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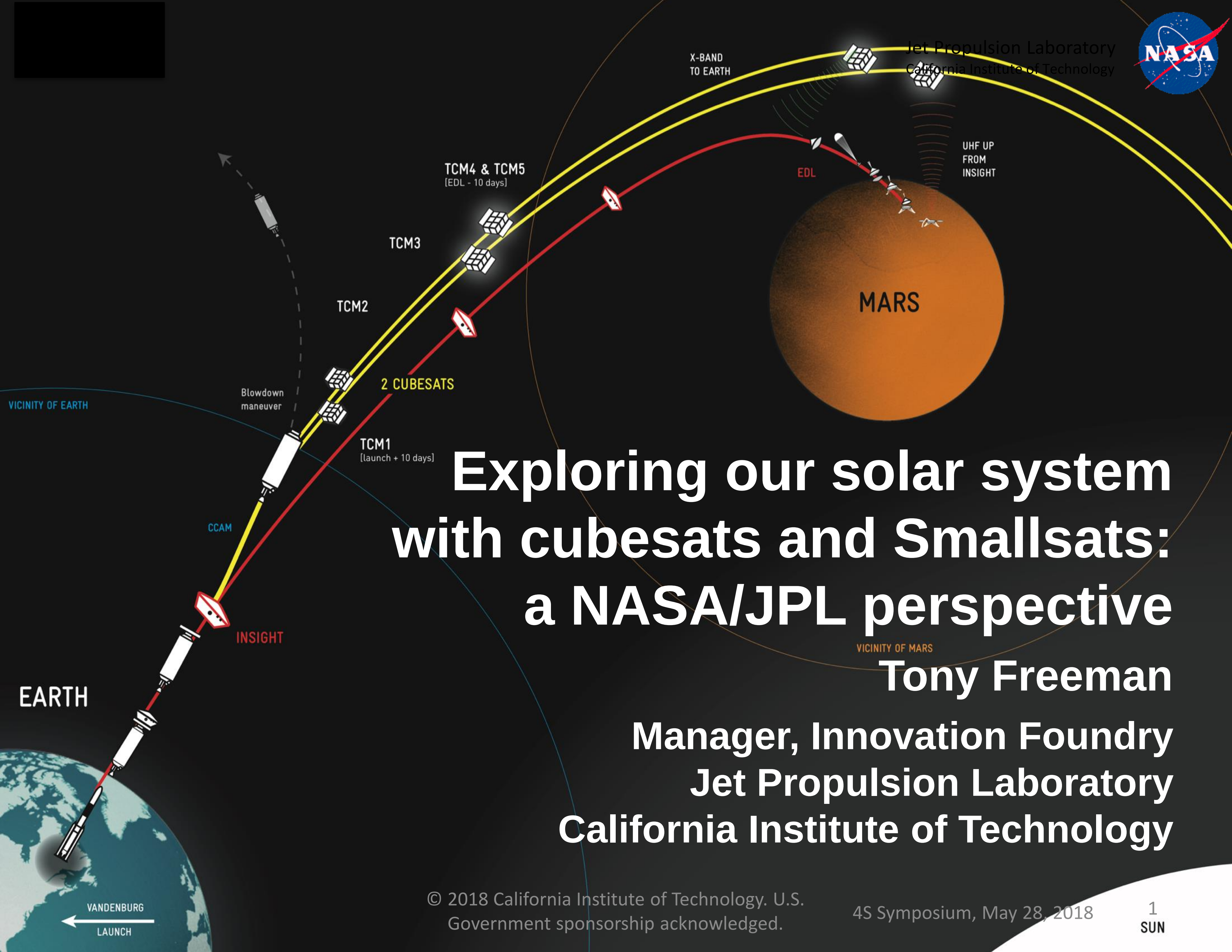


Exploring our solar system with cubesats and Smallsats: a NASA/JPL perspective

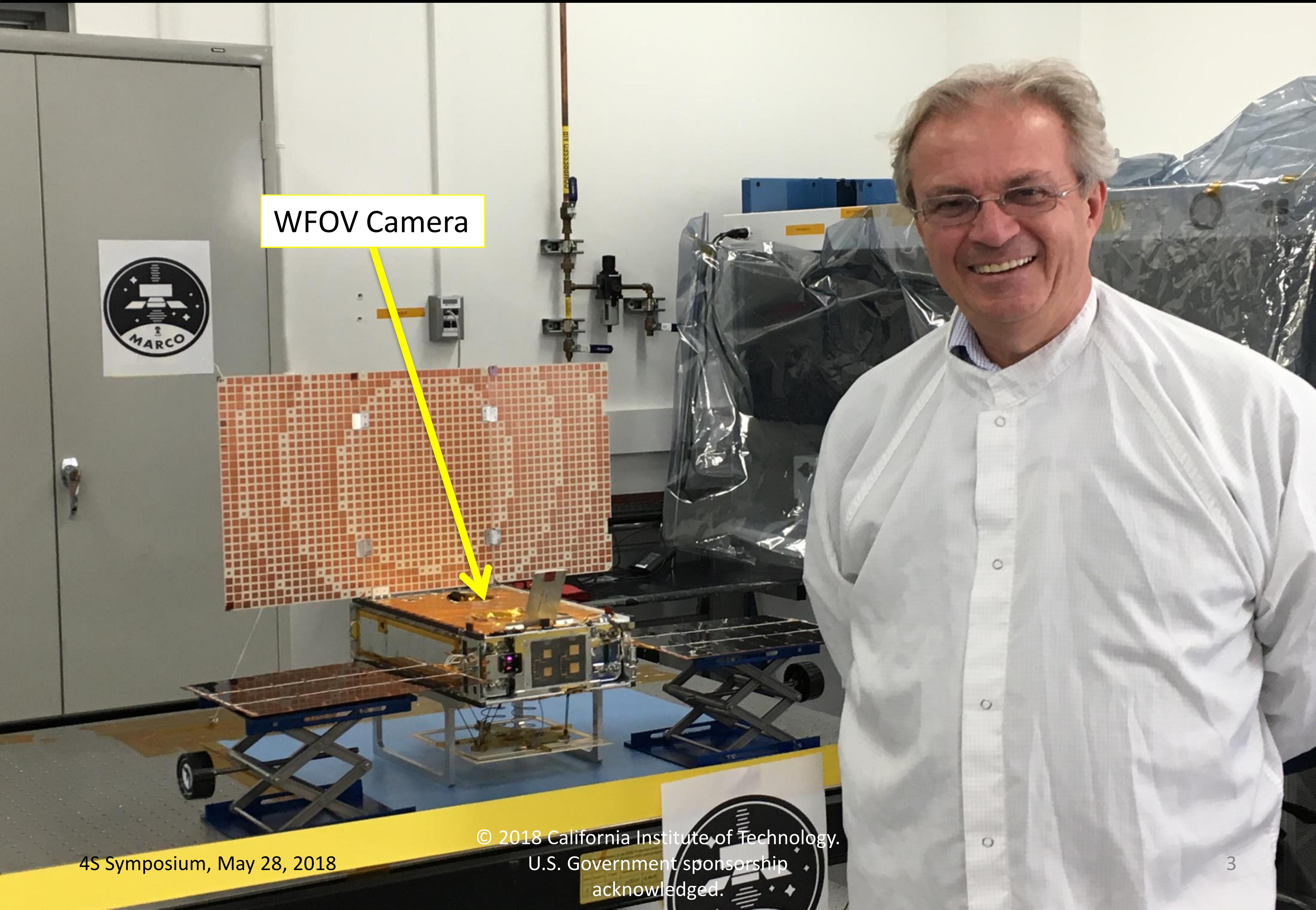
Tony Freeman

Manager, Innovation Foundry
Jet Propulsion Laboratory
California Institute of Technology

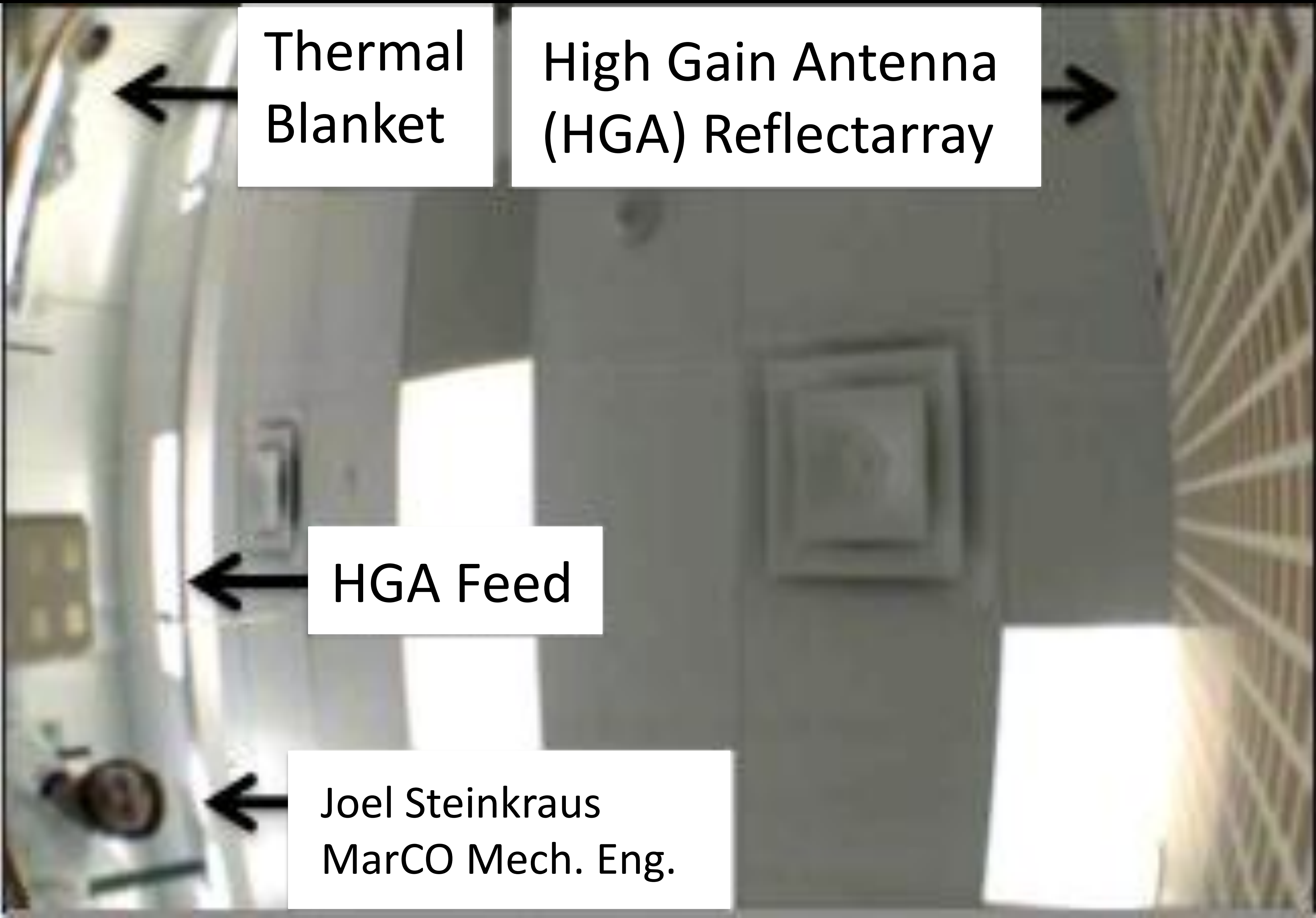
Introduction

- At the last 4S Symposium in 2016, I described a future in which deep space cubesats are used to explore our solar system

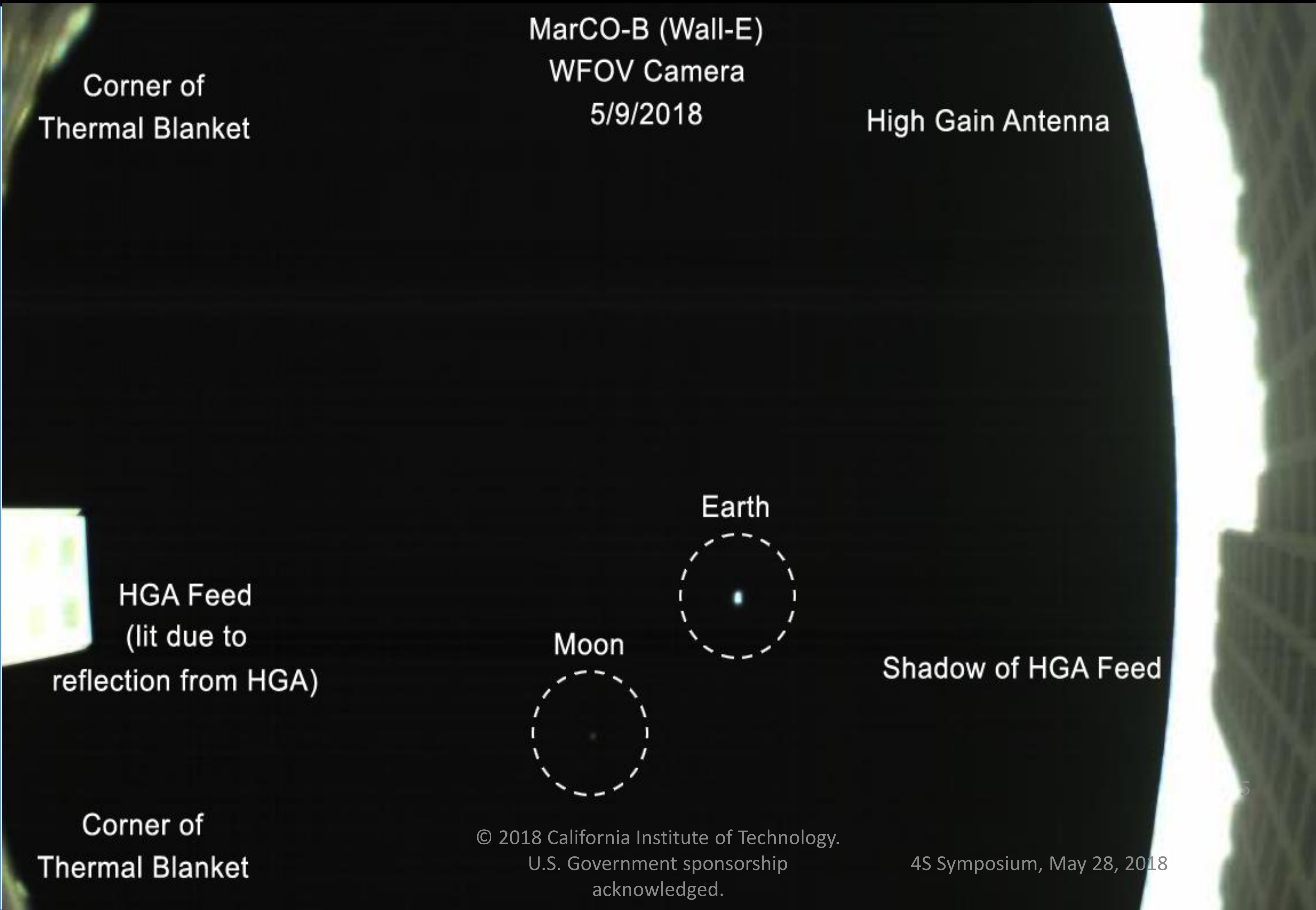
MarCO Pre-Ship Configuration



MarCO-B WFOV Image Pre-Launch



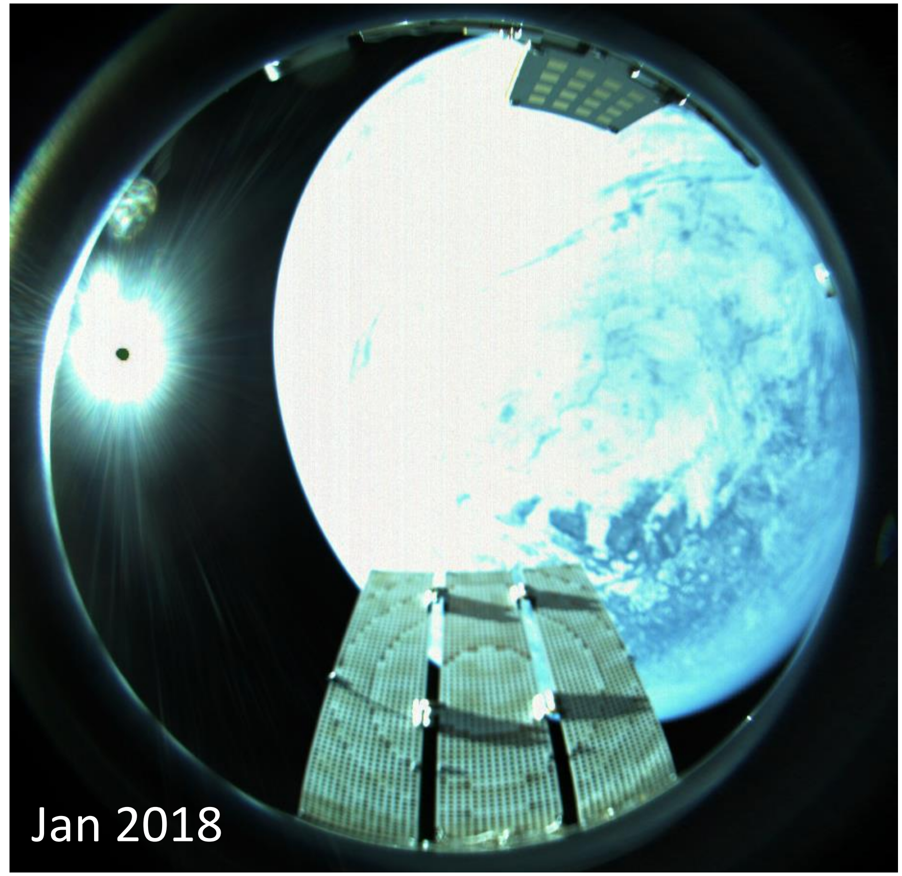
Marco-B: The View from Deep Space



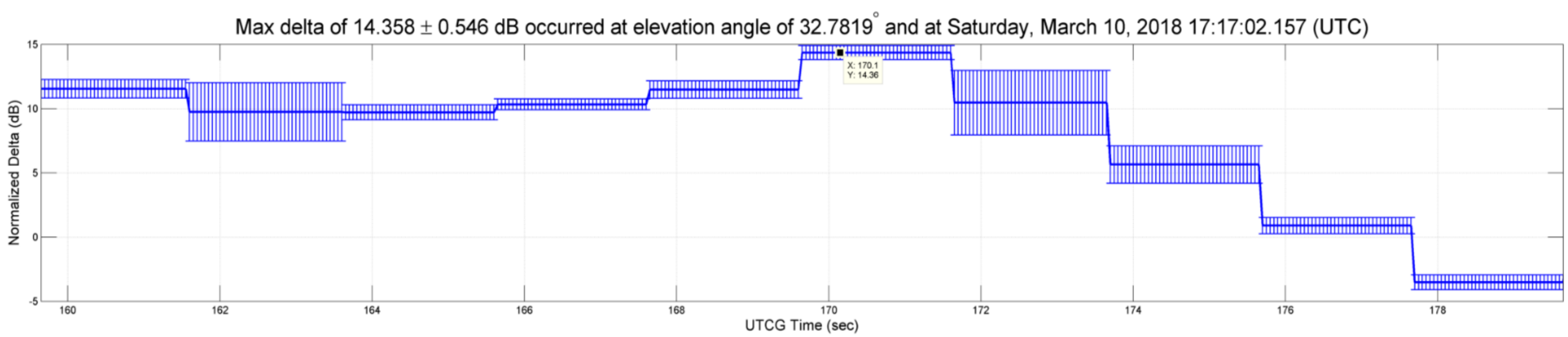
Before MarCo there was ISARA

Slide courtesy Richard Hodges and the ISARA team

- ✓ First reflectarray antenna flown in space
- ✓ First high gain antenna integrated with solar panels (low mass delta)
- ✓ First calibrated antenna gain measurement performed from space – 33.4 dB peak
- ✓ First 100 Mbps CubeSat telecom downlink capability (from LEO)



Signal Power Measurements



And before that there was ASTERIA…

Slide courtesy Matt W. Smith and the ASTERIA team

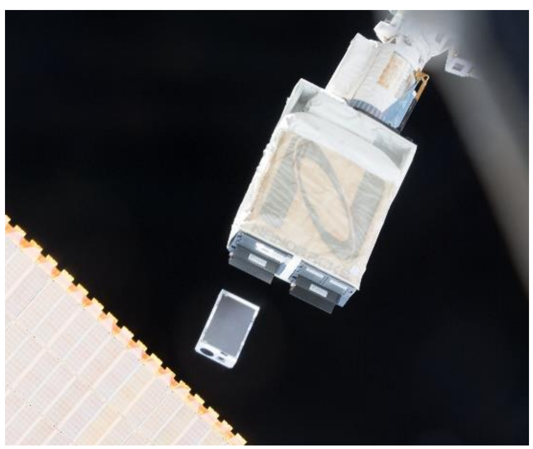
Arcsecond Space Telescope Enabling Research in Astrophysics (ASTERIA)

- ✓ Precision pointing to better than 0.5 arcsec RMS
- ✓ Thermal control of the focal plane to < 0.01K
- ✓ Goal: Exoplanet transits using stellar photometry?

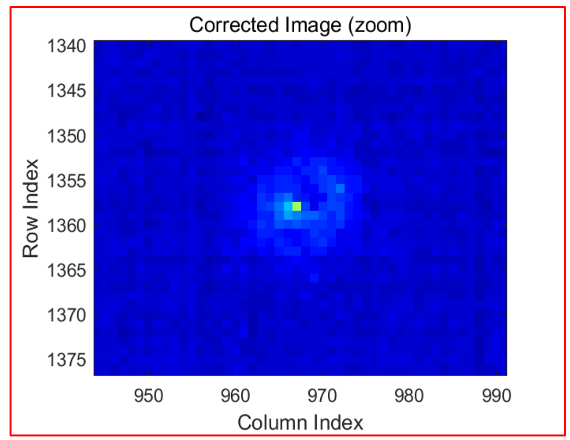
Summer 2017: ASTERIA in I&T

8/17: Launch

11/17: Deployed from ISS



12/17: First Image

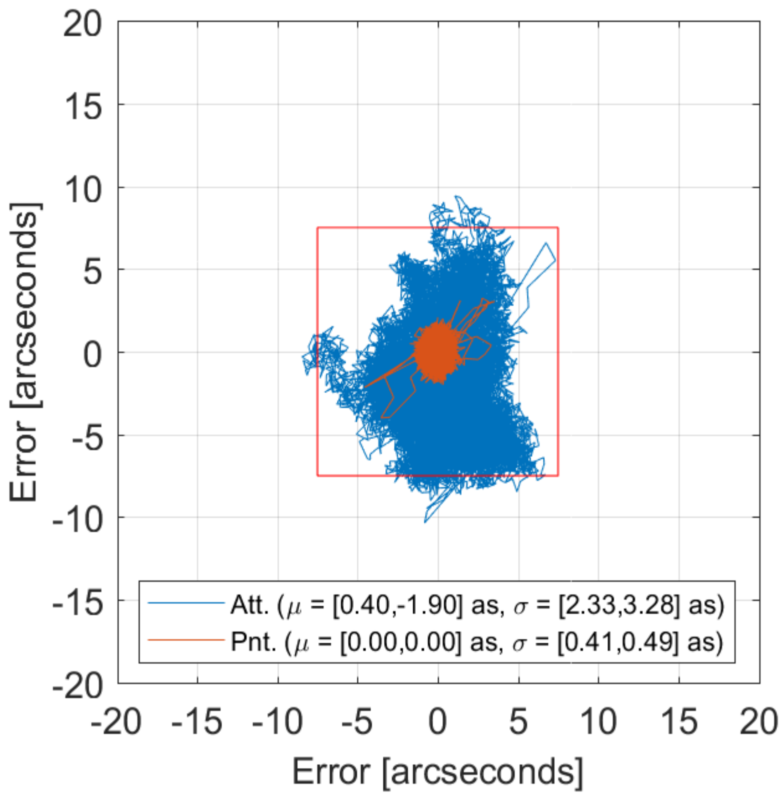


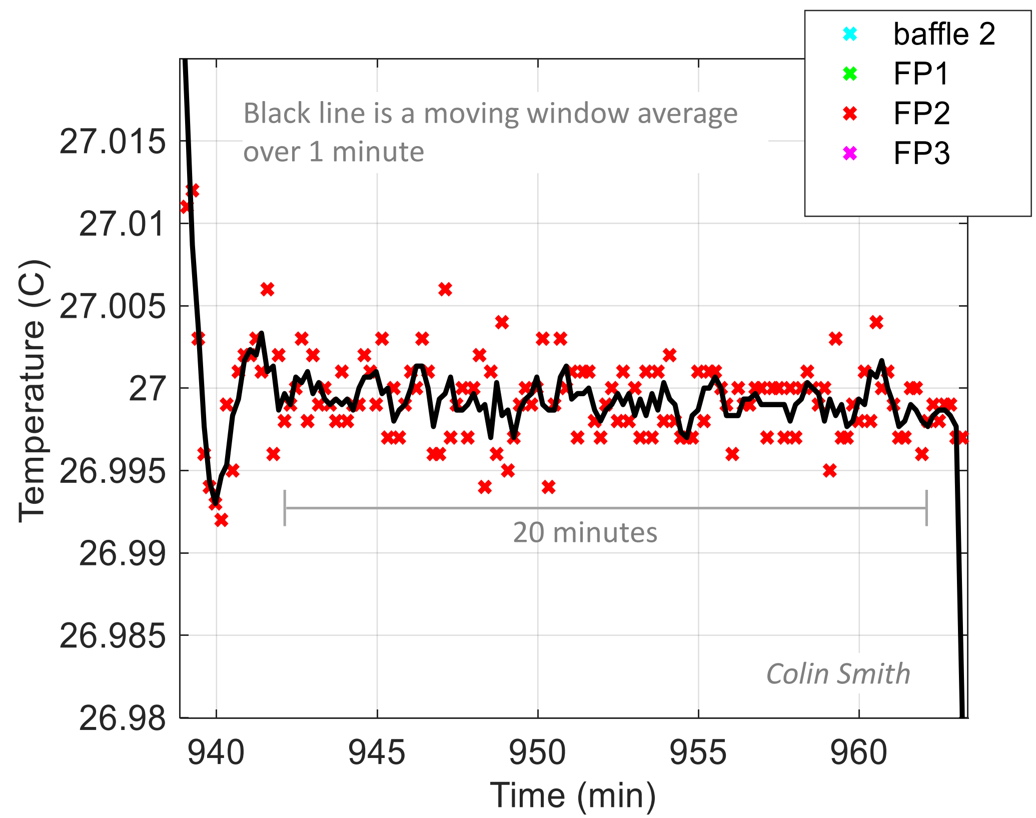
ASTERIA - Pointing and Thermal Control

Slide courtesy Matt W. Smith and the ASTERIA team

- ✓ Achieved pointing error < 0.5 arcseconds RMS over 20 minutes
- ✓ Blue scatter points show pointing without piezo stage correction
- ✓ Red scatter points show pointing <u>with</u> piezo stage correction

- ✓ Achieved focal plane thermal control < ±0.01 K over 20 minutes
- ✓ Optical Telescope Assembly is thermally isolated, stable
- ✓ Trim heaters and coarse/fine control loop maintain temperature stability



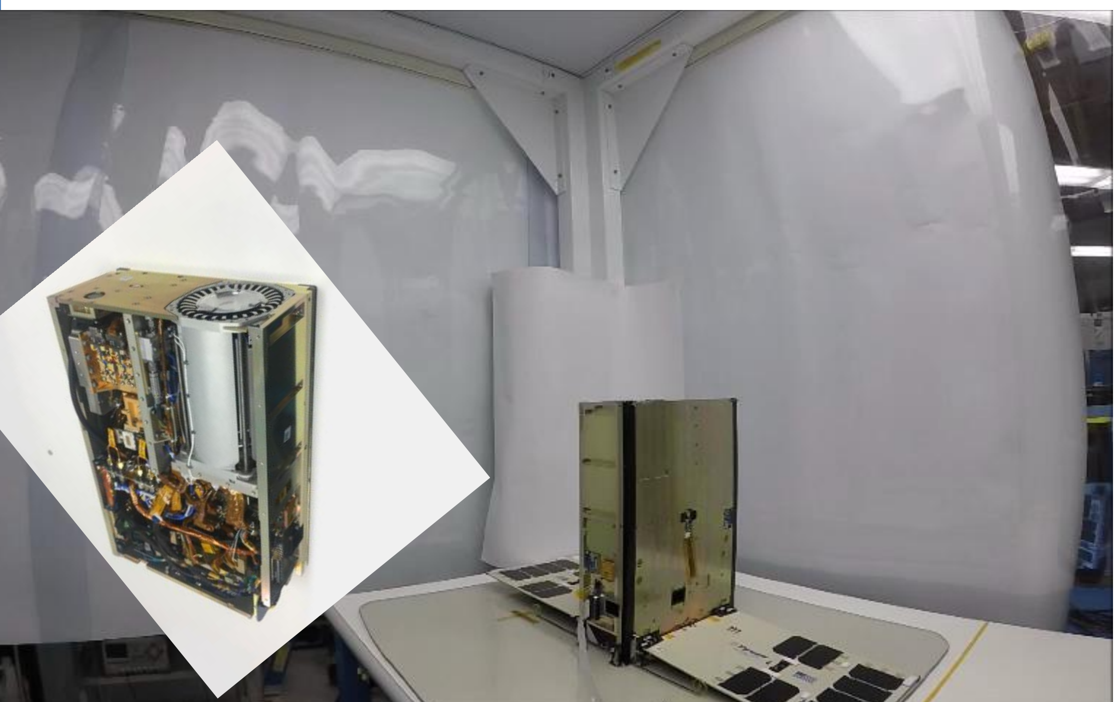


Coming up soon is RainCube

Slide courtesy Eva Peral and the RainCube team

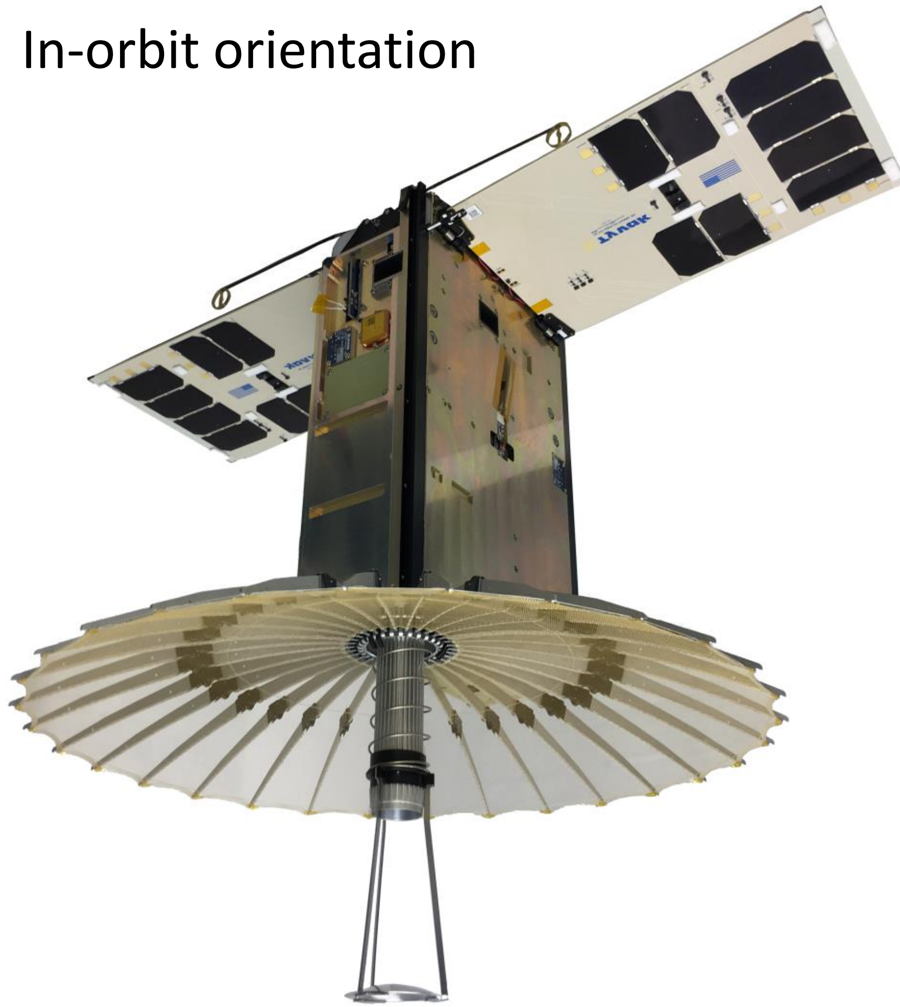
- ✓ First radar cubesat (6U)
- ✓ Vertically sounding, precipitation measurements
- ✓ 0.5 m diameter Ka-Band antenna (1.5U when stowed)
- ✓ 2.5U radar electronics

01/18: I&T

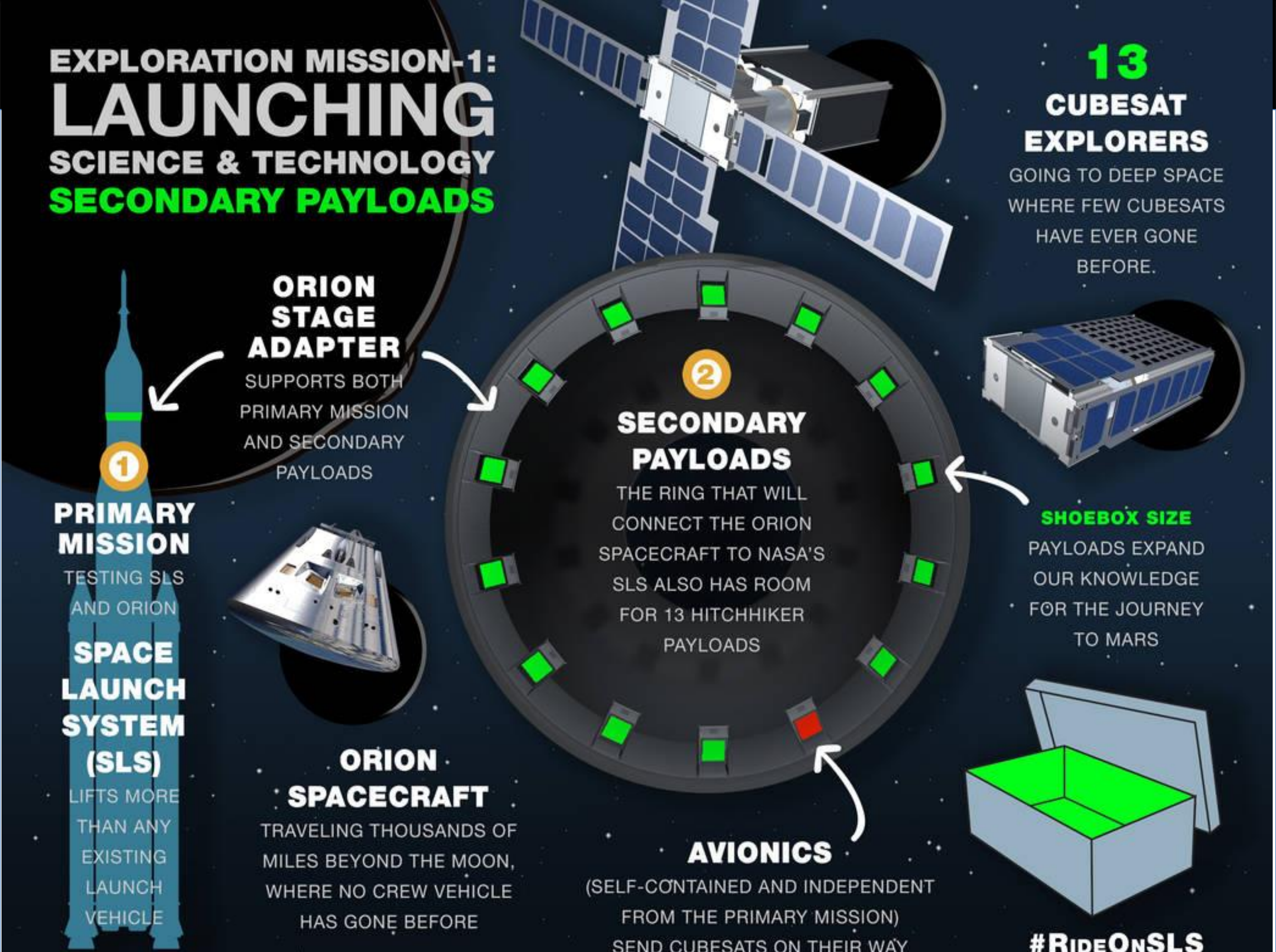


- ✓ Launched to ISS May 21, 2018

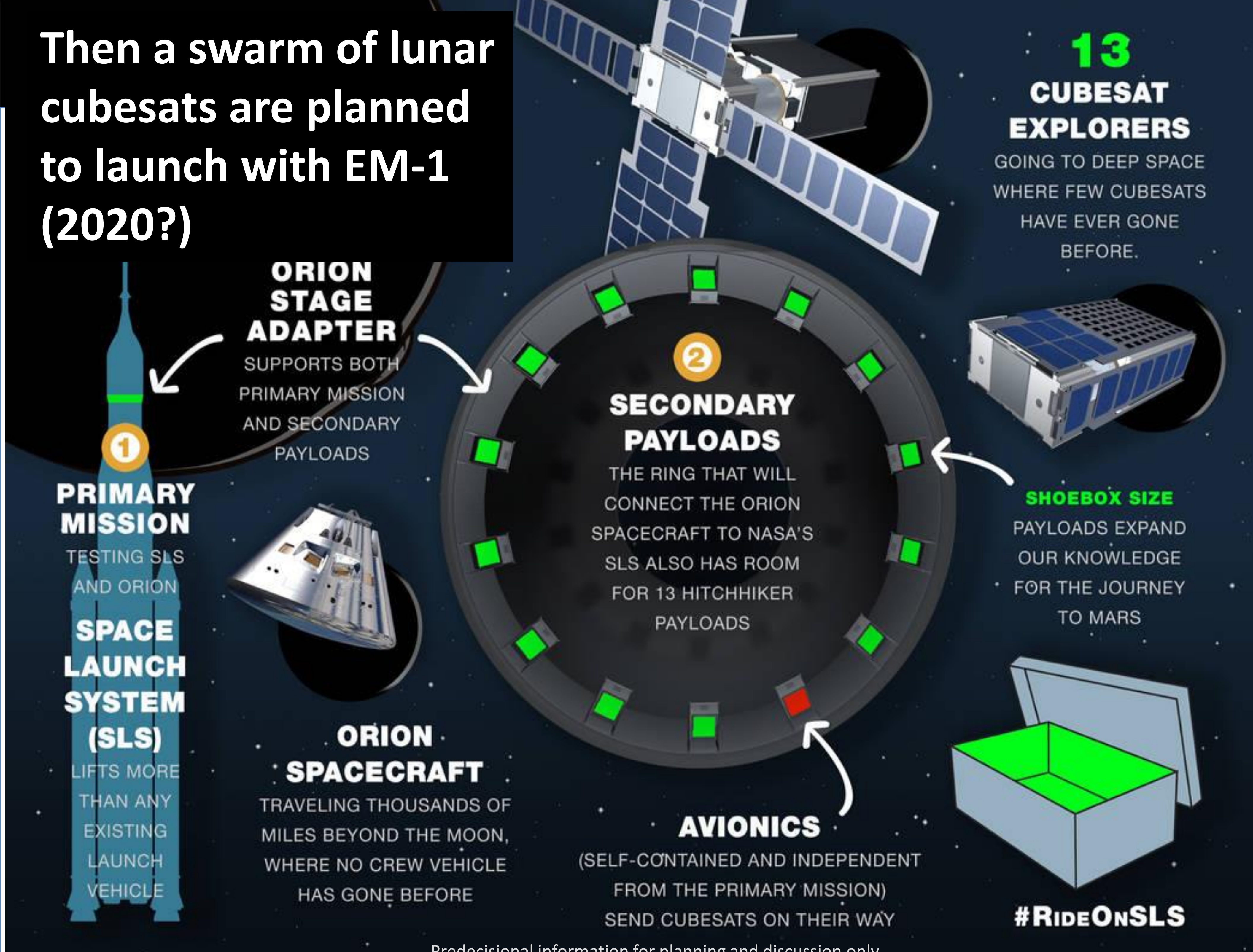
In-orbit orientation



And in 2020 the Mars Helicopter…


EXPLORATION MISSION-1:
LAUNCHING
SCIENCE & TECHNOLOGY
SECONDARY PAYLOADS
ORION STAGE ADAPTER
SUPPORTS BOTH PRIMARY MISSION AND SECONDARY PAYLOADS
1
PRIMARY MISSION
TESTING SLS AND ORION
SPACE LAUNCH SYSTEM (SLS)
LIFTS MORE THAN ANY EXISTING LAUNCH VEHICLE
ORION SPACECRAFT
TRAVELING THOUSANDS OF MILES BEYOND THE MOON, WHERE NO CREW VEHICLE HAS GONE BEFORE
2
SECONDARY PAYLOADS
THE RING THAT WILL CONNECT THE ORION SPACECRAFT TO NASA'S SLS ALSO HAS ROOM FOR 13 HITCHHIKER PAYLOADS
AVIONICS
(SELF-CONTAINED AND INDEPENDENT FROM THE PRIMARY MISSION) SEND CUBESATS ON THEIR WAY
13
CUBESAT EXPLORERS
GOING TO DEEP SPACE WHERE FEW CUBESATS HAVE EVER GONE BEFORE.
SHOEBOX SIZE
PAYLOADS EXPAND OUR KNOWLEDGE FOR THE JOURNEY TO MARS
#RIDEONSLS

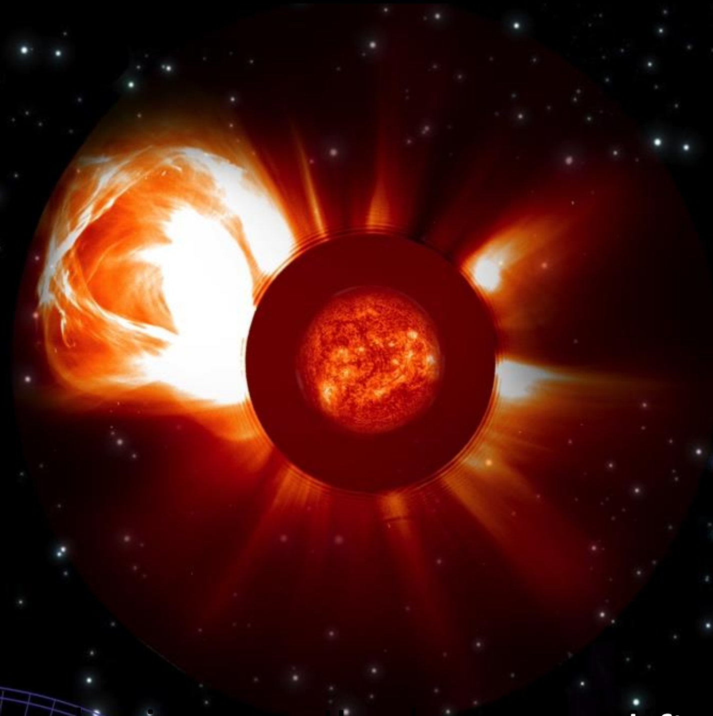
Then a swarm of lunar cubesats are planned to launch with EM-1 (2020?)

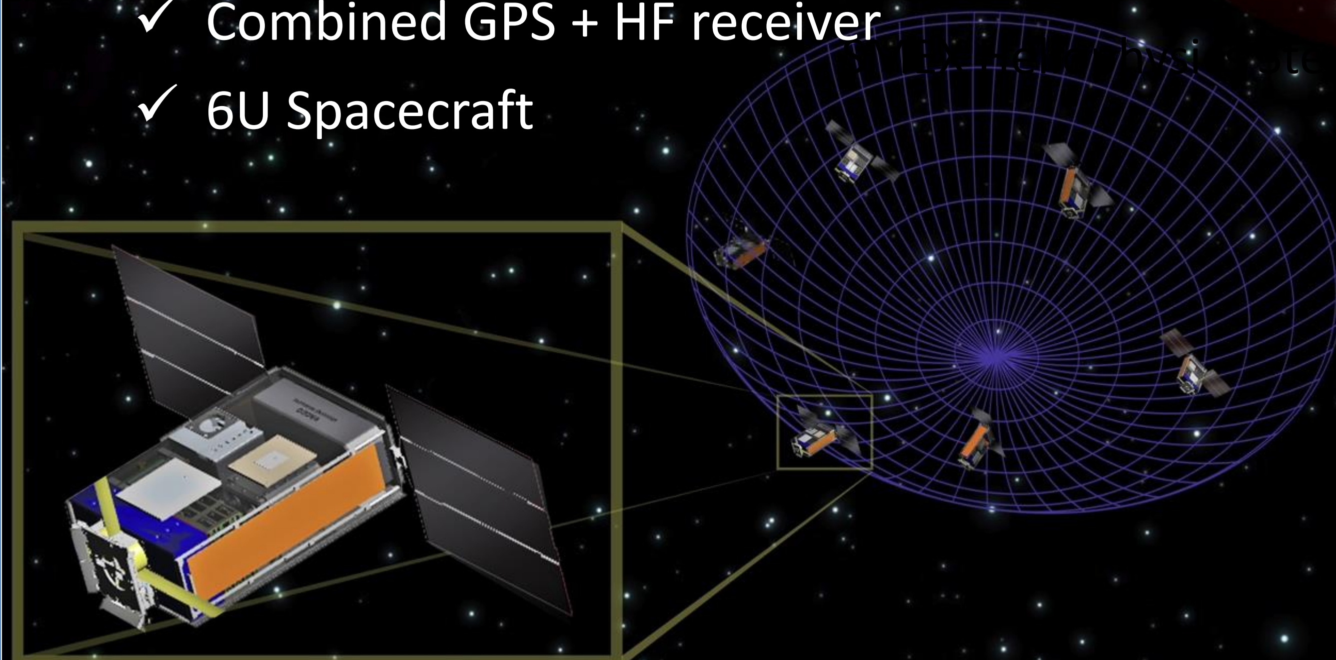


We may see a SunRISE later in the decade…

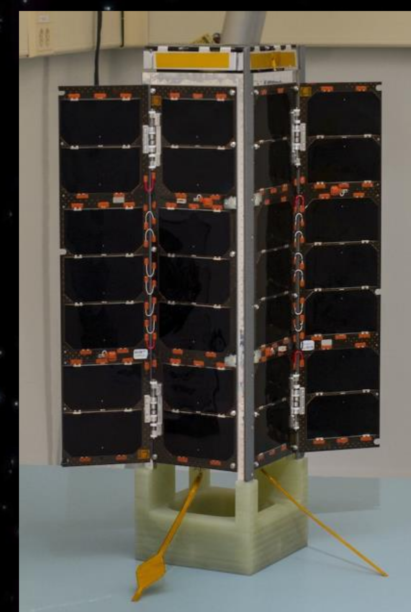
Sun Radio Imaging Space Experiment (SunRISE)

- ✓ Proposed science swarm to form an RF Interferometer
- ✓ Use radio emission to track solar CME particle acceleration and transport
- ✓ 6 spacecraft synthetic aperture
- ✓ Combined GPS + HF receiver
- ✓ 6U Spacecraft





Pathfinder (2017/18)



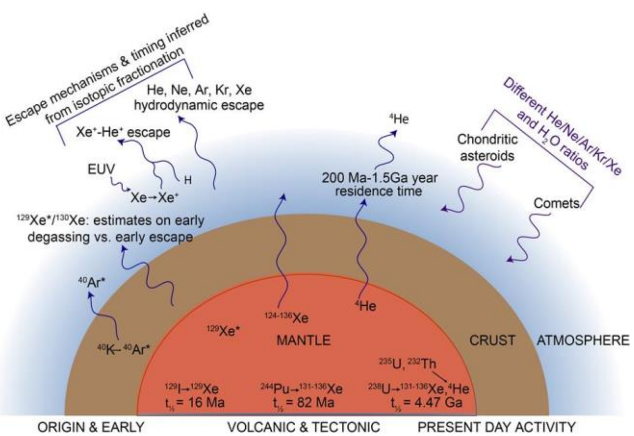
Looking Ahead: Cupid's Arrow Mission Concept

Decadal-Survey-Class Science

Address Planetary Decadal Survey Priority Q3: What governed the accretion, supply of water, chemistry, and internal differentiation of the inner planets and the evolution of their atmospheres, and what roles did bombardment by large projectiles play?'

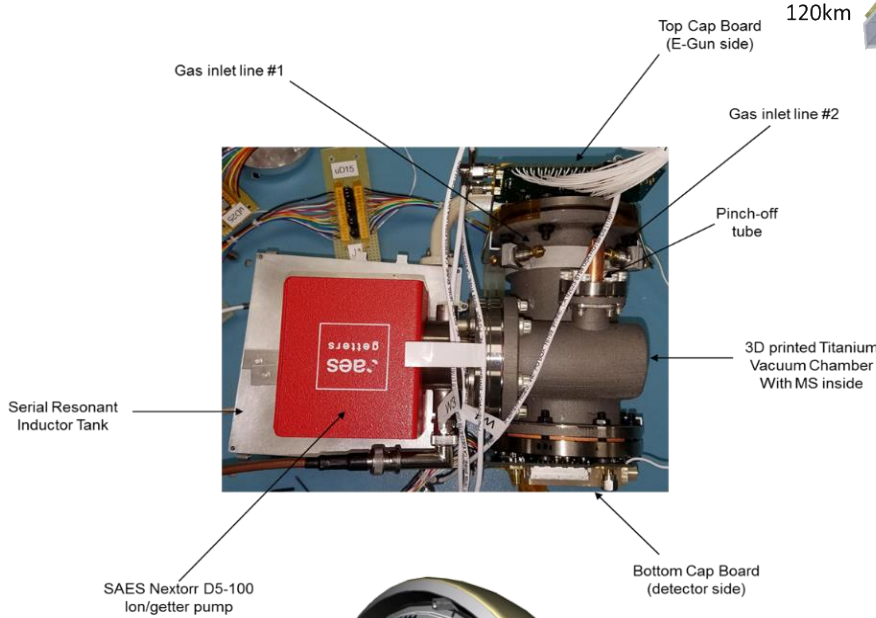
#1 investigation of objective A of goal I of the VEXAG "Goals-Objectives-Investigation for Venus Exploration"

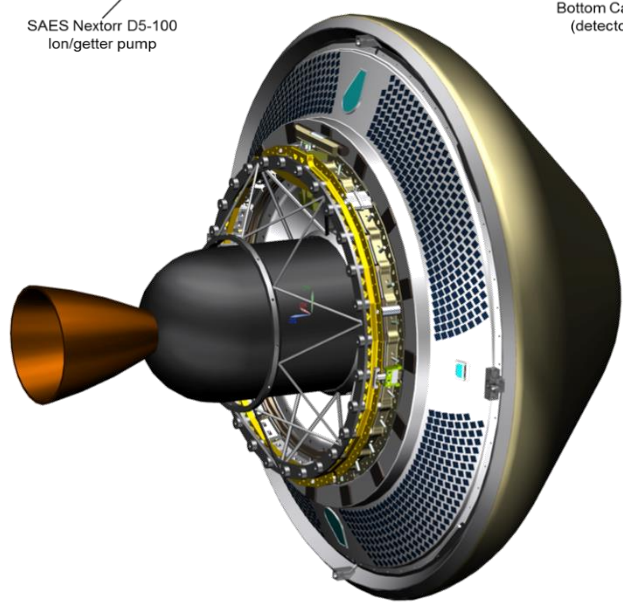
Measure concentrations of noble gases and isotope ratios in Venus atmosphere (below the homopause @110 km).



JPL Mini-QITMS to analyze 4 samples/pass

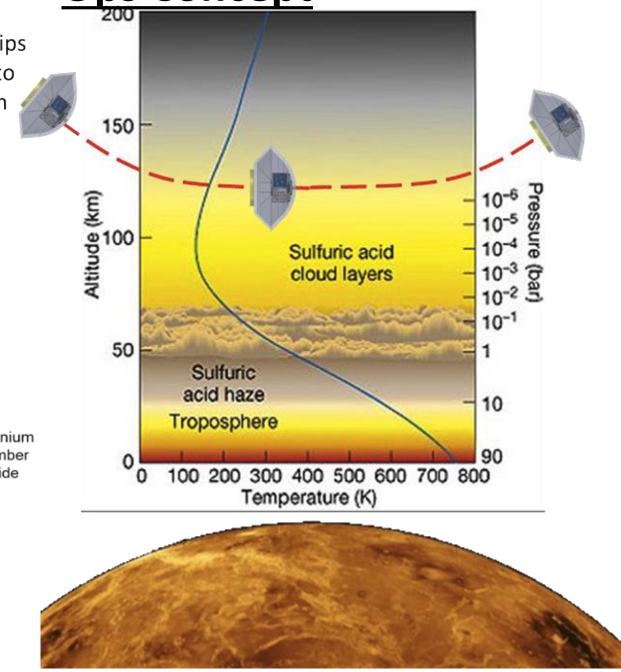
Sample chamber and electronics below





Skimmer Vehicle Concept

Ops Concept



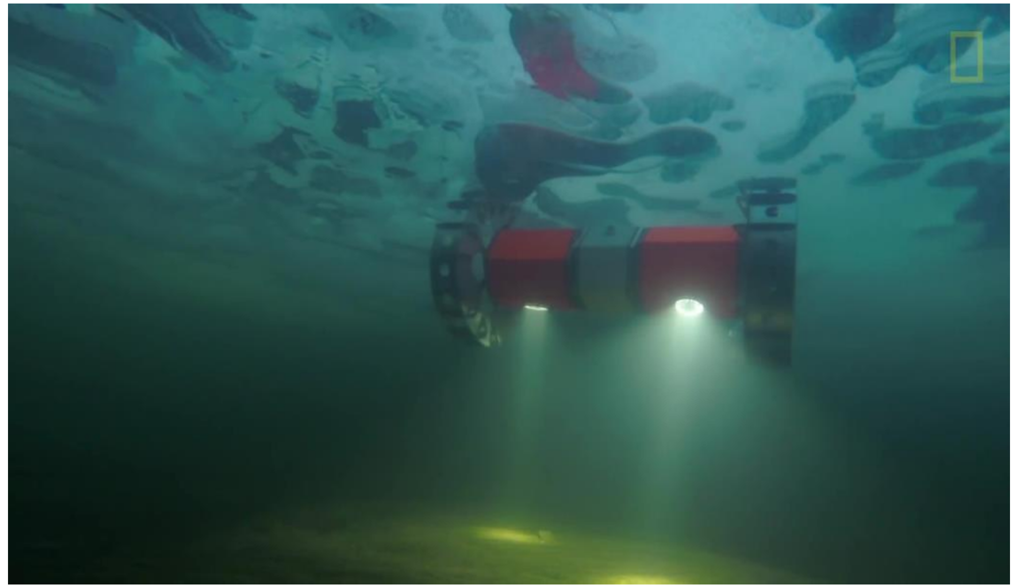
Study Team:

Christophe Sotin (PI)
John Baker (JPL)
Tony Freeman (JPL)
Glenn Lightsey (GATech)
Terry Stevenson(GATech)
Murray Darrach (JPL)
Bernard Marty (CRPG, FR)

Miniaturized Concepts for Mobility Systems

Clockwork rovers on Venus

Probing under the Ice



Puffer minibots

Gecko Grippers to Climb in Lava Tubes

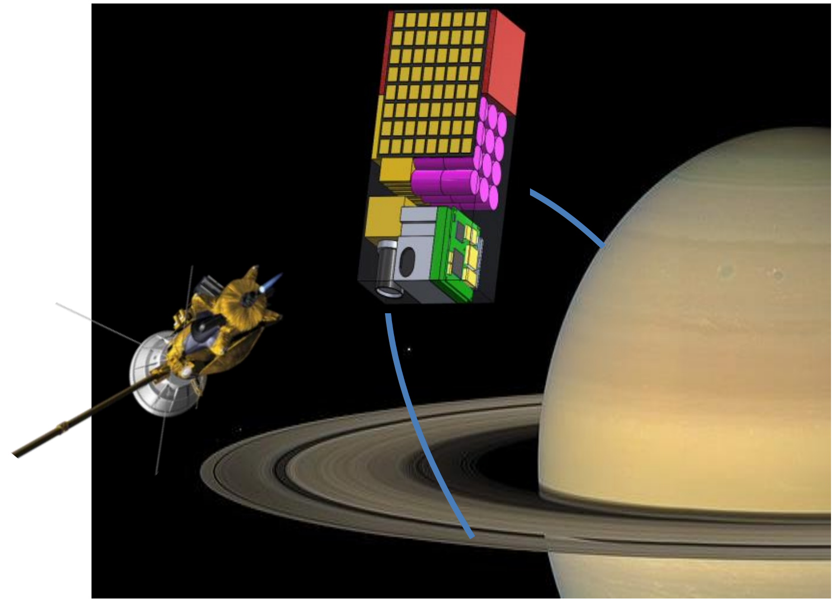
Clip + still courtesy Andrew Shapiro-Scharlotta, JPL

Gecko Clip courtesy Aaron Parness, JPL

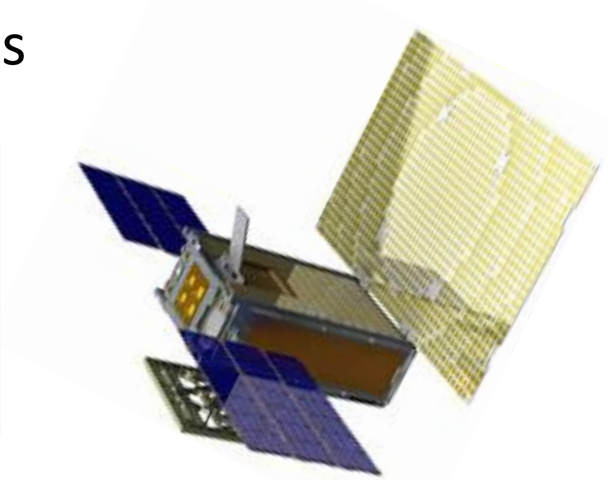
CubeSats at Saturn?

- ✓ Power – 11 days to fully charge a 200 Whr capacity battery with 1.2-2W solar power @ Saturn
- ✓ Control – need <0.003° pointing; >35°/sec slew rates
- ✓ X-Band Communications (relay to primary) with 28 dBi reflectarray
- ✓ Propulsion (chemical) – up to 250 m/s ΔV
- ✓ Thermal – compact RHUs

Saturn Ring Diver Concept



Lunar IceCube: 120 W @ Earth



MarCo 28 dBi reflectarray

1W; 40g RHU

Slide courtesy Andrew Bocher, Cal Poly SLO

Conclusions

- Cubesat and nanosat spacecraft are enabling ground-breaking, focused science missions
- We are just at the beginning – the state of the art is continually moving forward
- In April, NASA released a SIMPLEX call for Planetary Science Smallsat missions for under $55M
- What’s next?

www.jpl.nasa.gov/cubesats