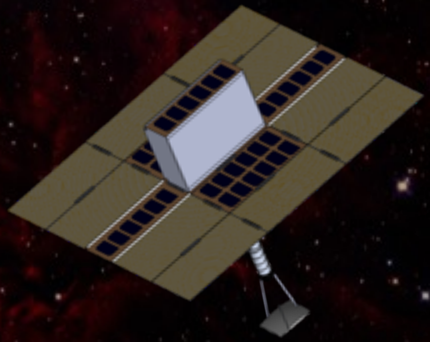
Jet Propulsion Laboratory
California Institute of Technology

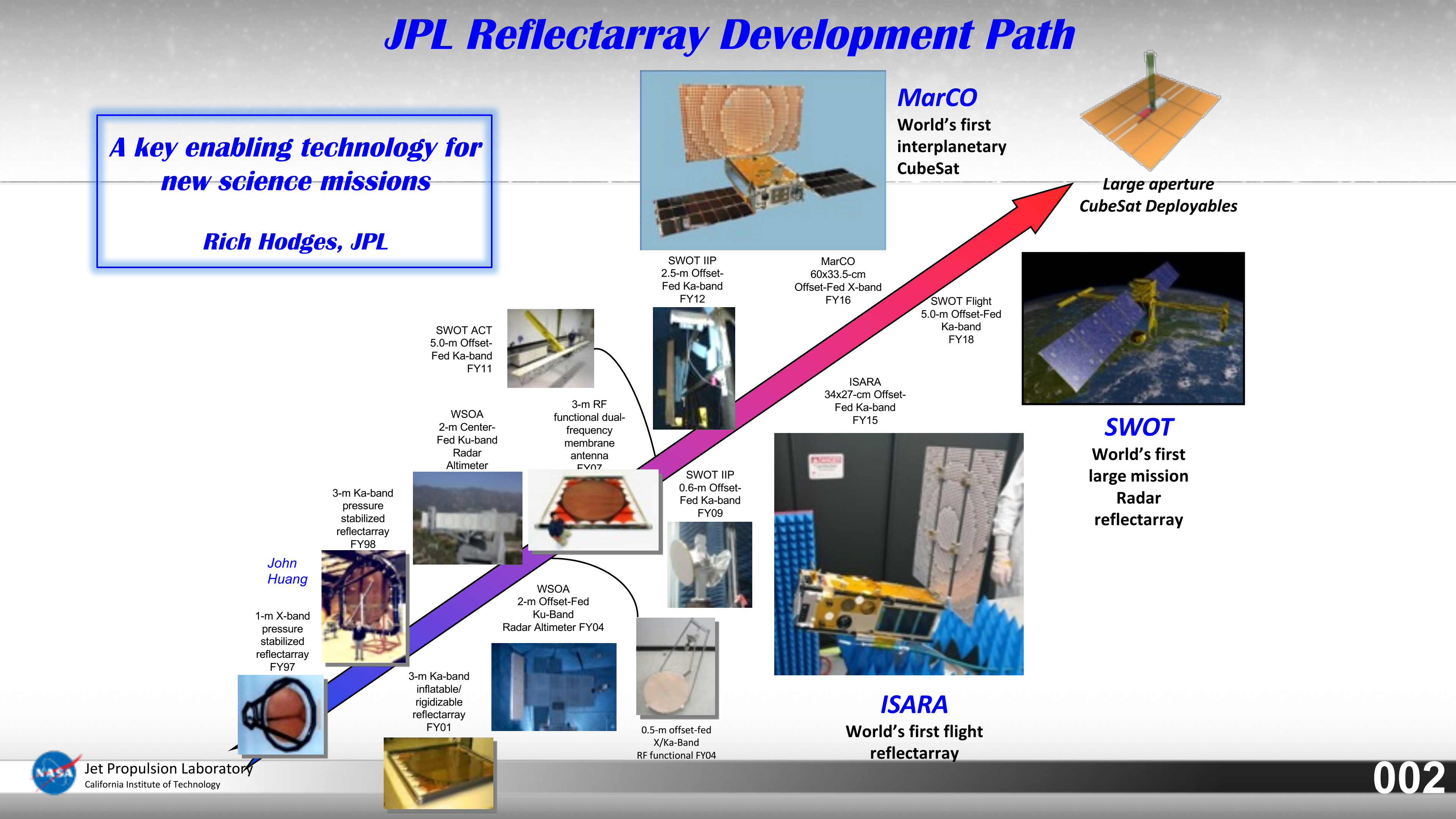
Antenna Technology for SmallSat

Deployable Reflectarray Antennas for Space Application

IEEE MTT/AP Orlando Chapter & Raj Mittra Distinguished Lecture Program

Thomas A. Cwik
Nacer Chahat, Jonathan Sauder, Gregory Agnes, Manan Arya.




JPL Reflectarray Development Path
A key enabling technology for new science missions
Rich Hodges, JPL
MarCO
World's first interplanetary CubeSat
Large aperture CubeSat Deployables
SWOT IIP
2.5-m Offset-Fed Ka-band
FY12
MarCO
60x33.5-cm
Offset-Fed X-band
FY16
SWOT Flight
5.0-m Offset-Fed
Ka-band
FY18
SWOT ACT
5.0-m Offset-Fed Ka-band
FY11
ISARA
34x27-cm Offset-Fed Ka-band
FY15
WSOA
2-m Center-Fed Ku-band
Radar Altimeter
3-m RF functional dual-frequency membrane antenna
FY07
SWOT
World's first large mission Radar reflectarray
SWOT IIP
0.6-m Offset-Fed Ka-band
FY09
3-m Ka-band pressure stabilized reflectarray
FY98
John Huang
1-m X-band pressure stabilized reflectarray
FY97
WSOA
2-m Offset-Fed
Ku-Band
Radar Altimeter FY04
3-m Ka-band inflatable/ rigidizable reflectarray
FY01
0.5-m offset-fed
X/Ka-Band
RF functional FY04
ISARA
World's first flight reflectarray
Jet Propulsion Laboratory
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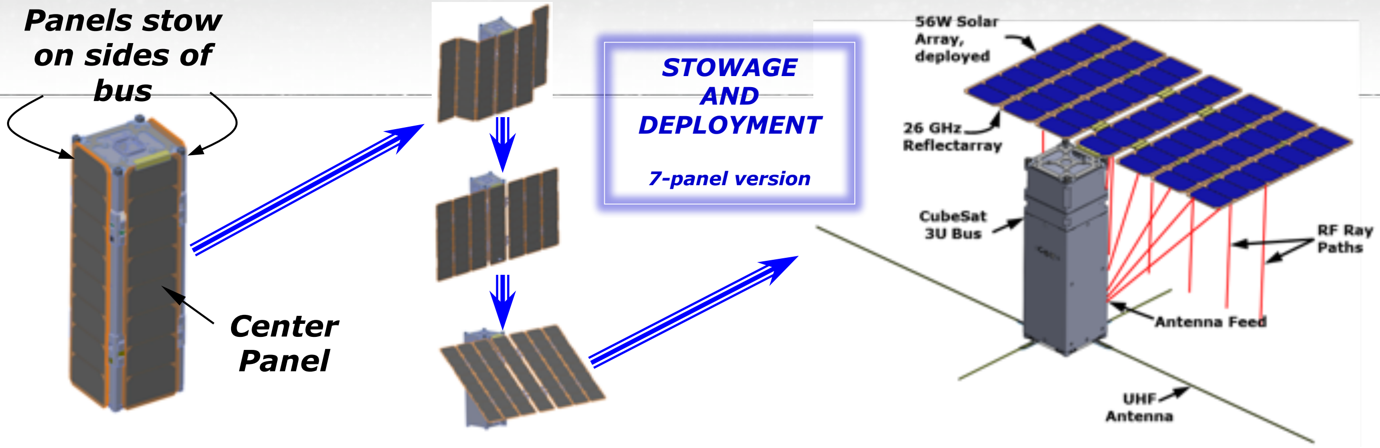
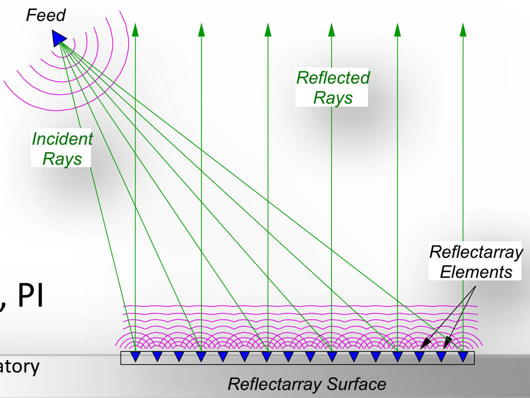
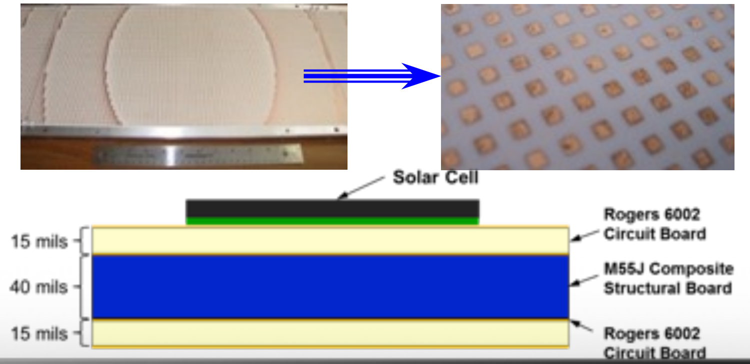
ISARA Concept – In a Nutshell



HOW A REFLECTARRAY WORKS



WHAT THE PANELS LOOK LIKE



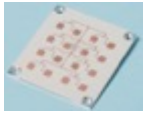
Rich Hodges JPL, PI

Printed Circuit Board Technology

ISARA as a System

Payload

Solar array/
Reflectarray
Antenna

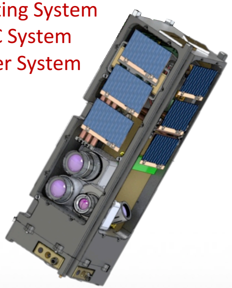


SGA
Antenna

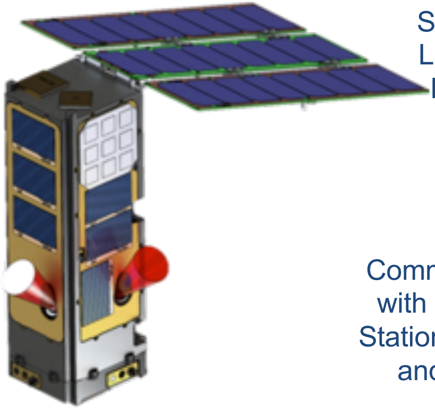
KB Exciter
Board

KBA
Feed

Pointing System
TT&C System
Power System

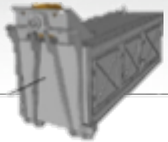


Spacecraft Bus - Aerospace



Integrated ISARA Flight
System

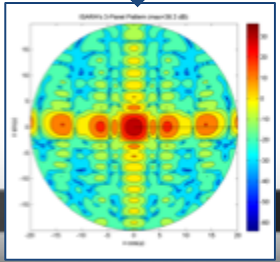
QuadPack
Dispenser on
Sherpa
Payload



Secondary
Launch on
Falcon 9

Communicate
with Ground
Stations at JPL
and TAC

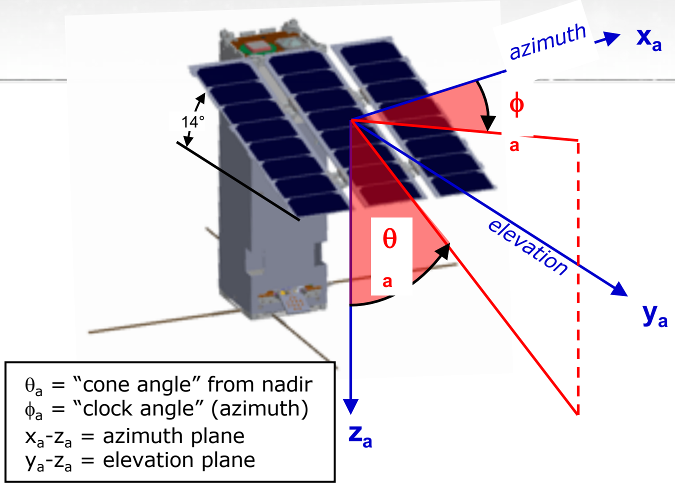
Measure KBA
Gain

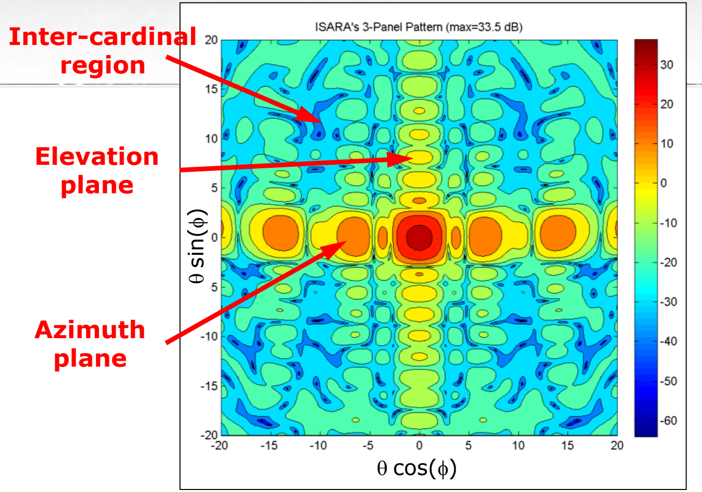


Tech Development - Level 1 Requirements

No.	Requirement	Verification Status
L1-1	The ISARA project shall measure the performance of a high-gain Ka-Band reflectarray antenna integrated with a solar array on a 3U CubeSat structure in a laboratory environment, and compare the results with those predicted by an antenna performance model.	✓ Completed reflectarray test ✓ Compared results to calculated ✓ EM and FM antenna in agree with model predict and meet performance requirements
L1-2	The ISARA project shall measure the performance of a high-gain Ka-Band reflectarray antenna integrated with a solar array on a 3U Cubesat in an operational environment.	✓ Completed FM antenna with solar array ✓ Draft Experiment plan completed ✓ Launch scheduled • 3U CubeSat development at FRR • ADACS system to achieve beam pointing • Measure on-orbit gain per experiment plan
L1-3	The technology advances that result from the ISARA project shall be made available for commercialization.	✓ Pumpkin, STABLCOR, MMR developed capability to build ISARA panels ✓ Develop commercialization plan
L1-4	The ISARA project shall demonstrate that the Ka-band reflectarray antenna supports 100 Mbps peak data rate from low Earth orbit via link budget analysis and measured relative antenna gain.	✓ Developed detailed link budget that shows 100 Mbps capability • Use measured on-orbit gain in link budget to verify 100Mbps capability.

Antenna Measurement Goals



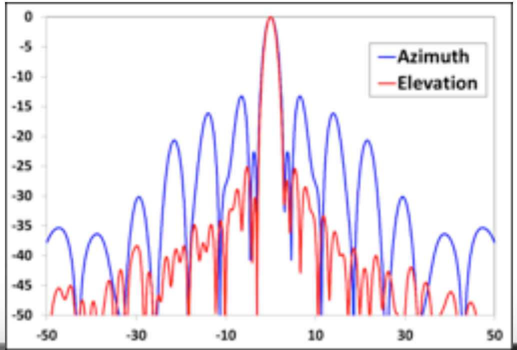


L1 Requirement: Measure Antenna Gain

- Validate 100 Mbps data rate
- Demonstrate operational telecom capability

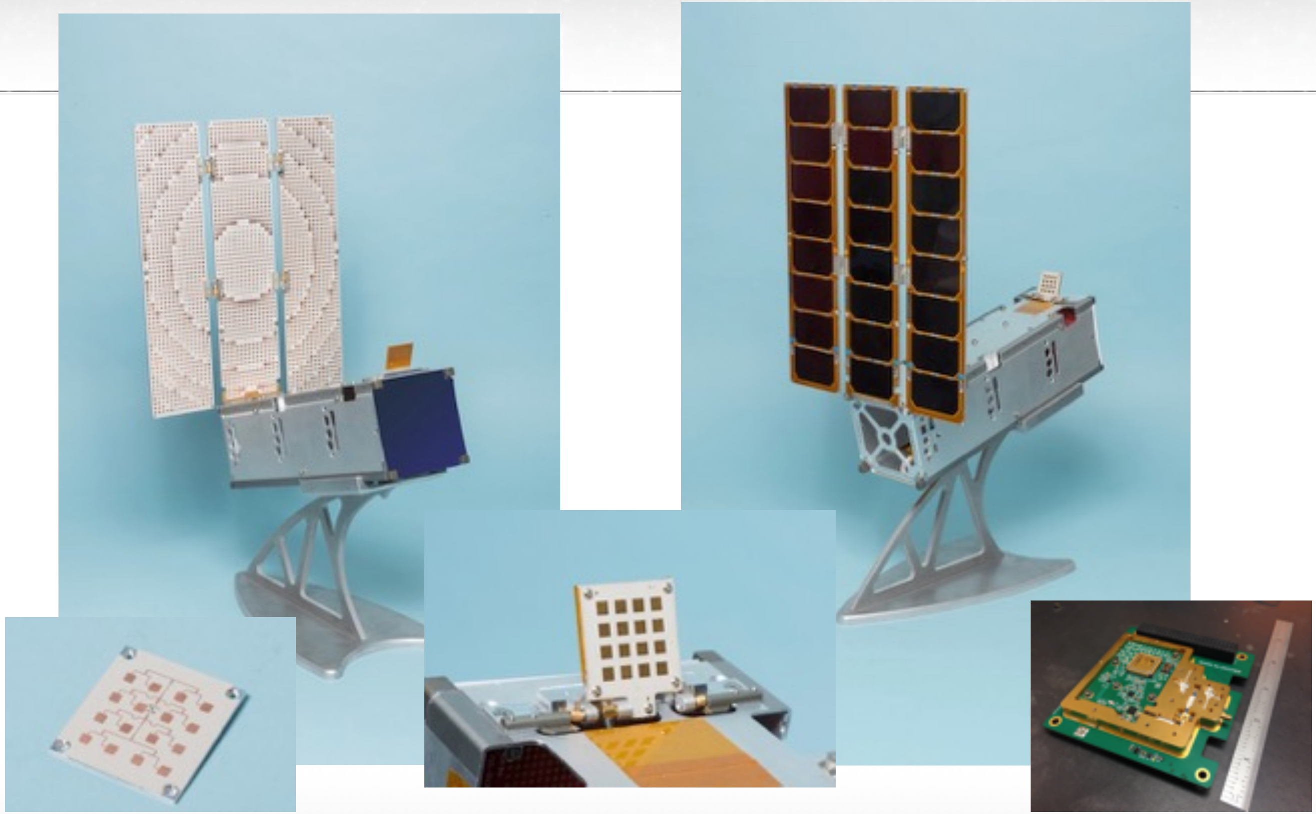
Secondary goal: Measure Antenna Patterns

- Verify beam pointing accuracy
- Verify quality of antenna deployment



Principal Plane Patterns

Payload Status

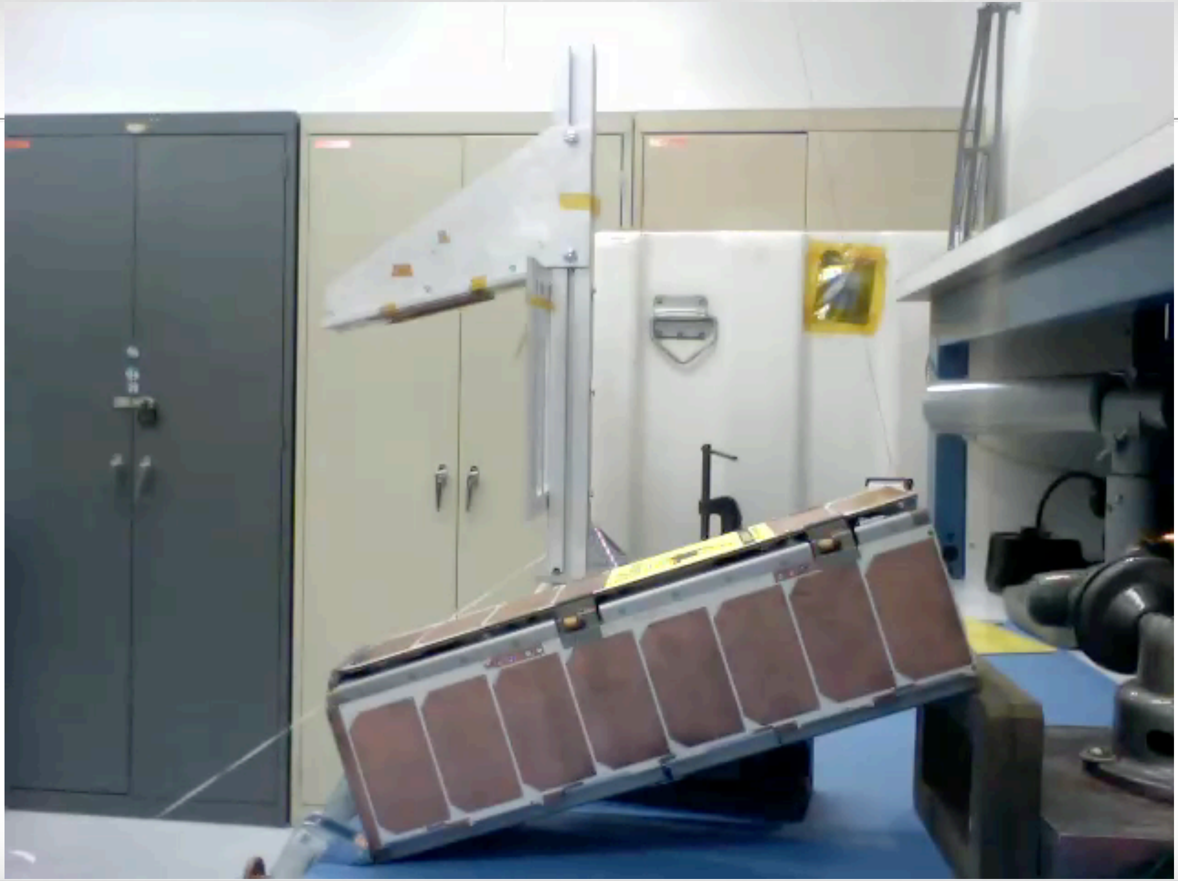


System Status

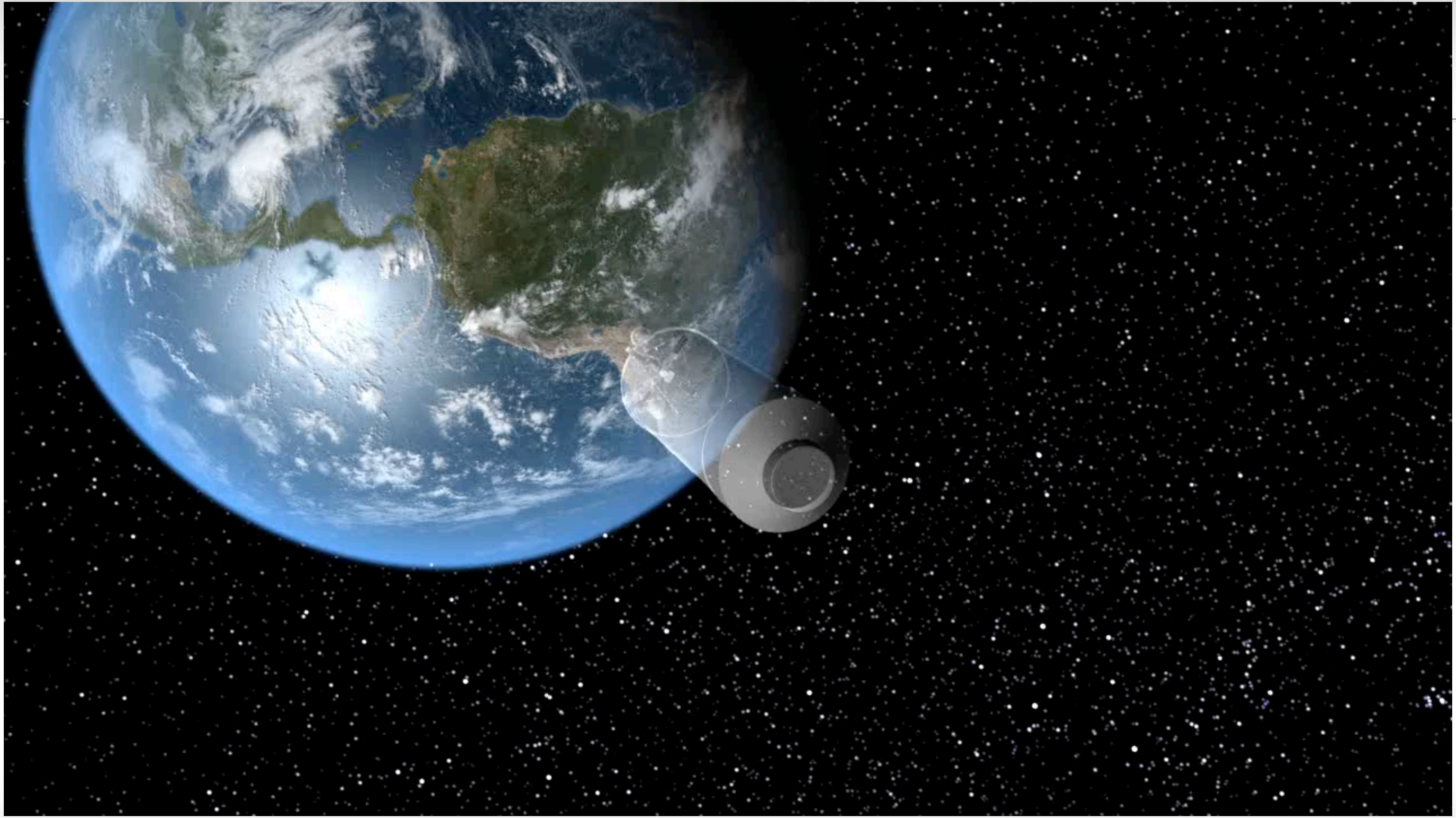
At The Aerospace Corporation

Full S/C at JPL in Functional Test

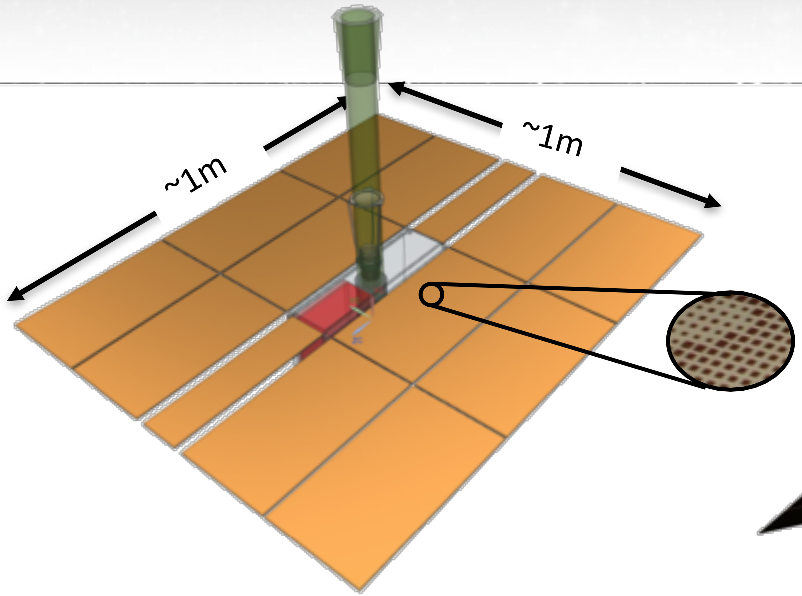
Deployment

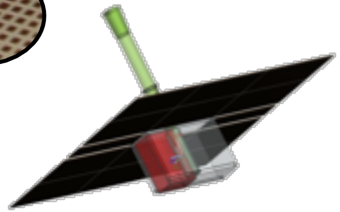


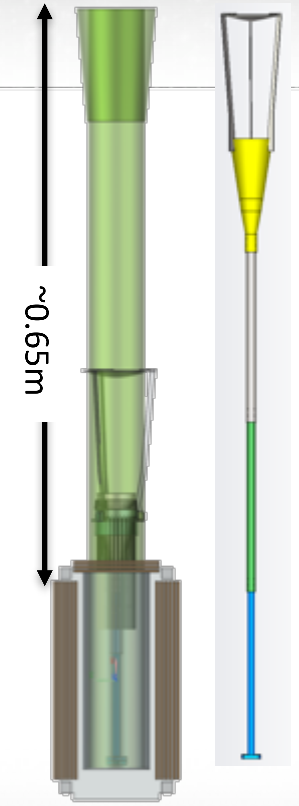
On-Orbit Operations



Toward larger deployable antennas



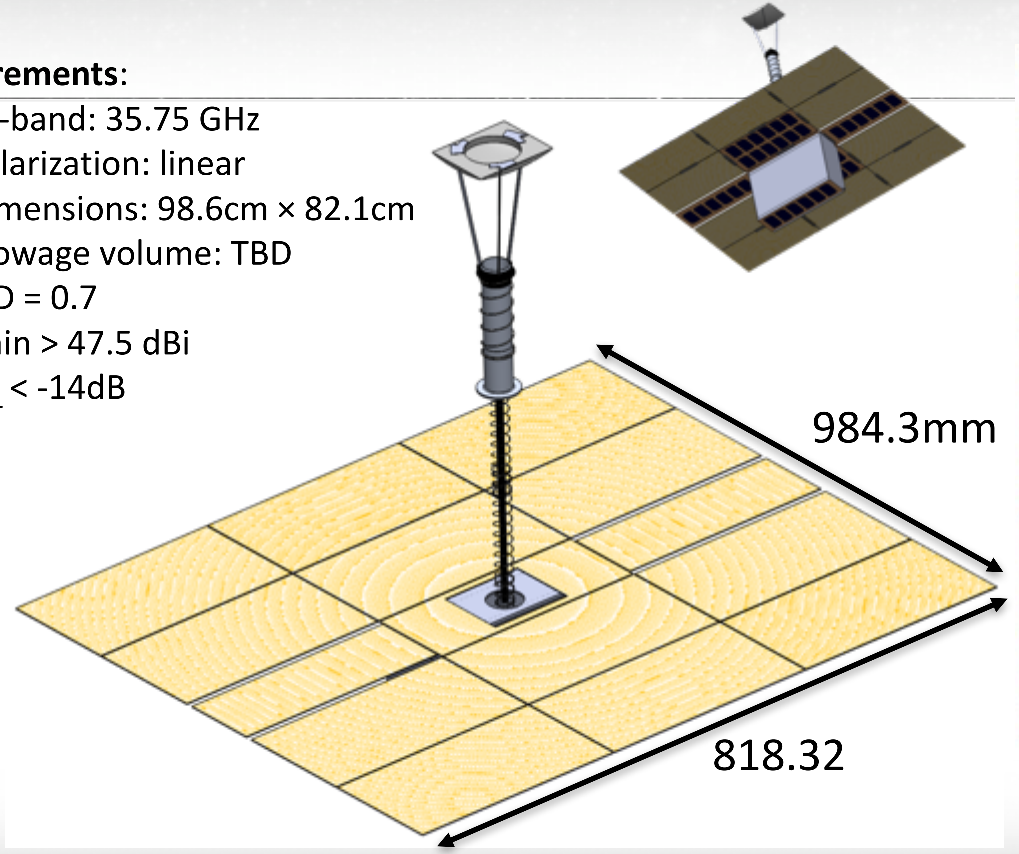


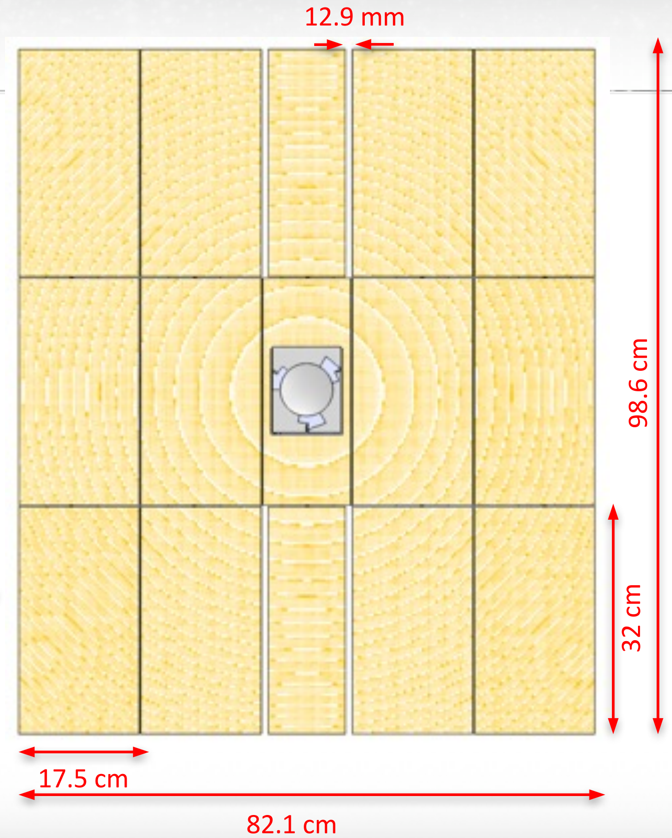


Configuration A2b (1 mm Gap) – *Courtesy Raul Polit Casillas*

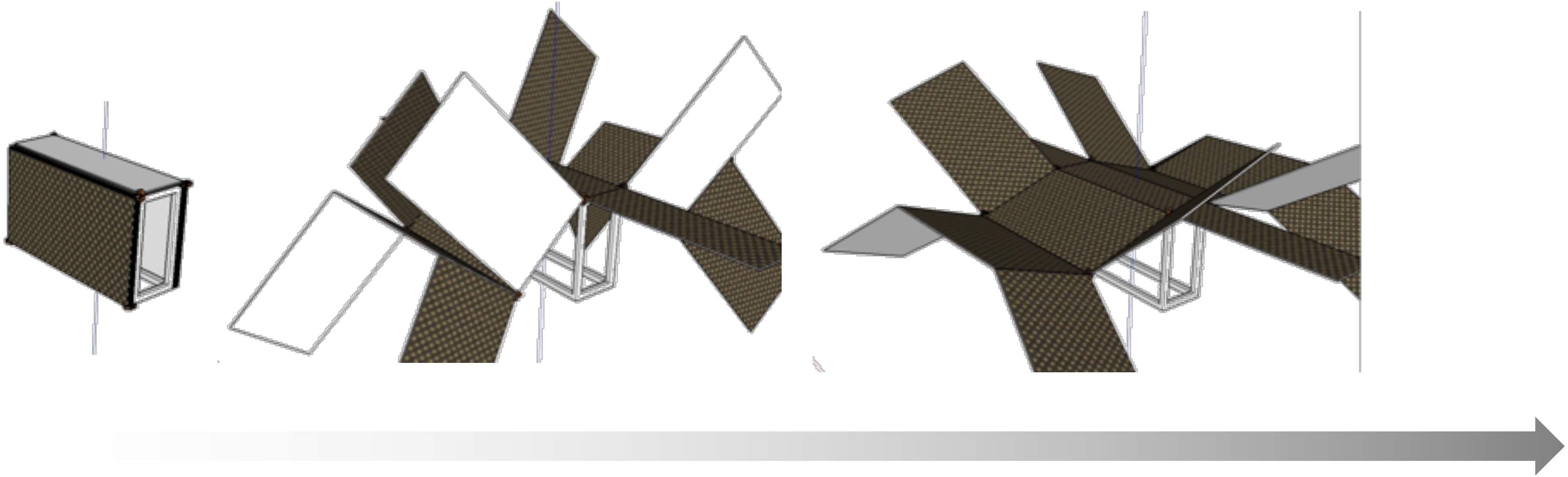
Requirements:

- Ka-band: 35.75 GHz
- Polarization: linear
- Dimensions: 98.6cm × 82.1cm
- Stowage volume: TBD
- F/D = 0.7
- Gain > 47.5 dBi
- S_{11} < -14dB

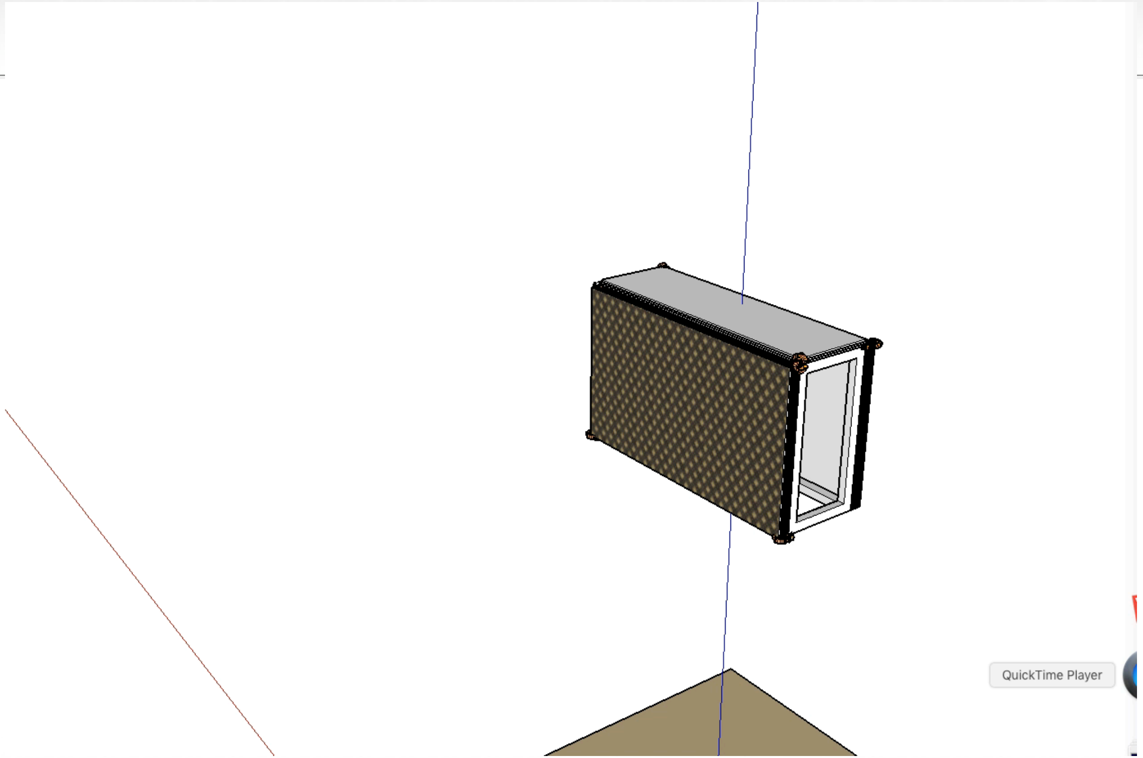




– Initial Deployment Scheme

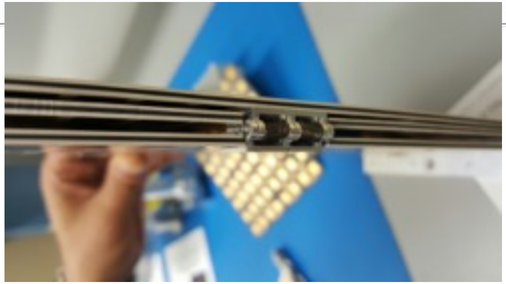


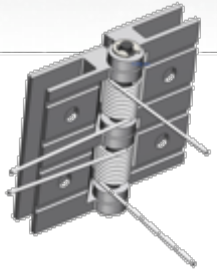
Deployment Simulation



Panels and Hinges

MarCO's reflectarray heritage[1]:





MarCO's hinge

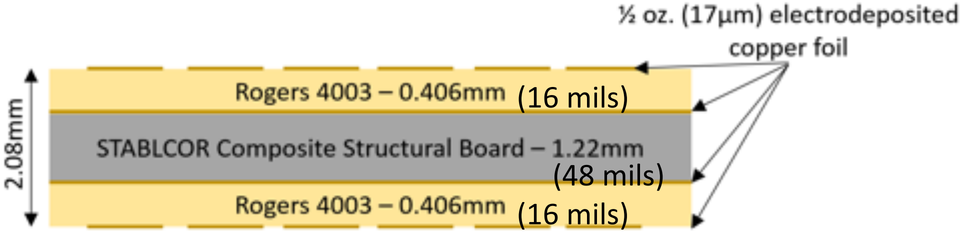
Panel structure:

- Survive launch vibration environment
- Maintain surface flatness over a range of temperature
- Panel symmetry for thermal management

MarCO's Hinges:

- Custom hinges with +/-0.1˚ deployment accuracy

OMERA panels and custom's hinges:

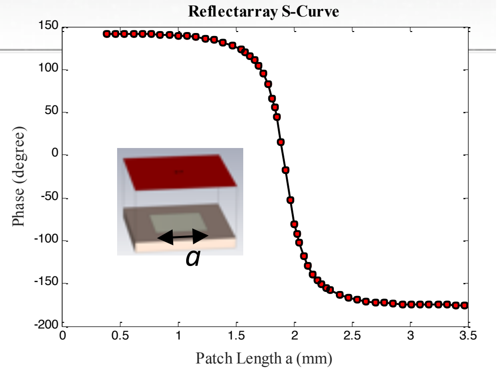


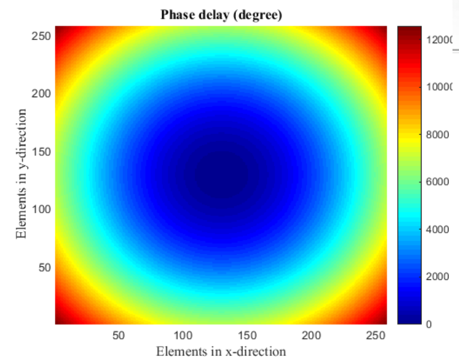
OMERA's hinge:

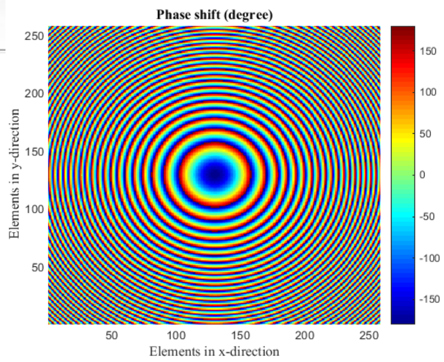
- Better deployment accuracy (+/-0.03˚)
- Smaller gap between folded panels ➔ better stowage volume

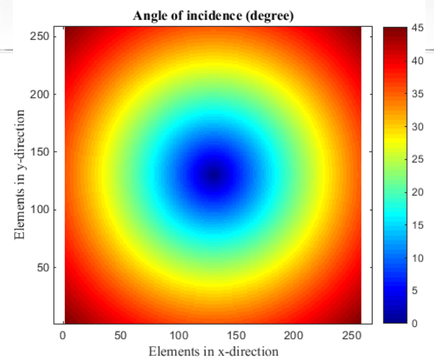
[1] R. E. Hodges, N. Chahat, D. J. Hoppe, and J. D. Vacchione, "A Deployable High-Gain Antenna Bound for Mars: Developing a new folded-panel reflectarray for the first CubeSat mission to Mars.," in *IEEE Antennas and Propagation Magazine* , Early access.

The Design S-Curve





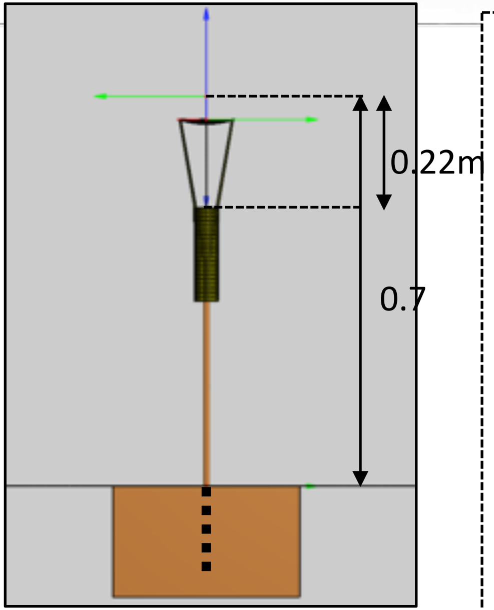


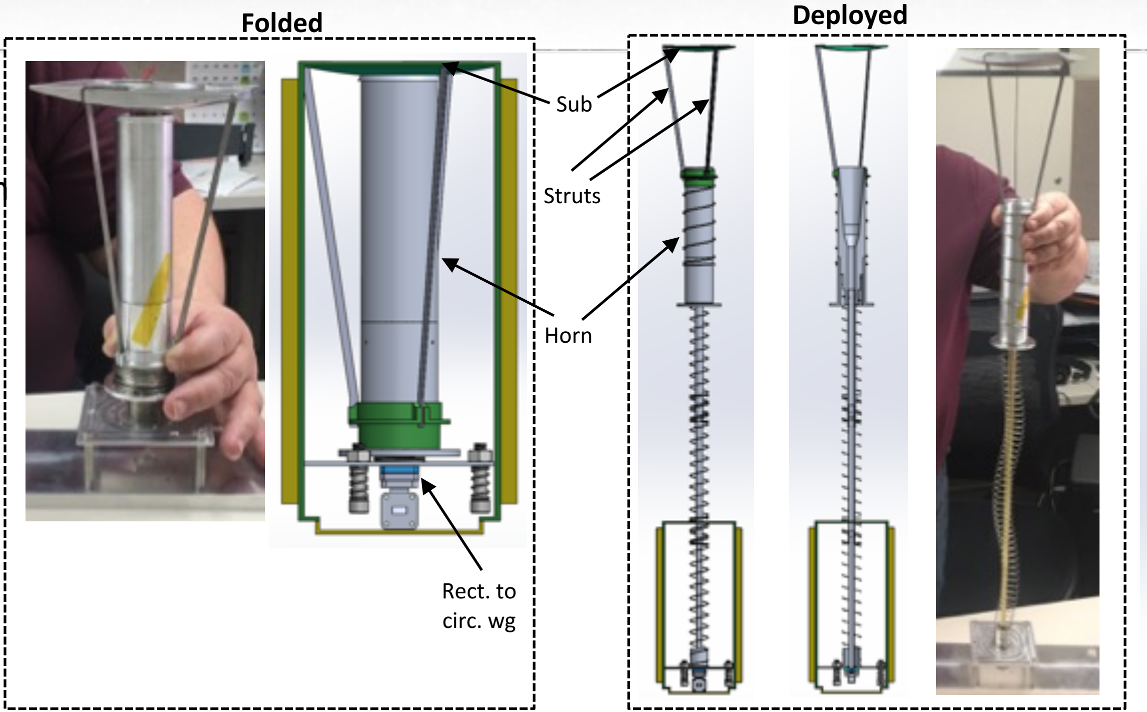


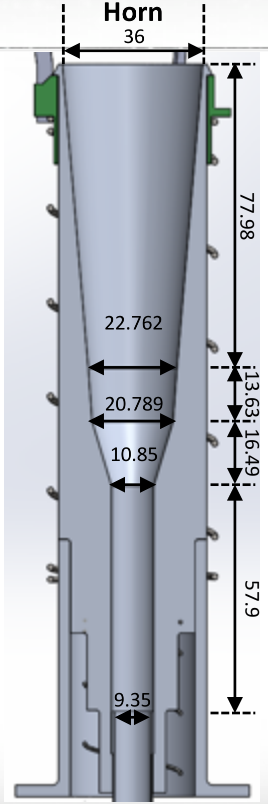
- Overall reflectarray dimensions of 984.3mm x 818.32mm
- Accounted for the angle of incidence because of low f/D
- Select the patch size providing the right phase shift for a given angle of incidence

Telescoping feed design (mechanical)

The feed and sub-reflector location are driven by the f/D and the mechanical constraints.
The feed and telescoping waveguide have heritage from Raincube[2].

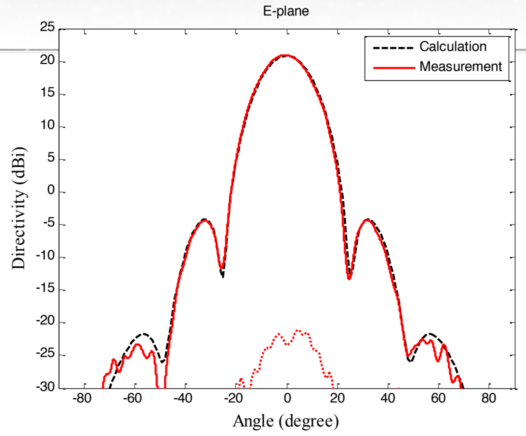


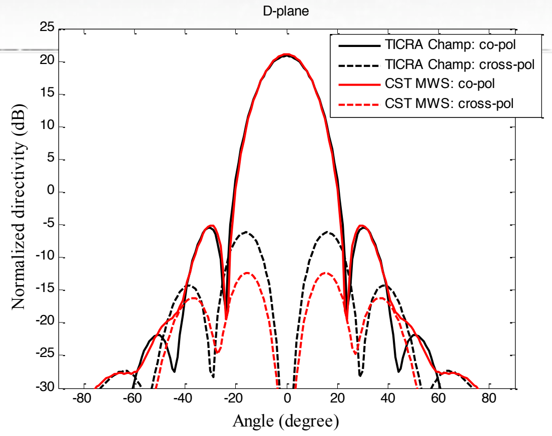


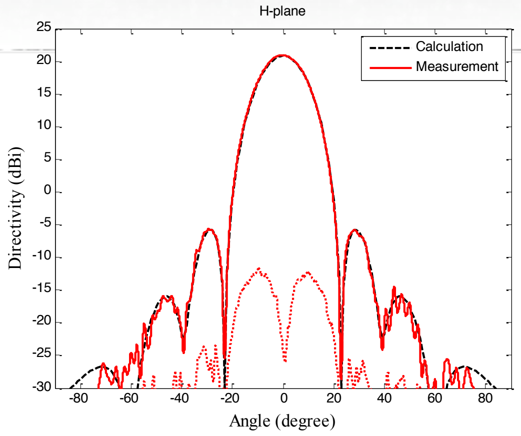


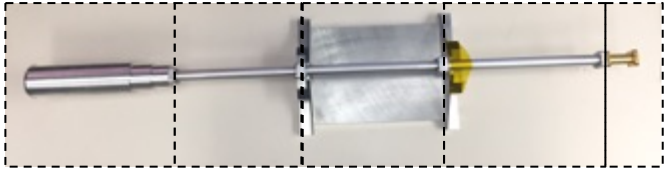
[2]N. Chahat, *et al.*, "CubeSat Deployable Ka-Band Mesh Reflector Antenna Development for Earth Science Missions," in *IEEE Transactions on Antennas and Propagation*, vol. 64, no. 6, pp. 2083-2093, June 2016.

Telescoping feed radiation pattern









Horn Wg1 Wg2 Wg3 Transition Rect-to-Circ

	Directivity (dBi)	Gain (dBi)
Calc.	20.82	20.52
Meas.	20.95	20.4

Reflectarray Gain loss Table

Updated Gain Table (deployed antenna)

	Gain (dBi)	Loss (dB)
Ideal directivity	51.58	-
Spillover	50.67	0.91
Taper	49.95	0.72
Blockage	49.67	0.28
Struts	49.37	0.3
Gap loss	49.22	0.15
Patch dielectric / conductivity loss	48.92	0.25
Surface accuracy (±0.2mm)*	48.57	0.4
Angle deployment accuracy	48.24	0.33
Feed loss / telescoping waveguide / transition	47.94	0.3
Feed mismatch (RL=17dB)	47.85	0.09
Overall performance	**47.85**	3.72

➔ **Aperture efficiency of 42.4%**

Updated Gain Table (fixed antenna)

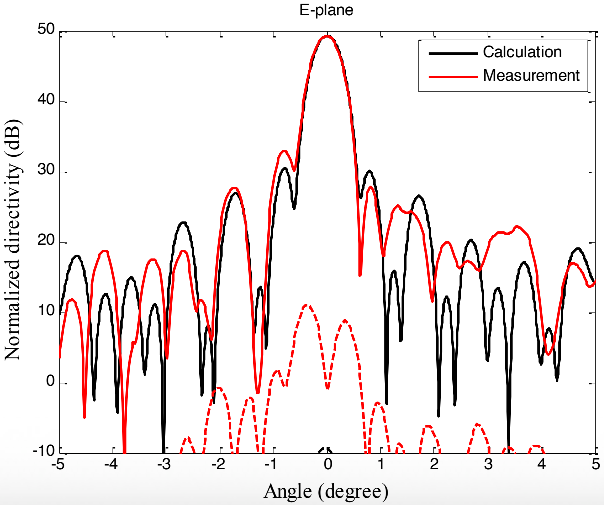
	Gain (dBi)	Loss (dB)
Ideal directivity	51.58	-
Spillover	50.67	0.91
Taper	49.95	0.72
Blockage	49.58	0.37
Struts	49.28	0.30
Patch dielectric / conductivity loss	49.03	0.25
Surface accuracy (±0.15mm)	48.81	0.22
Feed loss / telescoping waveguide / transition	48.51	0.3
Feed mismatch (RL=13dB)	48.31	0.2
Overall performance	**48.31**	3.27

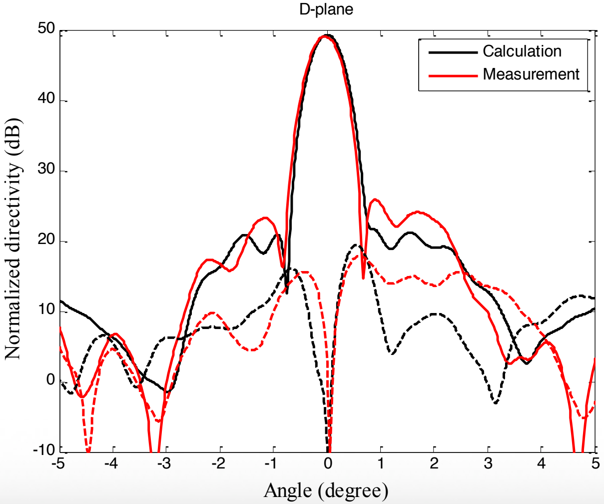
➔ **Aperture efficiency of 47.1%**

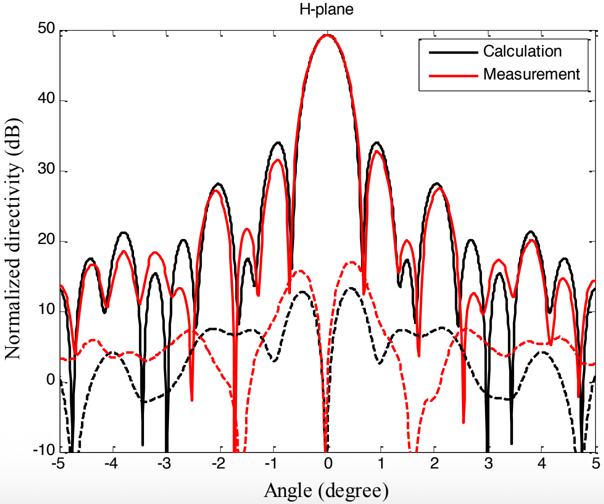
Reflectarray radiation pattern

- The simulation includes the reflectarray, the 3 telescoping waveguides, the horn, the 3 struts, and the sub-reflector.
- No gaps are included yet between the panels.

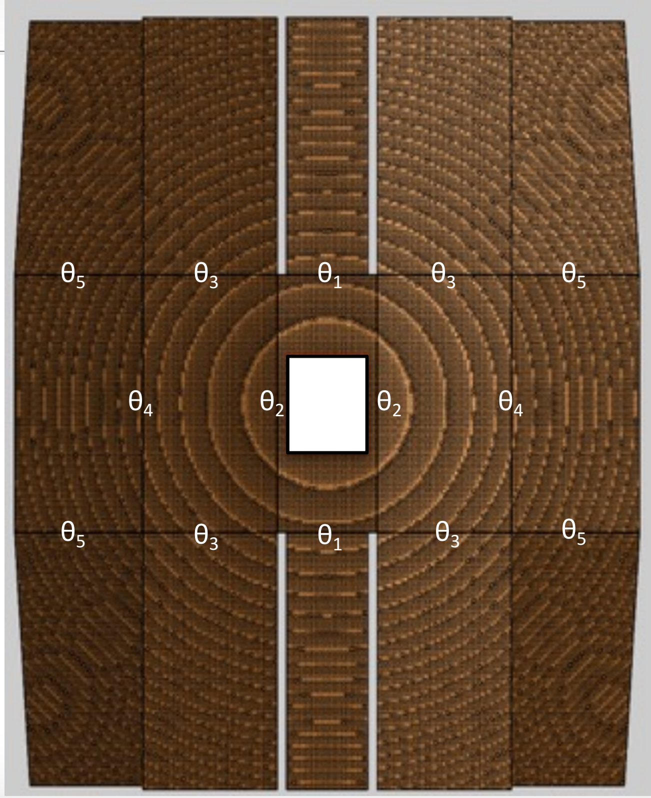
	Directivity (dBi)		Gain (dBi)		Loss (dB)*		Efficiency (%)	
	Calc.	Meas.	Calc.	Meas.	Calc.	Meas.	Calc.	Meas.
Fixed	49.28	49.27	48.31	48.5	0.97	0.77	47.10	49.20
Deployable	48.9	TBD	47.85	TBD	0.65	TBD	42.4	TBD

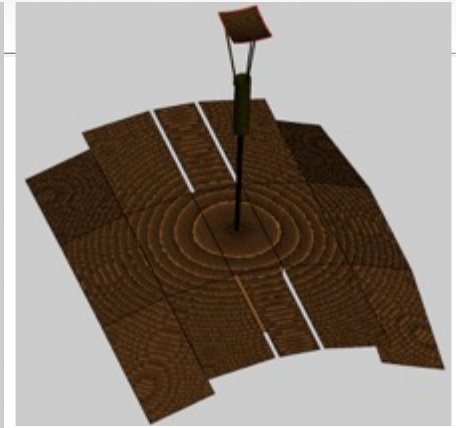






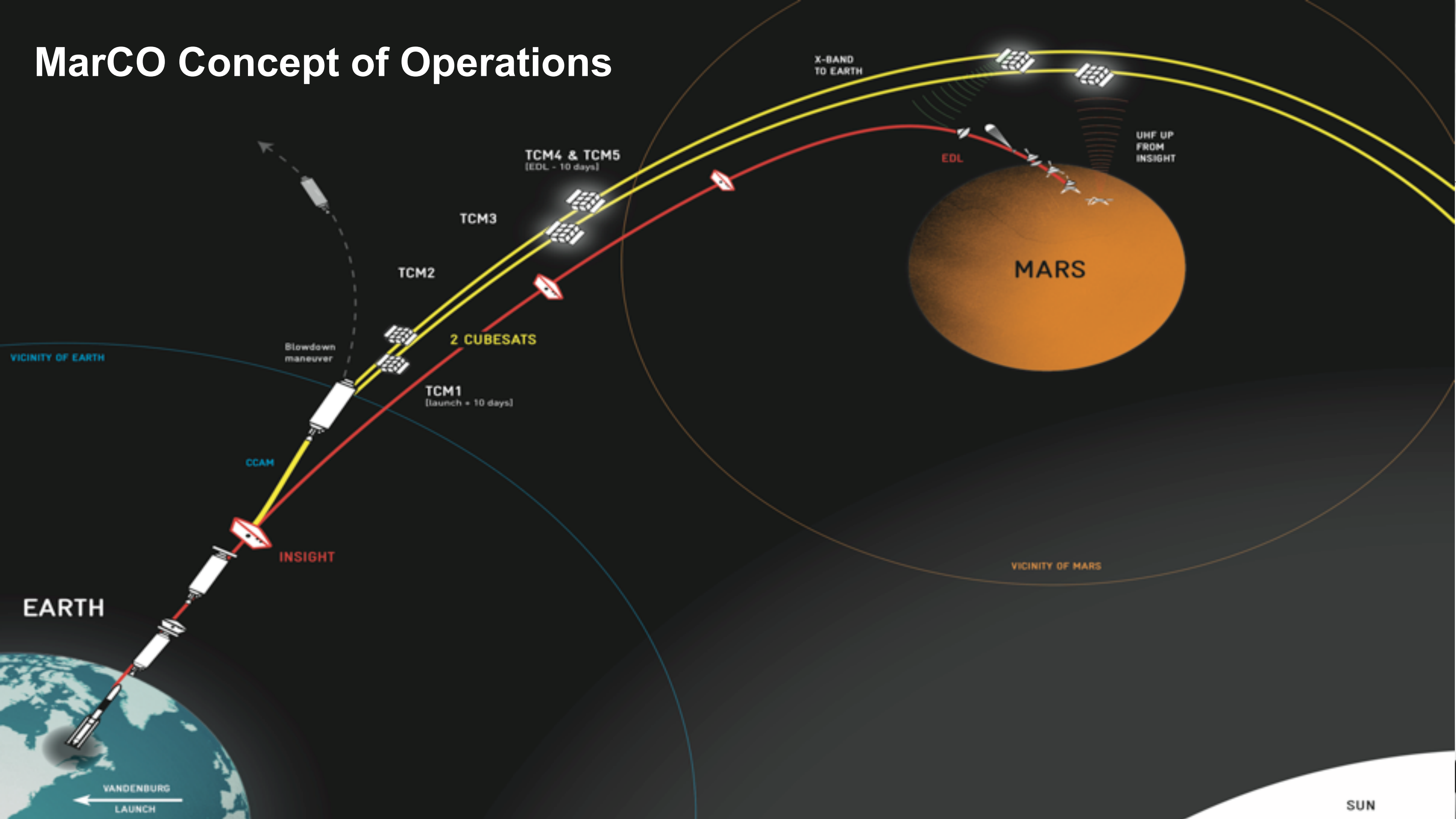
Angle required deployment accuracy



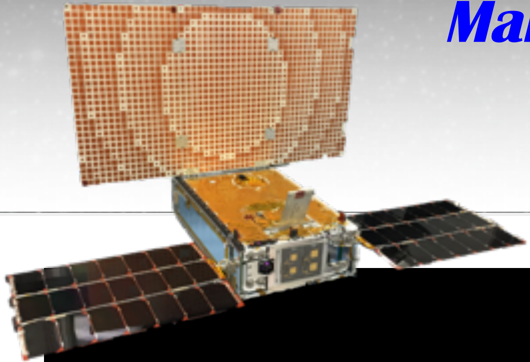


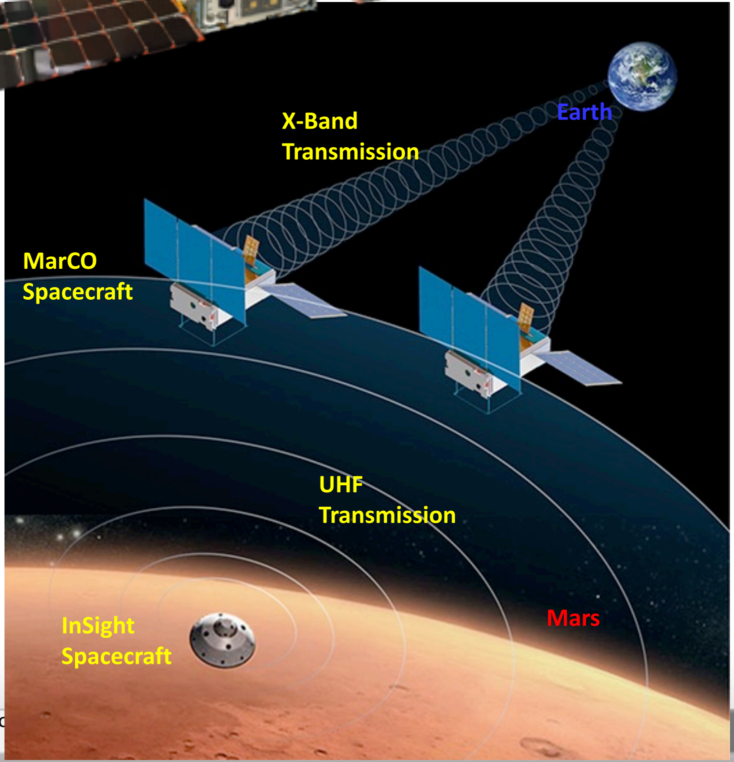
Angles	Accuracy (degree)
θ_1	-0.04/+0.04
θ_2	-0.03/+0.03
θ_3	-0.03/+0.03
θ_4	-0.04/+0.04
θ_5	-0.1/+0.1

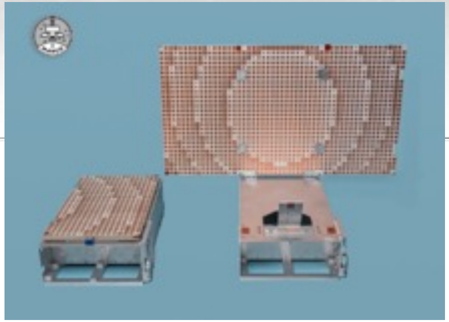
MarCO Concept of Operations

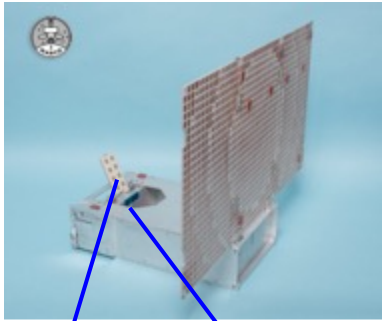


MarCO Mission to Mars

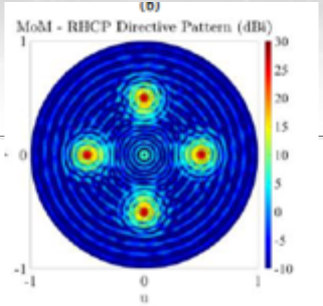


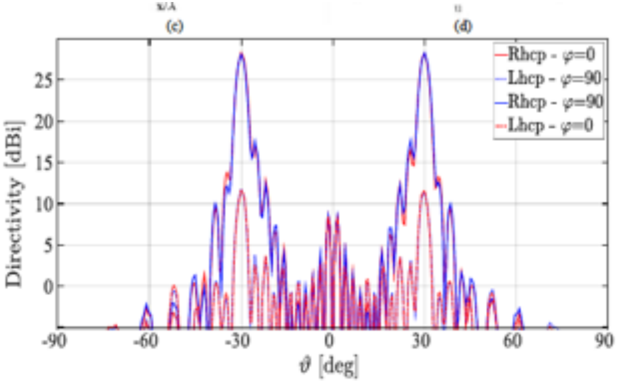






Can we use metasurface antennas?





Multibeam by Metasurface Antennas

David González-Ovejero, *Member, IEEE*, Gabriele Minatti, Goutam Chattopadhyay, *Fellow, IEEE* and Stefano Maci, *Fellow, IEEE*

IEEE Transactions on Antennas and Propagation, to be pubished