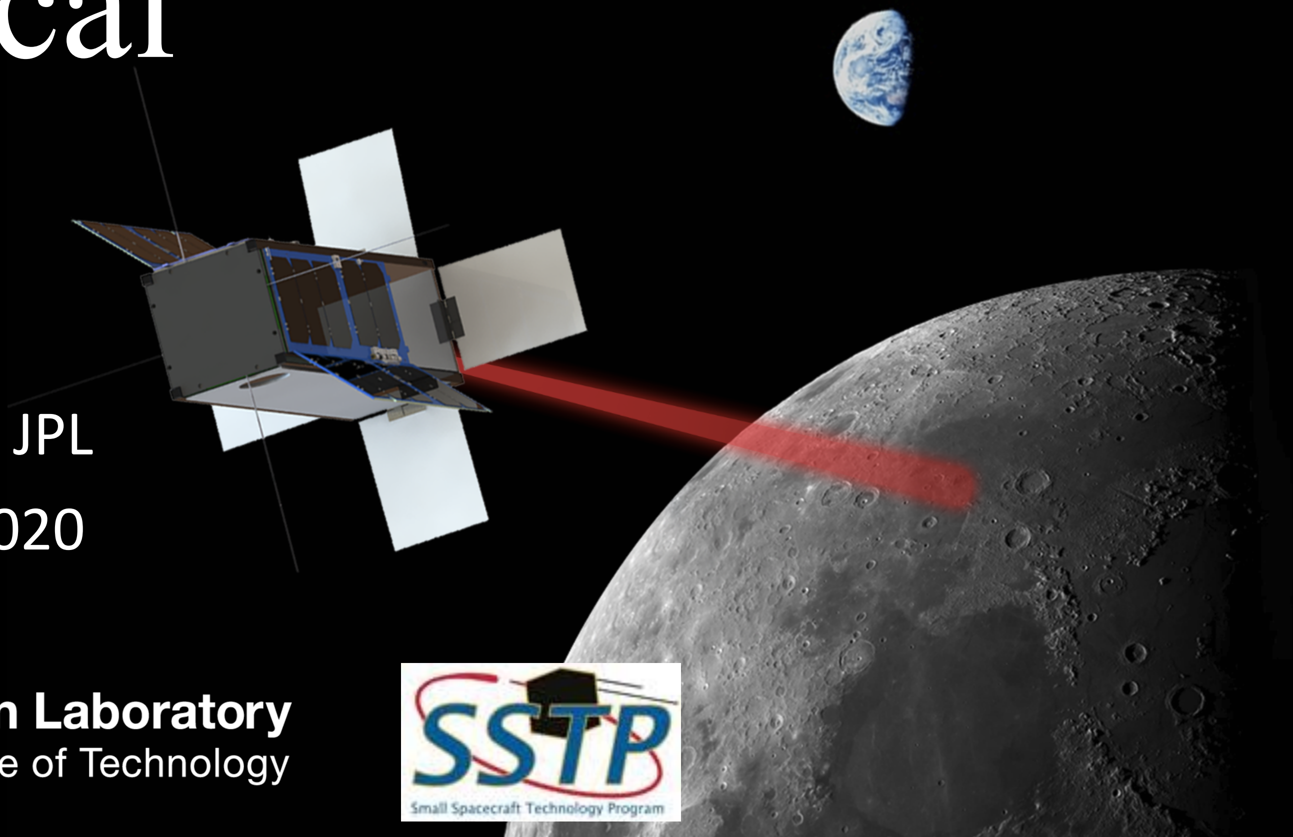
Deployable Optical Receiver Array

Cubesat demonstration

NASA Smallsat Technology Program, ASU, JPL

D. Jacobs – Engineering Coffee – 4 Sept 2020



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SSTP
Small Spacecraft Technology Program

Dora Team

Jet Propulsion Laboratory
California Institute of Technology

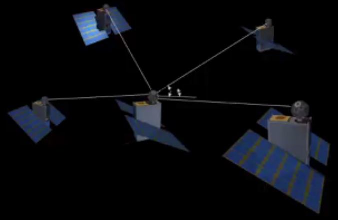
- Jose Velazco (333M)
- Andy Klaib
- Uriel Escobar (UC Irvine)
- Sean Cornish (USC)
- Sarah Spector (Umilwaukee, 2020 Intern)
- Charles Lindsey (MIT, 2020 Intern)

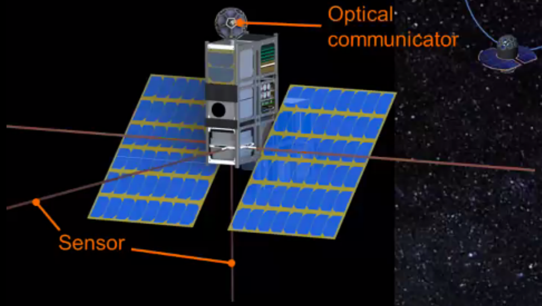
ASU School of Earth and Space Exploration
Arizona State University

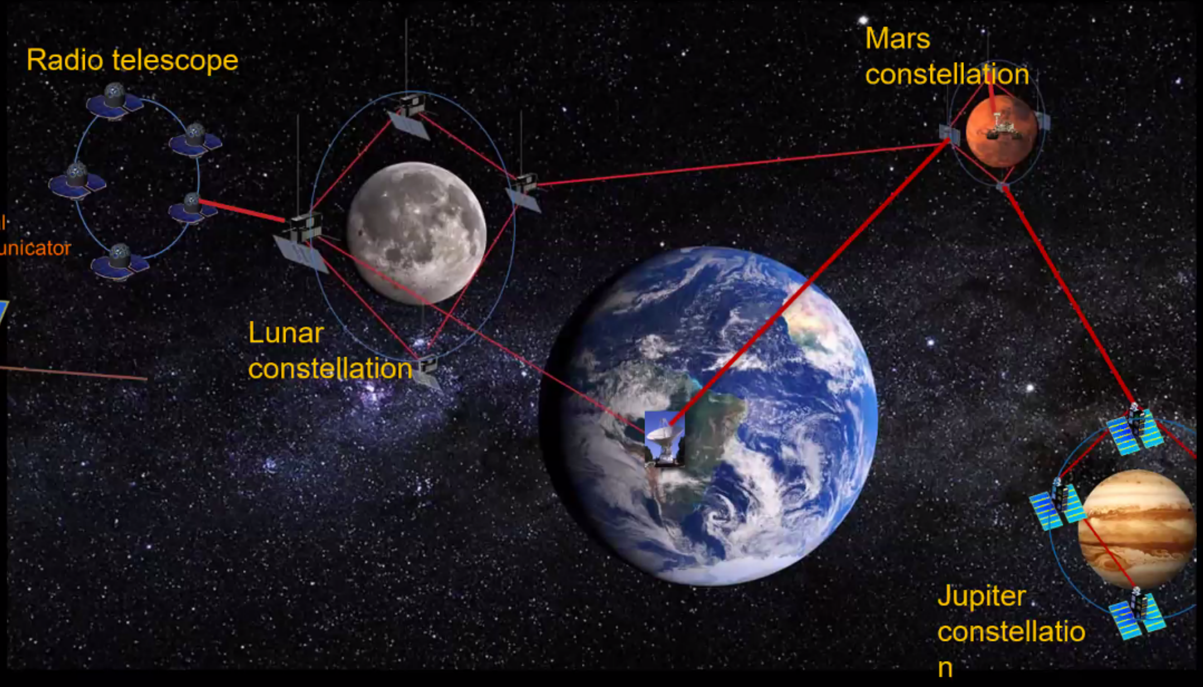
- Danny Jacobs (PI)
- Judd Bowman
- Mickey Horn
- Jaime Sanchez de La Vega (II Lab)
    - Katrina Lewis (SESE)
    - Isabella All (Aerospace)
- CSE Capstone Group
    - Zachary Hoffman (CS/Robotics)
    - Jah Markabowski (CS/Robotics)
    - Justin Colyar

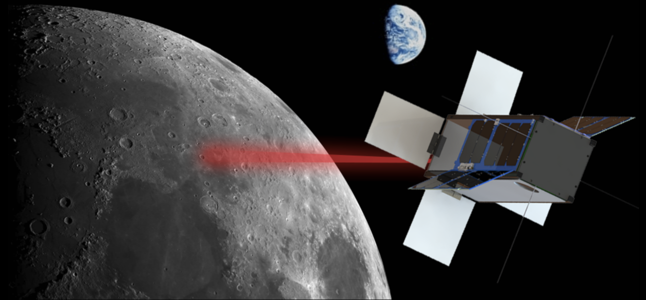
Need for high bandwidth interconnect

- Crosslink between spacecraft
- Swarm instruments
- Reduce DSN load in planetary networking









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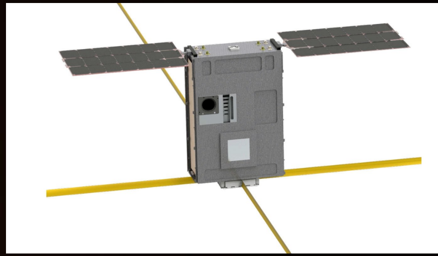
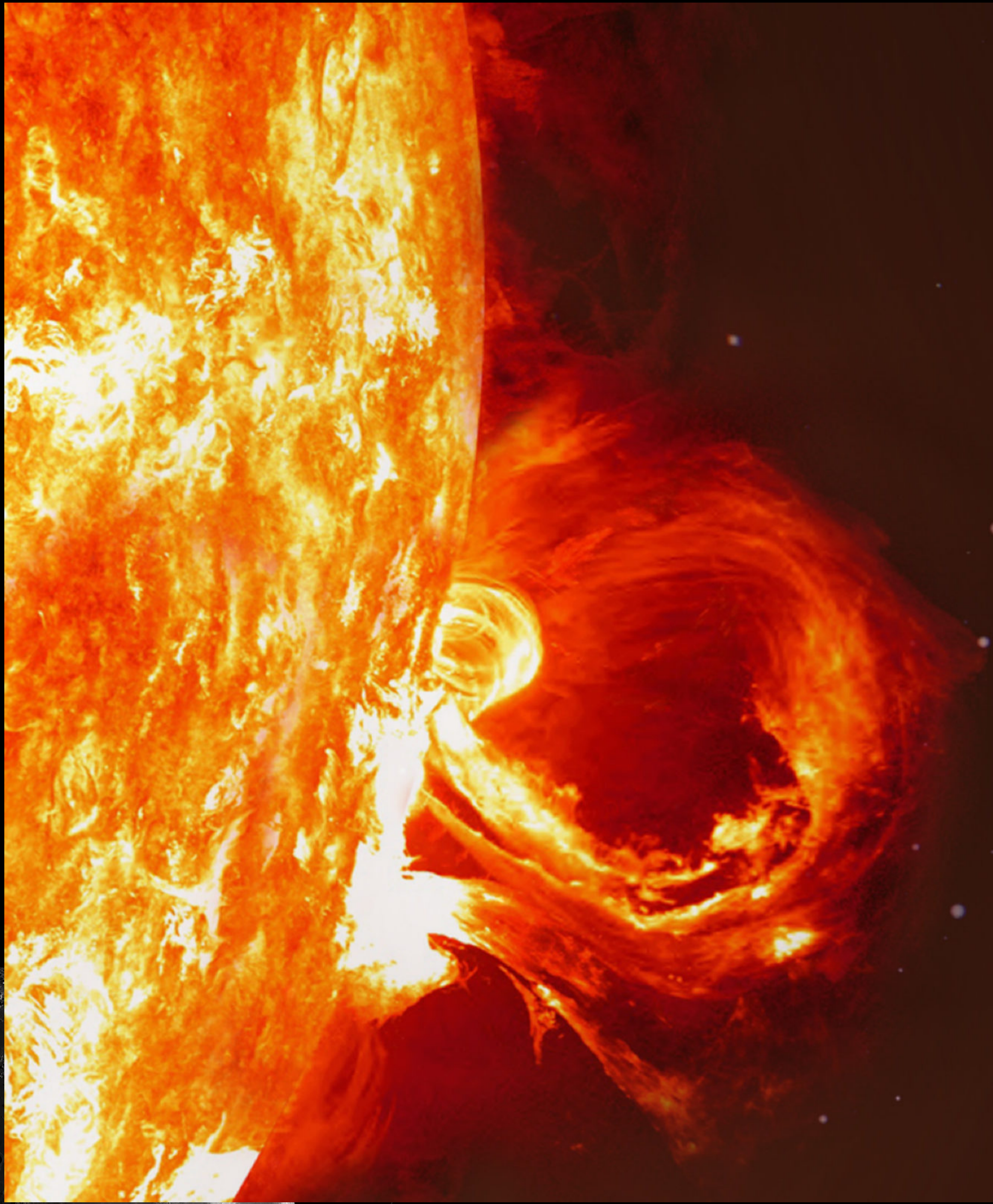
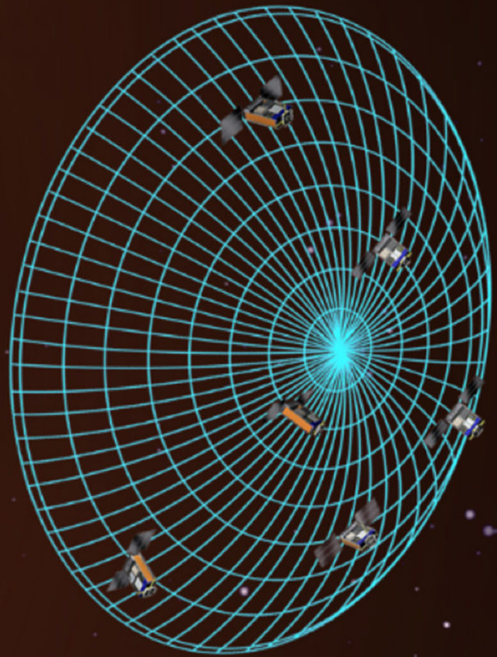
SunRISE



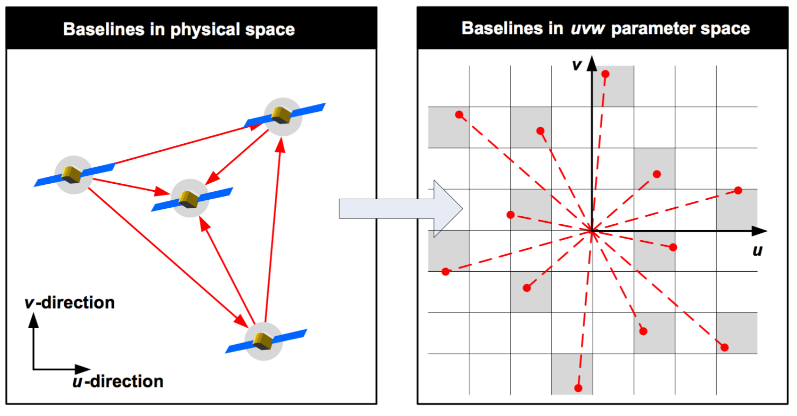
3U Cubesat

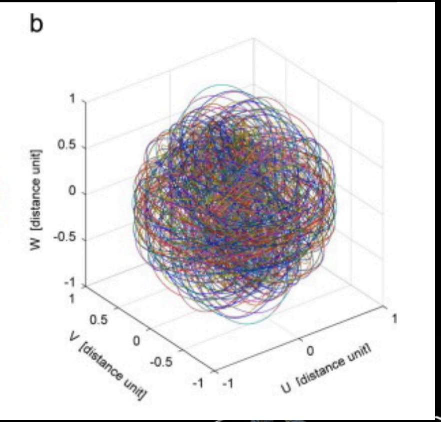


6 element radio interferometer
0.1 to 30MHz

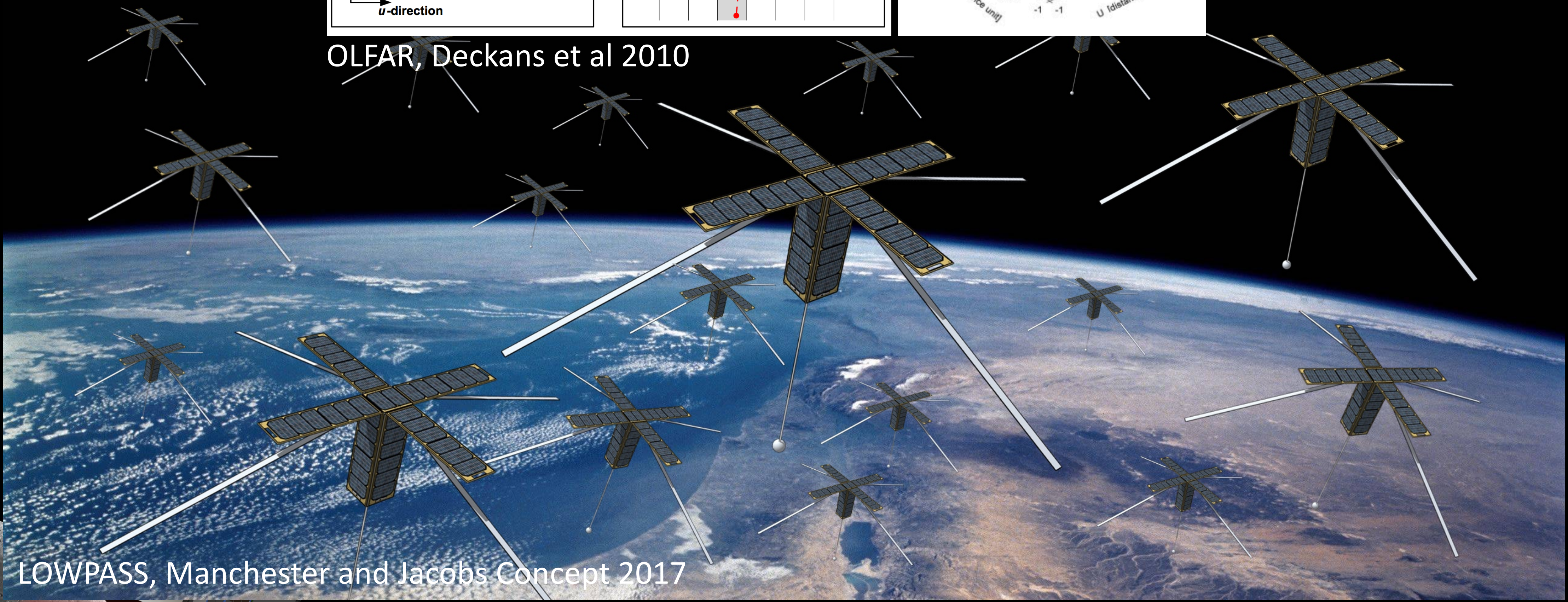


Downlink via DSN and correlates on the ground

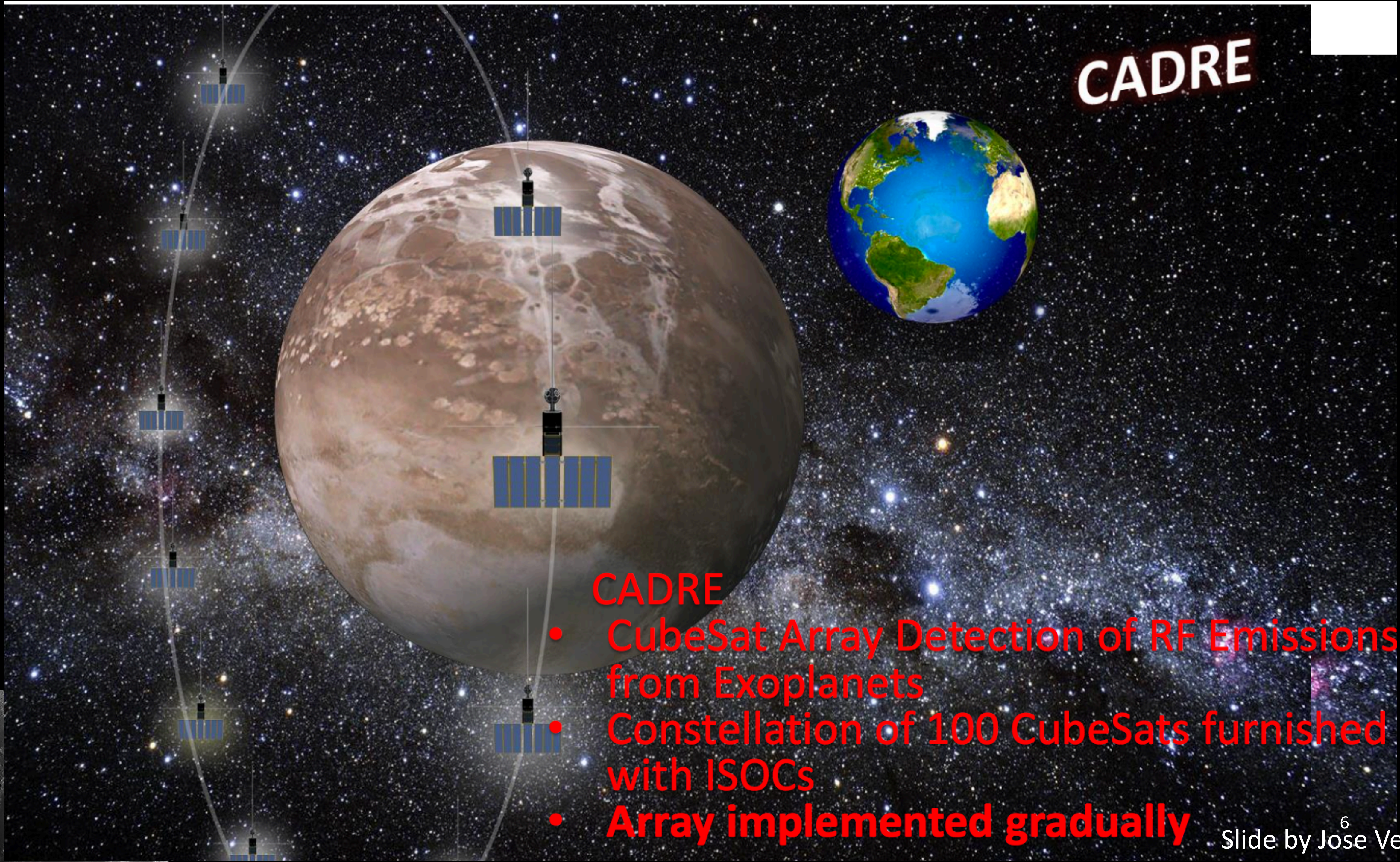




OLFAR, Deckans et al 2010

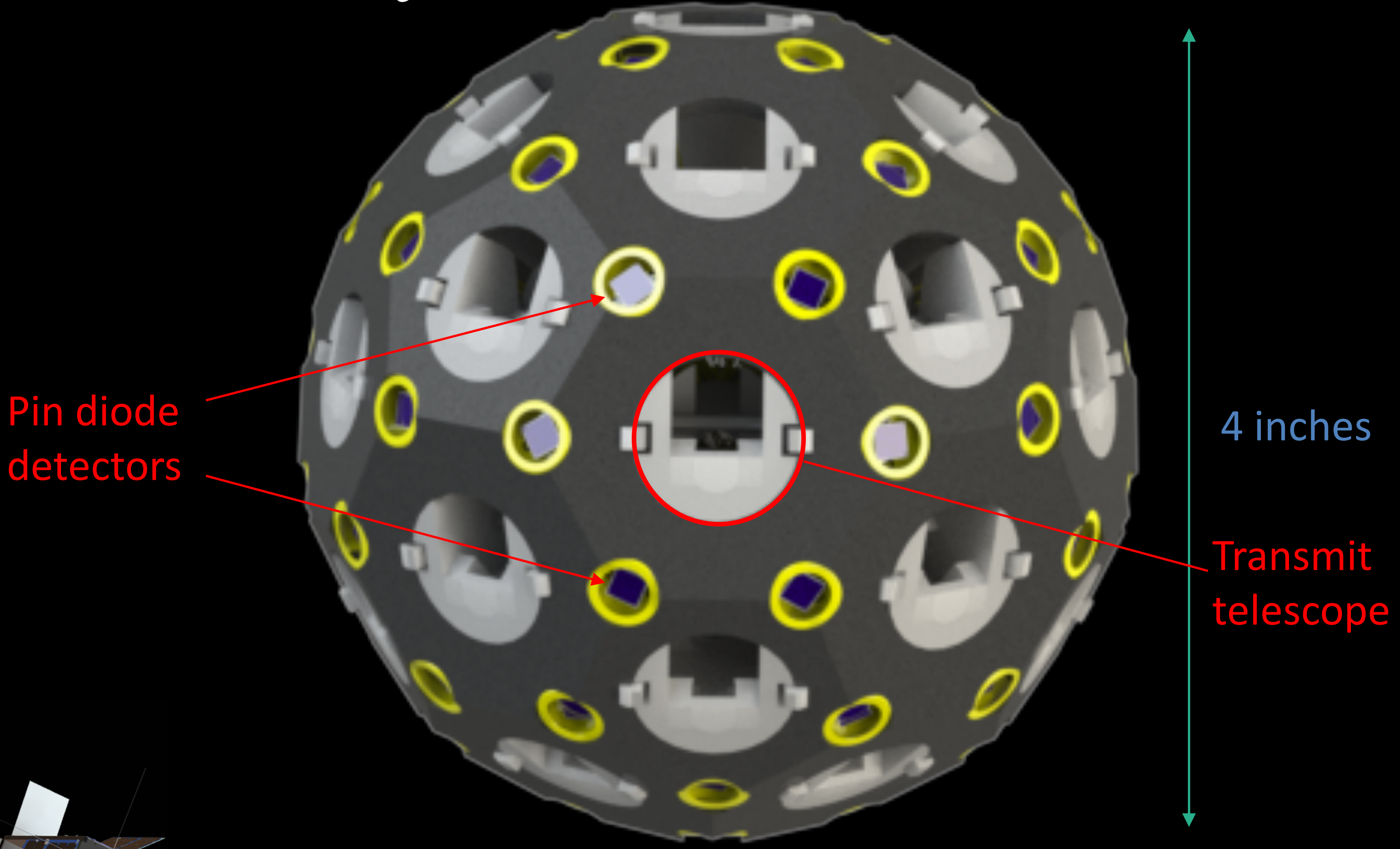


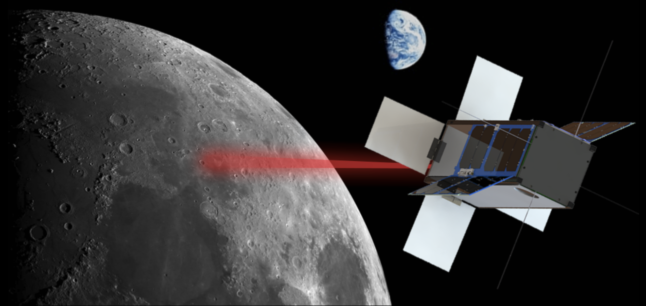
LOWPASS, Manchester and Jacobs Concept 2017



Slide by Jose Velazco

ISOC Geometry





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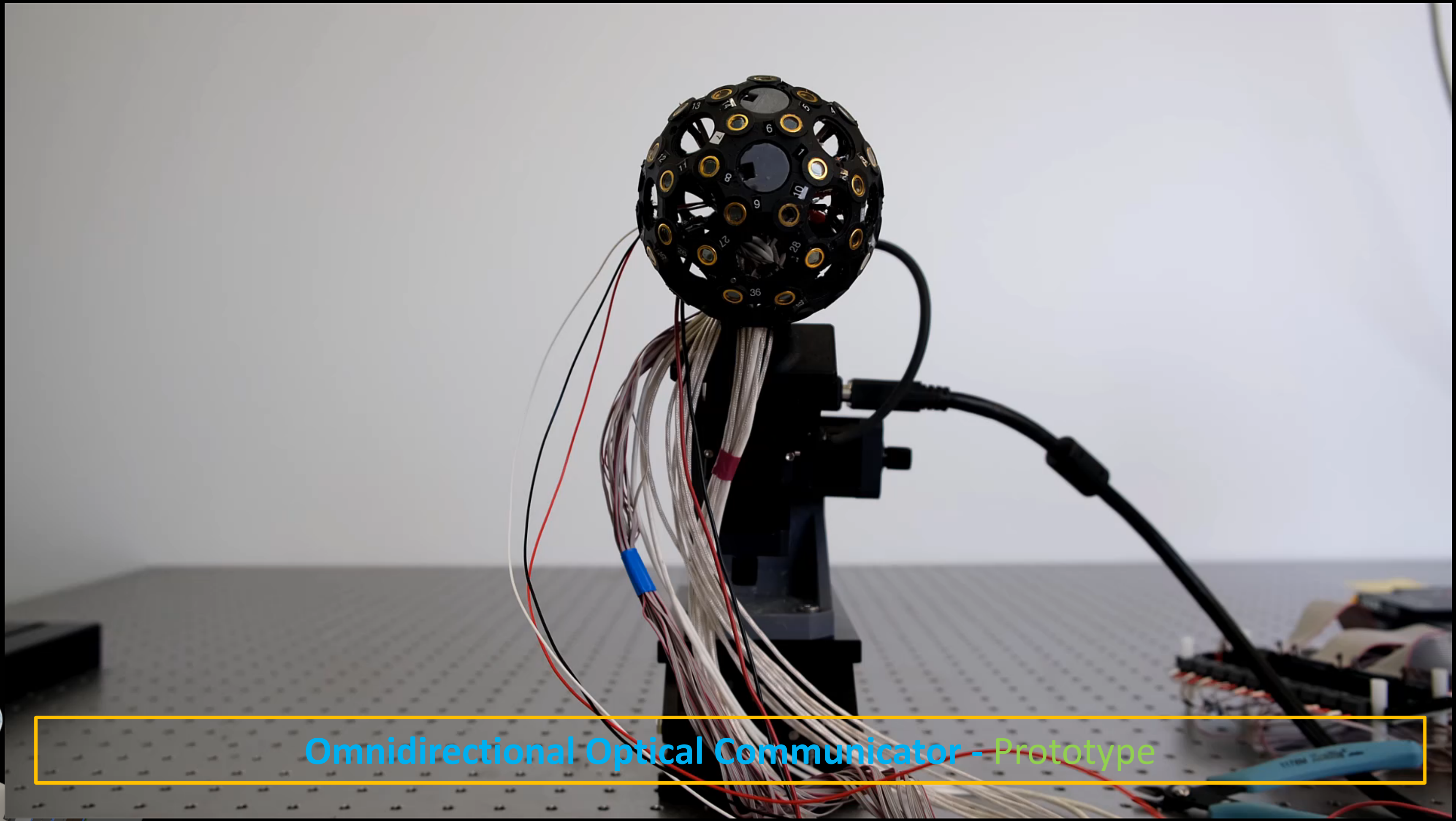
Description of ISOC



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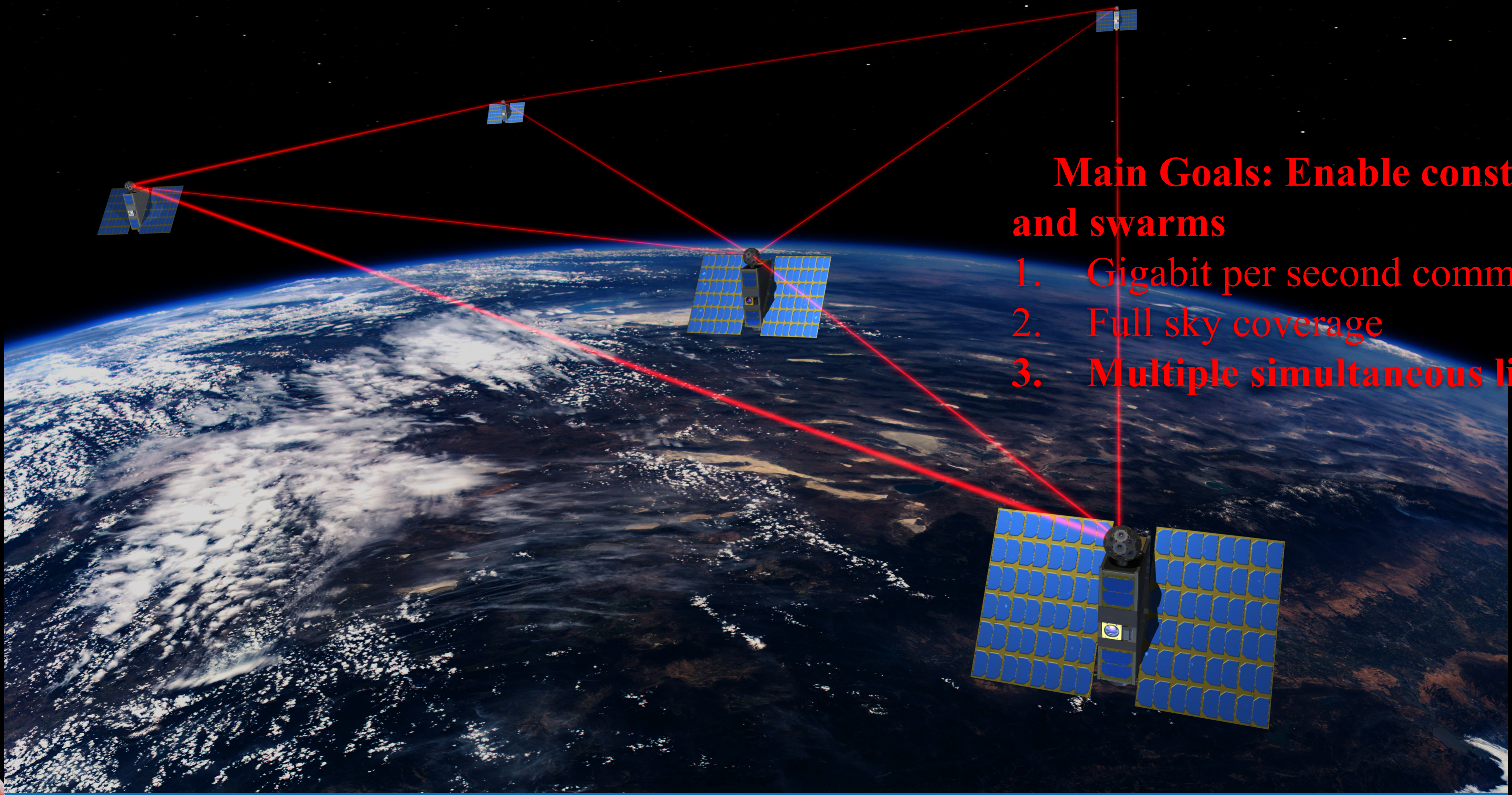
ISOC



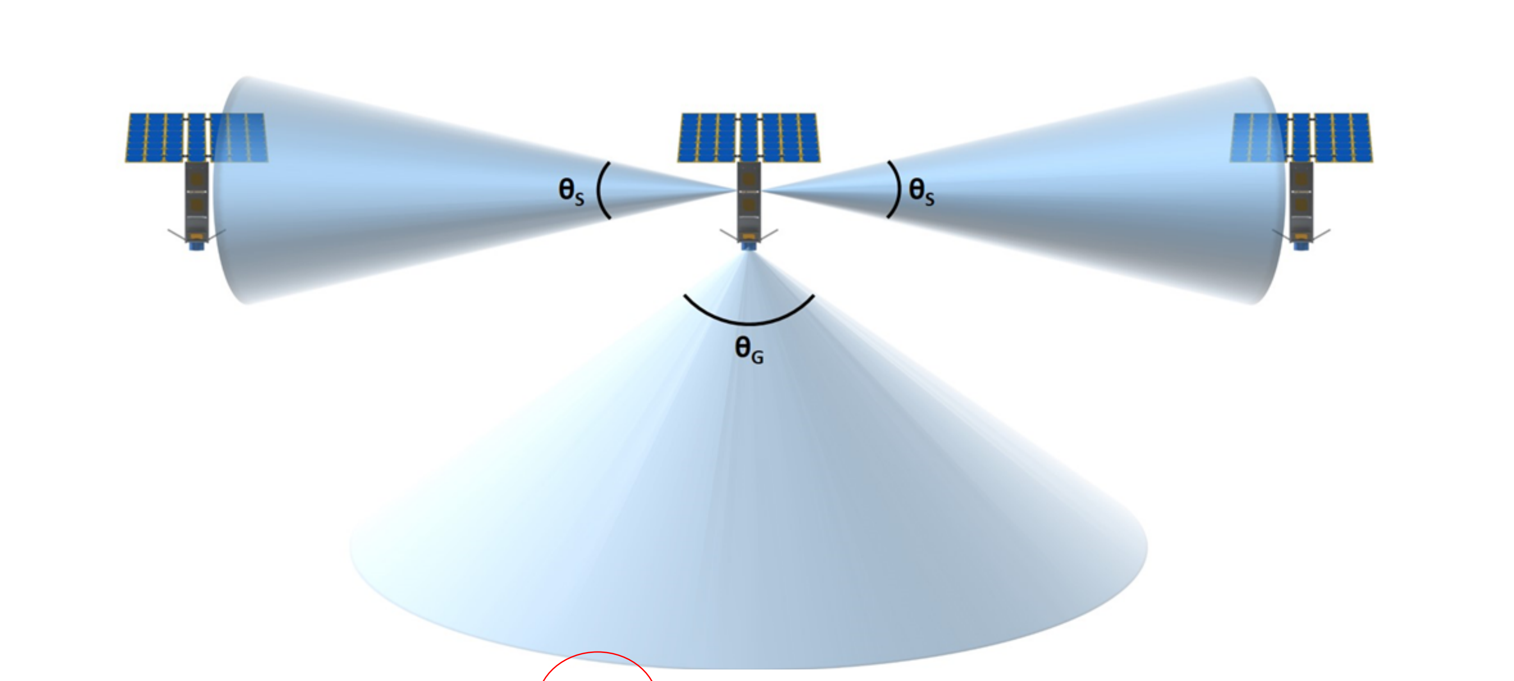
Main Goals: Enable constellations and swarms

1. Gigabit per second communications
2. Full sky coverage
3. **Multiple simultaneous links**

ISOC enabled Swarm

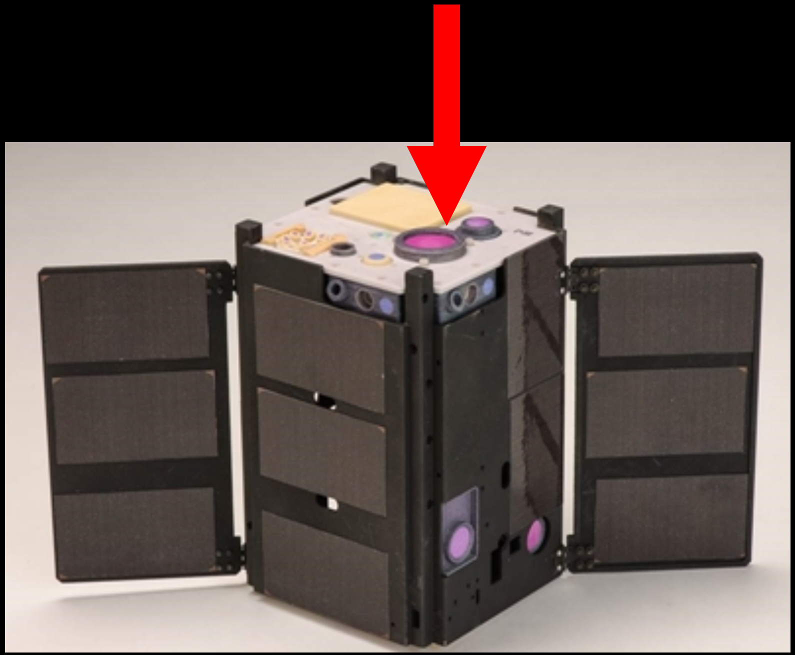
Slide by Jose Velazco

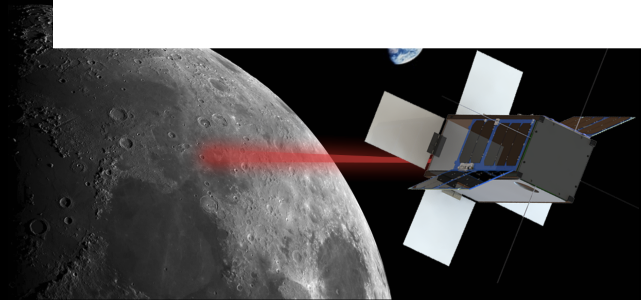
DORA



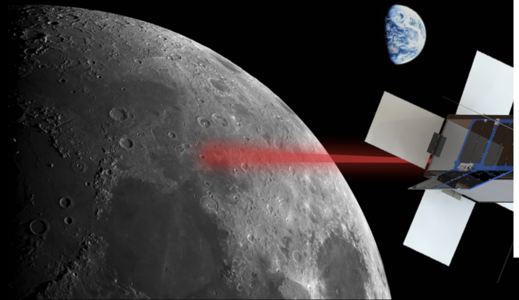
$$P_s = \frac{P_T A_T A_R}{(z\lambda_T)^2}(\eta_T \eta_A \eta_R) L_{TP} L_{atm} L_{pol} L_{RP}$$

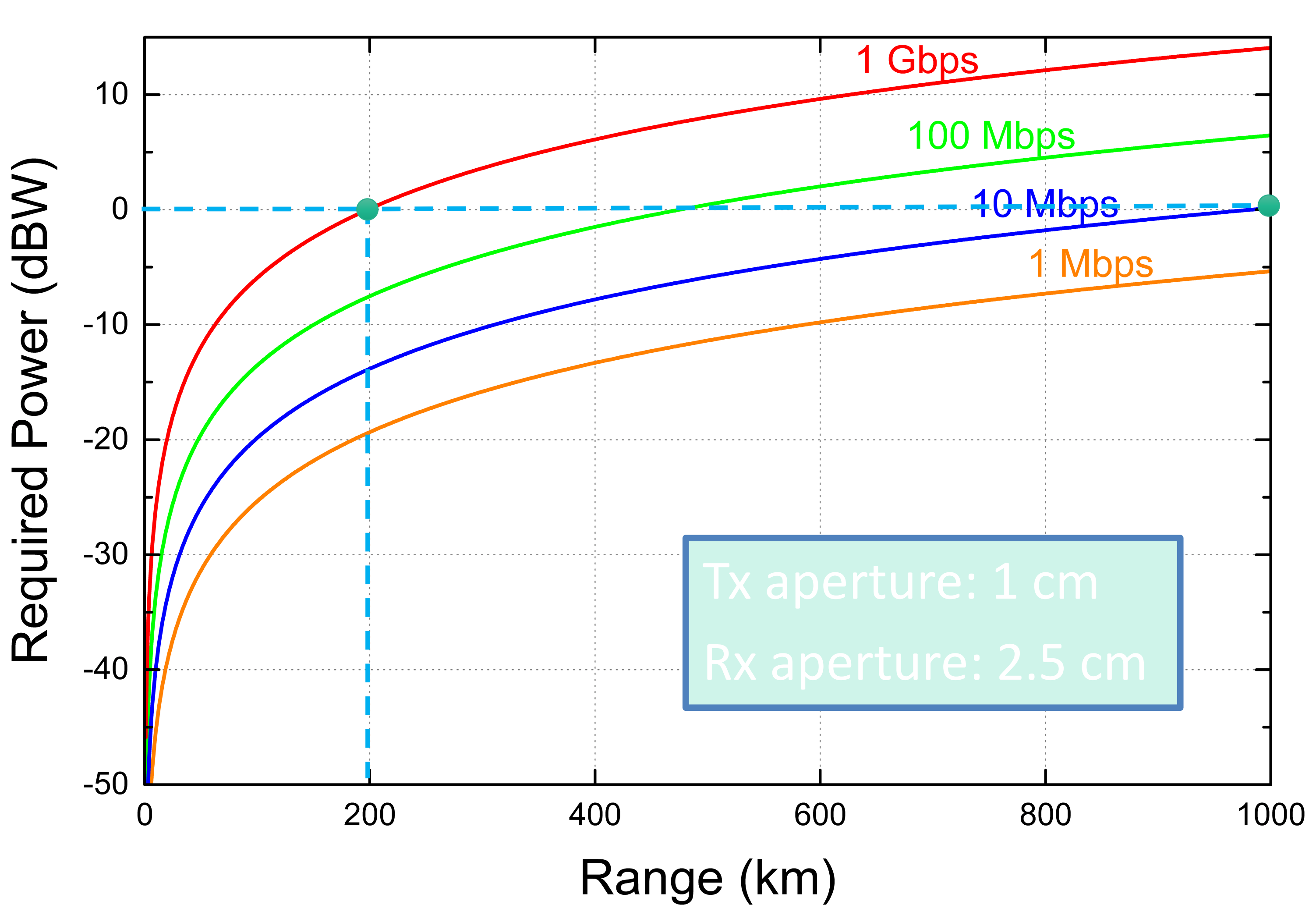
- One of the limitation for high data rate optical communications is the Tx/Rx **aperture size**
- Tx/Rx apertures are typically **compact** and **conformal** to the spacecraft body
- This also limits pointing freedom





ISOC Link Budget





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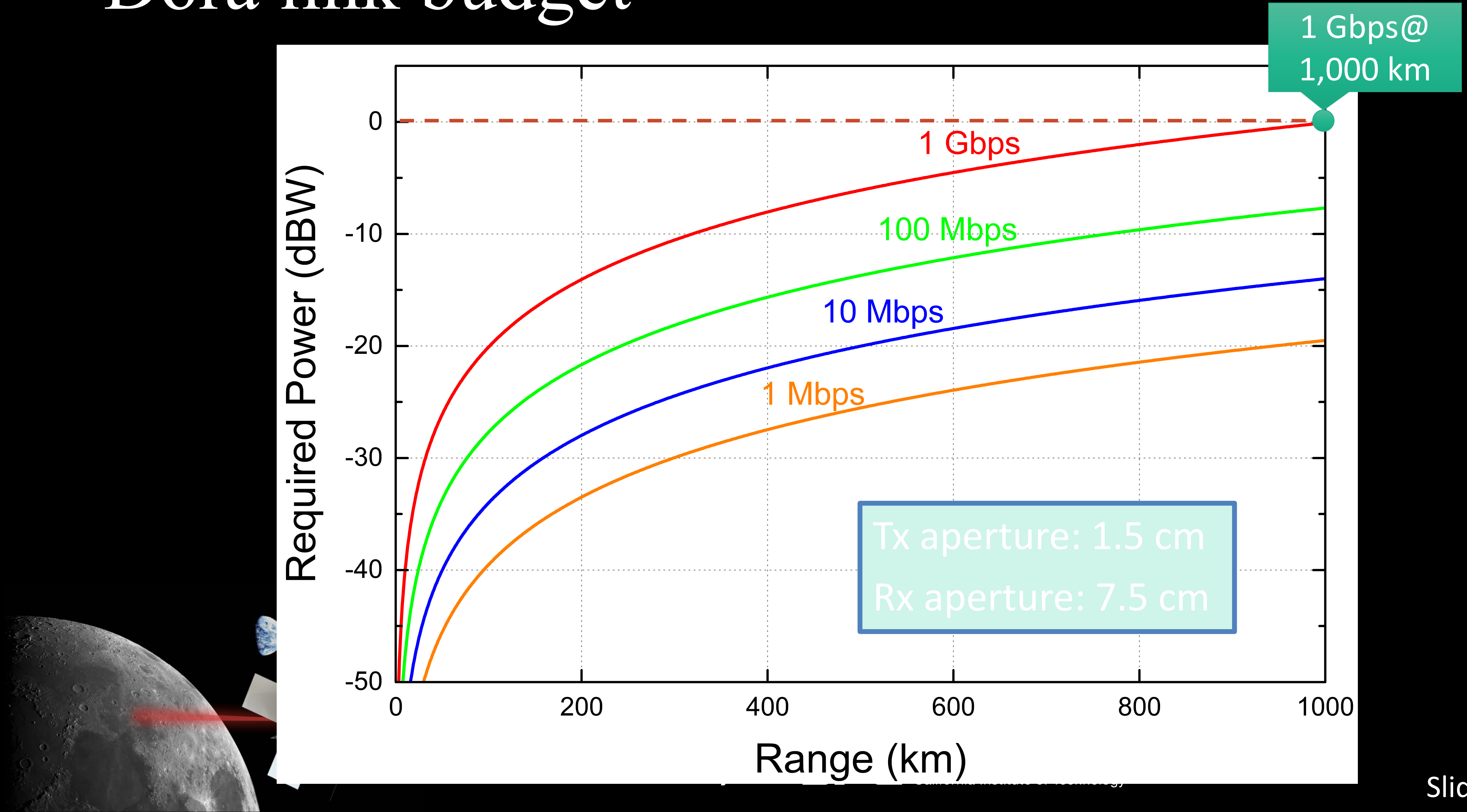
Dora link budget



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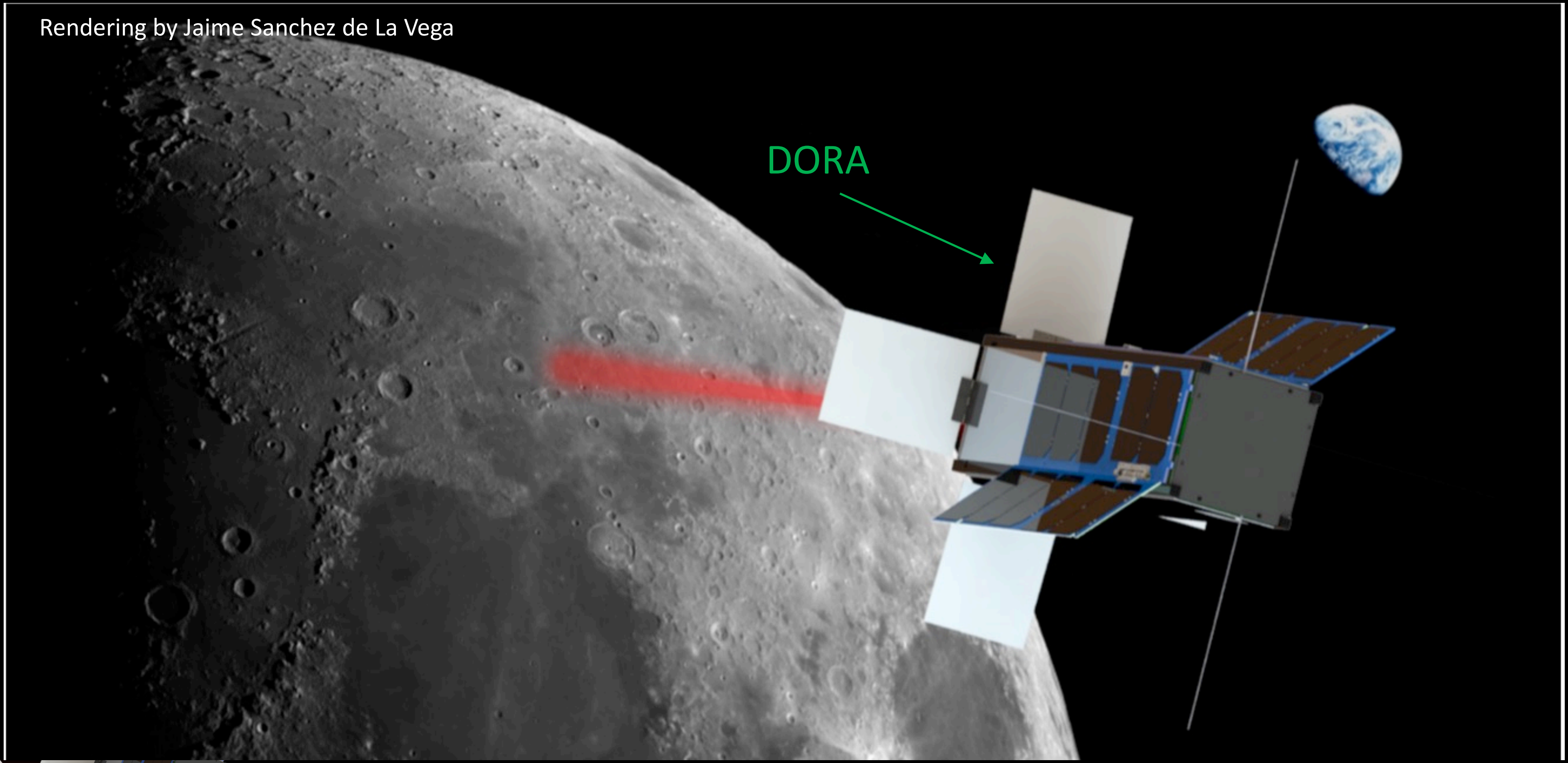
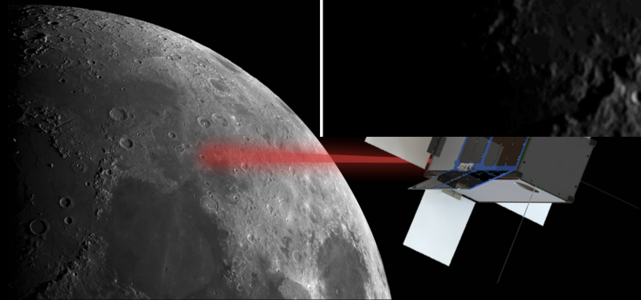
DORA Supporting LUNAR NET





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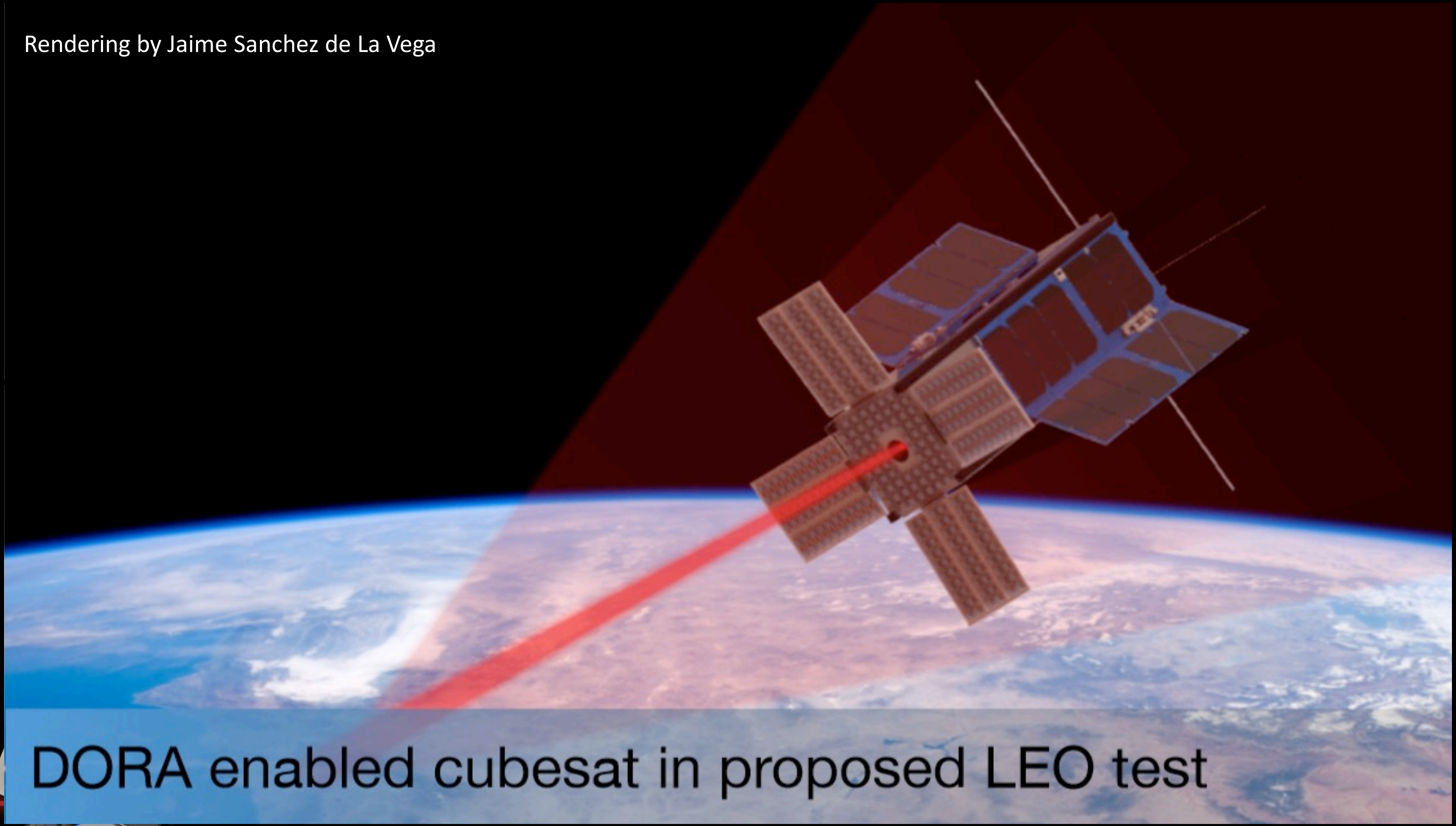
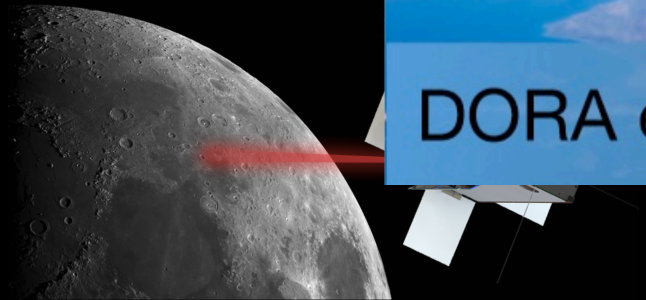
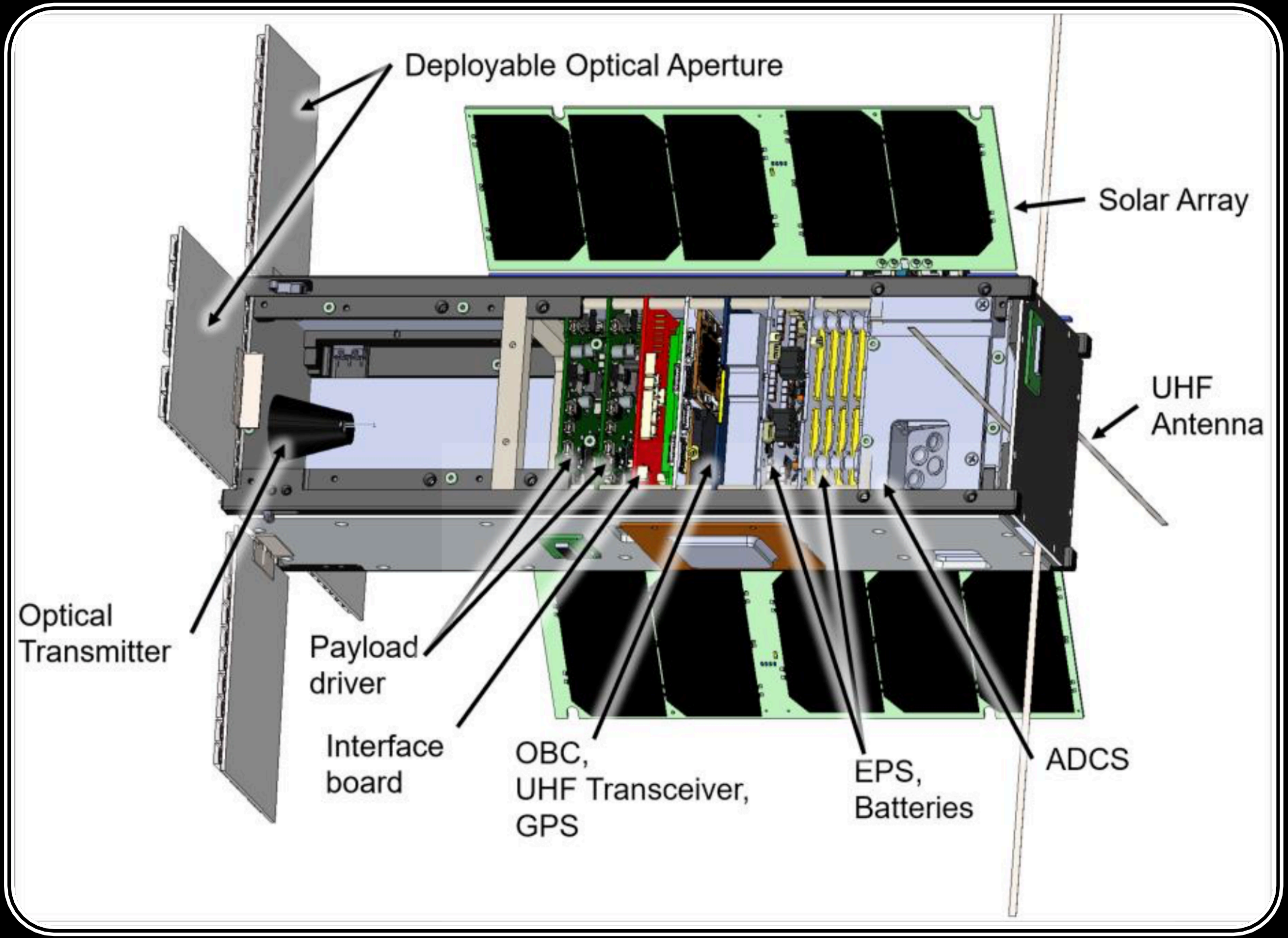
DORA in LEO

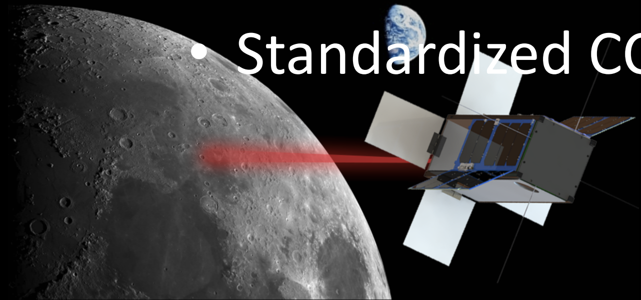

Rendering by Jaime Sanchez de La Vega
DORA enabled cubesat in proposed LEO test



DORA Cubesat Design

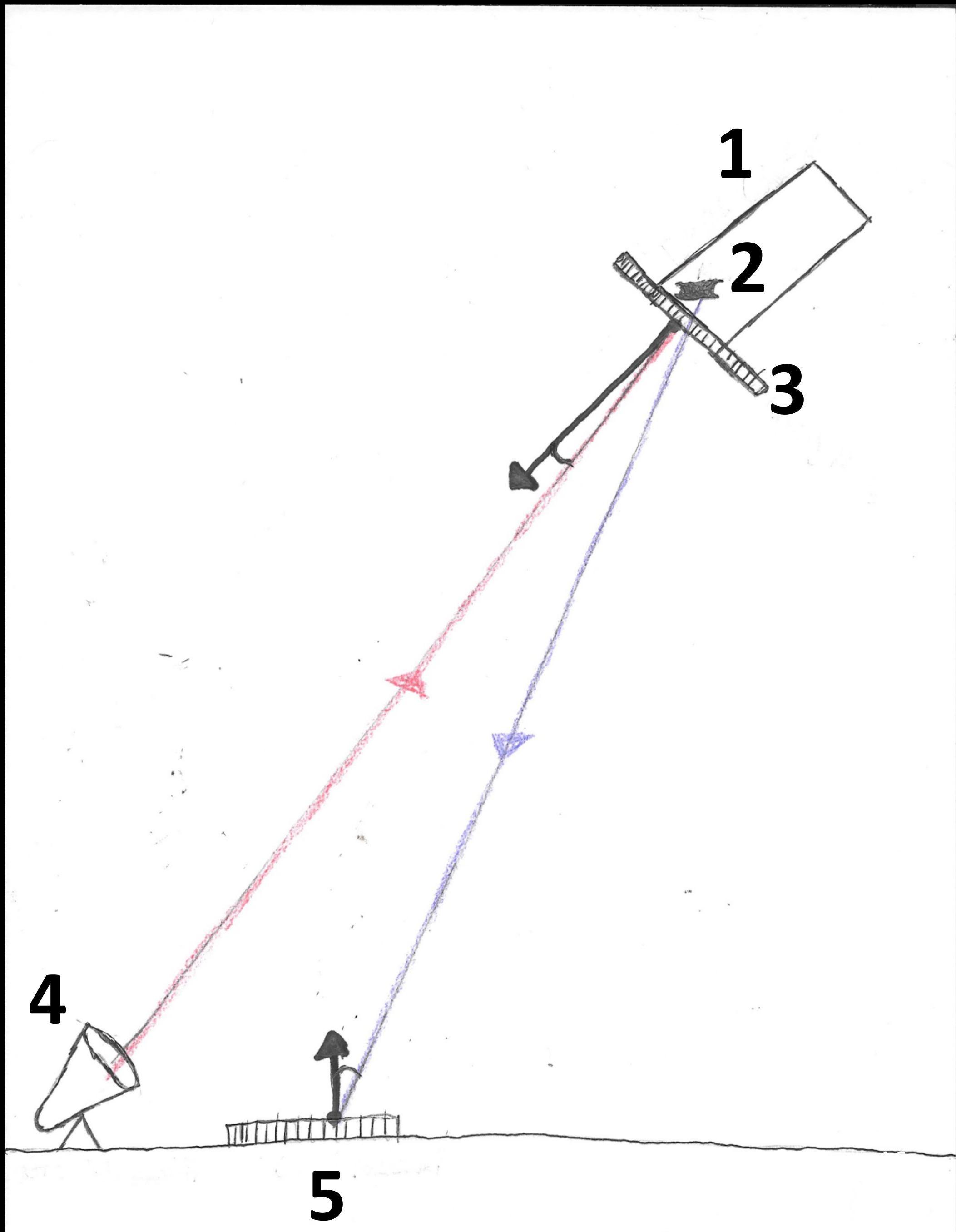
- Pheonix Heritage with updates
  - Beagle bone computer
  - MAI attitude controller
  - Planet openLST radio
  - 6x2U panels. 2 deployable, 4 fixed
  - GPS
  - More Batteries
- KubeOS Linux-based OS
- Standardized CCSDS protocol



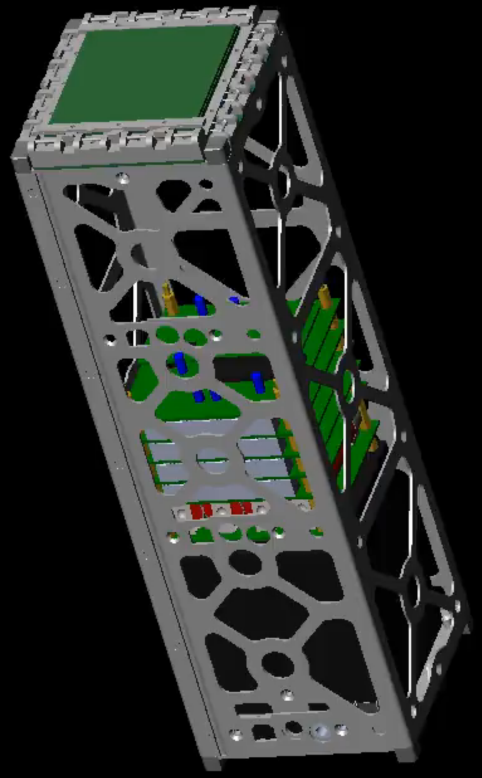


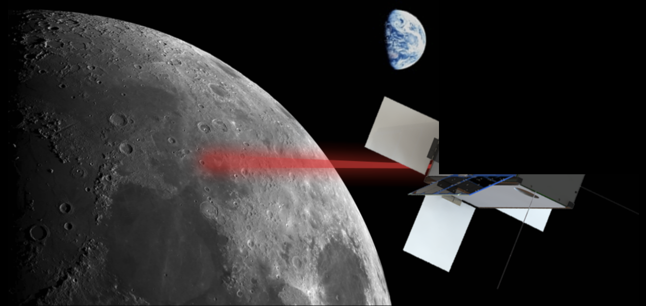
System Architecture

1. DORA CubeSat
2. MEMS mirror
3. DORA Receiving Panels
4. Ground Transmitter
5. Ground Receiving Panel

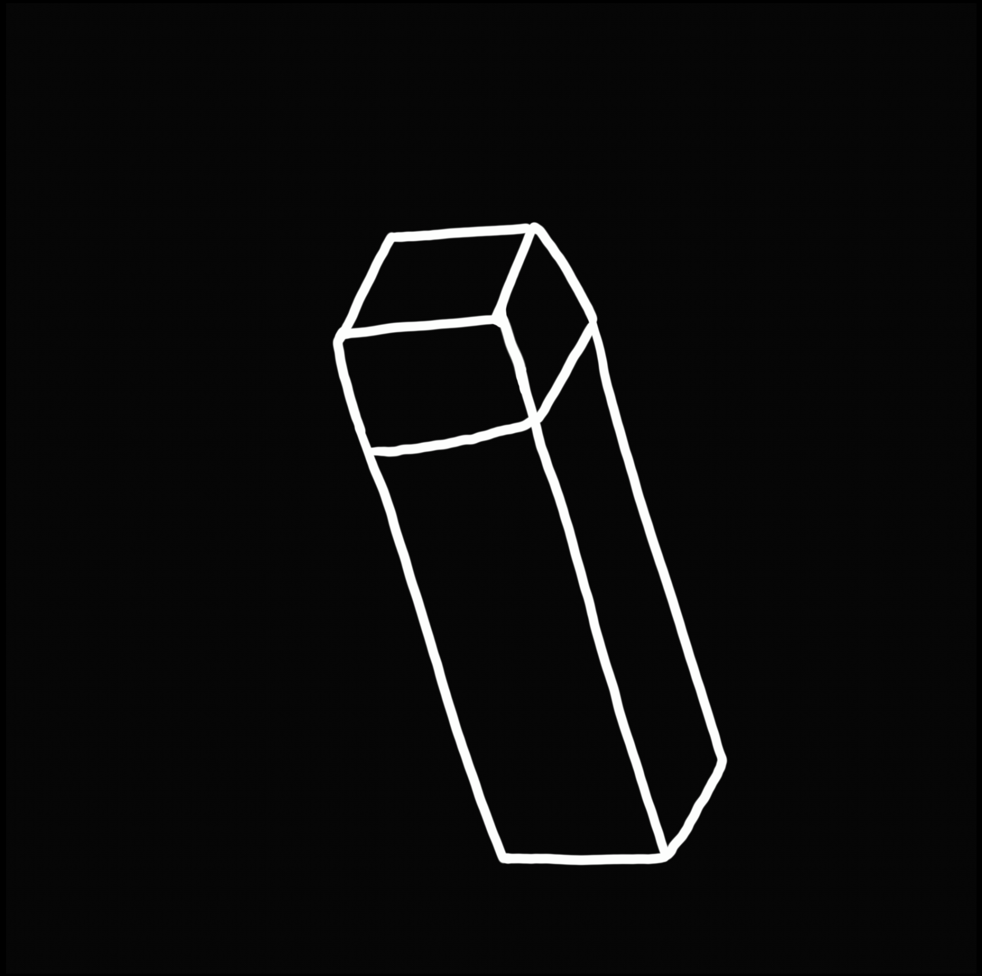


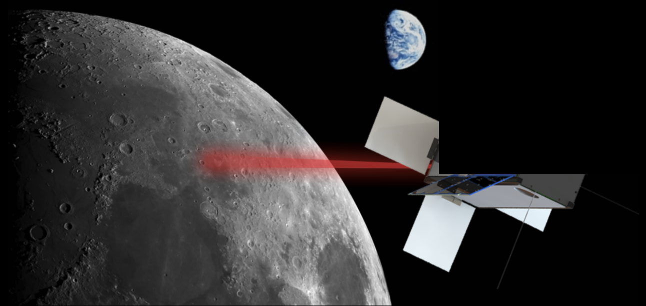
DORA DEployment





DORA Deployment (Fold –in mode)





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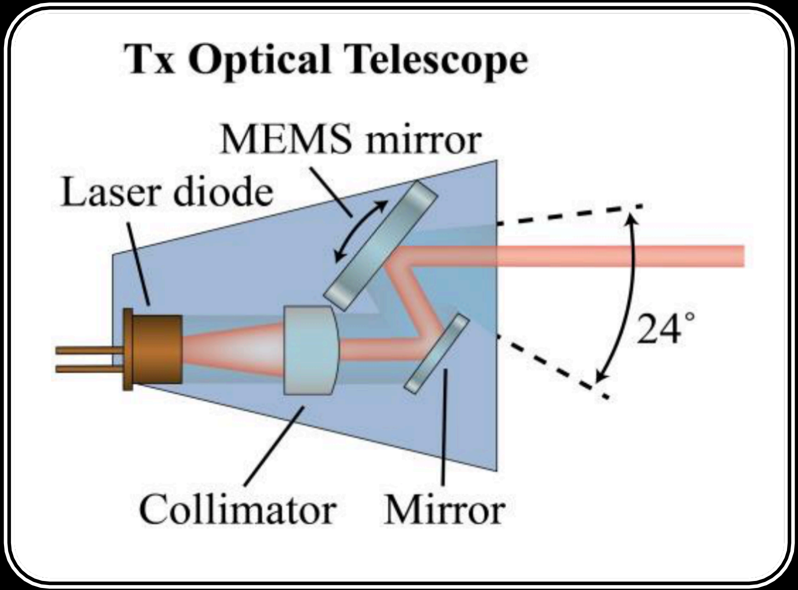
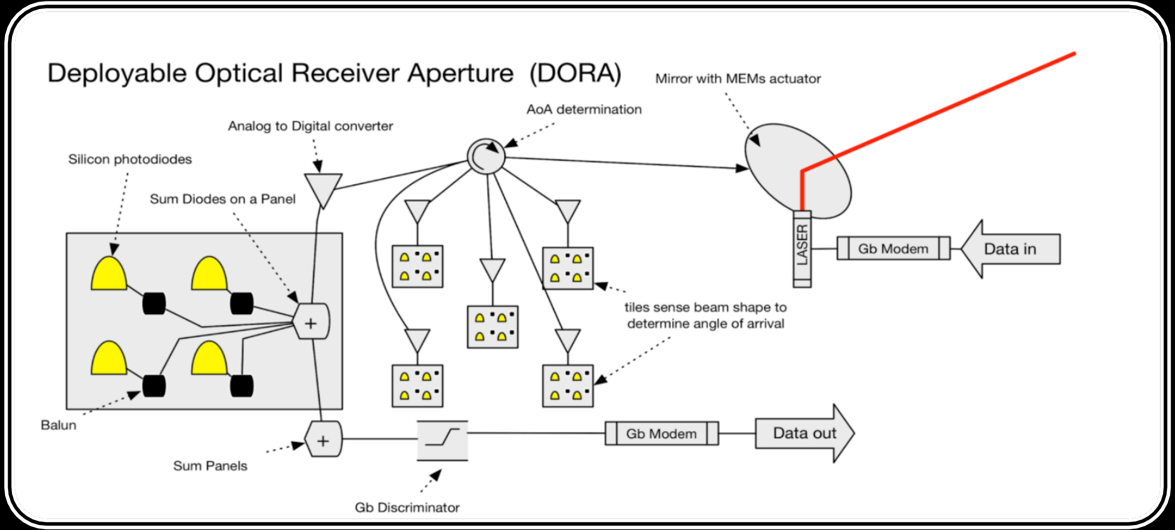
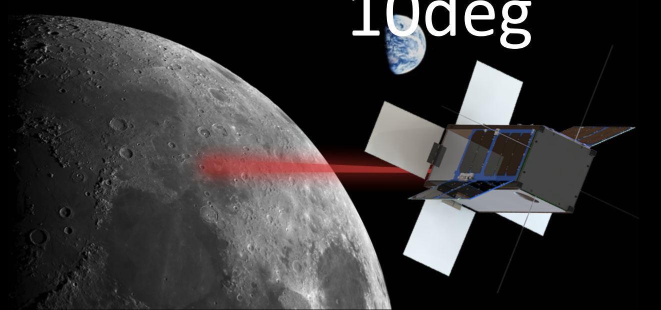
DORA Transciever functional Diagram

- Silicon Photomultiplier detectors
- Order 100 detectors combined per panal
- ADC for Angle detirmination
- MEMS mirror steers +/- 10deg







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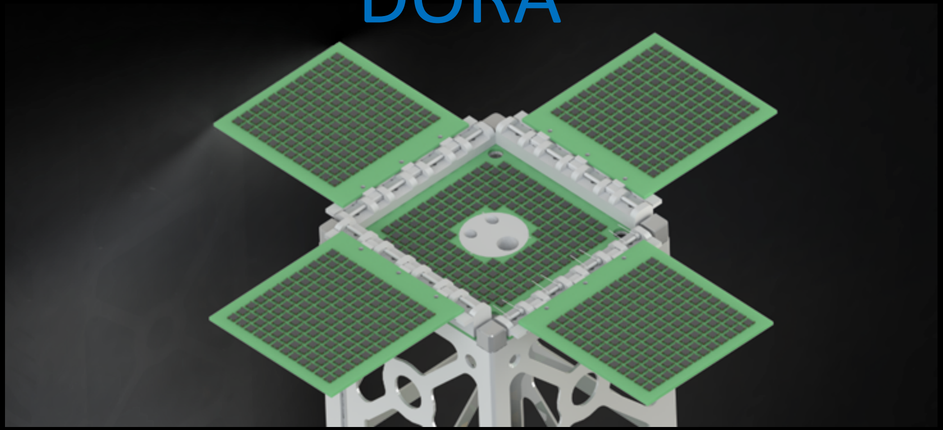
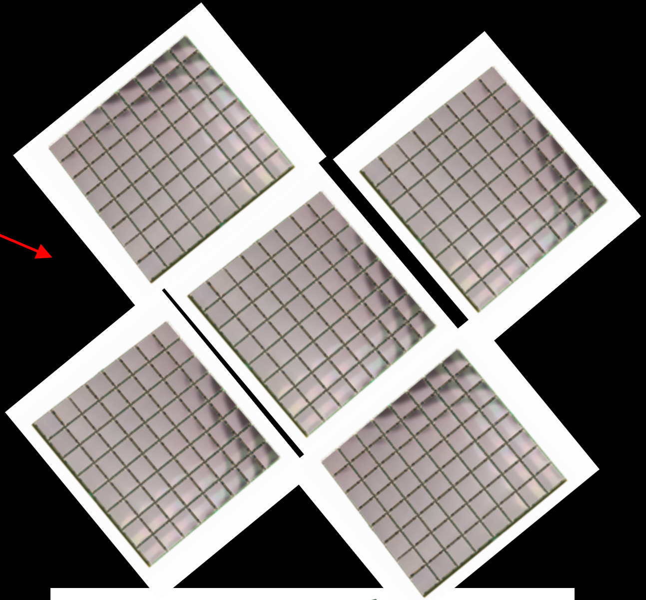
DORA Payload subsystems

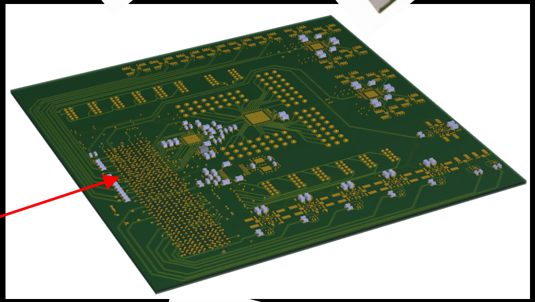
DORA



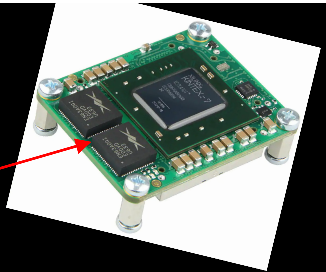
SiPM array

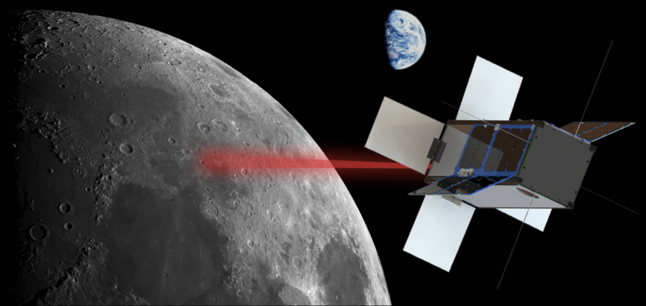


Mixed-signal PCB



TE0741 Xilinx Kintex-7





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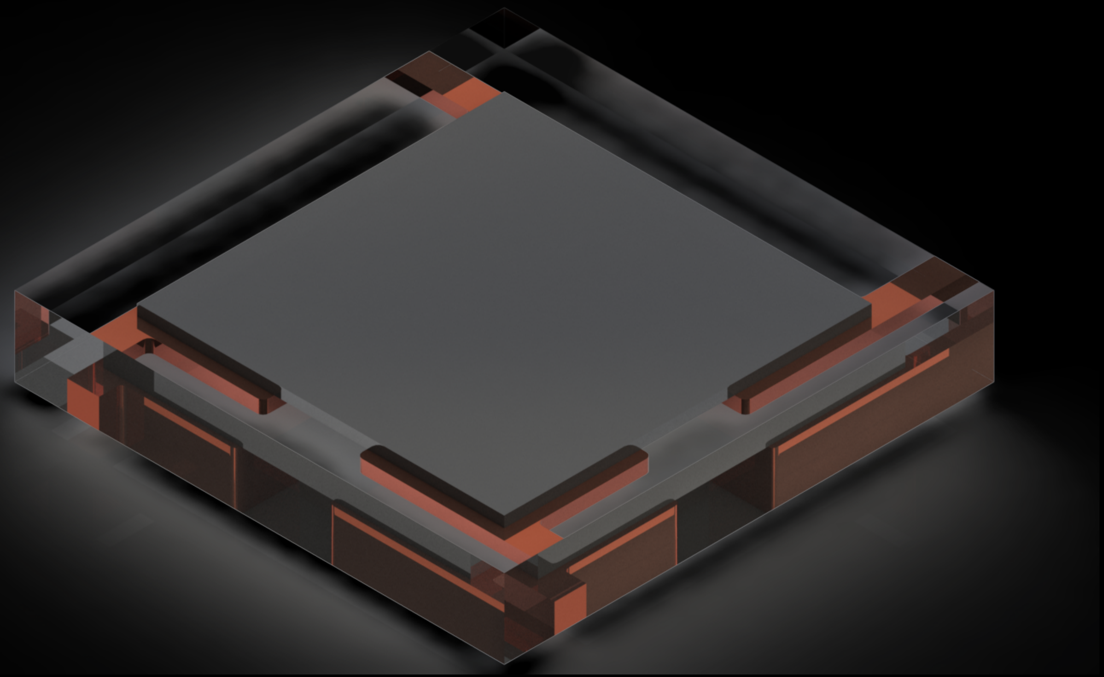
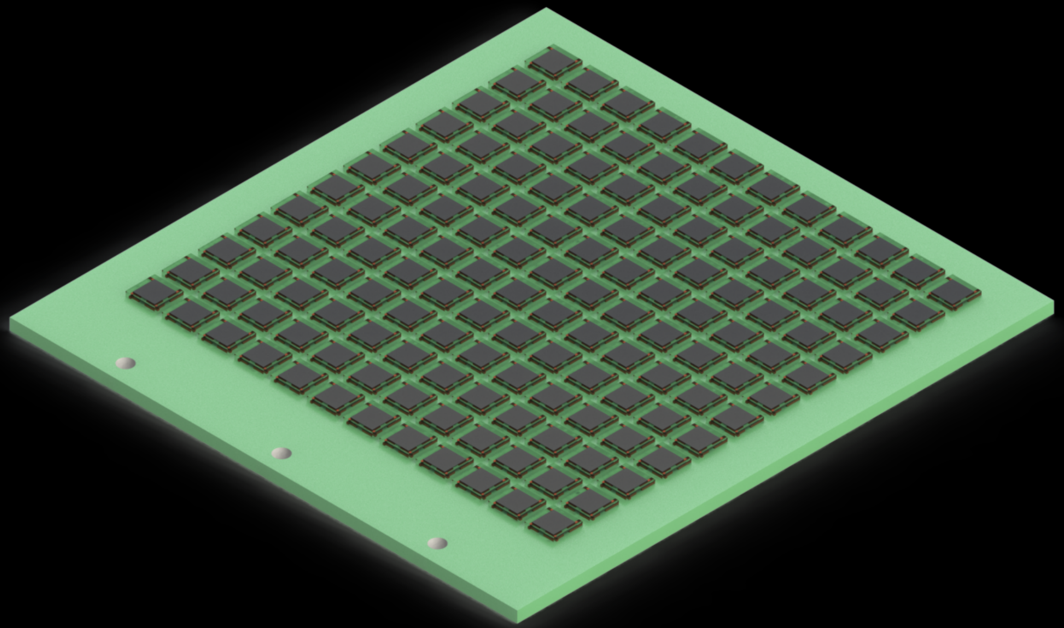
Slide by Jose Velazco

SensL SiPMs and Panels



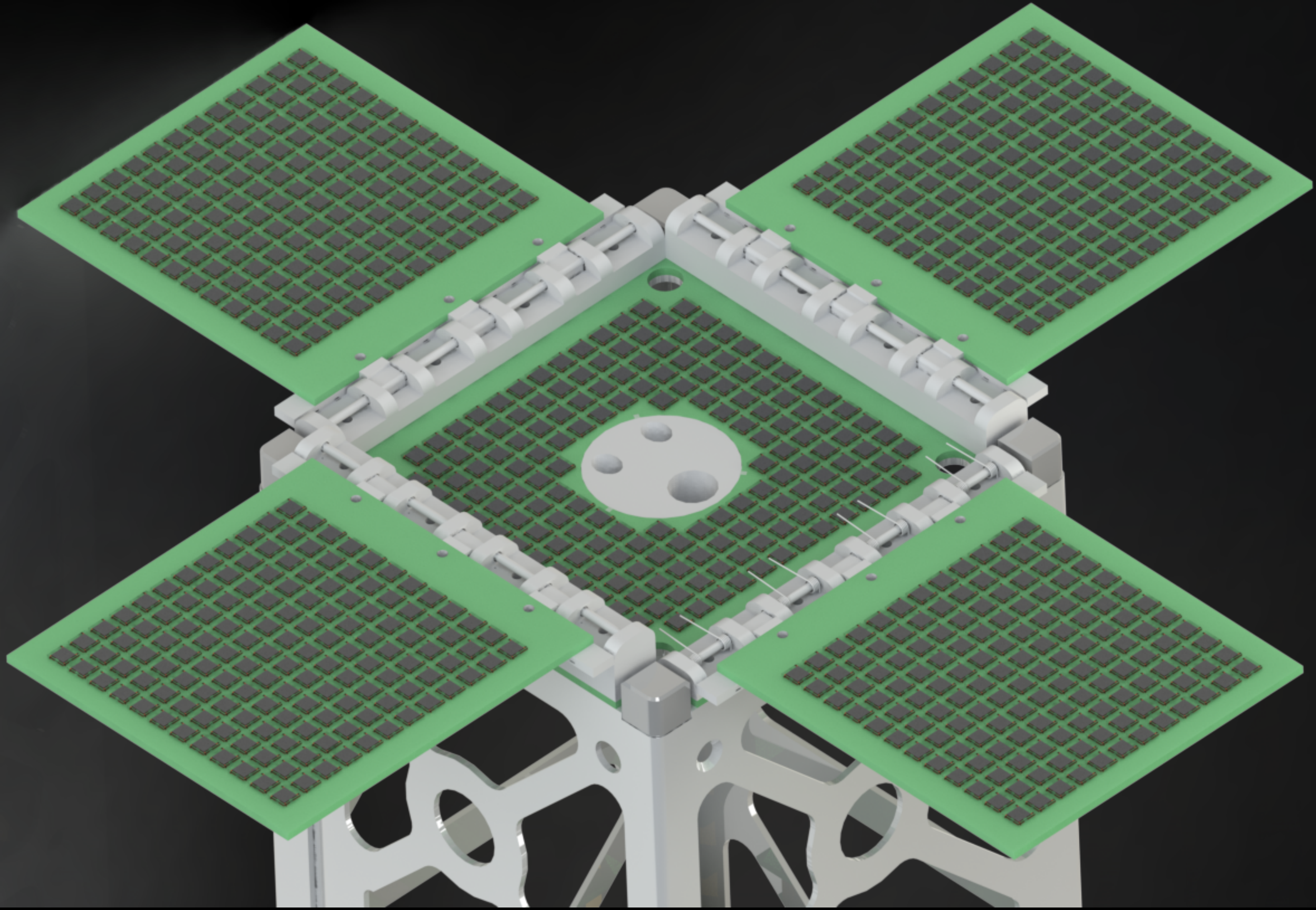
SensL 3mm x 3mm
C Series SiPM



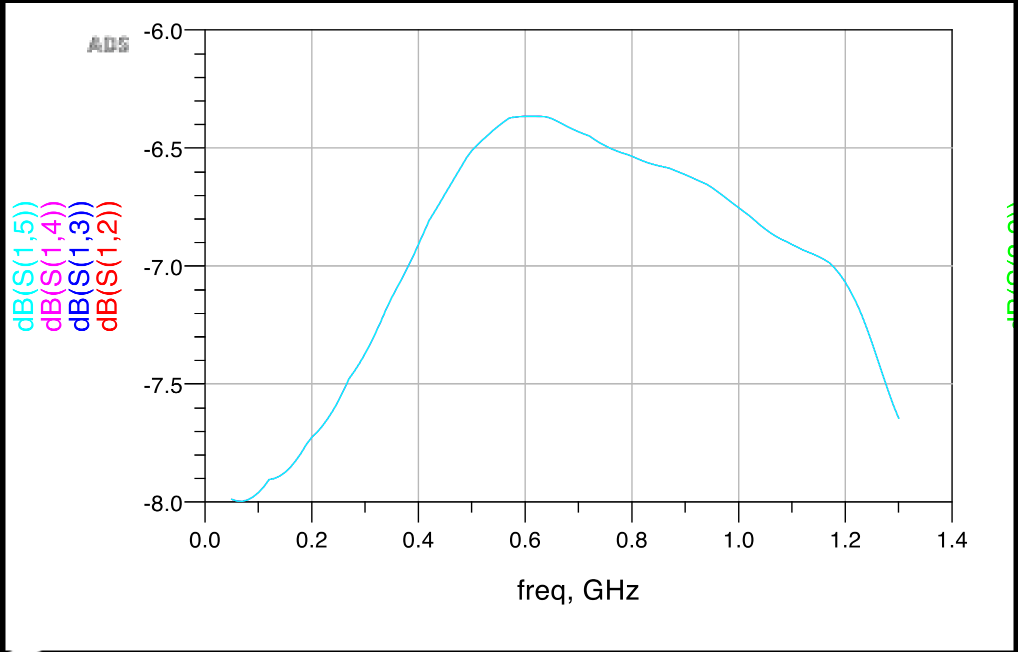
144 SiPMs populated on
standard 1.57mm thick
2 layer PCB with 1mm spacing

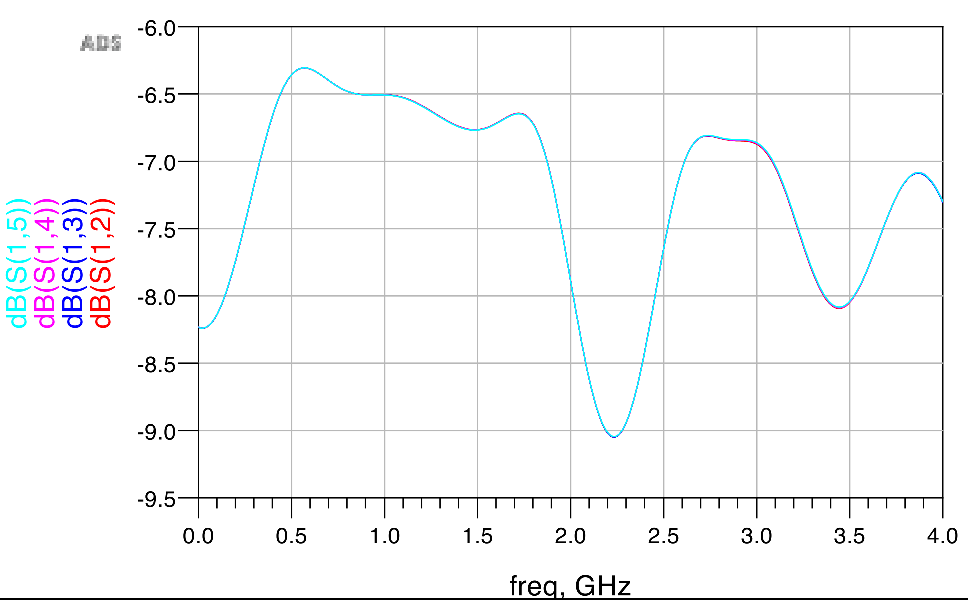
Slide by Sean Cornish

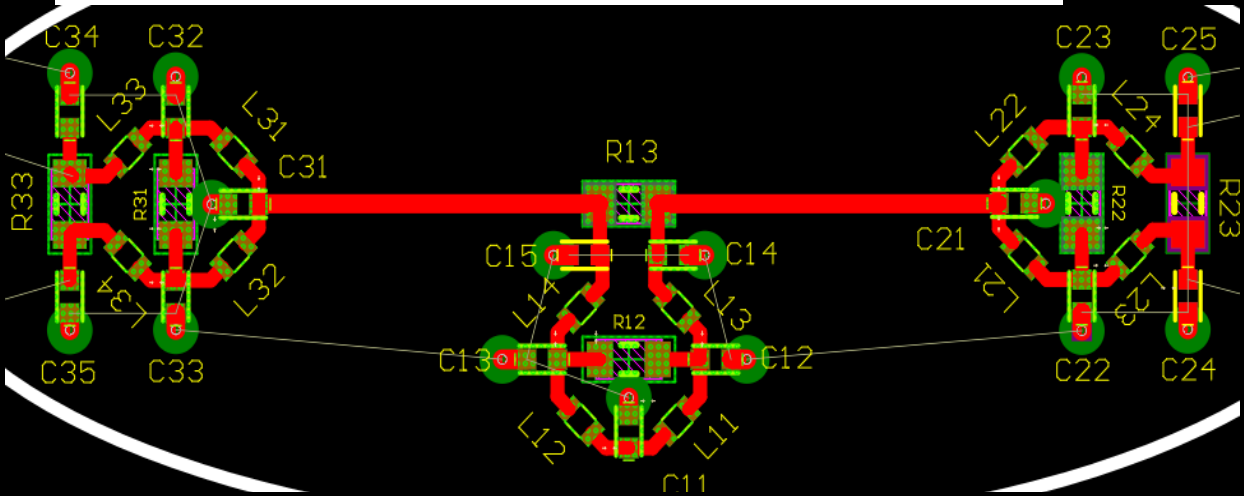
DORA Aperture - 736 SiPMs

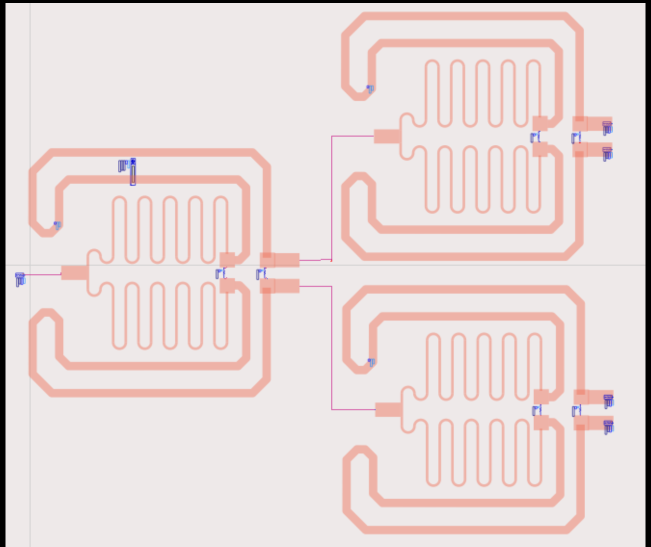


Lumped Element vs Microstrip

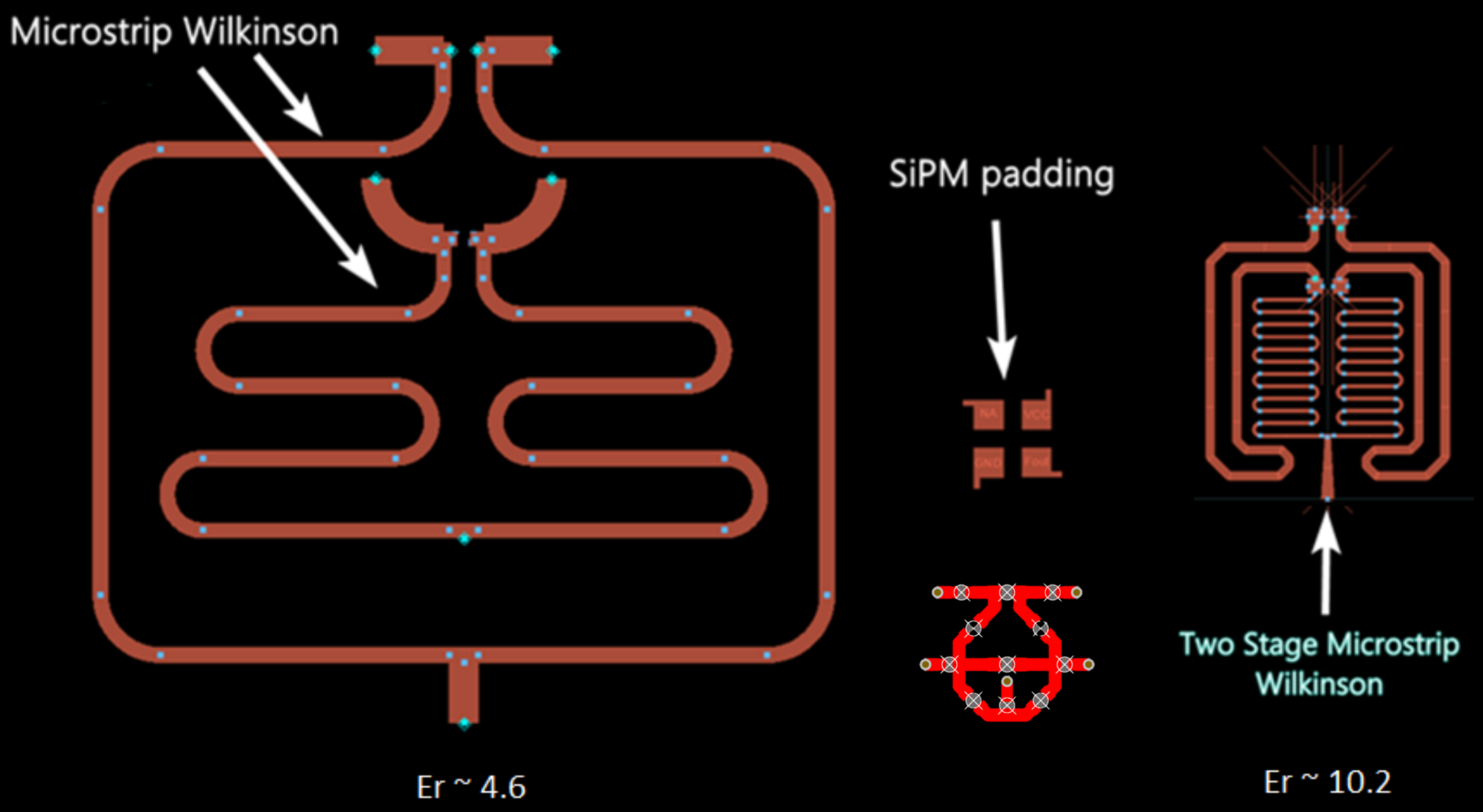






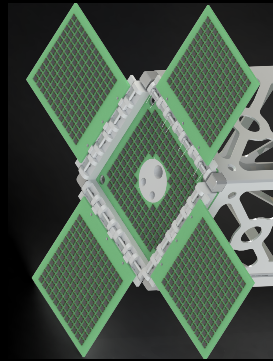


Lumped vs strip

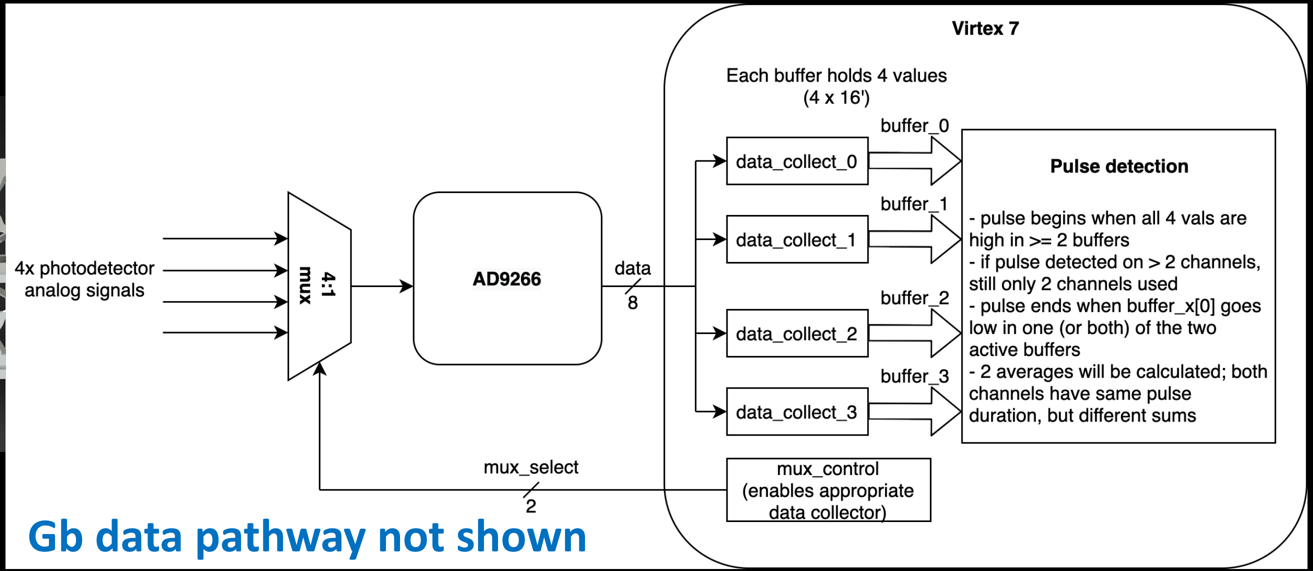


FPGA ANGLE CALCULATION

- 100us pulse embedded in incoming signal
- ADC reads power
- FPGA detects pulse
- If enough panels see pulse,
- Use known angular response of SiPM panels to infer incoming Angle
- Steer Tx beam back towards Rx



This prototype design uses 4 panels



Simulation using lab measured detector noise
AoA accuracy required: 1.4mdeg

	(degrees)
Ideal AOA	31.000
AOA with noise	30.870
AOA noise corrected	30.972
	(mdeg)
Error without noise correction	-130
Error with noise correction	-28

Inverse Variance Weighting to compensate for bad sensor input

Sarah Spector

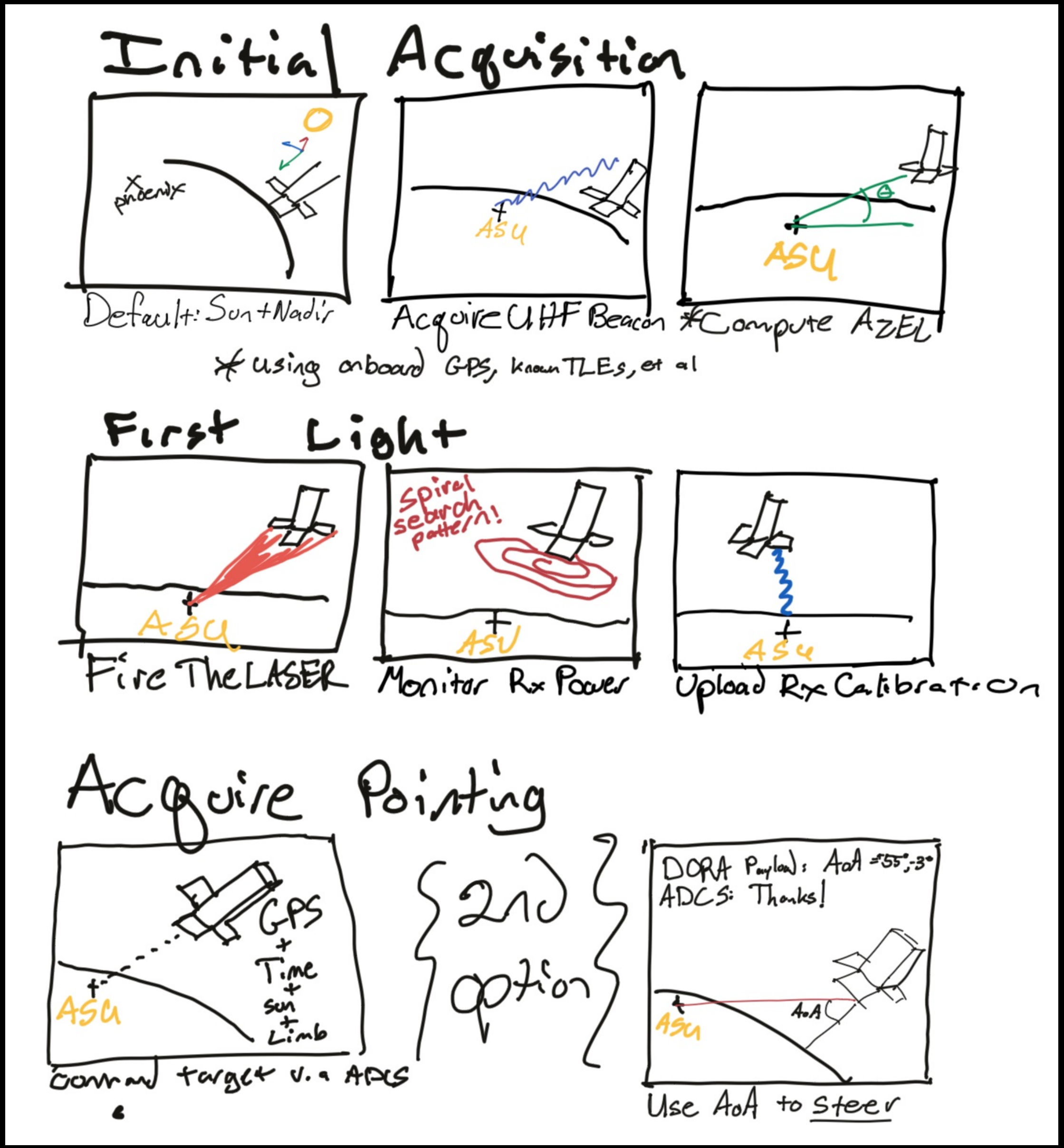
DORA Operations

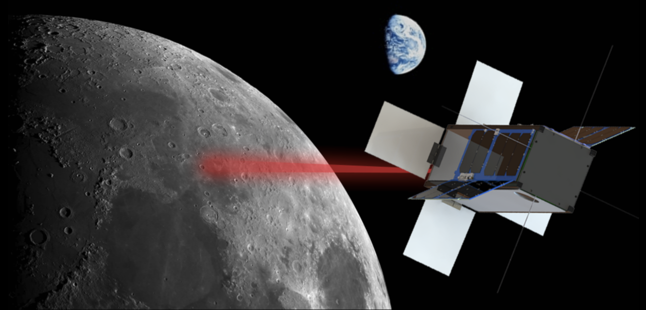
Conops and ground station

- Fly in Sun-Nadir mode
- Turn towards laser source (either by command or using AoA)
- Uplink BER test
  - Against stored pattern
  - Download upload via UHF
- Downlink BER test
  - Uplink required to close, use loopback
- Possibly support networking
- Possibly support direction
- Safety / Regulatory
  - 1W IR Laser

Conops

- Fly in Sun-Nadir mode
- Confirm health via UHF
- Find with Ground laser
- Calibrate panels
- Turn towards laser source (either by command or using AoA)





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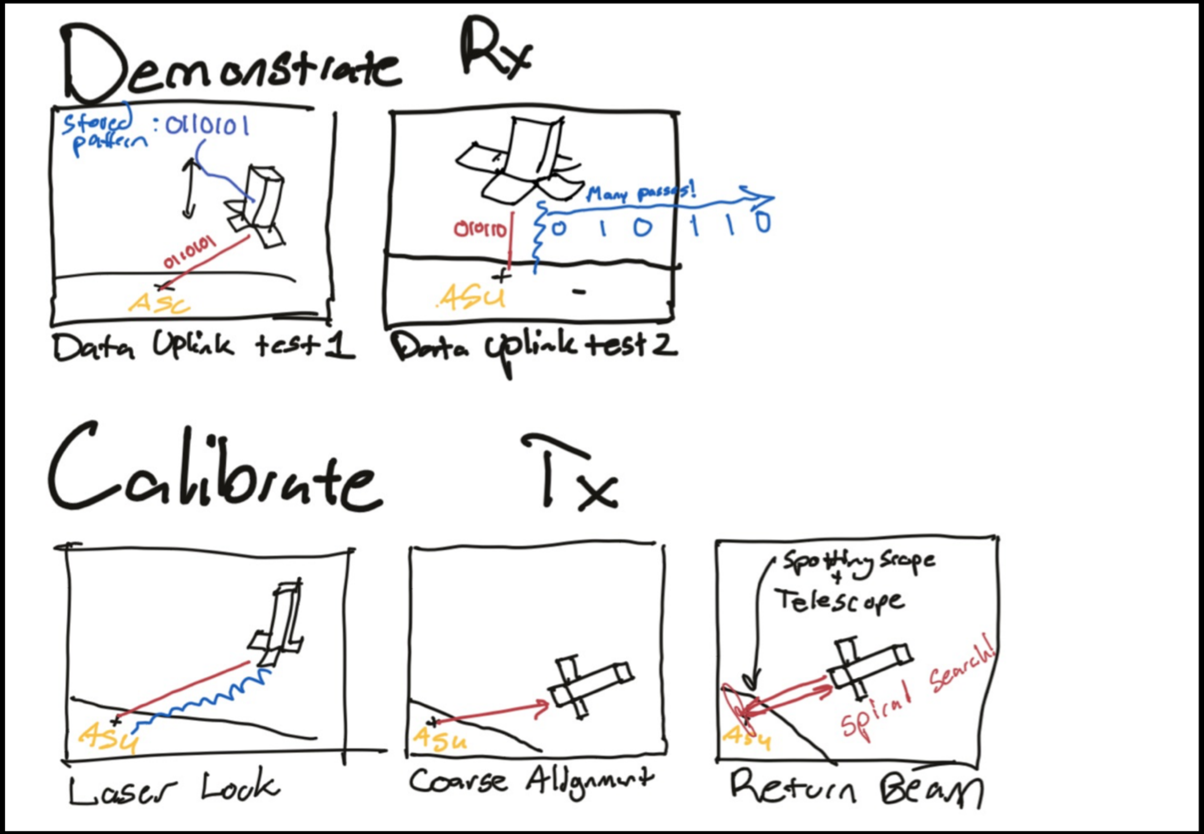
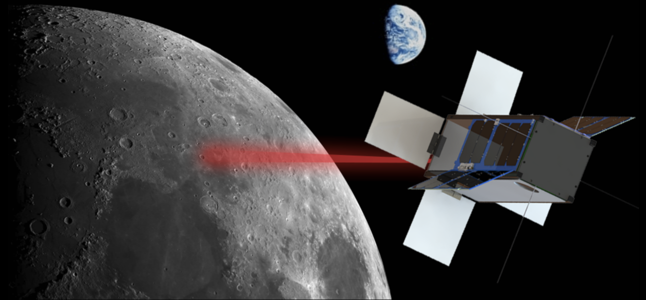
Conops with working Rx panel and pointing





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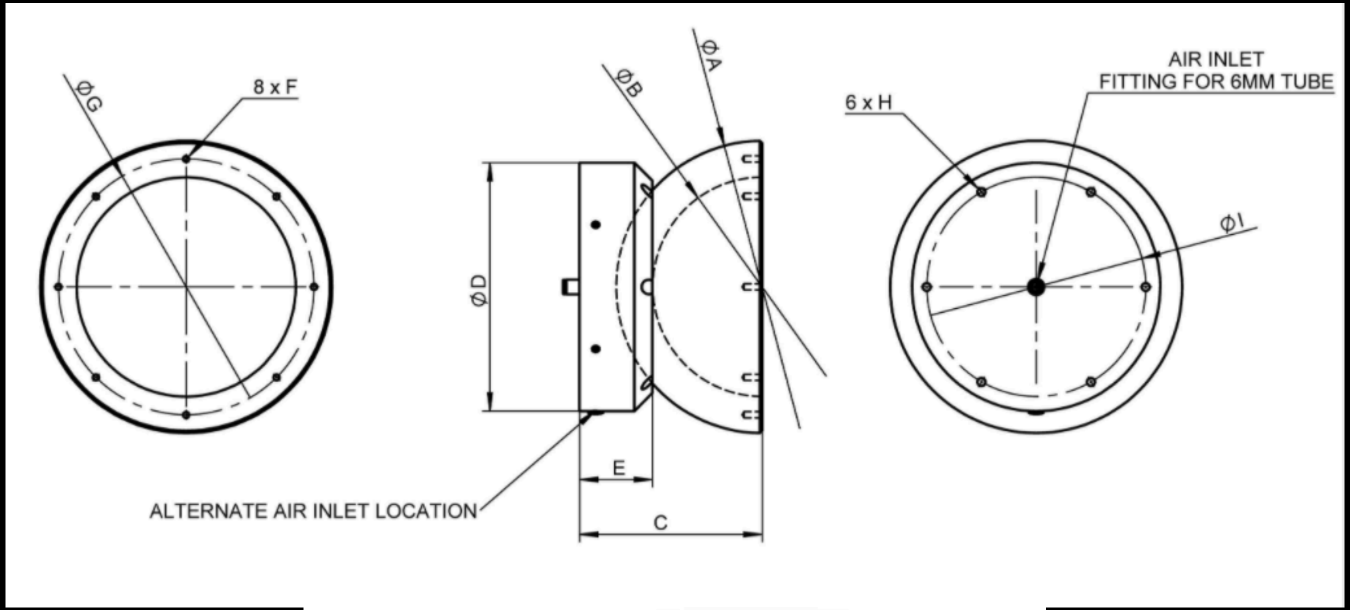
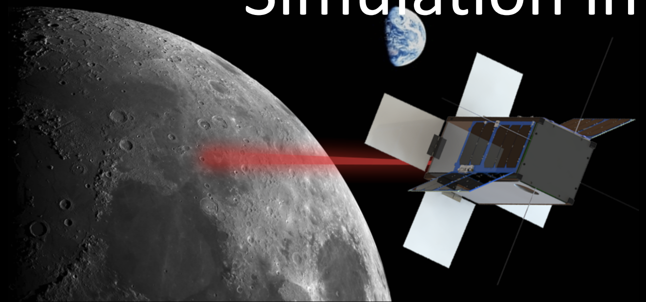
Pointing testing

- II Lab facility under development
- Test and calibrate cubesat pointing
- Air bearing
- Helmholtz coils
- Sun simulator
- Simulation in the loop

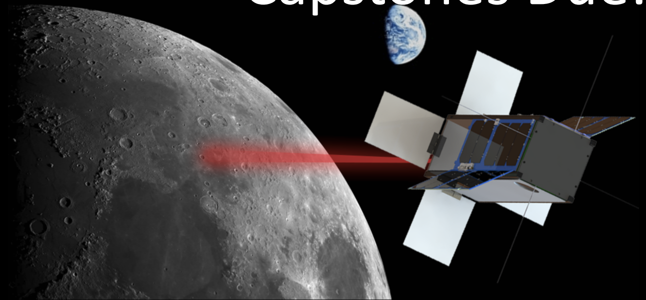




Schedule

- Preliminary Design work (summer 2020)
  - Software and computer eval
  - Concept of operations
  - Cubesat parts selection
  - Payload: FPGA design, signal board, power combiners
- First flatsat prototype: Dec 2020
- First laser prototype: Dec 2020
- First Mechanical prototype: Dec 2020
- First combined prototype: April 2020
- Capstones Due: May 2020

- Summer 2021
  - Spacecraft EDU
  - Ground terminal
- CDR Aug 2021
- Fall 2021:
  - SC Testing
  - Second laser prototype testing
- Spring 2021
  - EDU and Payload integration testing
- Project complete July 2021



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Thanks!

Key Performance Parameters

Parameter	Required	Target
KPP #1 - Angle of Arrival Accuracy	20 arcseconds	5 arcseconds
KPP #2 - MEMS Pointing Accuracy	20 arcseconds	5 arcseconds
KPP #3 - Maximum Tolerable Drift Rate	0.1° / second	1° / second
KPP #4 - Maximum Off-Axis Angle	5°	36°
KPP #5 - Sustained Data Rate	0.5 Gbps	1 Gbps
KPP #6 - Bit Error Rate	10^{-8}	10^{-9}
Transmit Power	1000 mW	2000 mW
Transmit Optics Collimation	100 arcseconds	20 arcseconds
Stray Light Rejection	Sun within 90°	Sun within 30°