28 and Counting: JPL's Involvement in Cubesat Missions

Tony Freeman,

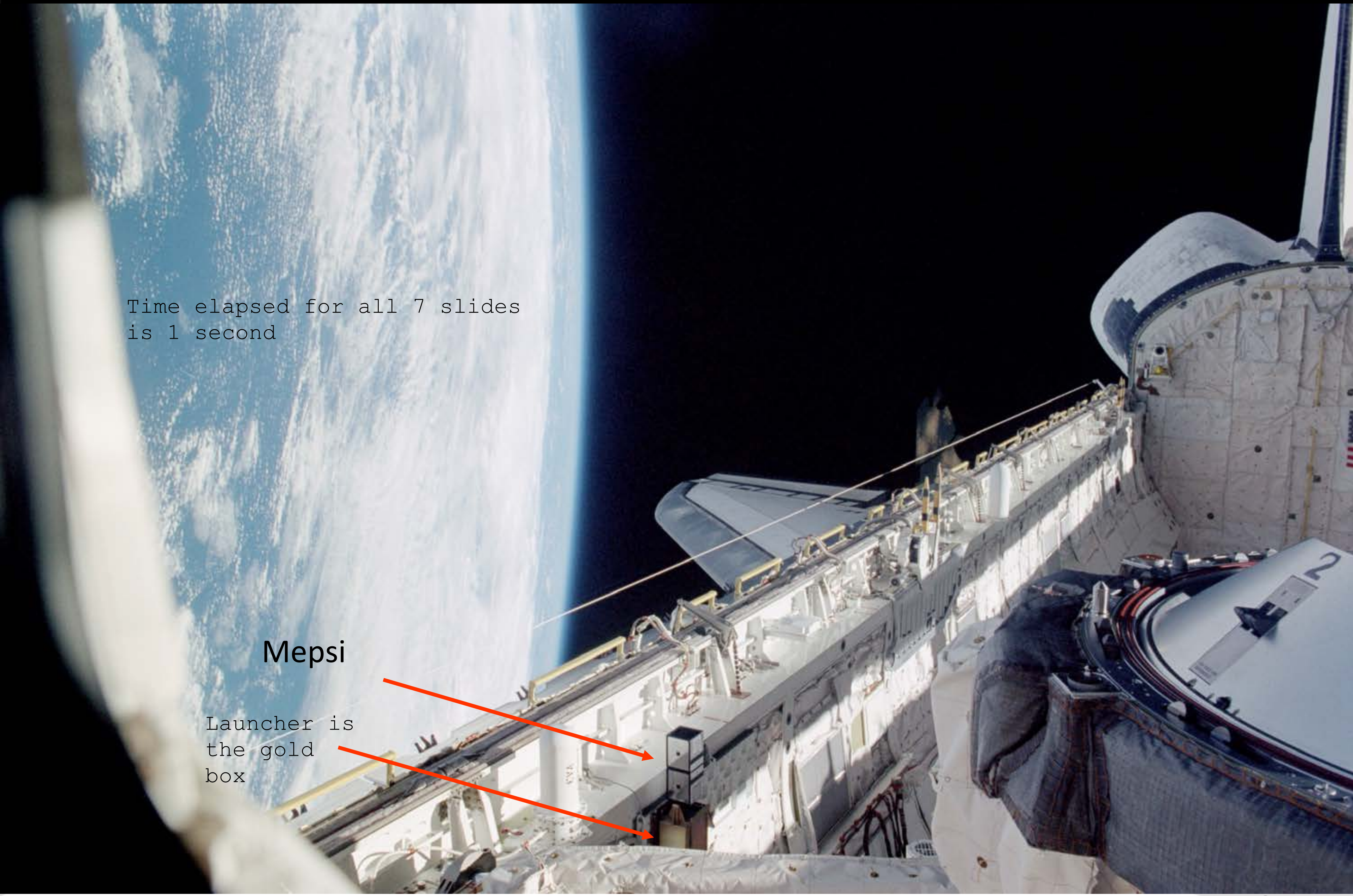
Jet Propulsion Laboratory, California Institute of Technology

Motivation

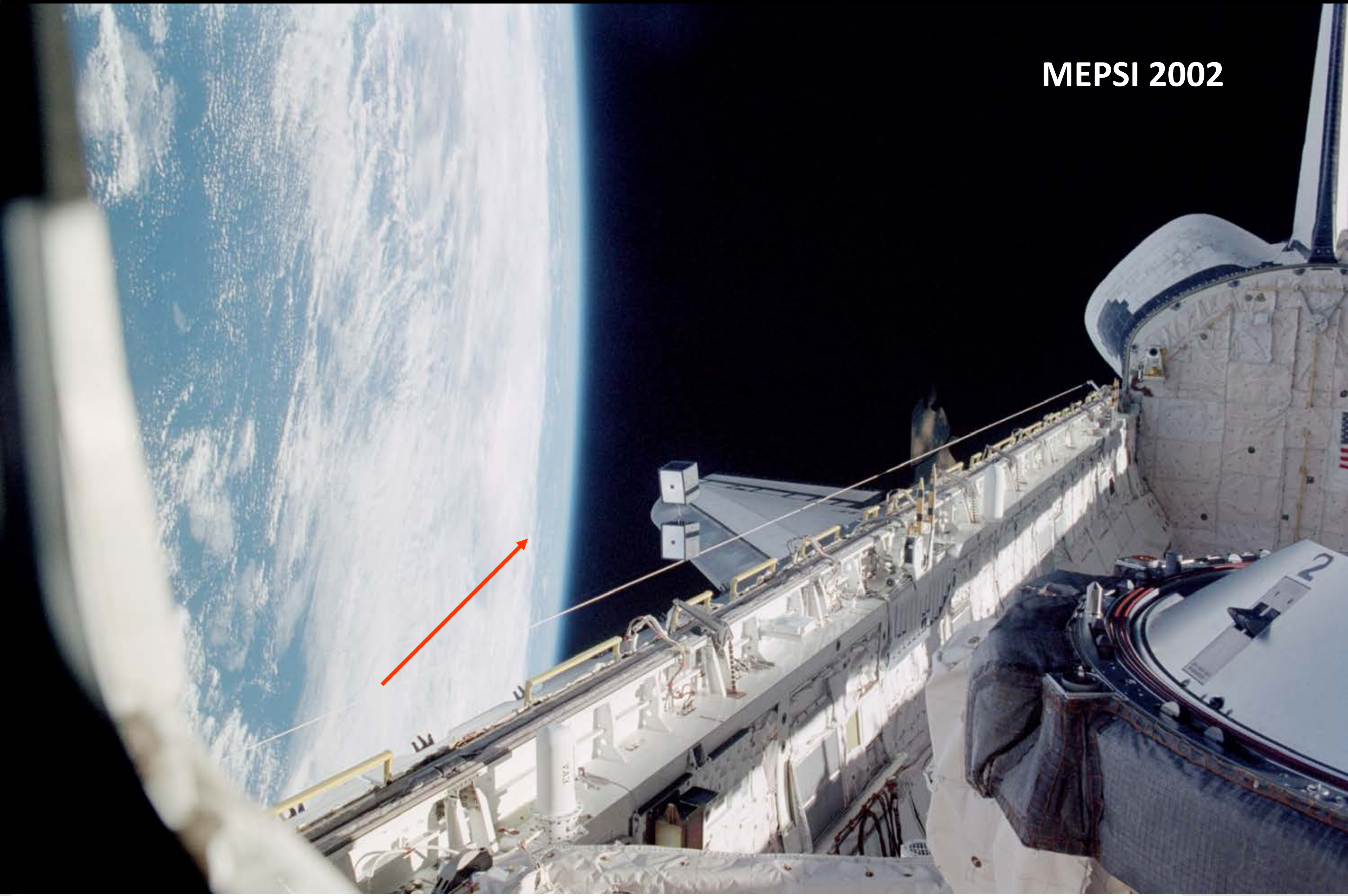
Why is JPL involved in cubesat missions?

- 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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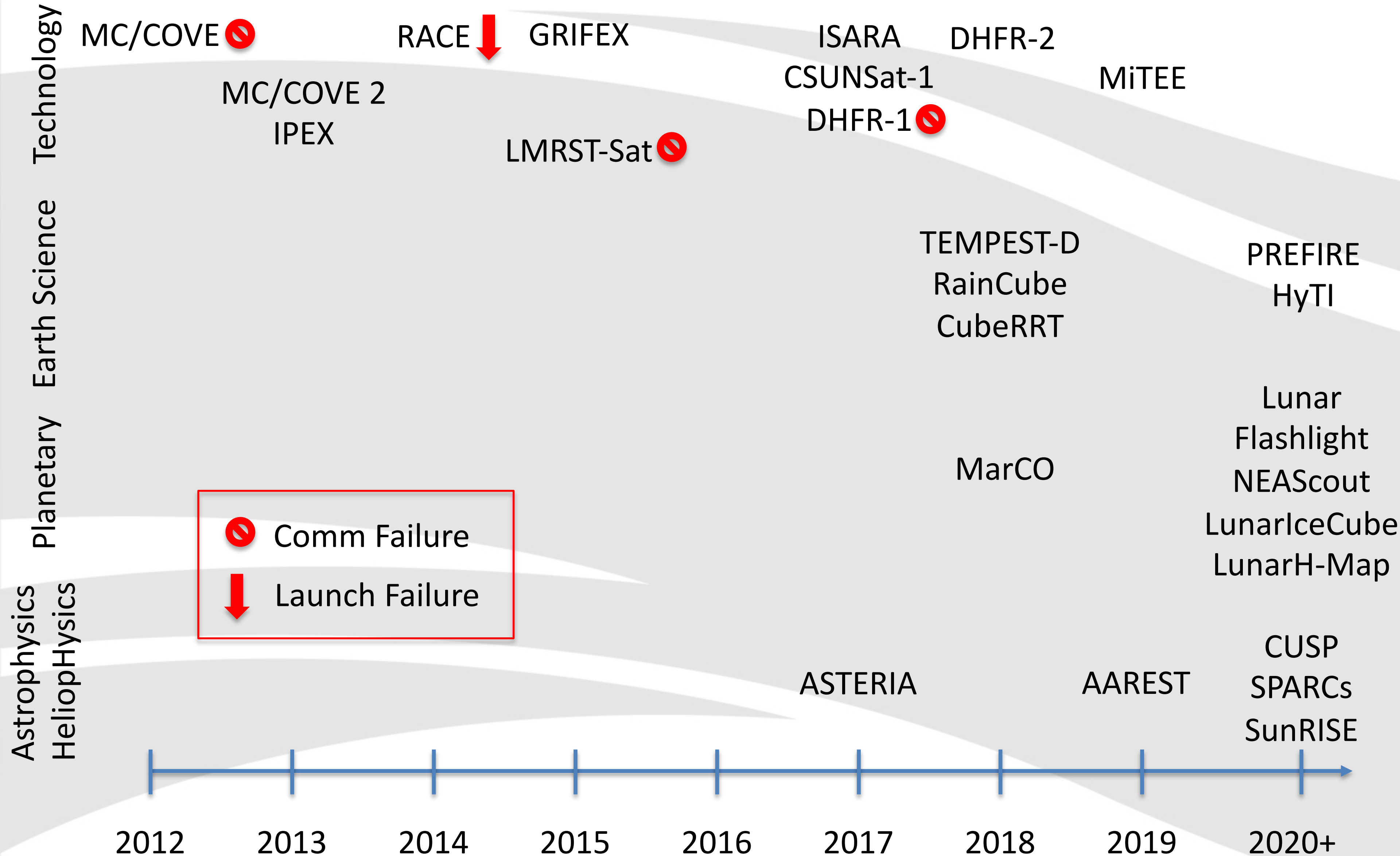
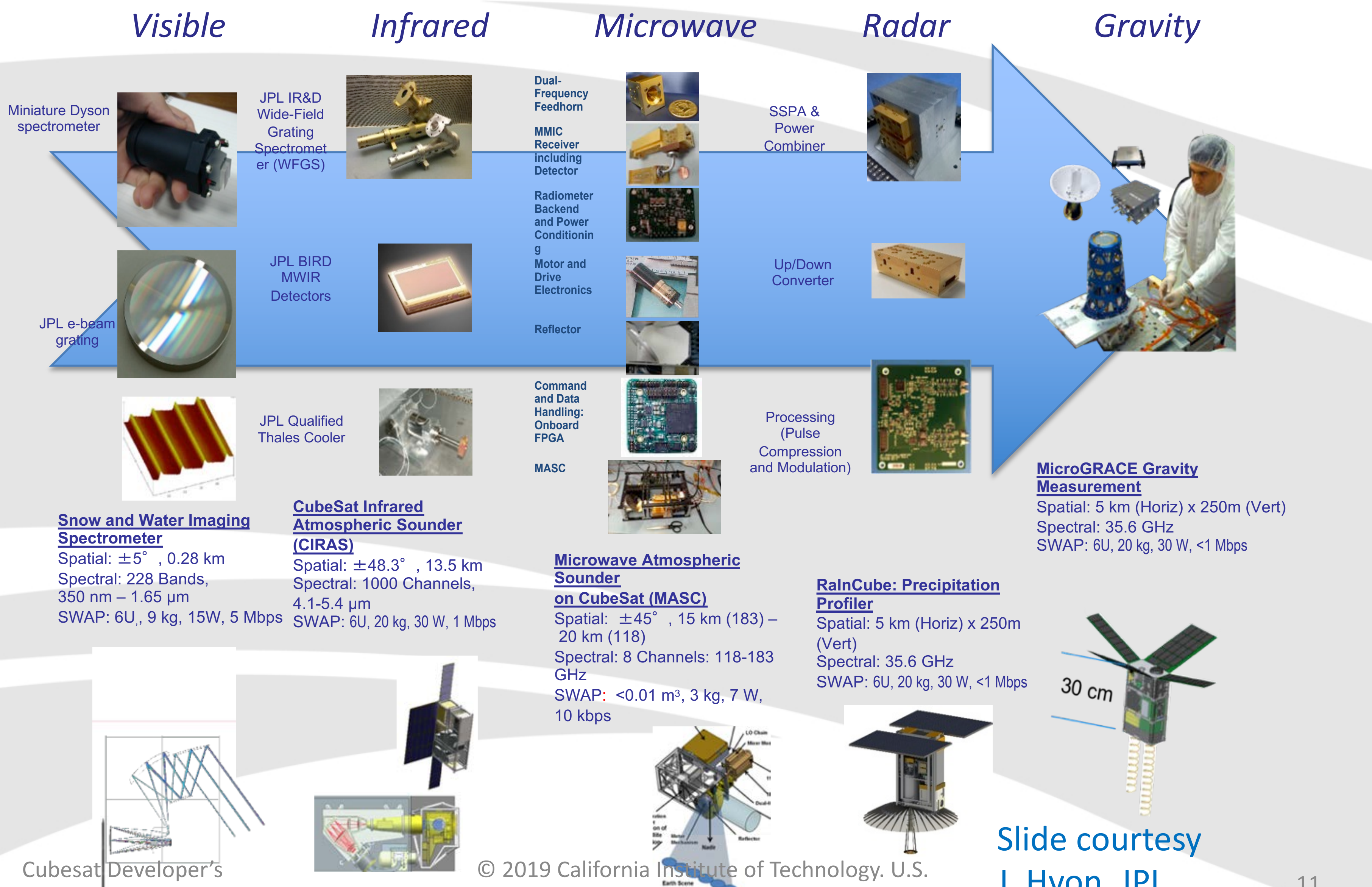
MEPSI 2002

JPL-involved Cubesat Timeline



Example RoadMap for Miniaturizing Instruments



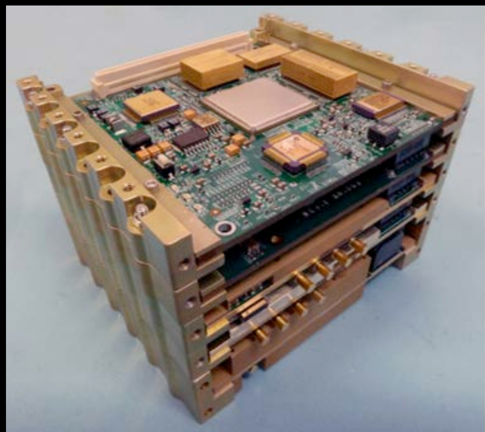
Slide courtesy J. Hyon, JPL

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 (μWave)	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

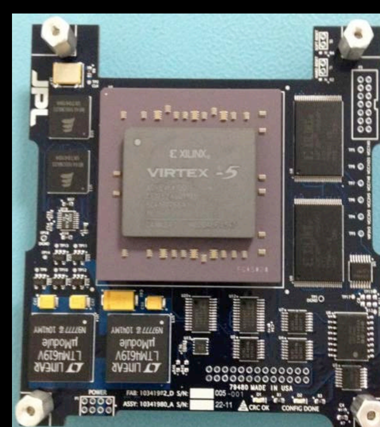


Deployable Reflector

Sphinx C&DH

DSN Communications and Navigation Protocols

OnBoard Data Reduction

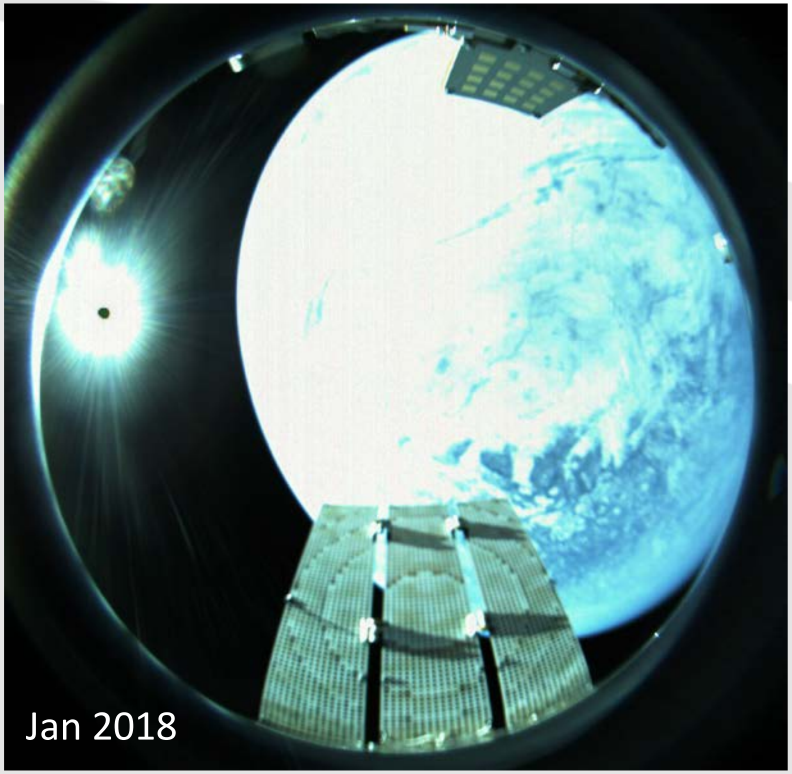


CubeSat Development Lab

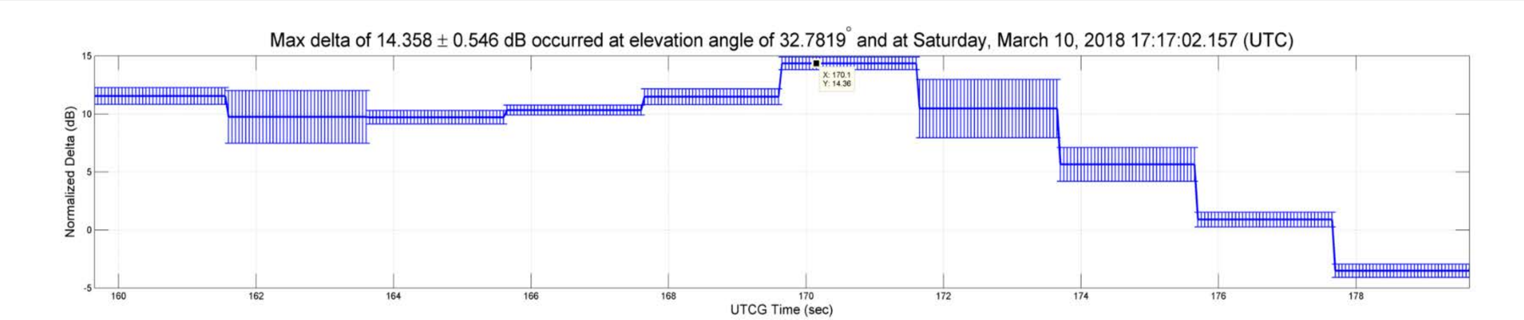
ISARA – 100 Mbps Downlink Capability

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

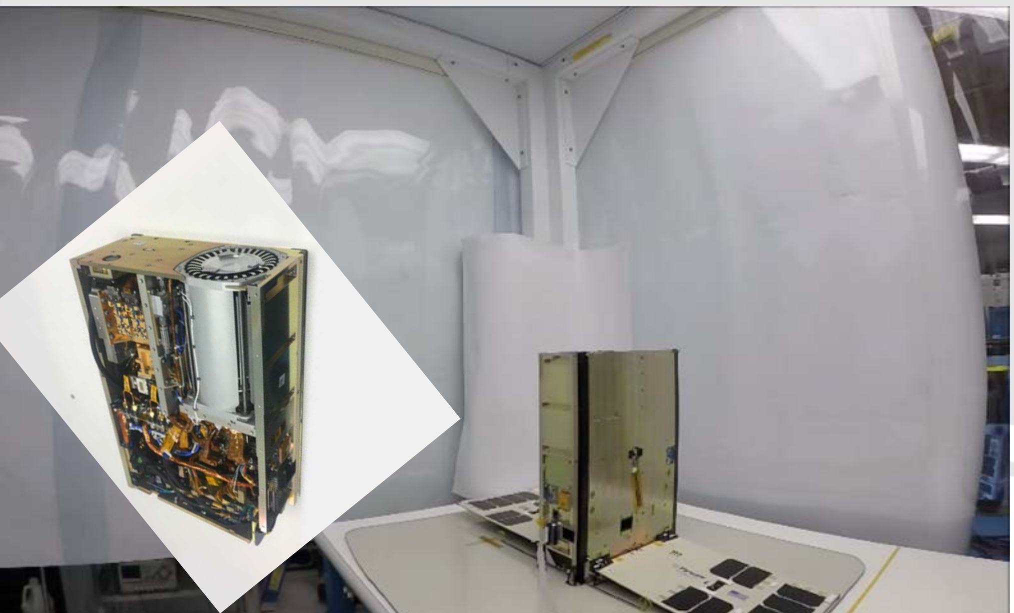


RainCube – first cubesat radar

Slide courtesy Eva Peral and the RainCube team

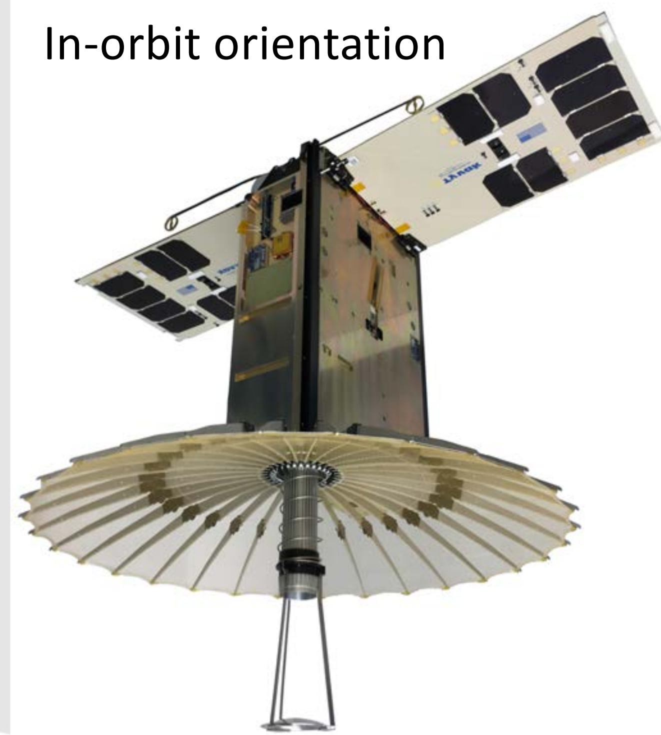
- ✓ First radar cubesat (6U)
- ✓ Vertically sounding, precipitation measurements
- ✓ 0.5 m diameter Ka-Band antenna (1.5U when stowed) – Tendeq license
- ✓ 2.5U radar electronics

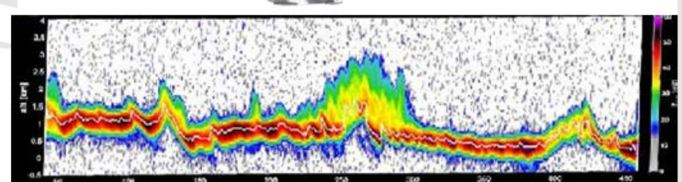
01/18: I&T



- ✓ Launched to ISS May 21, 2018
- ✓ First science data August, 2018

In-orbit orientation





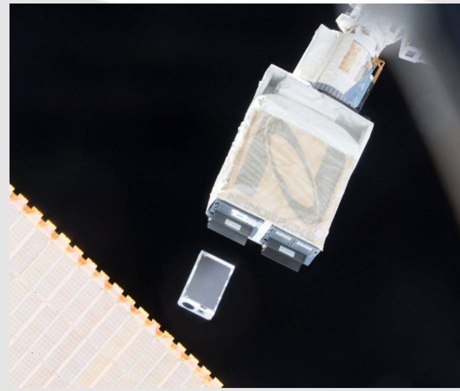
ASTERIA – hunting exoplanets one star at a time

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

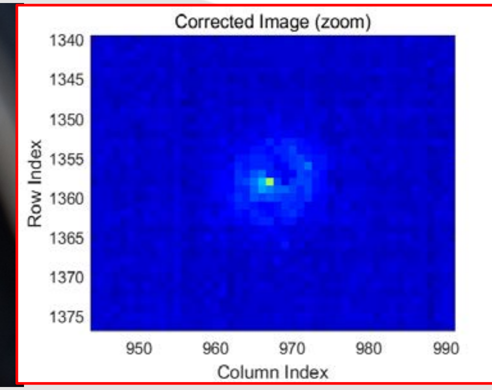
Arcsecond Space Telescope Enabling Research in Astrophysics (ASTERIA)

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

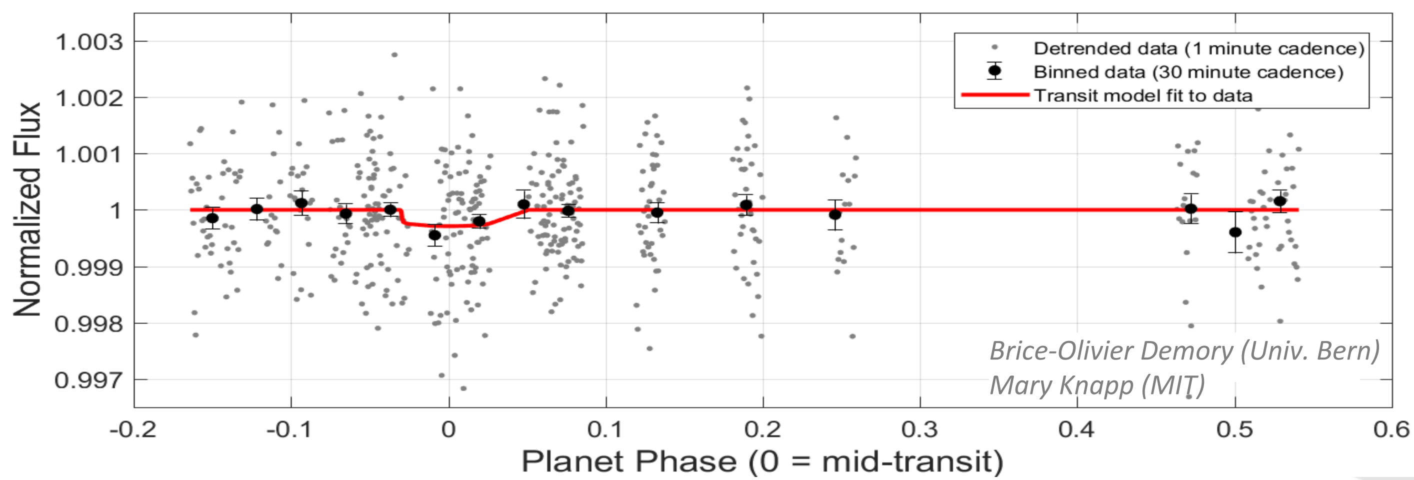
11/17: Deployed from ISS



12/17: First Image



ASTERIA 55 Cancri e Transit Light Curve



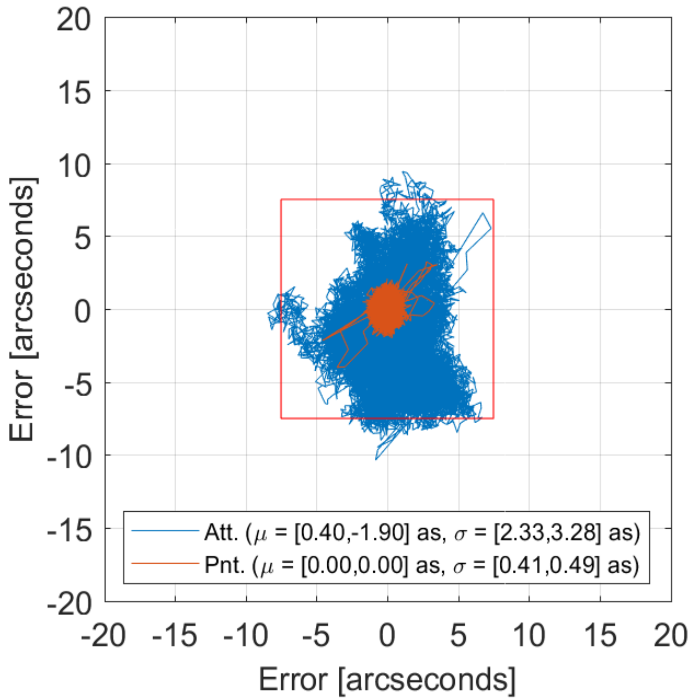
$2R_E$ exoplanet around a V=5.95 Sun-like star

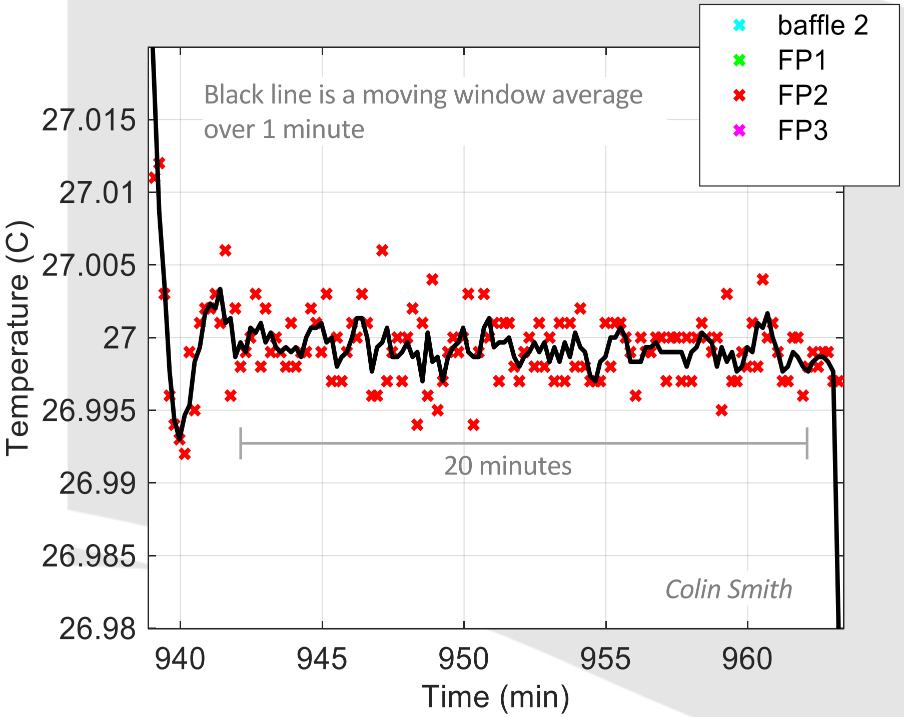
ASTERIA - Pointing and Thermal Control

Slide courtesy Matt W. Smith and the ASTERIA team

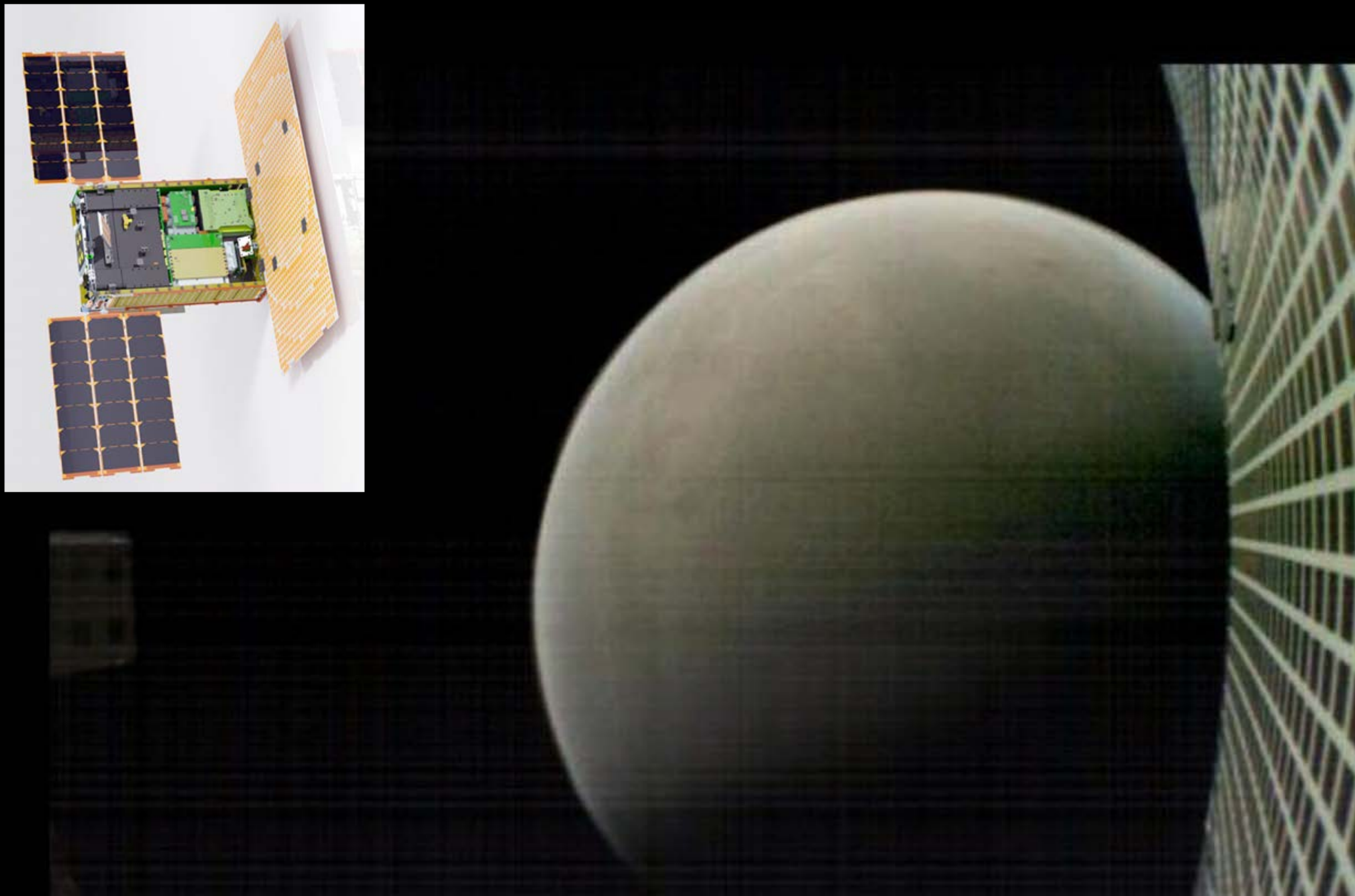
- ✓ Achieved pointing error < 0.5 arcseconds RMS over 20 minutes
- ✓ Blue scatter points show pointing without piezo stage correction
- ✓ Red scatter points show pointing <u>with</u> piezo stage correction

- ✓ 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



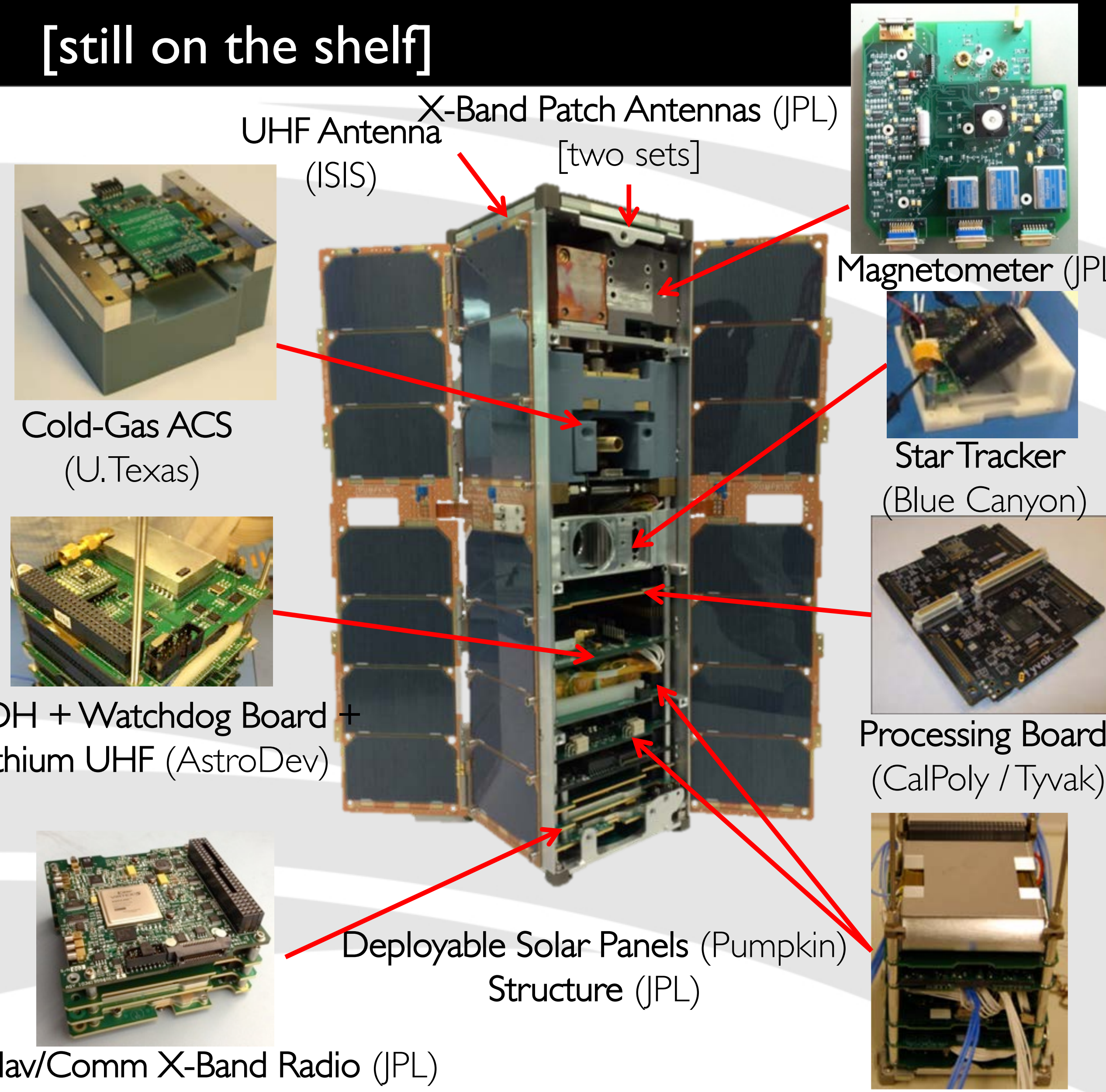


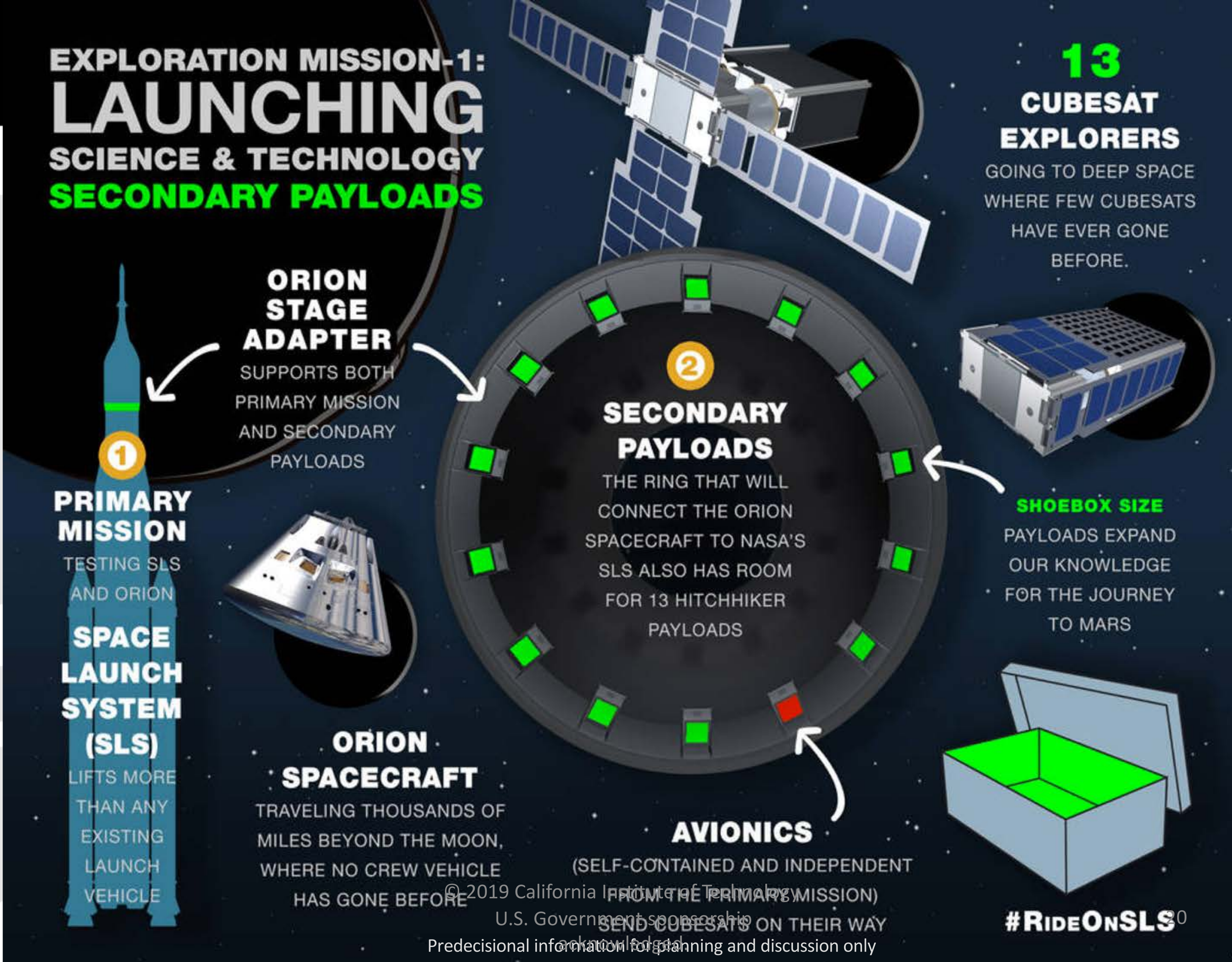
MarCO – the first Interplanetary Cubesats



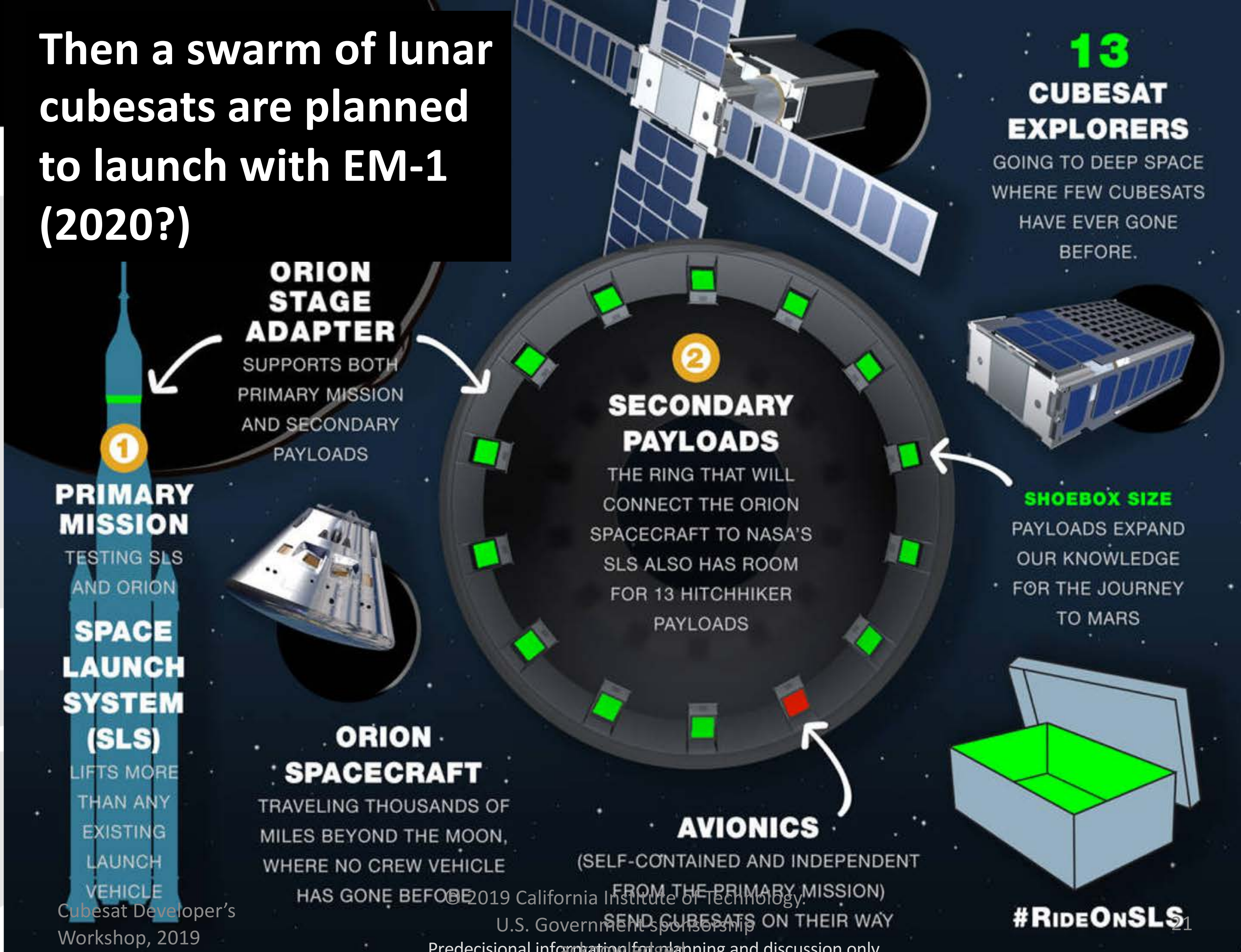
INSPIRE – Pathfinder for MarCO
[still on the shelf]

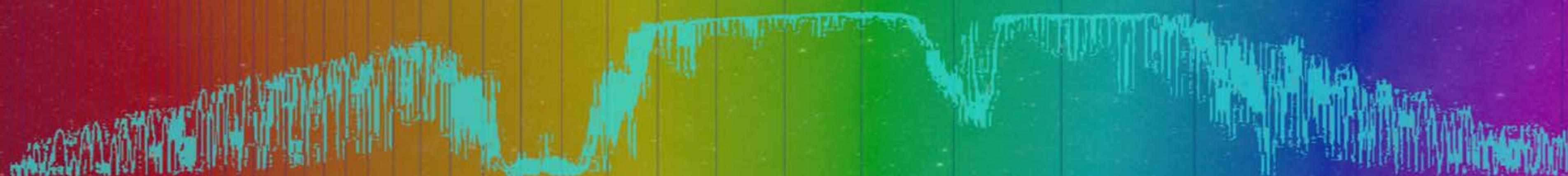
Ready for launch since 2014




EXPLORATION MISSION-1:
LAUNCHING
SCIENCE & TECHNOLOGY
SECONDARY PAYLOADS
13
CUBESAT
EXPLORERS
GOING TO DEEP SPACE WHERE FEW CUBESATS HAVE EVER GONE BEFORE.
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
2
SECONDARY PAYLOADS
THE RING THAT WILL CONNECT THE ORION SPACECRAFT TO NASA'S SLS ALSO HAS ROOM FOR 13 HITCHHIKER PAYLOADS
SHOEBOX SIZE
PAYLOADS EXPAND OUR KNOWLEDGE FOR THE JOURNEY TO MARS
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) SEND CUBESATS ON THEIR WAY
#RIDEONSLS

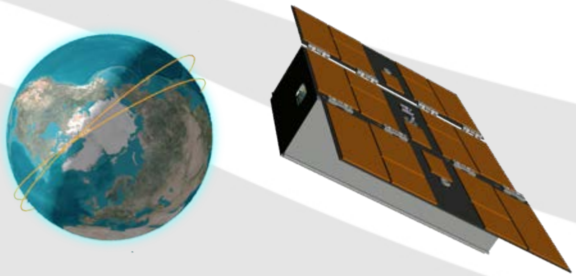
Then a swarm of lunar cubesats are planned to launch with EM-1 (2020?)





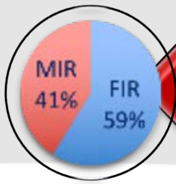
PREFIRE - PolaR Energy in the Far InfraRed Experiment

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

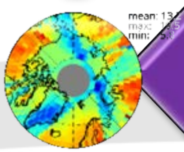


- ✓ Two 3-U CubeSats in asynchronous polar orbits
- ✓ Miniaturized IR spectrometer

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



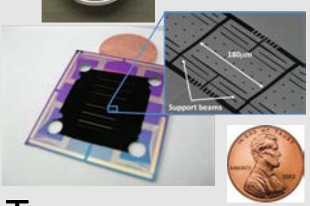
Nearly 60% of Arctic emission occurs at wavelengths > 15 μm (FIR) that have never been systematically measured.



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

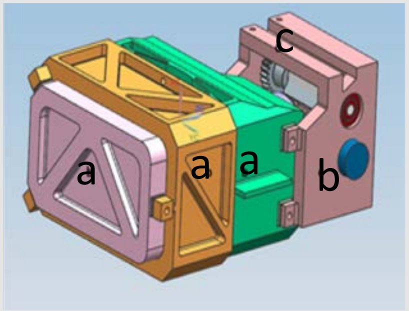
Planned launch in 2021

GRATING



THERMOPILE

2U Thermal IR Spectrometer



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

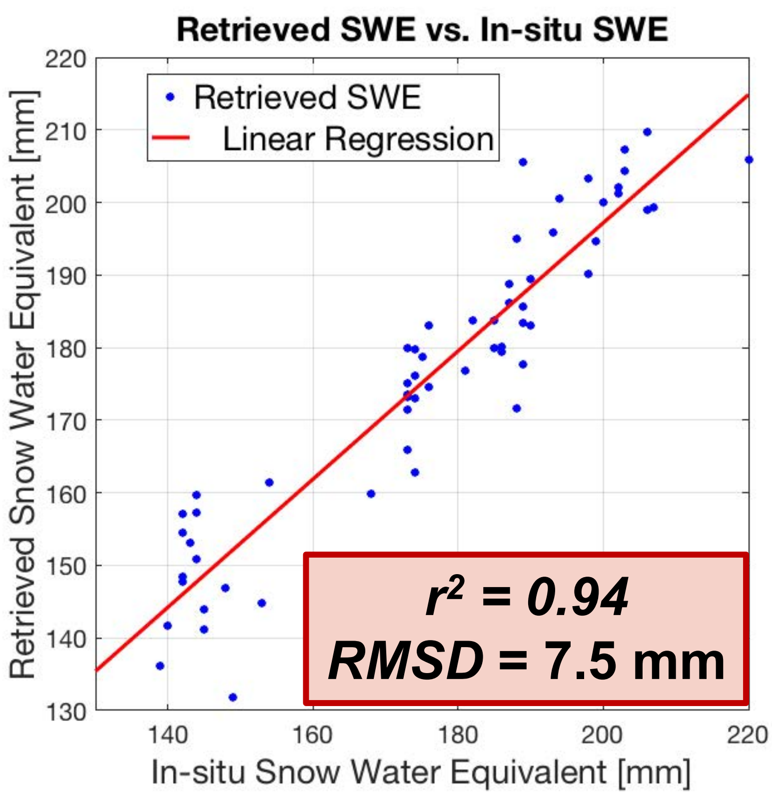
Thermopile array	Spectral resolution	Spatial coverage	Mass	Data rate	Power peak/avg
64 × 16 pixels	0.84 μm from 0–45 μm	16 cross-track pixels with 1.2° footprints	0.97 kg	35 kbps	6.74 / 1.74 W

WISCONSIN UNIVERSITY OF WISCONSIN–MADISON | SSEC | NASA | Jet Propulsion Laboratory California Institute of Technology | Space Dynamics Laboratory Utah State University Research Foundation | University of Colorado Boulder | UNIVERSITY OF MICHIGAN

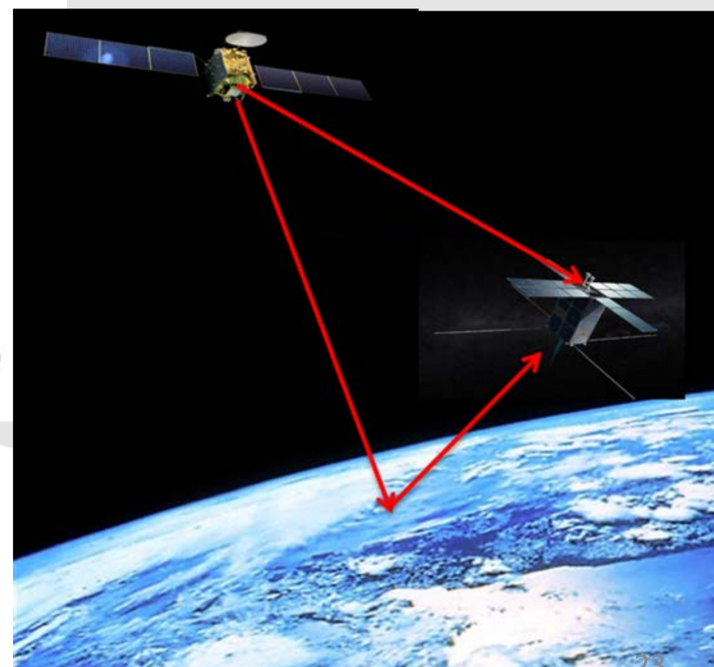
SNOOPI – SIGNALS OF OPPORTUNITY INVESTIGATION

Slide courtesy co-I Rashmi Shah, JPL

Fraser Experimental Forest



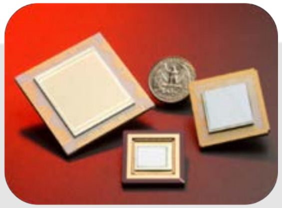
- ✓ PI: Jim Garrison, Purdue U.
- ✓ UHF Signals of Opportunity track Snow Water Equivalent (and Soil Moisture)
- ✓ SoOp altimeter
- ✓ Planned launch in 2021



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

Slide courtesy Tom Pagano, JPL

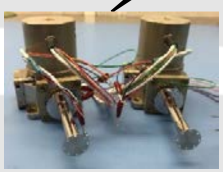
FPA HOTBIRD (JPL)

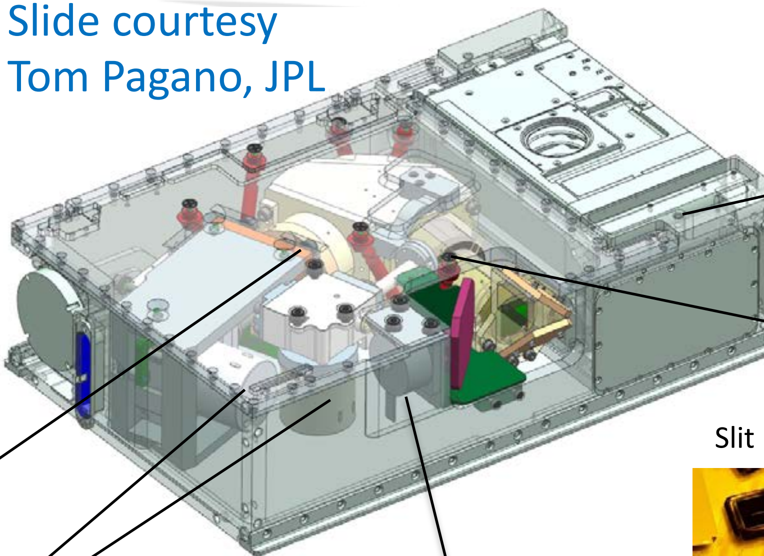


Camera Electronics (IR Cameras)

Dewar (IDCA) (IR Cameras)

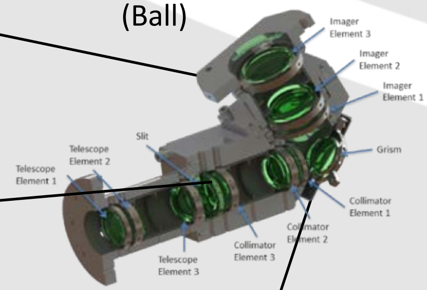
Cryocoolers + Electronics (Ricor K508N)





Spacecraft (BCT)

Optics Assembly (Ball)

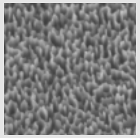


Slit (JPL)

Payload Electronics

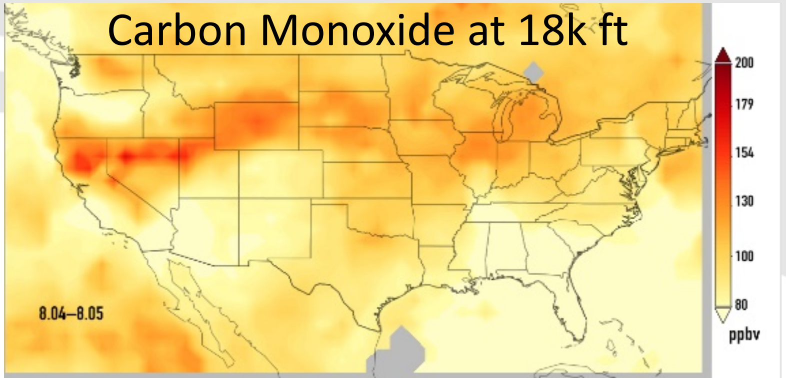
Stepper Motor + Mirror

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



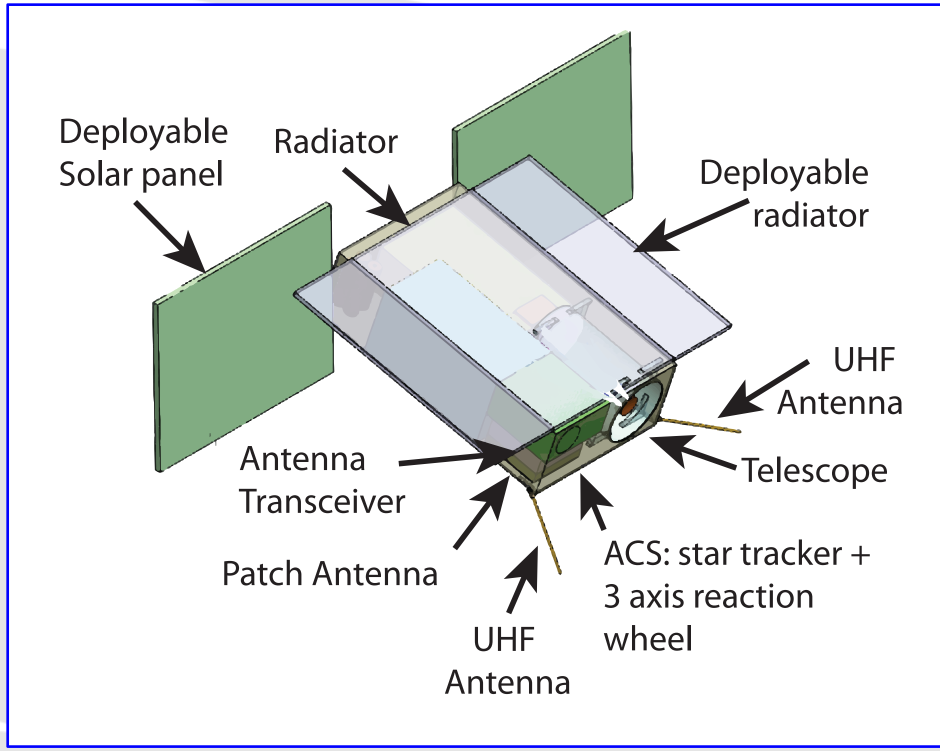
SPARCS 6U cubesat mission

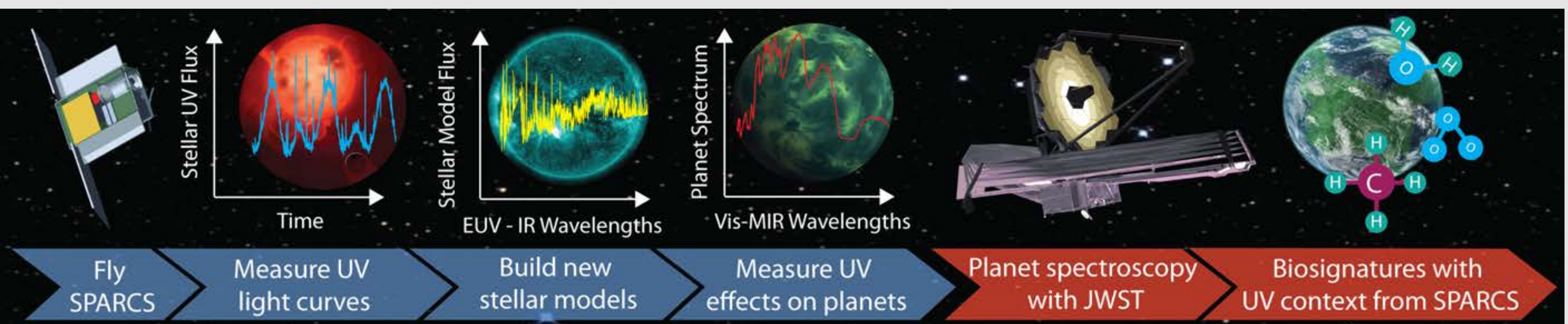
Study UV environment of exoplanets around M dwarf stars

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



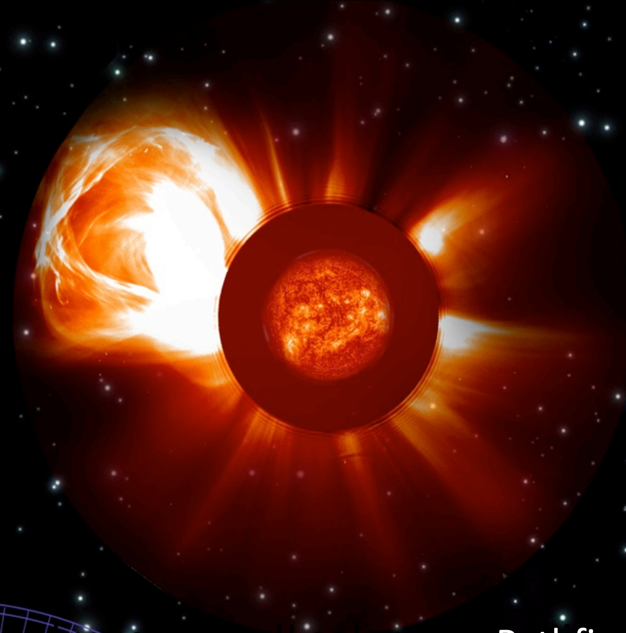


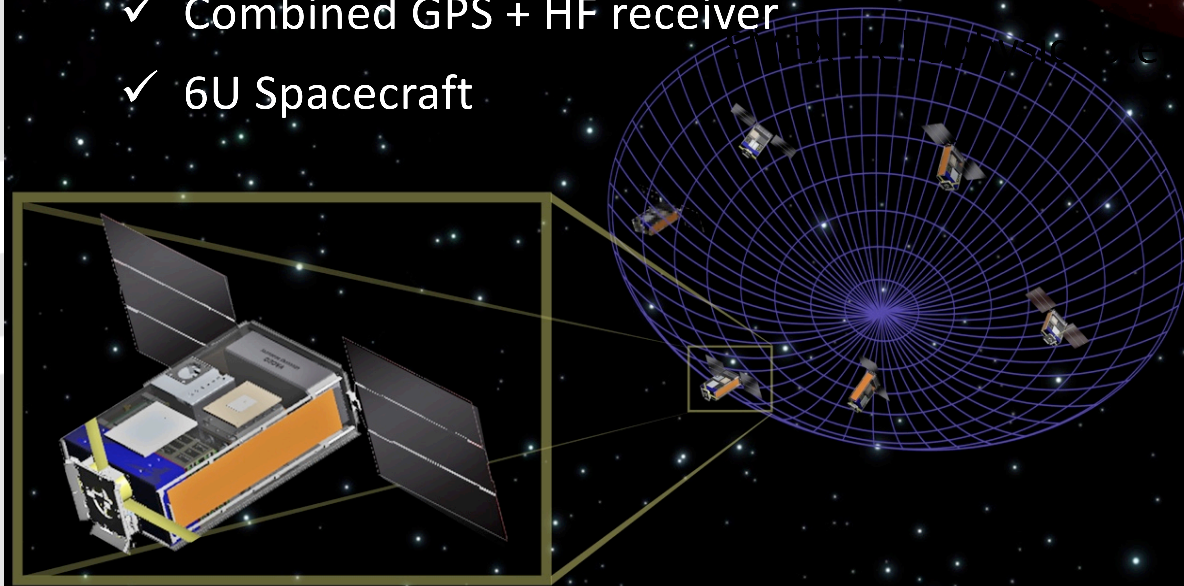
acknowledged.

SunRISE is in extended Phase A

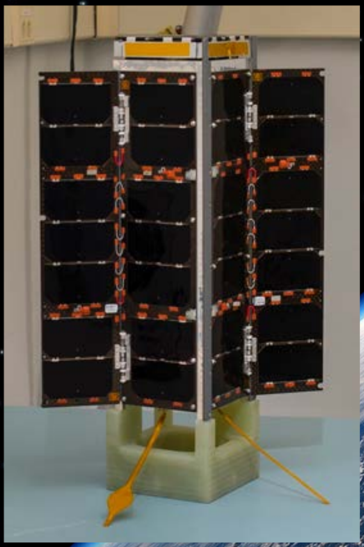
Sun Radio Imaging Space Experiment (SunRISE)

- ✓ 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



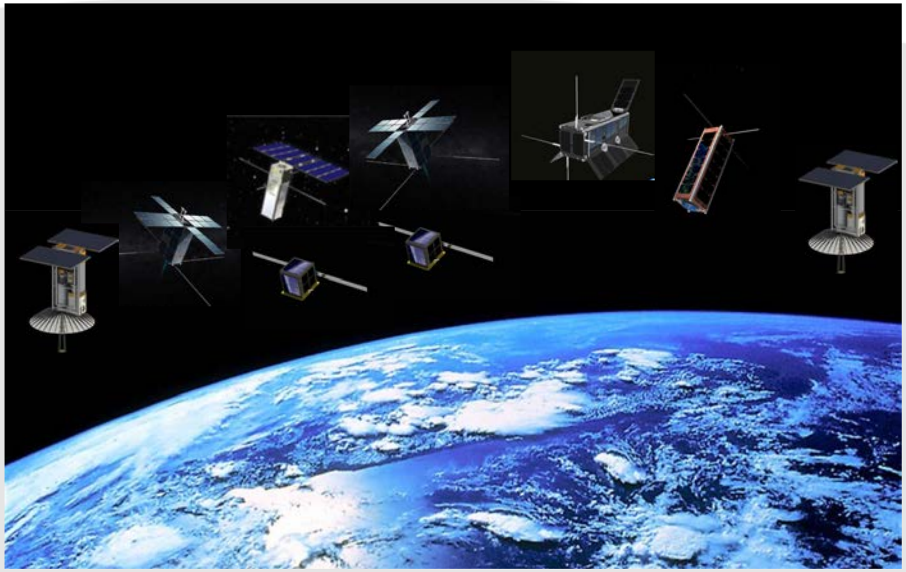


Pathfinder (2017/18)

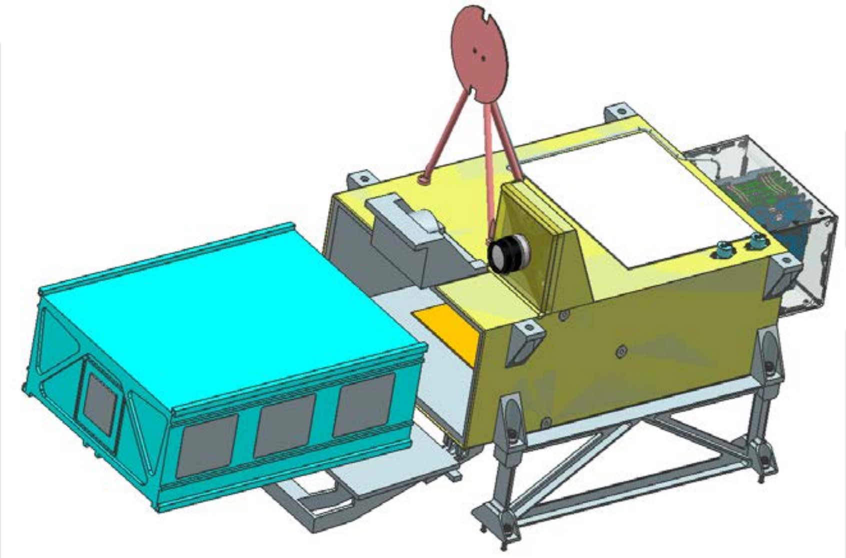


Looking at the Horizon

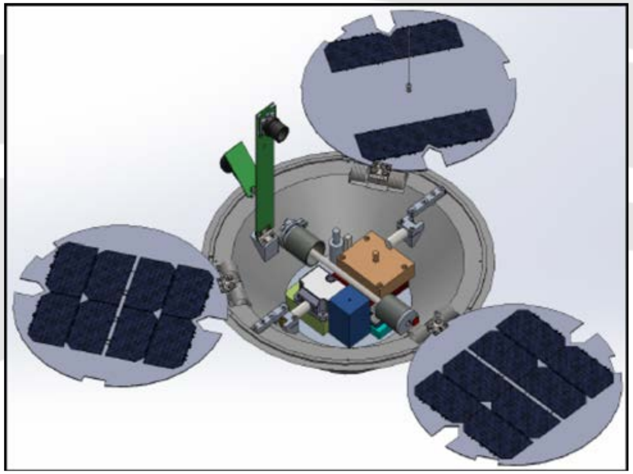
Cube-train Constellations for Earth Science



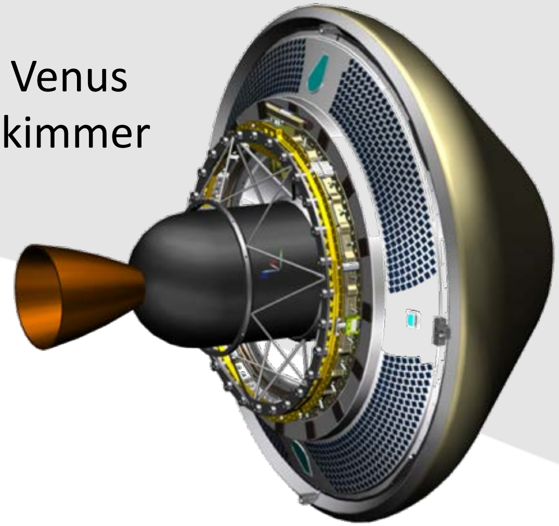
Deep Space P-Pod



MarsDrop Micro-lander



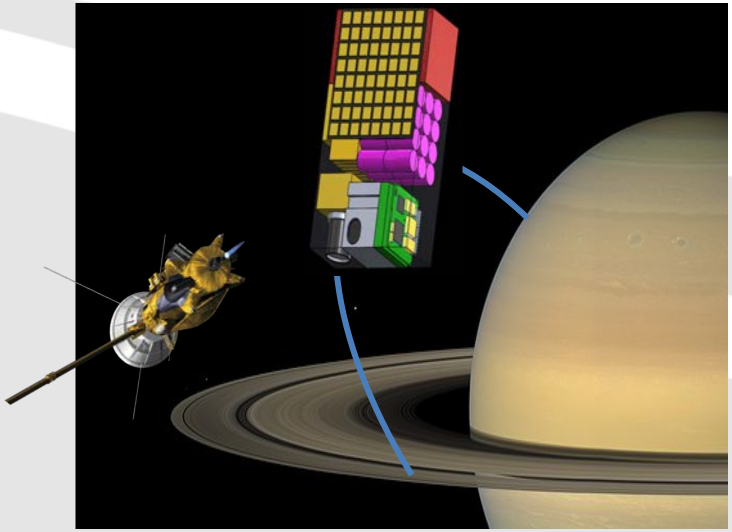
Cupid's Arrow Venus
Atmosphere Skimmer



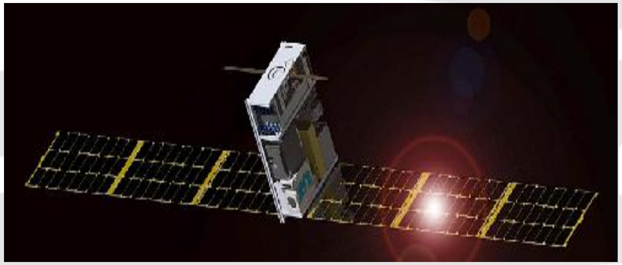
CubeSats at Saturn?

- ✓ Power – 11 days to fully charge a 200 Whr capacity battery with 1.2-2W solar power @ Saturn
- ✓ Control – need <0.003° 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

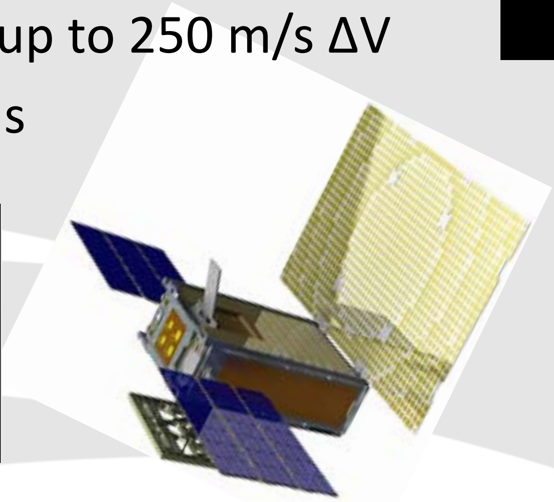
Saturn Ring Diver Concept



1W; 40g RHU



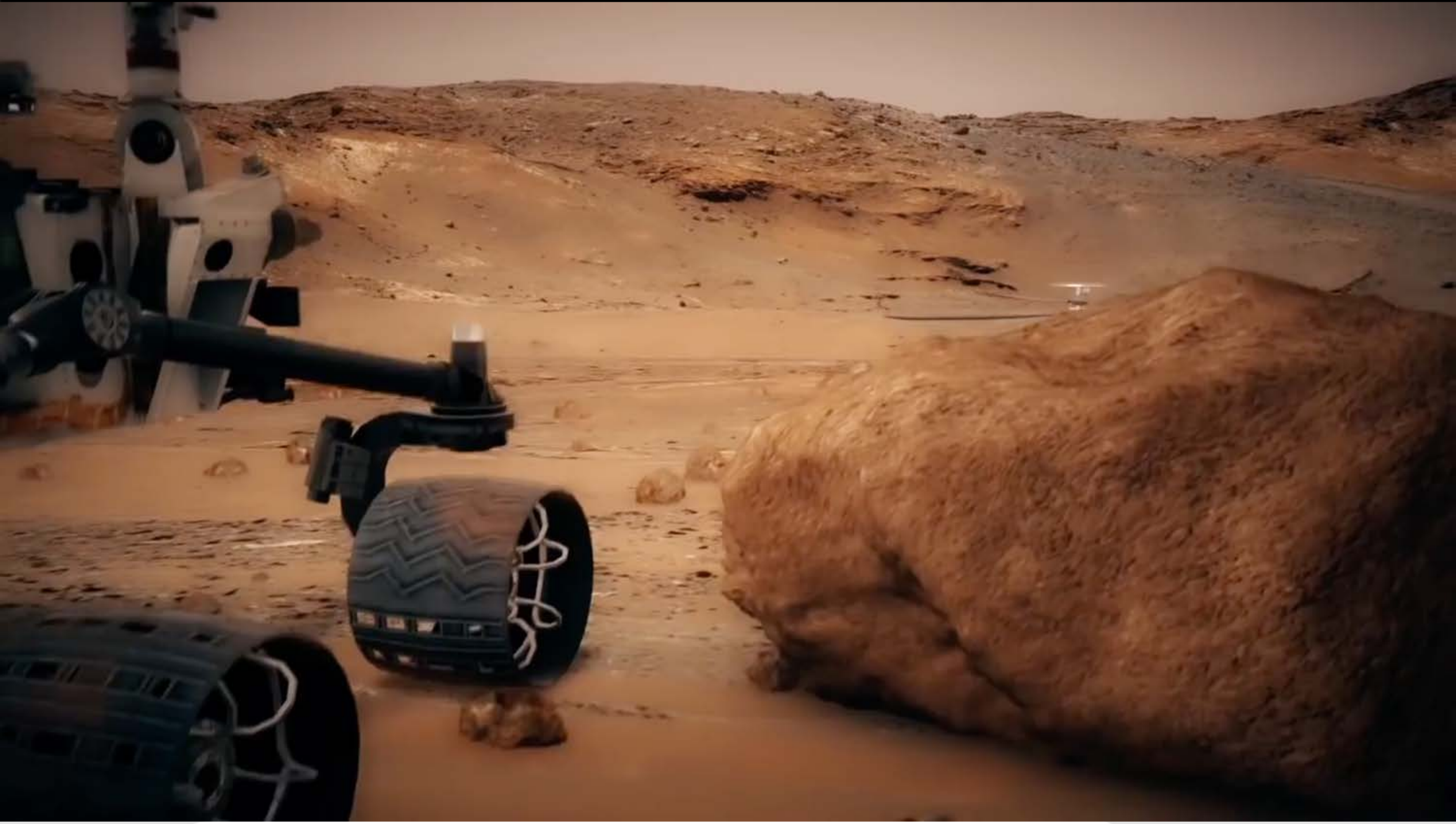
Lunar IceCube: 120 W @ Earth



MarCo 28 dBi reflectarray

Slide courtesy Andrew Bocher, Cal Poly SLO

And in 2020 the Mars Helicopter…



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www.jpl.nasa.gov/cubesats