



28 and Counting: JPL's Involvement in Cubesat Missions

Tony Freeman,

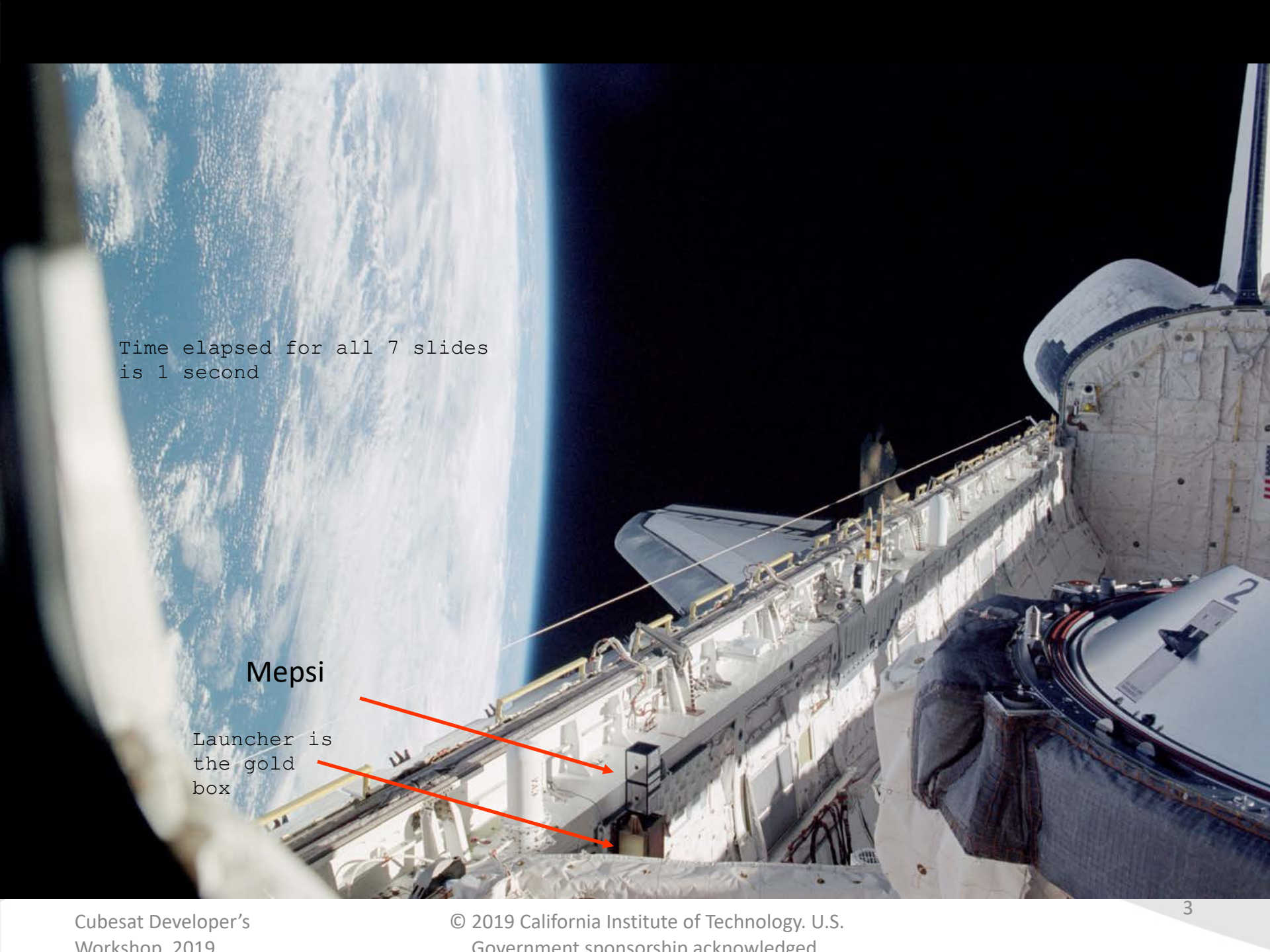
Jet Propulsion Laboratory, California Institute of Technology

28 and Counting Motivation

Why is JPL involved in cubesat missions?

- Fast Infusion of New Technology
- High Value Science Missions
- Miniaturization of Instruments
- More Flight Opportunities
- To “Dare Mighty Things”
- Lay down tracks for others to follow

Involvement began in 2011 (or did it?)



Time elapsed for all 7 slides
is 1 second

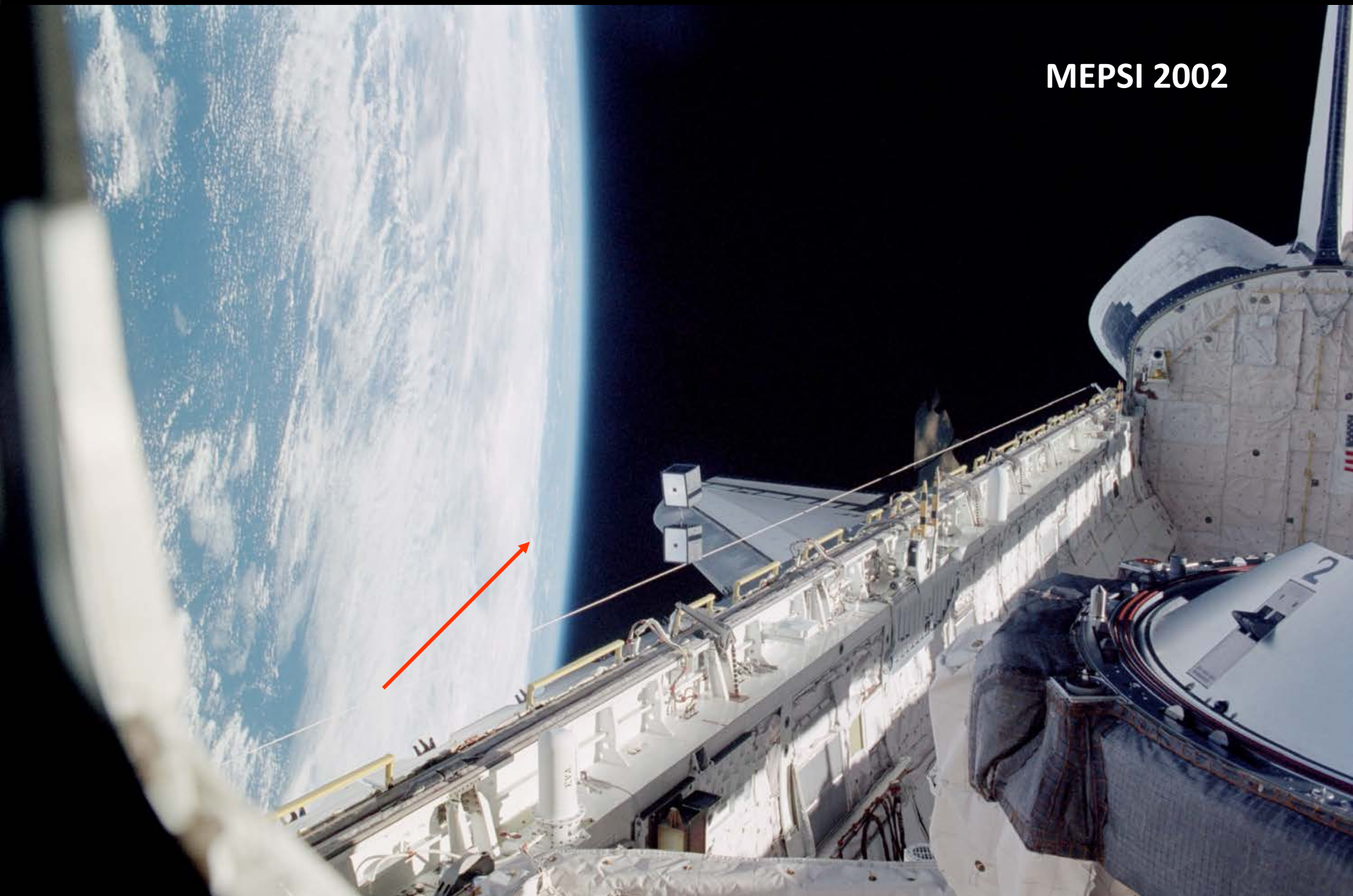
Mepsi

Launcher is
the gold
box

MEPSI 2002



MEPSI 2002



A photograph taken from the Space Shuttle Columbia during the STS-107 mission. The shuttle is oriented vertically, with the Earth's blue and white cloud-covered surface on the left. The payload bay is open, revealing various equipment. Two small, white, cube-shaped payloads are suspended in the center of the bay. The shuttle's white thermal blankets and structural components are visible on the right side of the frame. The text "MEPSI 2002" is overlaid in the top right corner.

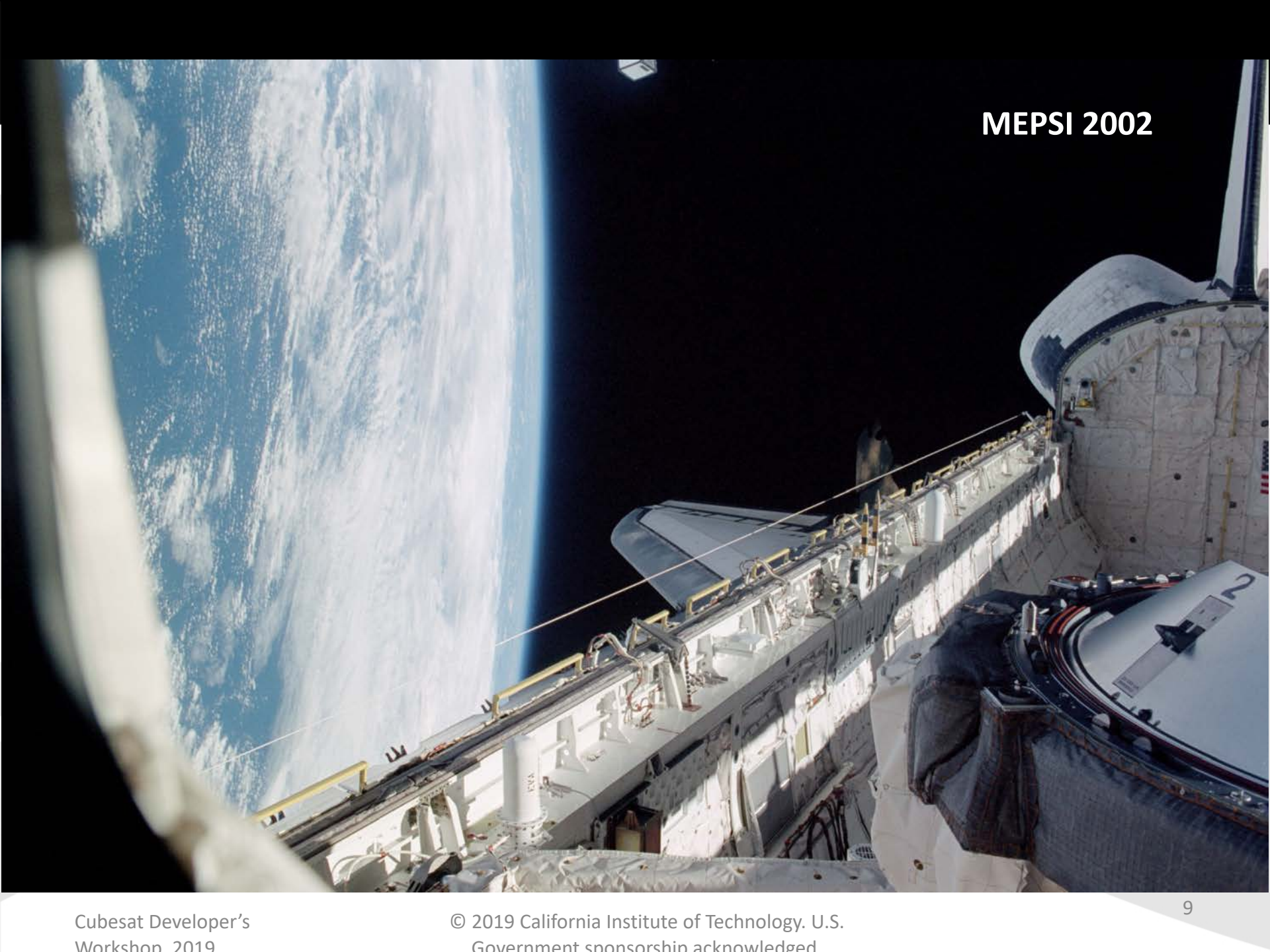
MEPSI 2002

A photograph taken from the Space Shuttle Columbia during the STS-107 mission. The shuttle is oriented vertically, with the Earth's blue and white cloud-covered surface on the left. The payload bay is open, revealing various equipment. Two small, white, cube-shaped payloads, the MEPSI 2002, are suspended in the center of the bay. The shuttle's white thermal blankets and structural components are visible on the right side of the frame.

MEPSI 2002

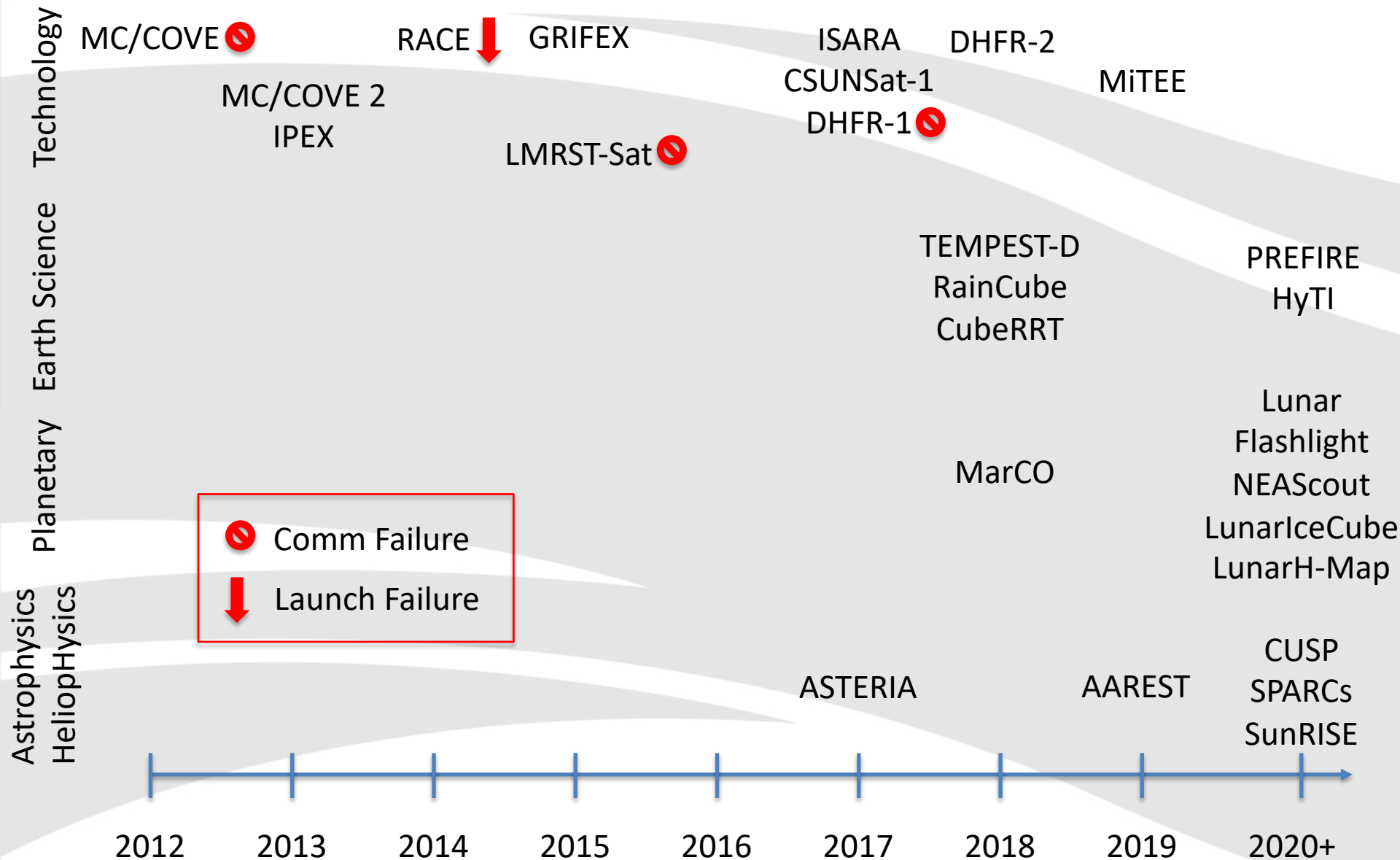




MEPSI 2002

A photograph taken from the exterior of the Space Shuttle Columbia during the STS-107 mission. The shuttle is oriented vertically, with the Earth's blue and white cloud-covered surface visible on the left. The right side of the image shows the white thermal protection tiles and various external components of the orbiter. A large, curved structure, likely part of the payload bay or external tank, is visible in the lower right foreground. The text "MEPSI 2002" is overlaid in the top right corner.

MEPSI 2002

JPL-involved Cubesat Timeline



 Comm Failure
 Launch Failure

Example RoadMap for Miniaturizing Instruments

Visible

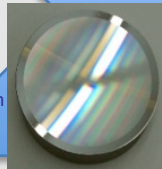
Miniature Dyson spectrometer



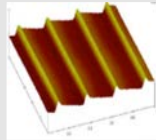
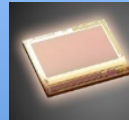
JPL IR&D Wide-Field Grating Spectrometer (WFGS)



JPL e-beam grating



JPL BIRD MWIR Detectors



JPL Qualified Thales Cooler



Snow and Water Imaging Spectrometer

Spatial: $\pm 5^\circ$, 0.28 km
Spectral: 228 Bands, 350 nm – 1.65 μm
SWAP: 6U, 9 kg, 15W, 5 Mbps

CubeSat Infrared Atmospheric Sounder (CIRAS)

Spatial: $\pm 48.3^\circ$, 13.5 km
Spectral: 1000 Channels, 4.1-5.4 μm
SWAP: 6U, 20 kg, 30 W, 1 Mbps

Infrared

Microwave

Dual-Frequency Feedhorn



MMIC Receiver including Detector



Radiometer Backend and Power Conditioning



Motor and Drive Electronics



Reflector



Command and Data Handling: Onboard FPGA



MASC

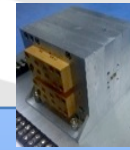


Microwave Atmospheric Sounder on CubeSat (MASC)

Spatial: $\pm 45^\circ$, 15 km (183) – 20 km (118)
Spectral: 8 Channels: 118-183 GHz
SWAP: $< 0.01 \text{ m}^3$, 3 kg, 7 W, 10 kbps

Radar

SSPA & Power Combiner



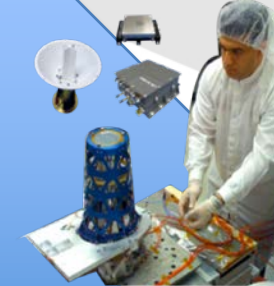
Up/Down Converter



Processing (Pulse Compression and Modulation)



Gravity

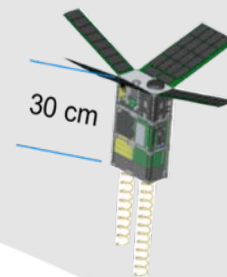


MicroGRACE Gravity Measurement

Spatial: 5 km (Horiz) x 250m (Vert)
Spectral: 35.6 GHz
SWAP: 6U, 20 kg, 30 W, $< 1 \text{ Mbps}$

RainCube: Precipitation Profiler

Spatial: 5 km (Horiz) x 250m (Vert)
Spectral: 35.6 GHz
SWAP: 6U, 20 kg, 30 W, $< 1 \text{ Mbps}$



Cubesat Developer's Workshop, 2019

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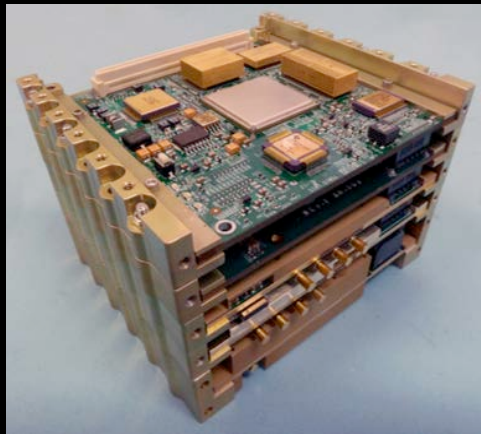
Slide courtesy J. Hyon, JPL

Cubesat-sized Instruments – 2012 and 2019

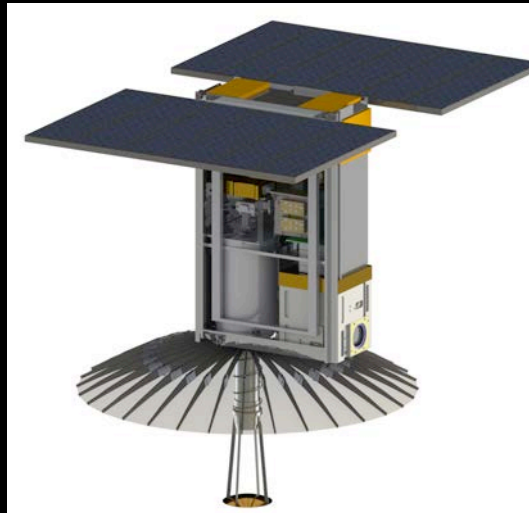
Technology	Selva* and Krejci, 2012	Freeman 2019	Justification
Atmospheric Chemistry Instruments	Problematic	Feasible	PICASSO, IR sounders
Atmos Temp and Humidity Sounders	Feasible	Feasible	CiRAS
Cloud Profile and rain radars	Infeasible	Feasible	RainCube
Earth Radiation Budget radiometers	Feasible	Feasible	SERB, RAVAN
Gravity Instruments	Feasible	Feasible	Need a demo mission
Hi-res Optical Imagers	Infeasible	Feasible	Planetlabs
Imaging microwave radars	Infeasible	Feasible	Ka-Band 12U design
Imaging multi-spectral radiometers (Vis/IR)	Problematic	Feasible	AstroDigital
Imaging multi-spectral radiometers (μ Wave)	Problematic	Feasible	TEMPEST-D, TROPICS
Lidars	Infeasible	Feasible	Lunar Flashlight
Lightning Imagers	Feasible	Feasible	RaioSat
Magnetic Fields	Feasible	Feasible	InSPIRE
Multiple direction/polarization radiometers	Problematic	Feasible	HARP Polarimeter
Ocean color instruments	Feasible	Feasible	SeaHawk
Precision orbit	Feasible	Feasible	CanX-4, -5
Radar altimeters	Infeasible	Feasible	SNoOPI
Scatterometers	Infeasible	Feasible	GNSS refl. (CyGNSS)

JPL Technologies and Capabilities

IRIS Radio



Deployable Reflector



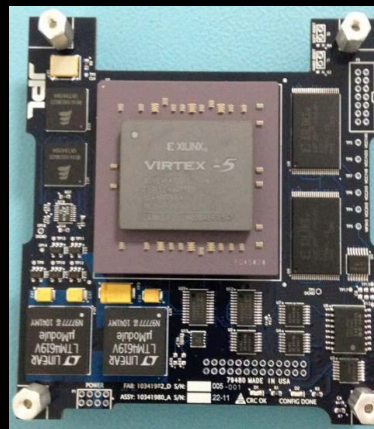
Sphinx C&DH



DSN Communications
and Navigation
Protocols



OnBoard Data
Reduction



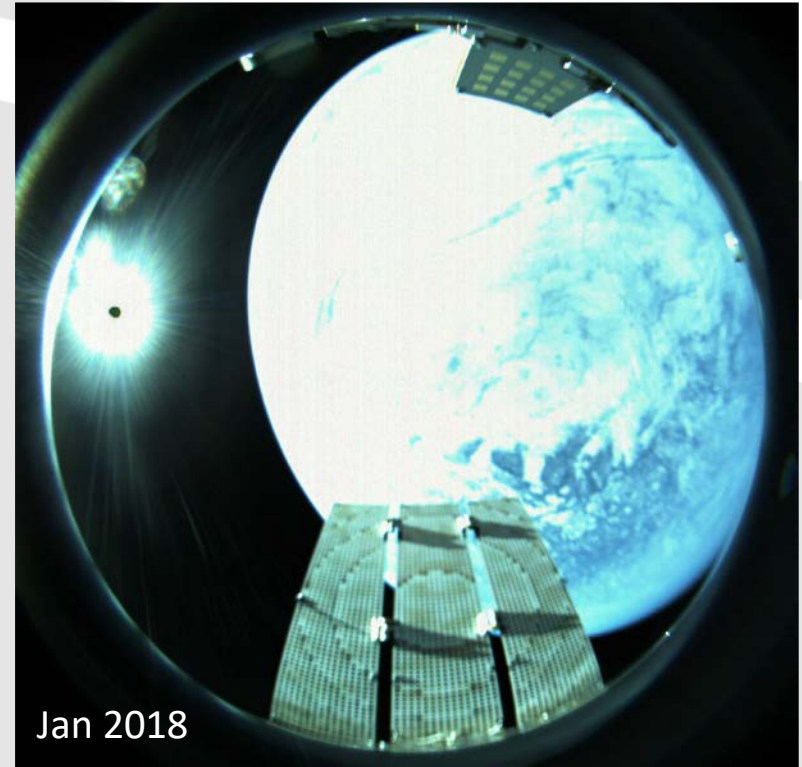
CubeSat Development Lab



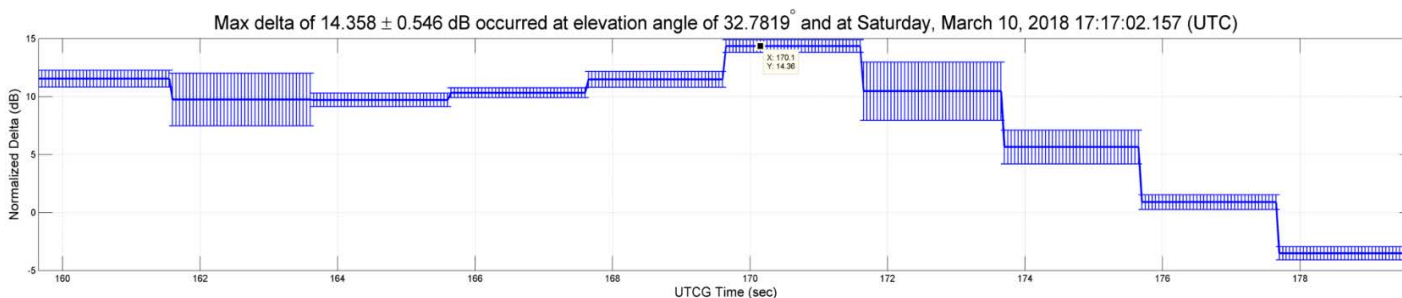
ISARA – 100 Mbps Downlink Capability

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 (3U) telecom downlink capability (from LEO)



Signal Power Measurements

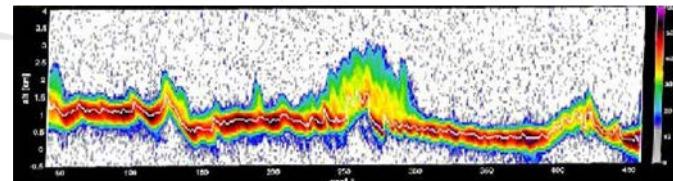
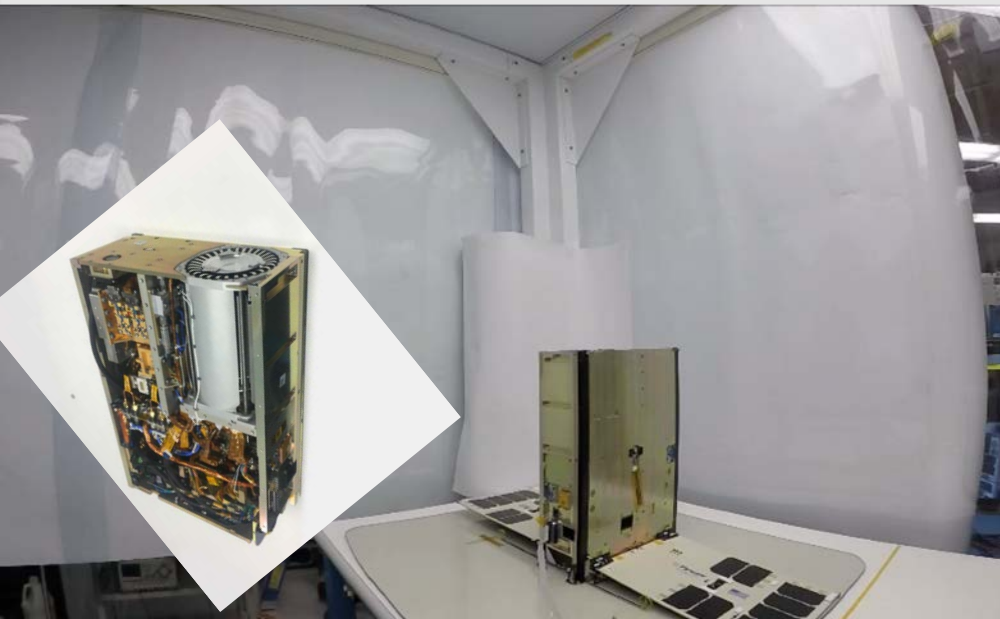


RainCube – first cubesat radar

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) – Tendeq license
- ✓ 2.5U radar electronics
- ✓ Launched to ISS May 21, 2018
- ✓ First science data August, 2018

01/18: I&T



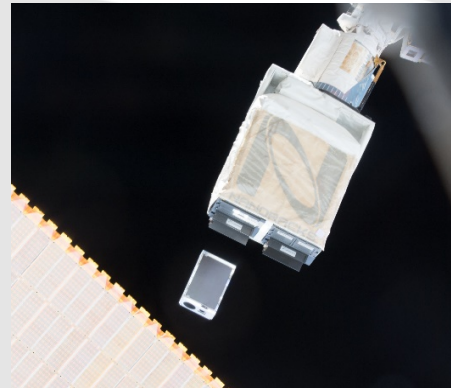
ASTERIA – hunting exoplanets one star at a time

PI: Sarah Seager, MIT; Slide courtesy Matt W. Smith and the ASTERIA team

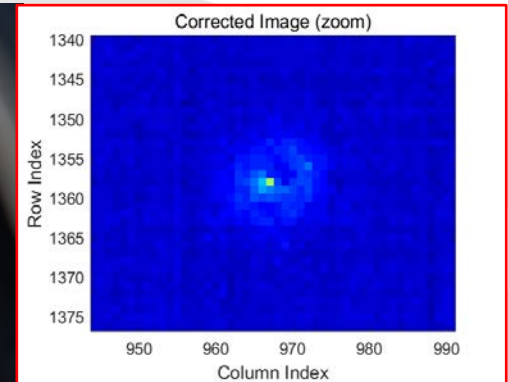
Arcsecond Space Telescope Enabling Research in Astrophysics (ASTERIA)

- ✓ Precision pointing to better than 0.5 arcsec RMS
- ✓ Thermal control of the focal plane to $< 0.01\text{K}$
- ✓ Exoplanet transits using stellar photometry
- ✓ Smallsat of the year 2018

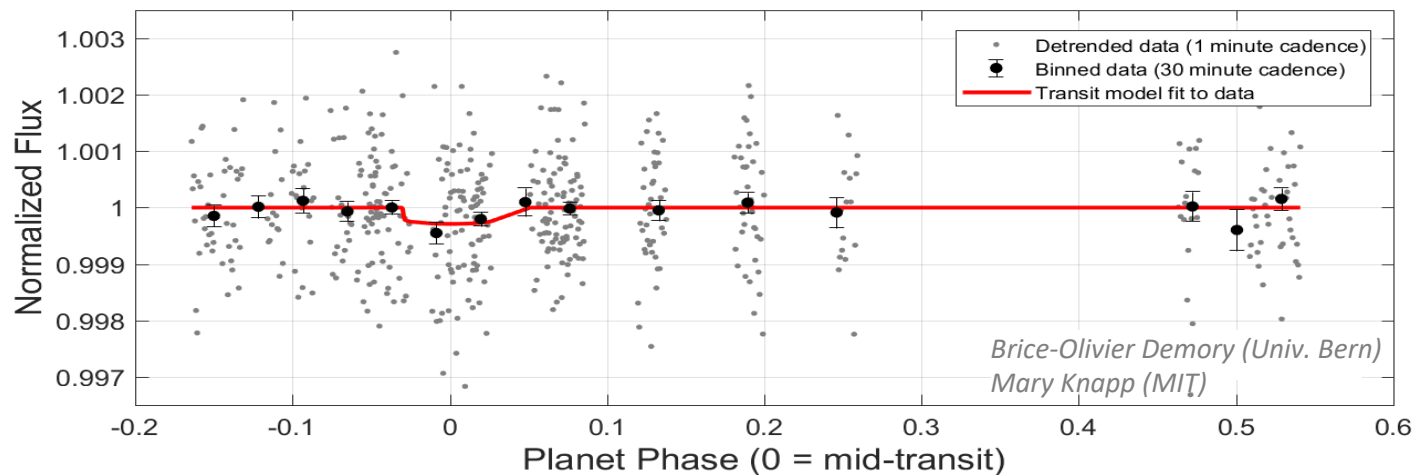
11/17: Deployed from ISS



12/17: First Image



ASTERIA 55 Cancri e Transit Light Curve

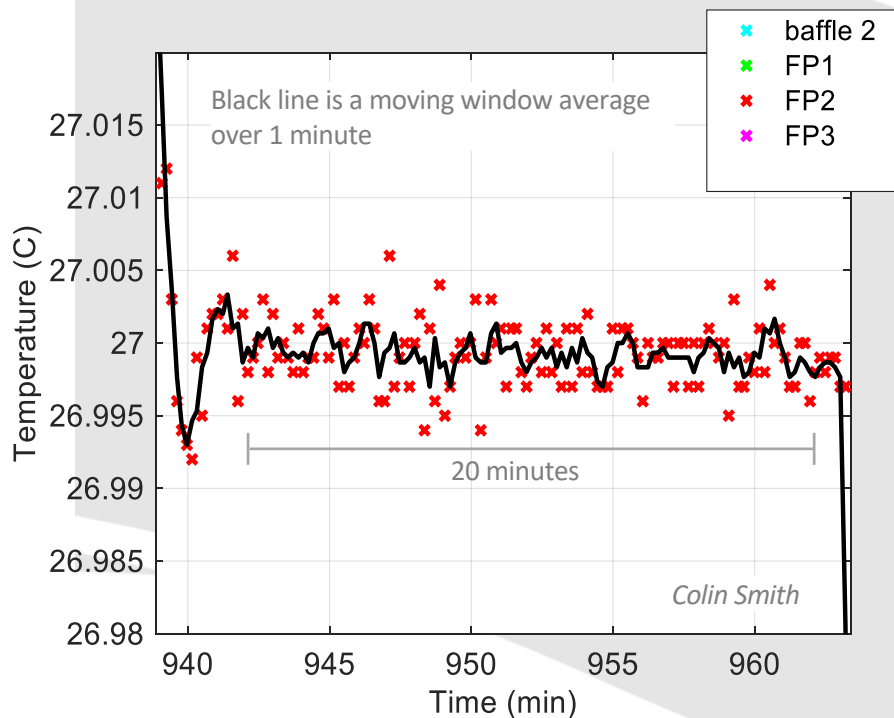
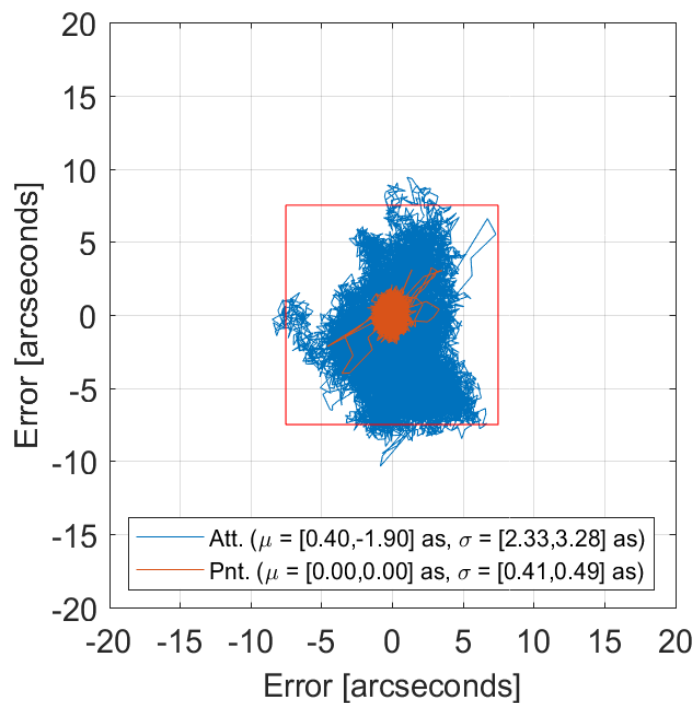


$2R_E$ exoplanet around
a $V=5.95$ Sun-like star

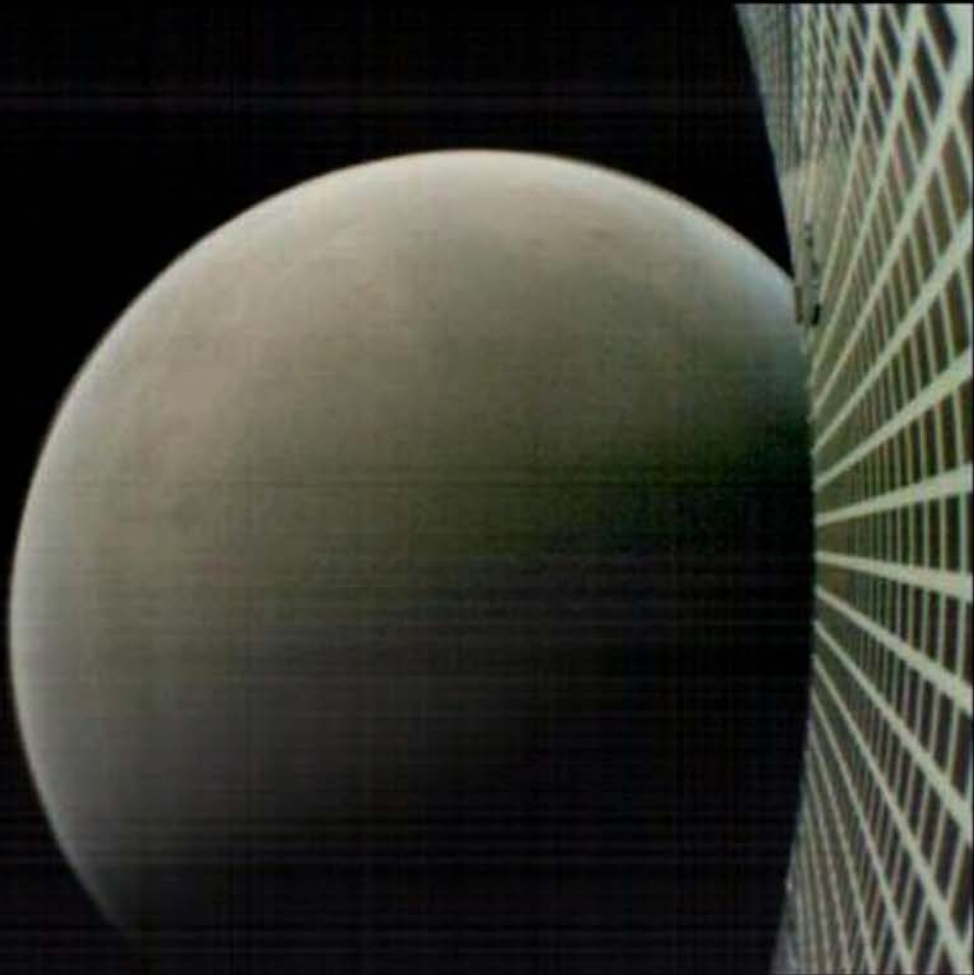
ASTERIA - Pointing and Thermal Control

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 with piezo stage correction
- ✓ Achieved focal plane thermal control $< \pm 0.01$ K over 20 minutes
- ✓ Optical Telescope Assembly is thermally isolated, stable
- ✓ Trim heaters and coarse/fine control loop maintain temperature stability



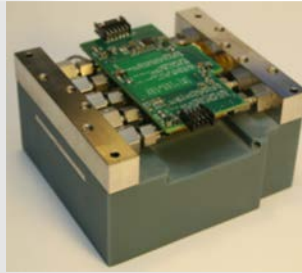
MarCO – the first Interplanetary Cubesats



INSPIRE – Pathfinder for MarCO

[still on the shelf]

Ready for launch since 2014



Cold-Gas ACS
(U.Texas)



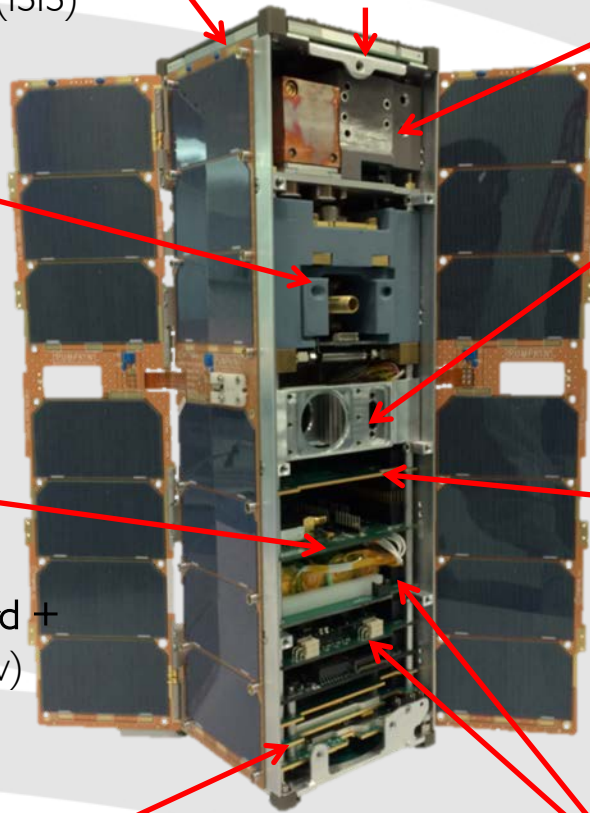
C&DH + Watchdog Board +
Lithium UHF (AstroDev)



Nav/Comm X-Band Radio (JPL)

UHF Antenna
(ISIS)

X-Band Patch Antennas (JPL)
[two sets]



Deployable Solar Panels (Pumpkin)
Structure (JPL)



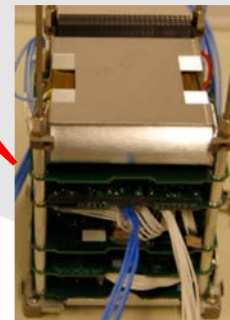
Magnetometer (JPL)



Star Tracker
(Blue Canyon)



Processing Board
(CalPoly / Tyvak)



Electrical Power System +
Battery Board (U. Michigan)

**EXPLORATION MISSION-1:
LAUNCHING
SCIENCE & TECHNOLOGY
SECONDARY PAYLOADS**

1

PRIMARY MISSION

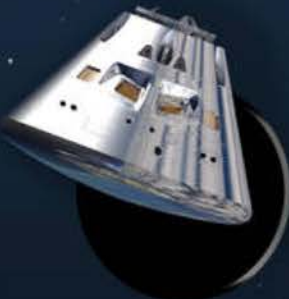
TESTING SLS AND ORION

SPACE LAUNCH SYSTEM (SLS)

LIFTS MORE THAN ANY EXISTING LAUNCH VEHICLE

ORION STAGE ADAPTER

SUPPORTS BOTH PRIMARY MISSION AND SECONDARY PAYLOADS



ORION SPACECRAFT

TRAVELING THOUSANDS OF MILES BEYOND THE MOON, WHERE NO CREW VEHICLE HAS GONE BEFORE

2

SECONDARY PAYLOADS

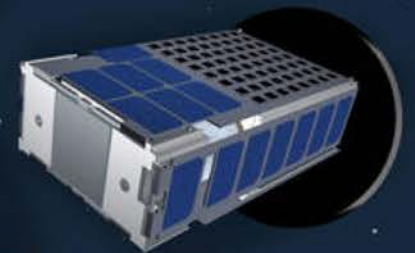
THE RING THAT WILL CONNECT THE ORION SPACECRAFT TO NASA'S SLS ALSO HAS ROOM FOR 13 HITCHHIKER PAYLOADS

AVIONICS

(SELF-CONTAINED AND INDEPENDENT FROM THE PRIMARY MISSION)

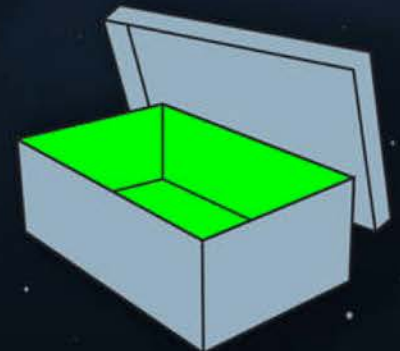
13 CUBESAT EXPLORERS

GOING TO DEEP SPACE WHERE FEW CUBESATS HAVE EVER GONE BEFORE.



SHOEBOX SIZE

PAYLOADS EXPAND OUR KNOWLEDGE FOR THE JOURNEY TO MARS



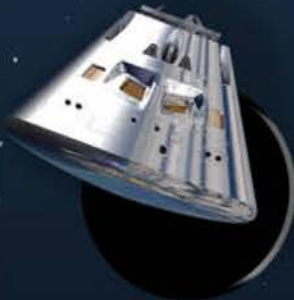
SEND CUBESATS ON THEIR WAY

#RIDEONSLS

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

1
PRIMARY MISSION
TESTING SLS AND ORION
SPACE LAUNCH SYSTEM (SLS)
LIFTS MORE THAN ANY EXISTING LAUNCH VEHICLE

ORION STAGE ADAPTER
SUPPORTS BOTH PRIMARY MISSION AND SECONDARY PAYLOADS

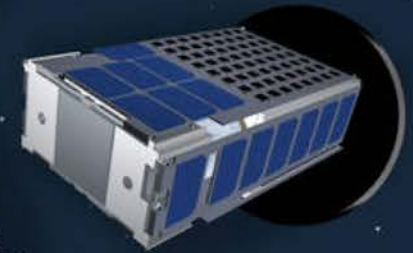


ORION SPACECRAFT
TRAVELING THOUSANDS OF MILES BEYOND THE MOON, WHERE NO CREW VEHICLE HAS GONE BEFORE

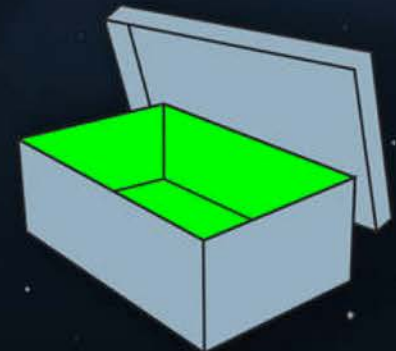


AVIONICS
(SELF-CONTAINED AND INDEPENDENT FROM THE PRIMARY MISSION)

13 CUBESAT EXPLORERS
GOING TO DEEP SPACE WHERE FEW CUBESATS HAVE EVER GONE BEFORE.



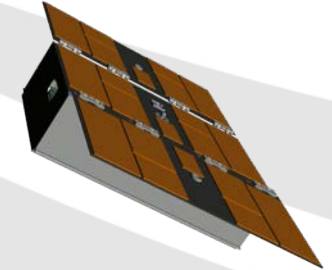
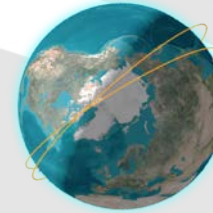
SHOEBOX SIZE
PAYLOADS EXPAND OUR KNOWLEDGE FOR THE JOURNEY TO MARS



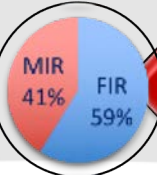
PREFIRE - PolaR Energy in the Far InfraRed Experiment

PI: Tristan L'Ecuyer, UWisc Slide courtesy Brian Drouin, JPL

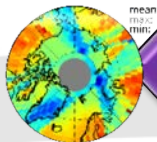
- ✓ Two 3-U CubeSats in asynchronous polar orbits
- ✓ Miniaturized IR spectrometer



The Arctic is Earth's thermostat. It regulates the climate by venting excess energy received in the tropics.



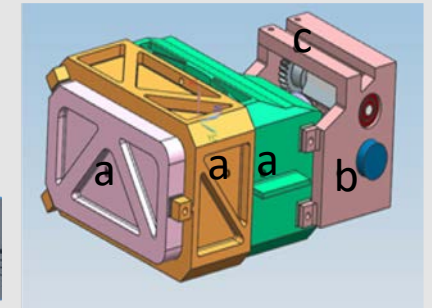
Nearly 60% of Arctic emission occurs at wavelengths > 15 μm (FIR) that have never been systematically measured.



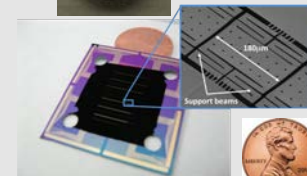
PREFIRE improves Arctic climate predictions by anchoring spectral FIR emission and atmospheric GHE

Planned launch in 2021

2U Thermal IR Spectrometer



GRATING



THERMOPILE

- a - Optical bench assembly
- b - Calibration motor assembly
- c - Calibration target

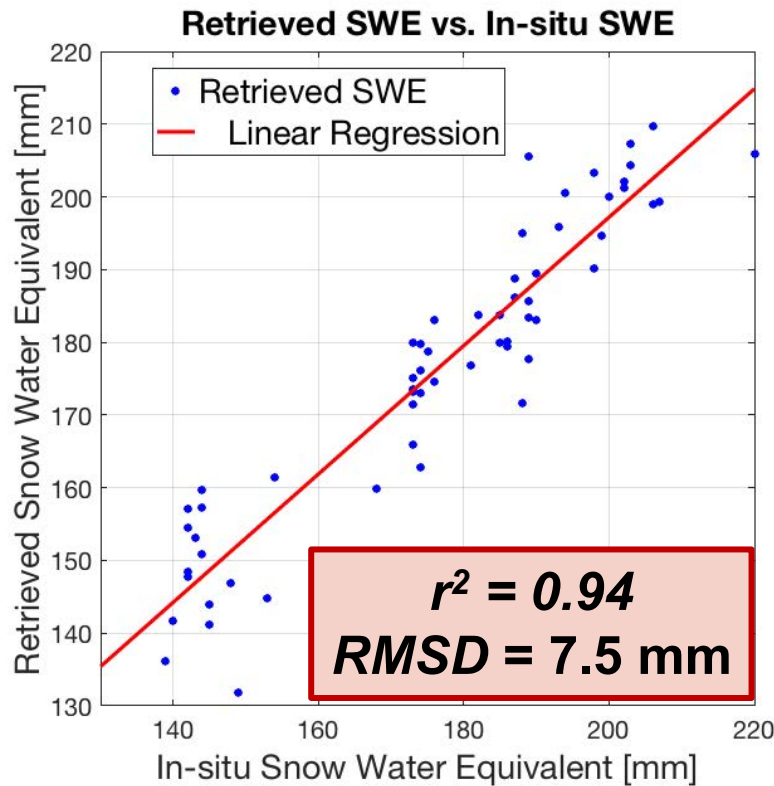
Thermopile array	Spectral resolution	Spatial coverage	Mass	Data rate	Power peak/avg
64 × 16 pixels	0.84 μm from 0–45 μm	16 cross-track pixels with 1.2° footprints	0.97 kg	35 kbps	6.74 / 1.74 W

SNoOPI – SIGNALS OF OPPORTUNITY INVESTIGATION

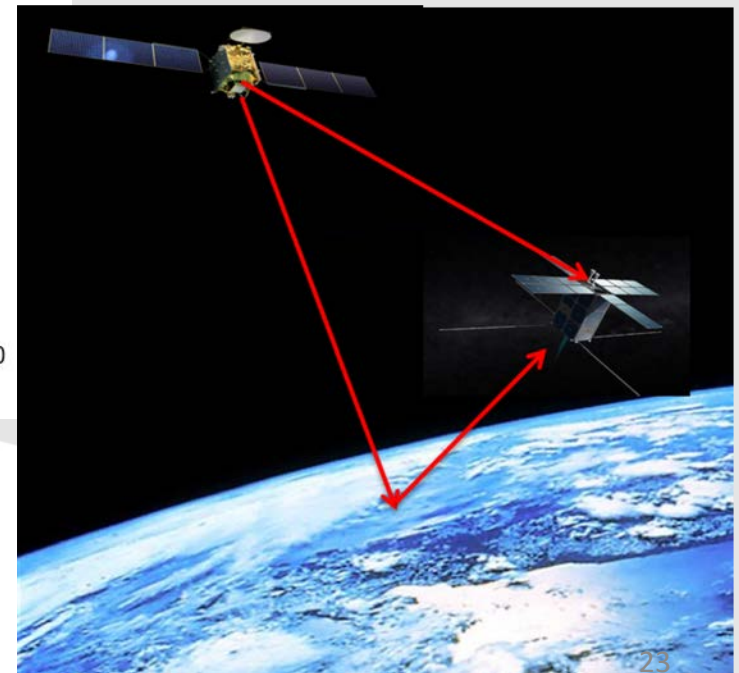


**Fraser
Experimental
Forest**

Slide courtesy co-I Rashmi Shah, JPL



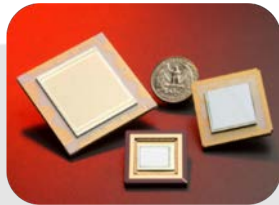
- ✓ PI: Jim Garrison, Purdue U.
- ✓ UHF Signals of Opportunity track Snow Water Equivalent (and Soil Moisture)
- ✓ SoOp altimeter
- ✓ Planned launch in 2021



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U.S. Government sponsorship
acknowledged.

CubeSat IR Atmospheric Sounder (CIRAS) [canceled but back in the game]

FPA HOTBIRD (JPL)



Camera Electronics
(IR Cameras)



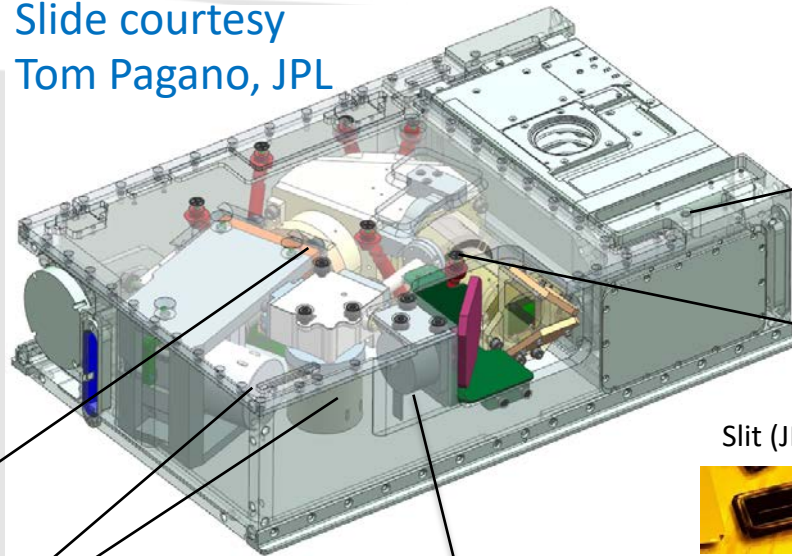
Dewar (IDCA)
(IR Cameras)



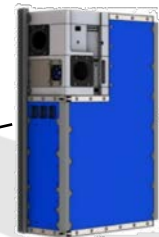
Cryocoolers +
Electronics
(Ricor K508N)



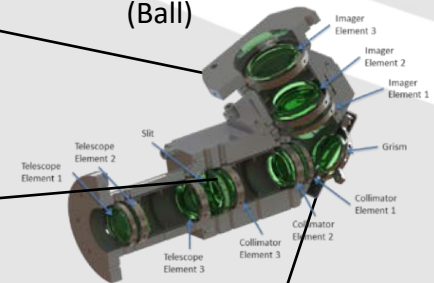
Slide courtesy
Tom Pagano, JPL



Spacecraft
(BCT)



Optics Assembly
(Ball)



Slit (JPL)



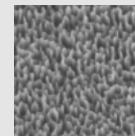
Payload
Electronics



Stepper Motor +
Mirror



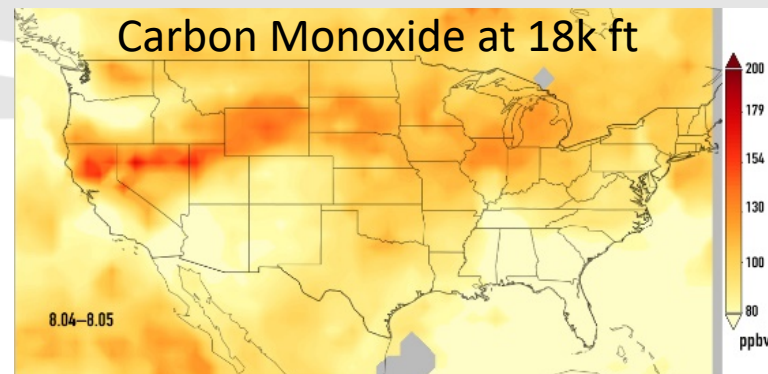
Blackbody
Assembly
Black Silicon



Immersion Grating
(JPL)



Parameter	CrIS	CIRAS
Orbit	833 km	600 km
Spectral Range	650-2550 cm^{-1}	1950-2450 cm^{-1}
Spectral Resolution	0.9 cm^{-1}	1.2-2.0 cm^{-1}
Spatial Coverage	2200 km	1520/139 km
Spatial Resolution	13.5 km	13.5/3 km
NEdT	<0.2 K	<0.2 K
Size	0.9 x 0.8 x 0.55 m	6U
Mass	117 kg	14 kg
Power	90 W	30 W



SPARCS 6U cubesat mission

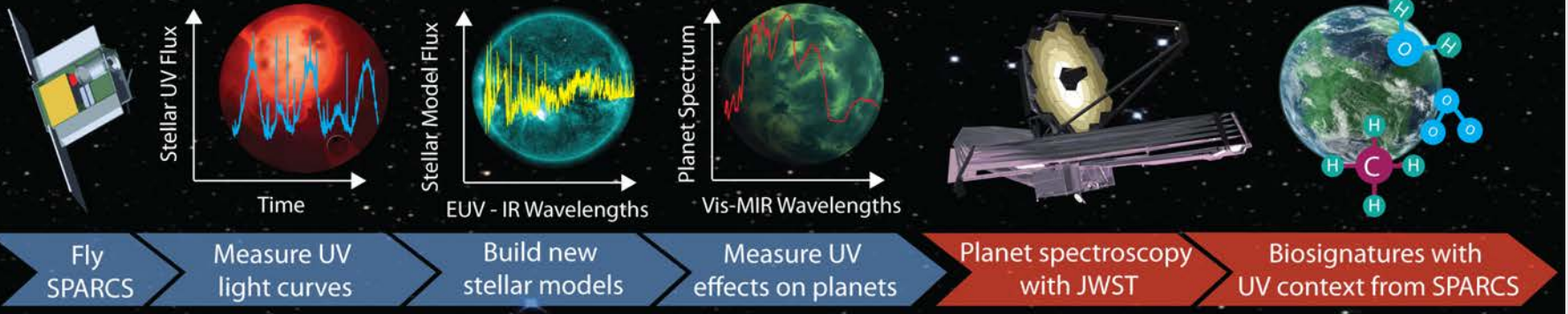
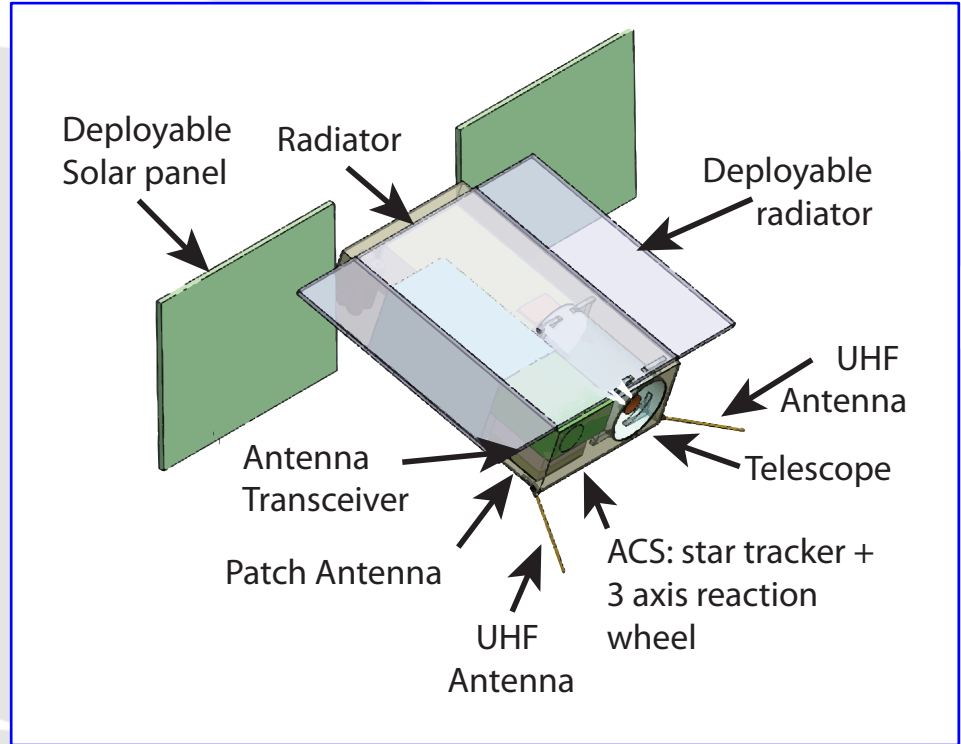
Study UV environment of exoplanets around M dwarf stars

Slide courtesy of David Ardila, JPL

Planned launch in late 2021



- 9 cm aperture
- 2-mirror telescope
- Dichroic + Two detectors
- Simultaneous observations FUV/NUV
- 1 day to 3 mth 'staring' mode

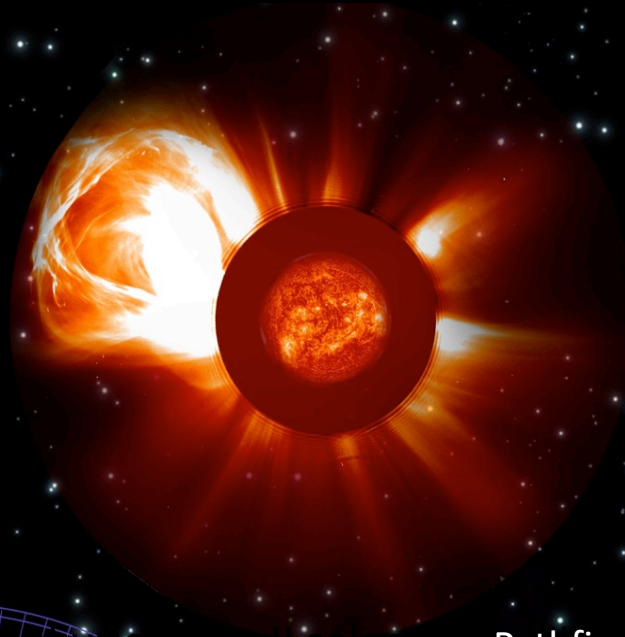


acknowledged.

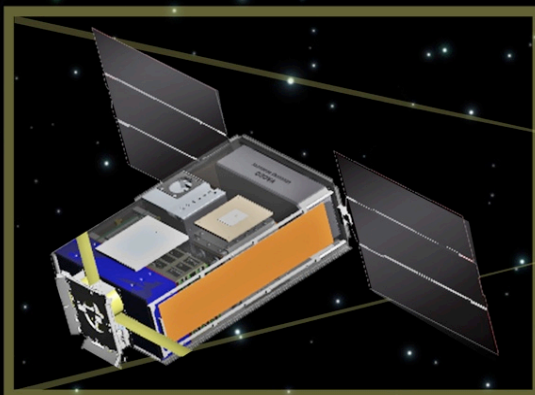
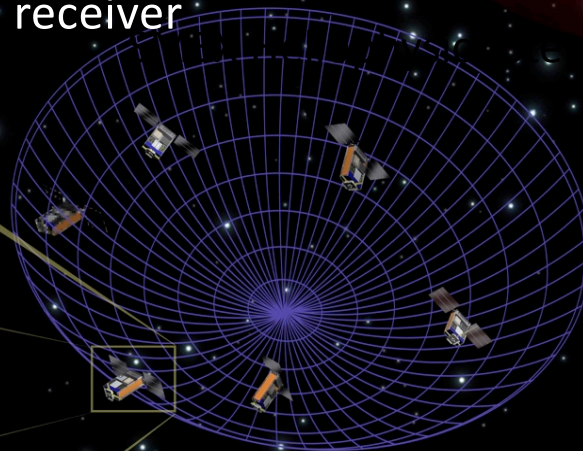
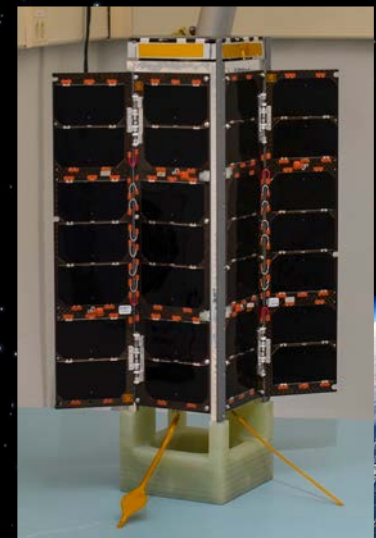
SunRISE is in extended Phase A

Sun Radio Imaging Space Experiment (SunRISE)

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



Pathfinder (2017/18)

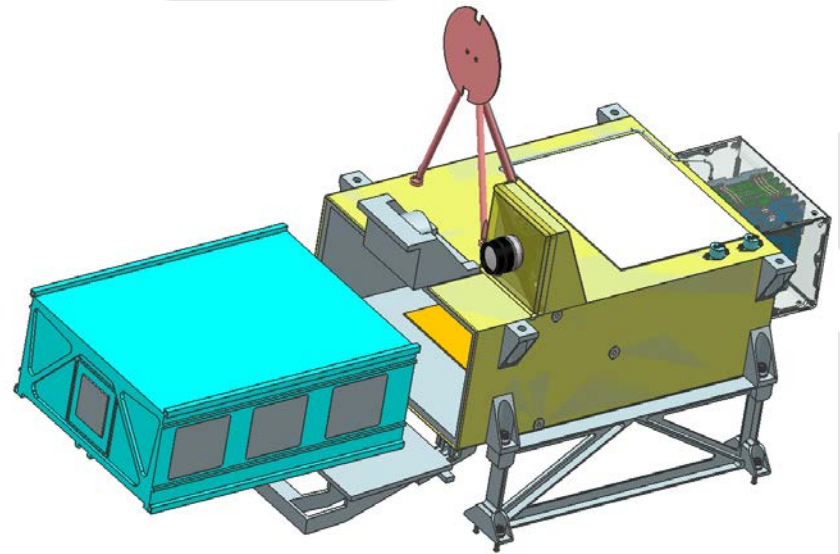


Looking at the Horizon

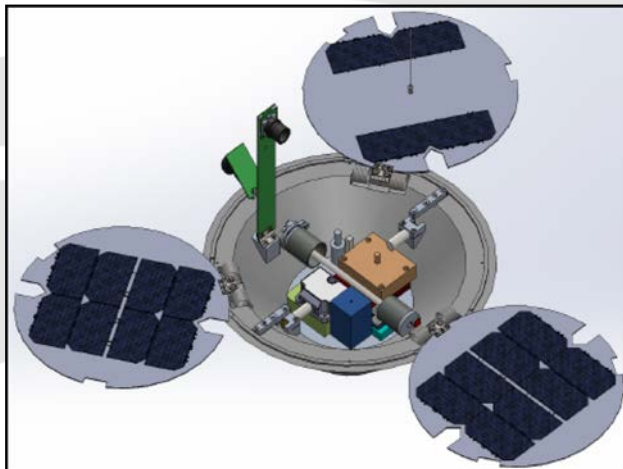
Cube-train Constellations for Earth Science



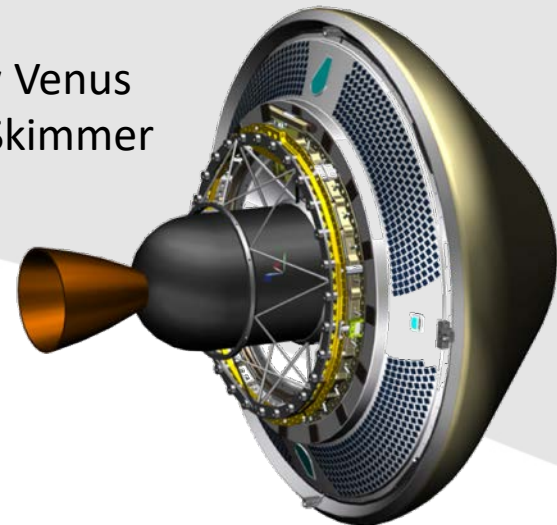
Deep Space P-Pod



MarsDrop Micro-lander



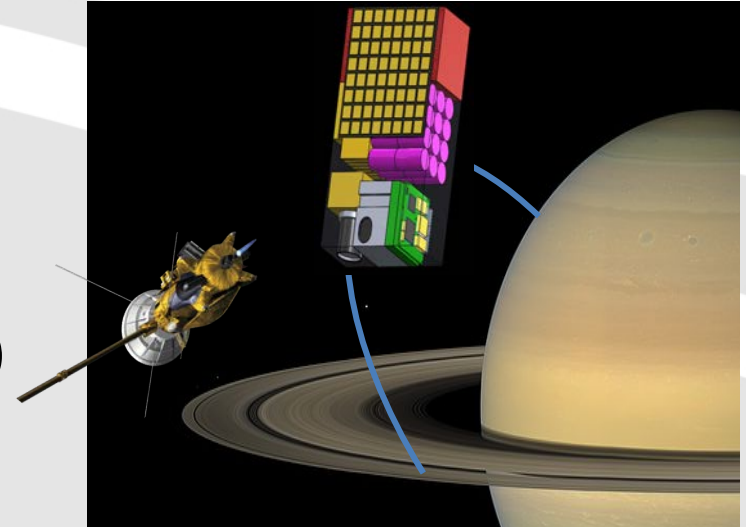
Cupid's Arrow Venus Atmosphere Skimmer



CubeSats at Saturn?

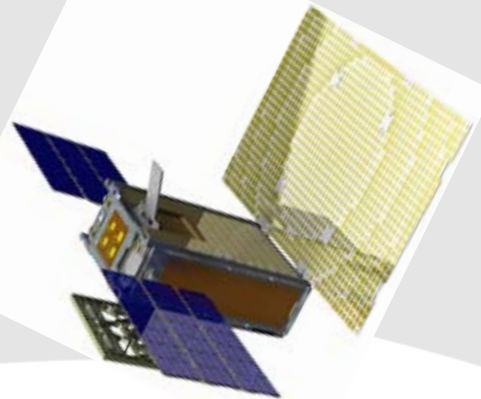
- ✓ Power – 11 days to fully charge a 200 Whr capacity battery with 1.2-2W solar power @ Saturn
- ✓ Control – need $<0.003^\circ$ pointing; $>35^\circ/\text{sec}$ slew rates
- ✓ X-Band Communications (relay to primary) with 28 dBi reflectarray
- ✓ Propulsion (chemical) – up to 250 m/s ΔV
- ✓ Thermal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

Saturn Ring Diver Concept



Lunar IceCube: 120 W @ Earth

Slide courtesy Andrew Bocher, Cal Poly SLO

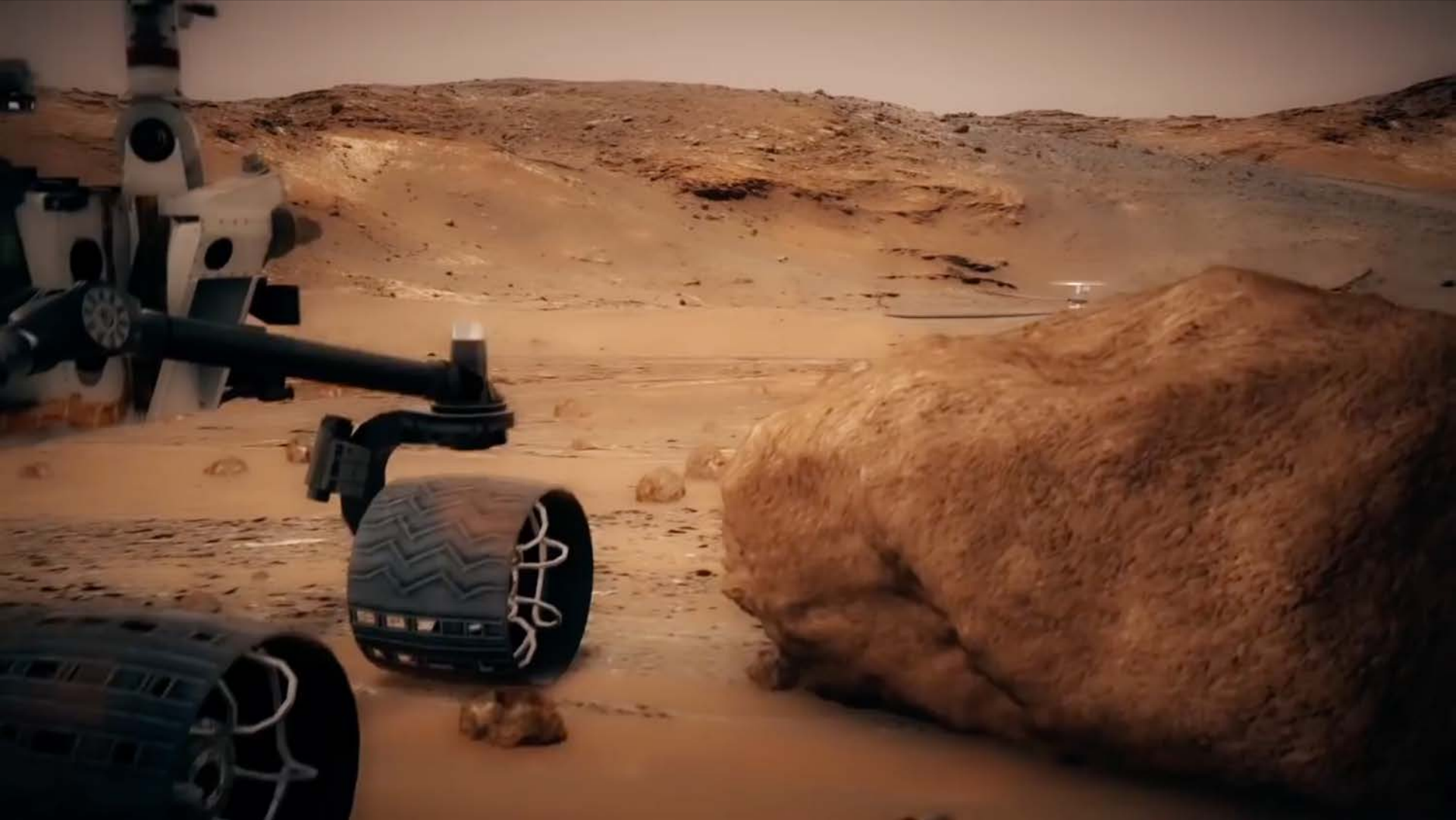


MarCo 28 dBi reflectarray

1W; 40g RHU



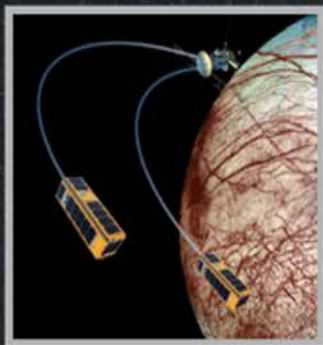
And in 2020 the Mars Helicopter...





The CubeSat Era in Space

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www.jpl.nasa.gov/cubesats