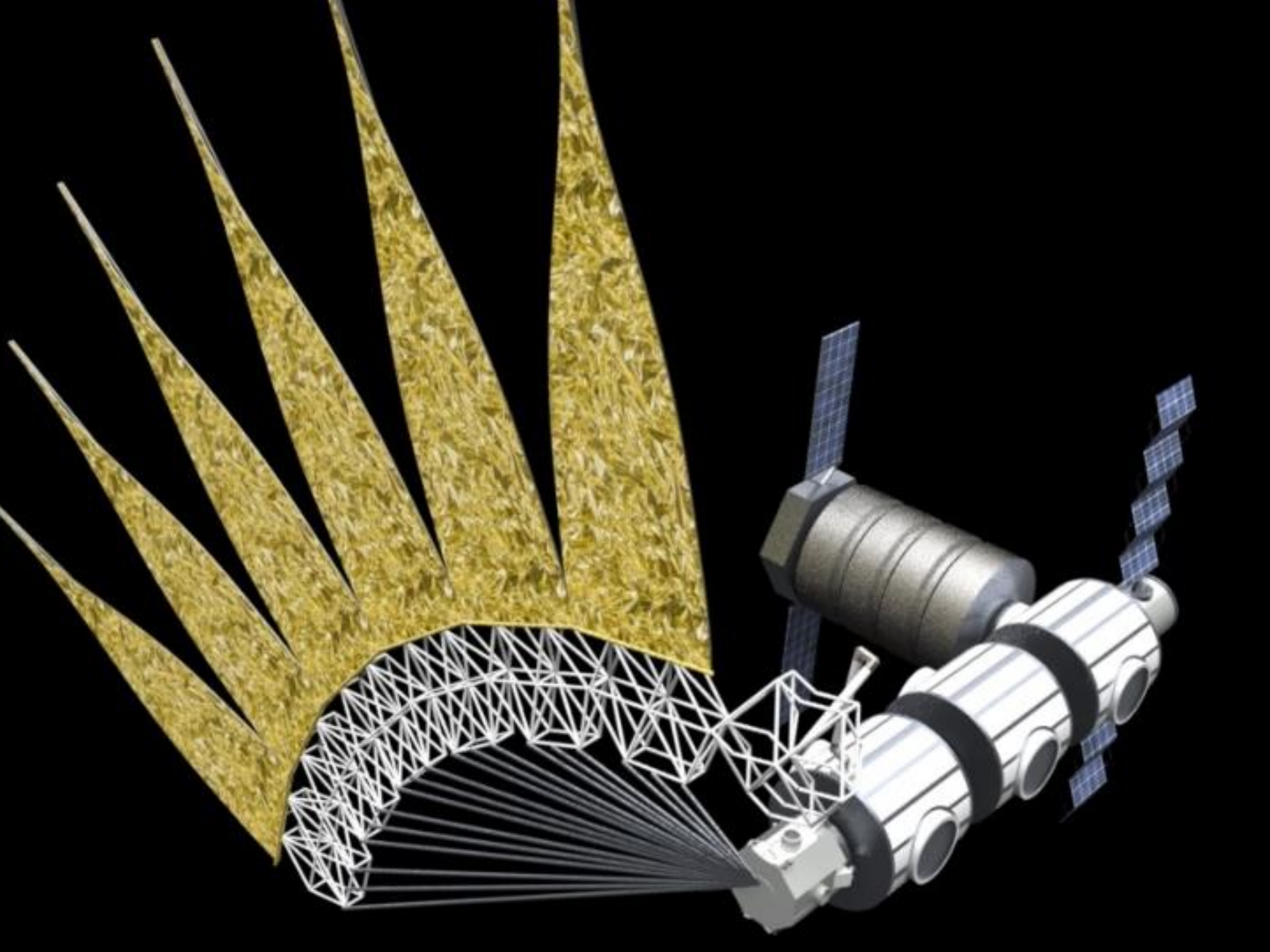


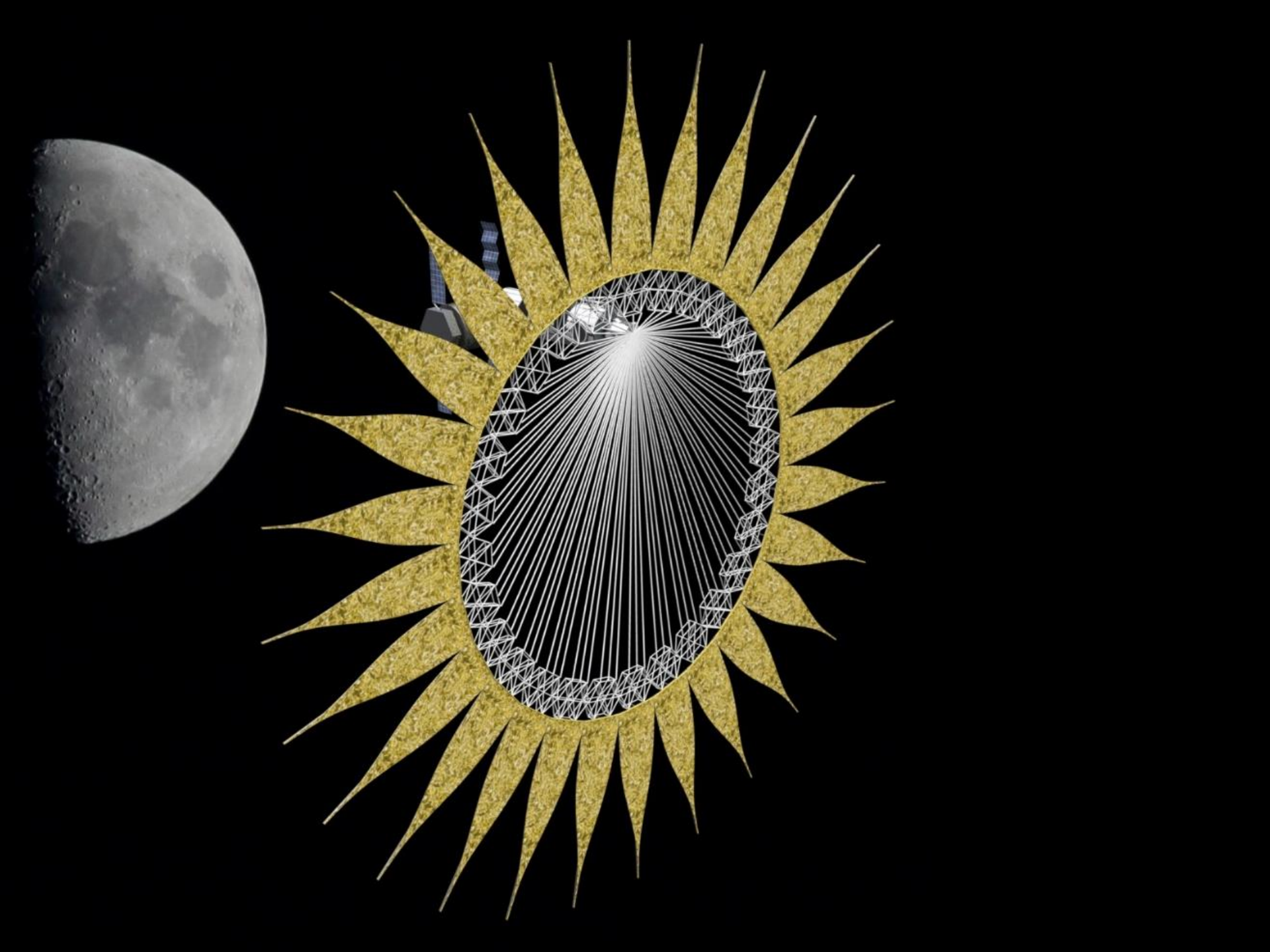


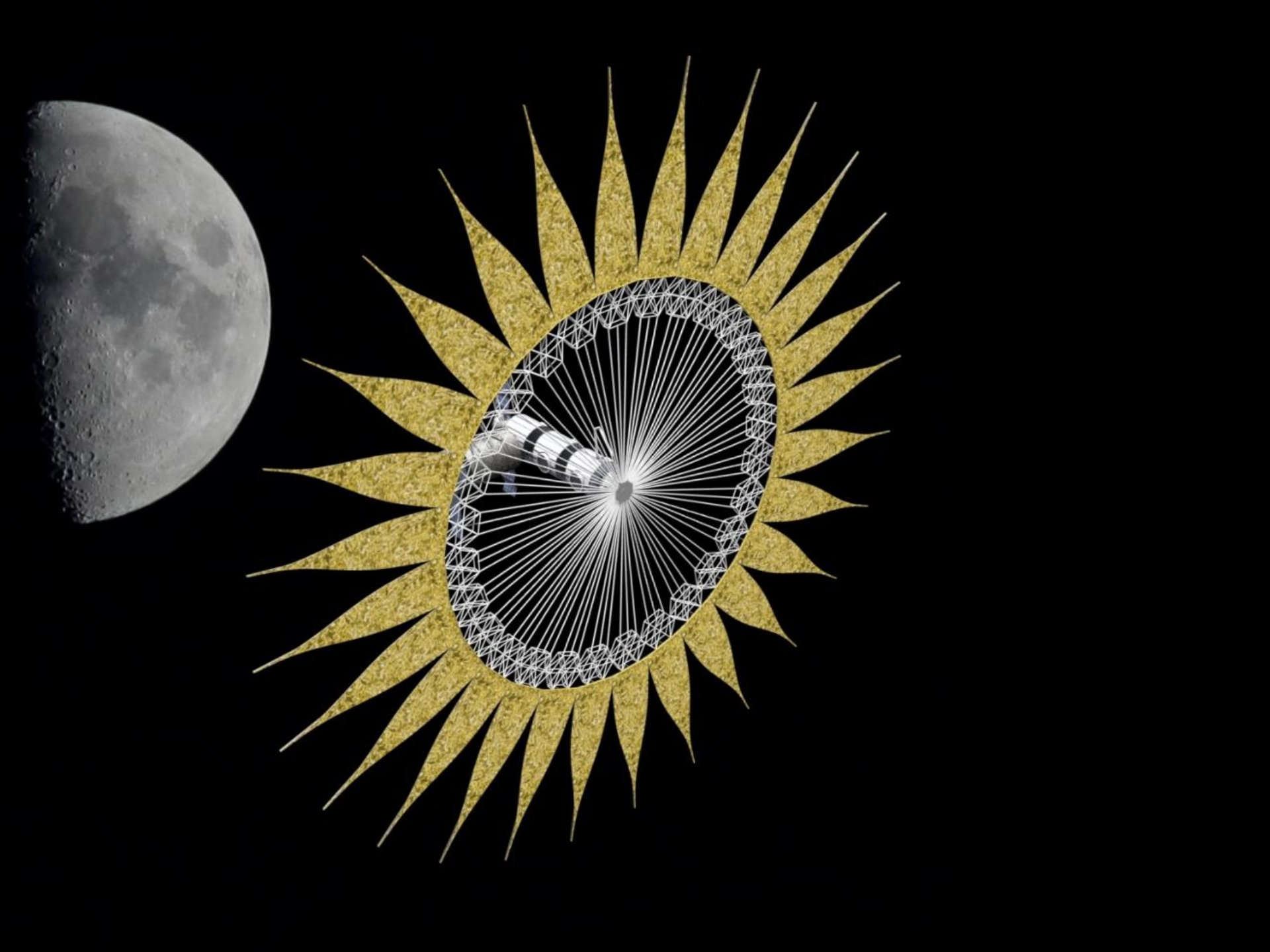
DARPA or NASA
RESTORE-L
free-flyer

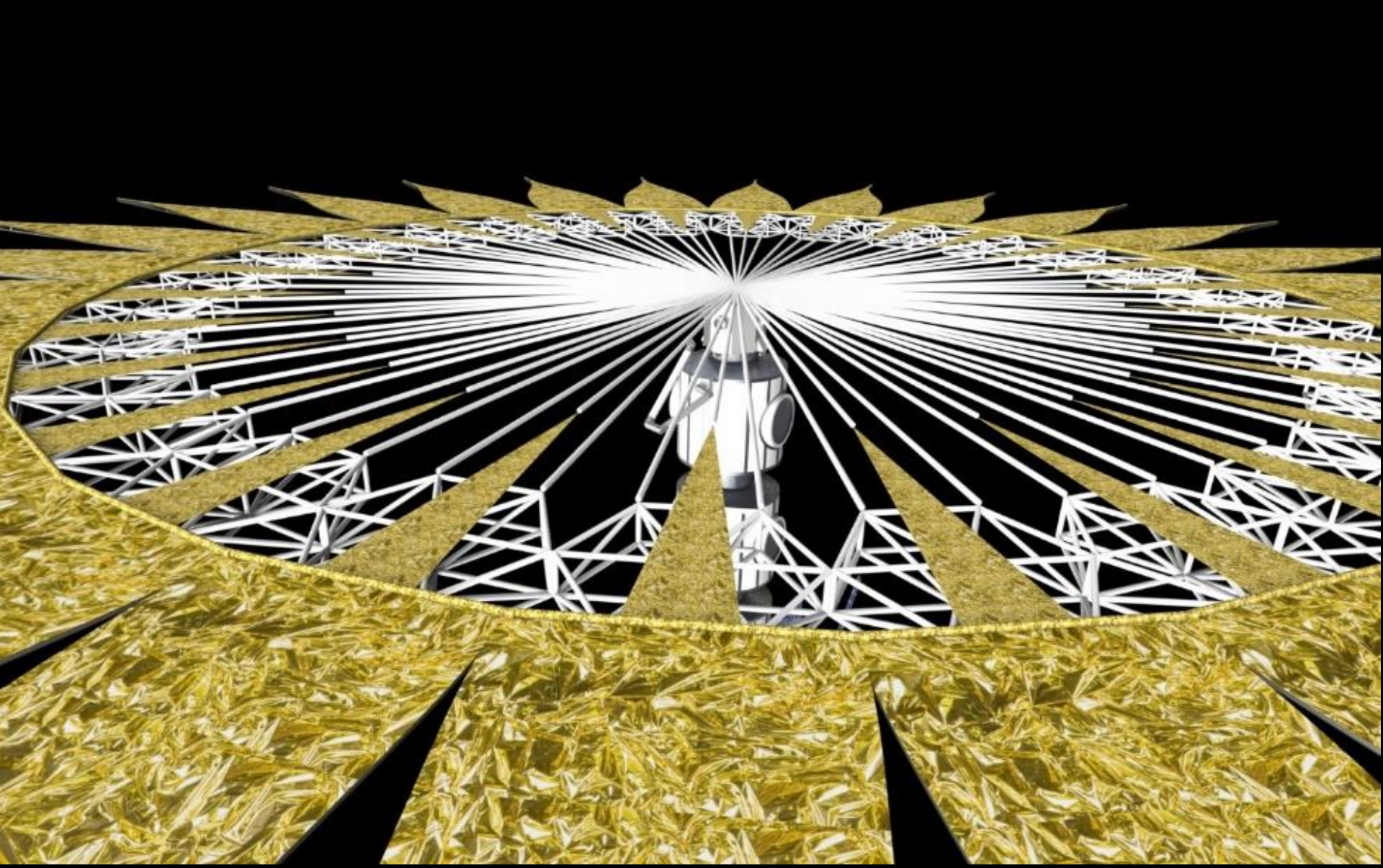
Credit: topnews.net.nz

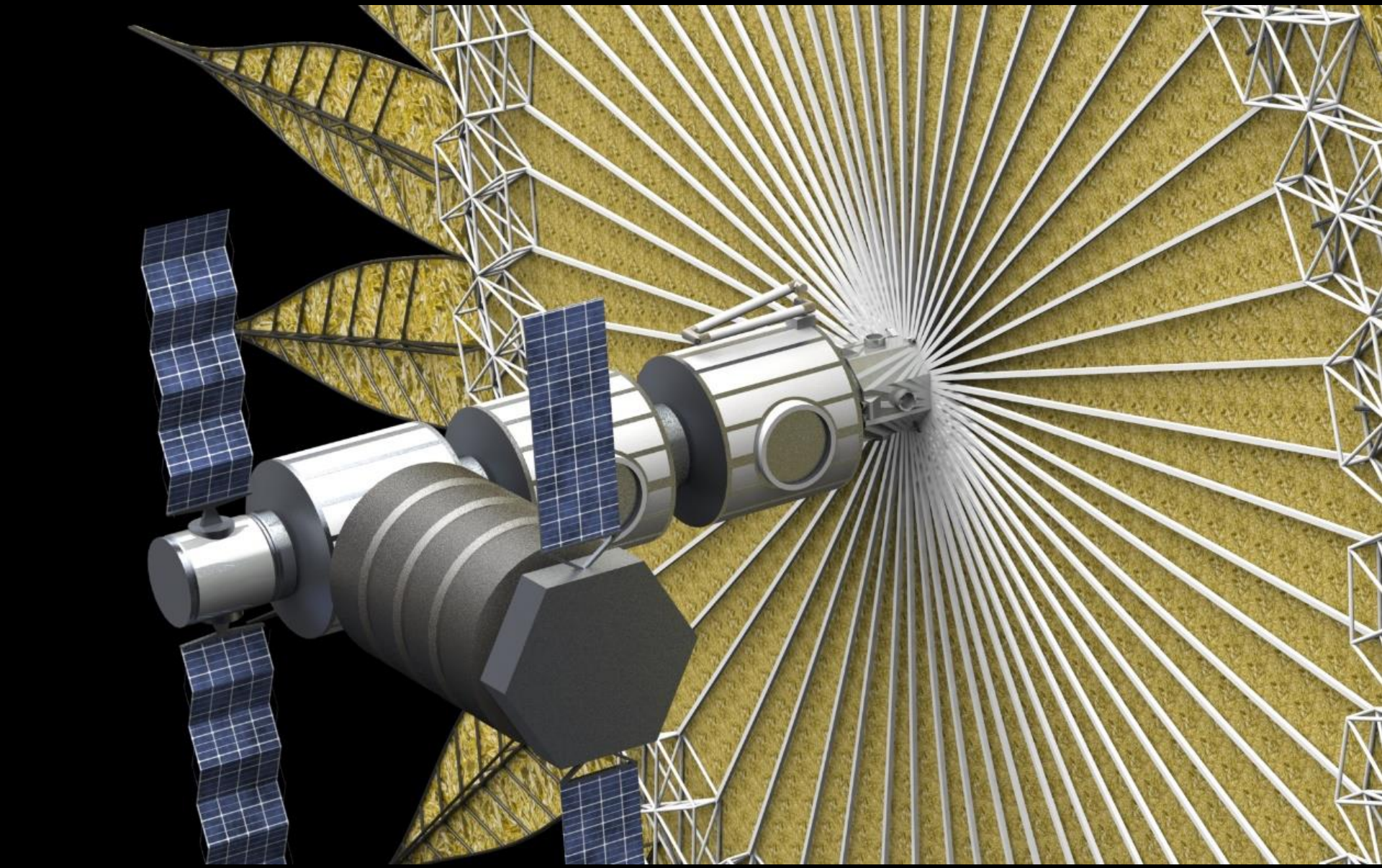

steel cables

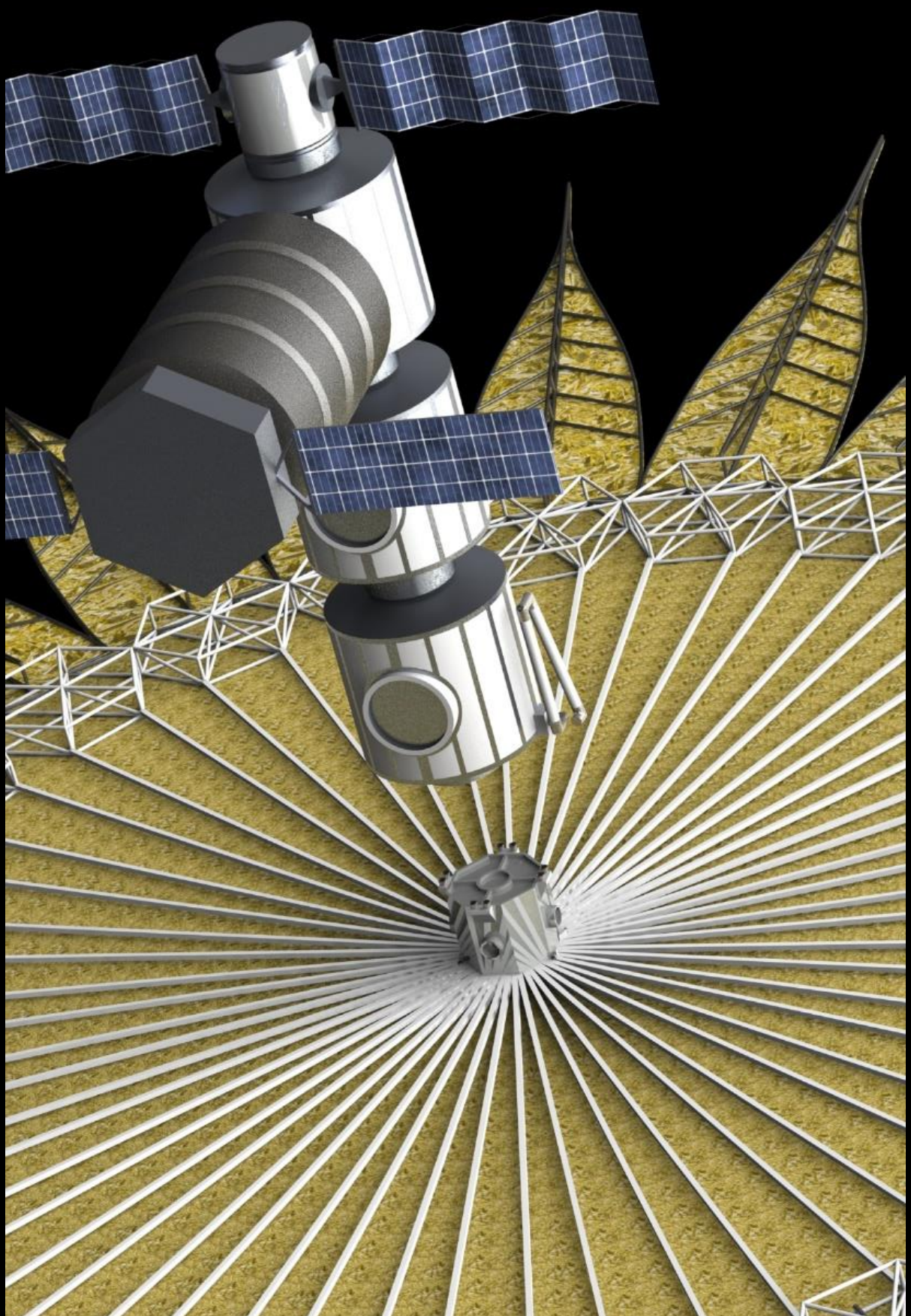


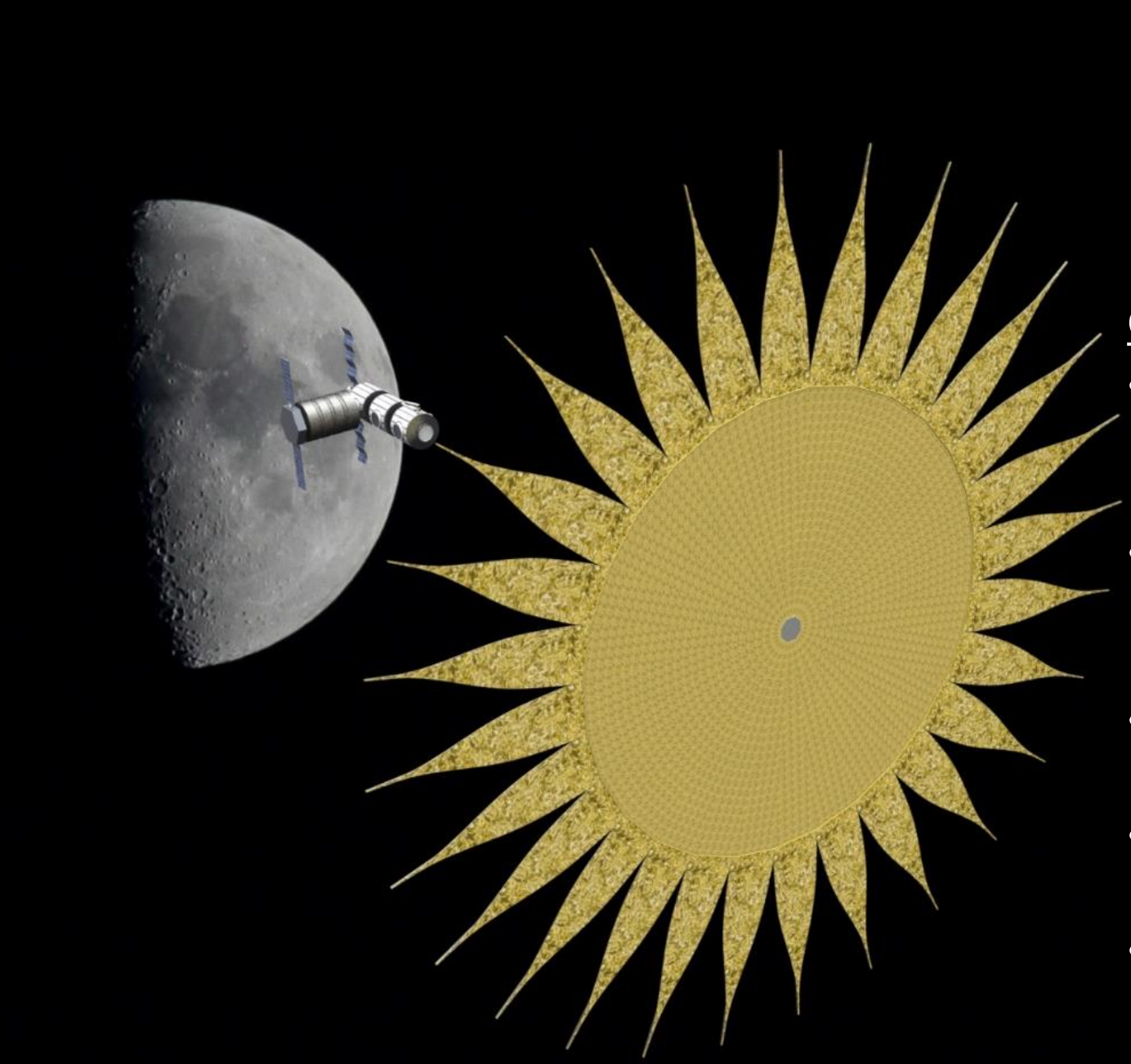










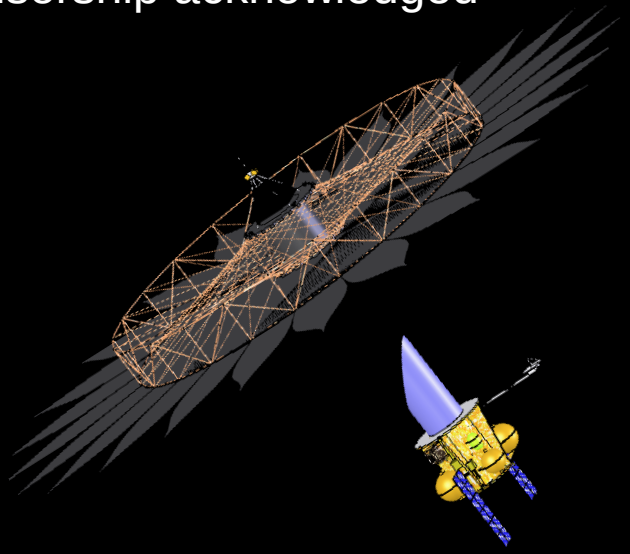


Open questions

- How are the petals and their positions inspected?
- And how are they adjusted or repaired?
- Orbit? Earth-Sun L2?
- Propulsion system/delta-V
- Refueling possibilities

Acknowledgements

This work was conducted at the Jet Propulsion Laboratory, California Institute of Technology, under contract with the National Aeronautics and Space Administration

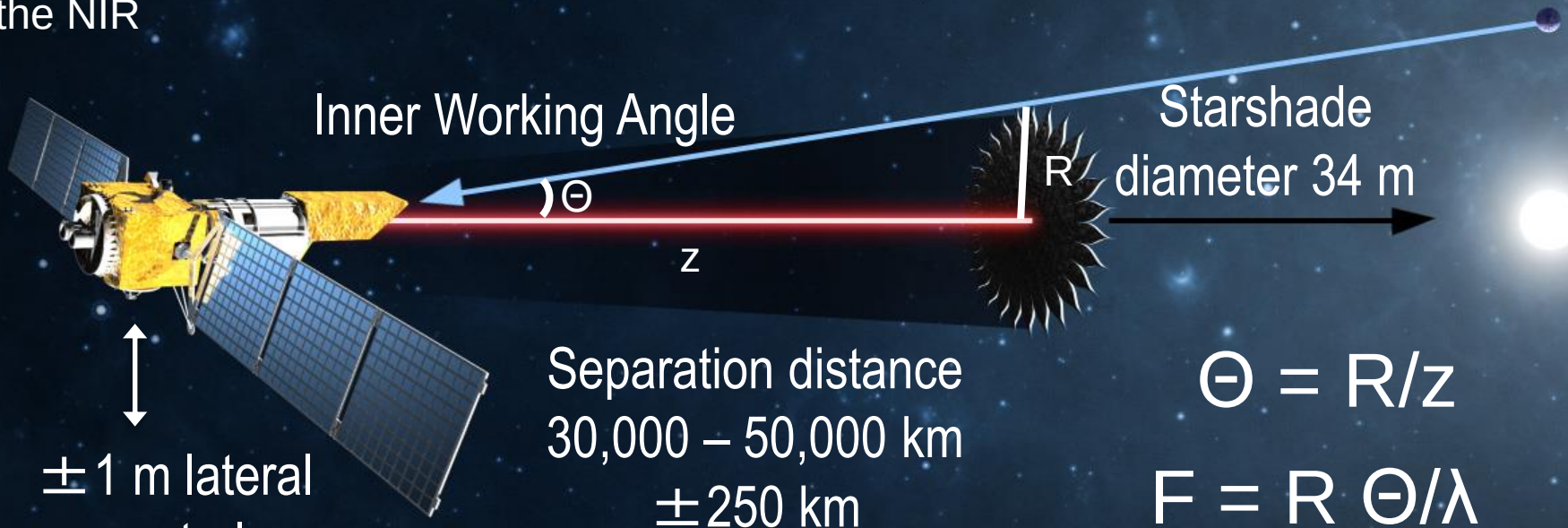


Additional Slides

Allows more exo-Earths to be characterized in the NIR

Inner Working Angle (mas)	Starshade Diameter (m)
100	34
73	72
20	100

→ 40-50 exo-Earths



Separation distance
30,000 – 50,000 km
±250 km

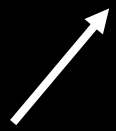
$$\Theta = R/z$$

$$F = R\,\Theta/\lambda$$

Θ = inner working angle
R = starshade radius
z = separation
λ = wavelength
F = Fresnel #

Bigger is Better

Mission Concept	Inner Working Angle (mas)	Starshade (m)	Telescope (m)
Rendezvous	100	34	2.4
HabEx	72	72	4
LUVOIR	19	100	15



Allows more exo-Earths to be characterized in the NIR

40-50 exo-Earths in the Habitable Zone

Delta-V's

From	To	delta-v (km/s)
Low Earth orbit (LEO)	Earth–Moon Lagrangian 1 (EML-1)	7.0
Low Earth orbit (LEO)	Geostationary Earth orbit (GEO)	6.0
Low Earth orbit (LEO)	Low Lunar orbit (LLO)	8.0
Low Earth orbit (LEO)	Sun–Earth Lagrangian 1 (SEL-1)	7.4
Low Earth orbit (LEO)	Sun–Earth Lagrangian 2 (SEL-2)	7.4
Earth–Moon Lagrangian 1 (EML-1)	Low Lunar orbit (LLO)	0.60–0.80
Earth–Moon Lagrangian 1 (EML-1)	Geostationary Earth orbit (GEO)	1.4–1.75
Earth–Moon Lagrangian 1 (EML-1)	Sun-Earth Lagrangian 2 (SEL-2)	0.30–0.40