Cubesat Missions and JPL

Tony Freeman,

Jet Propulsion Laboratory, California Institute of Technology

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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?)

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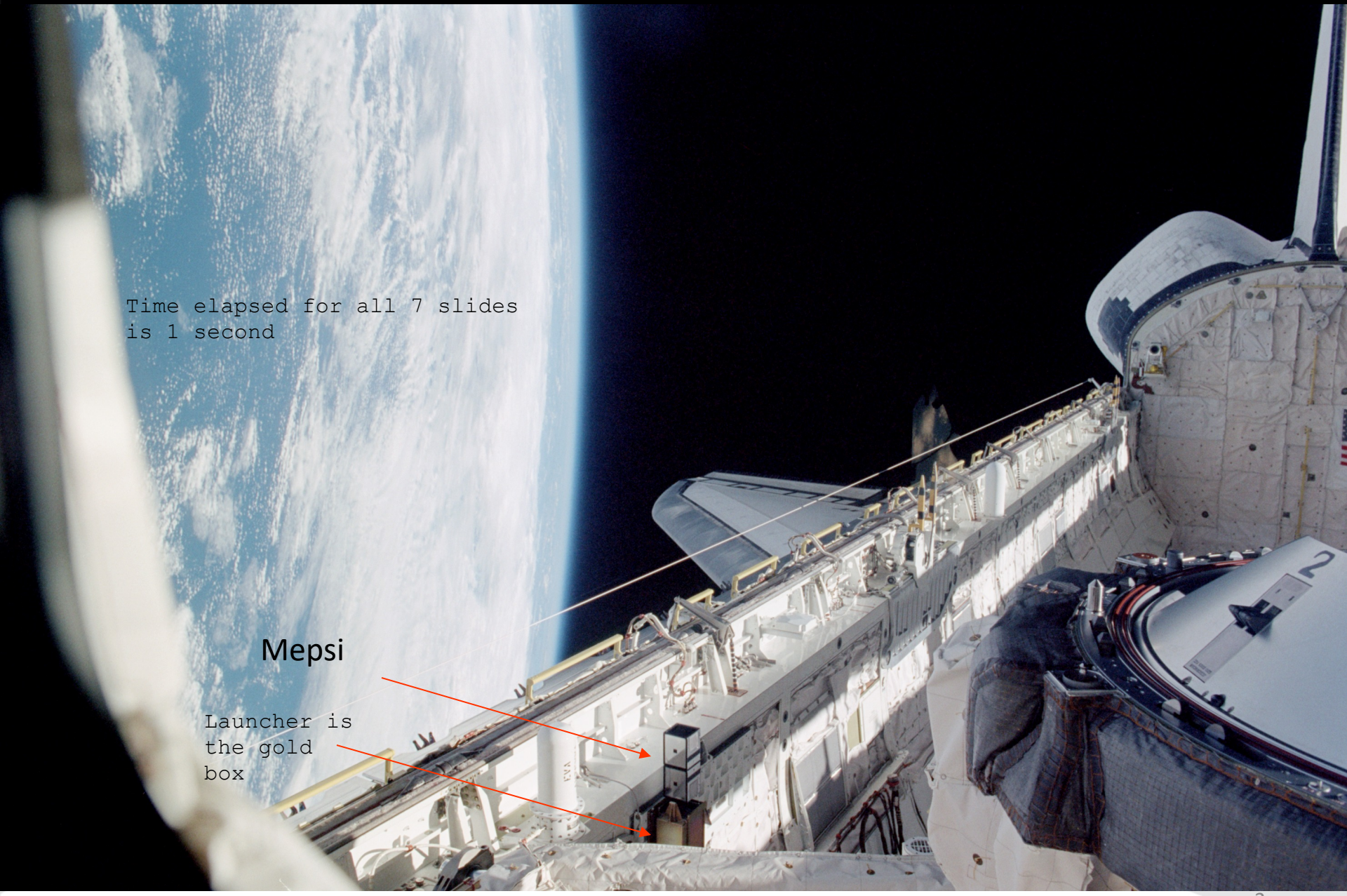

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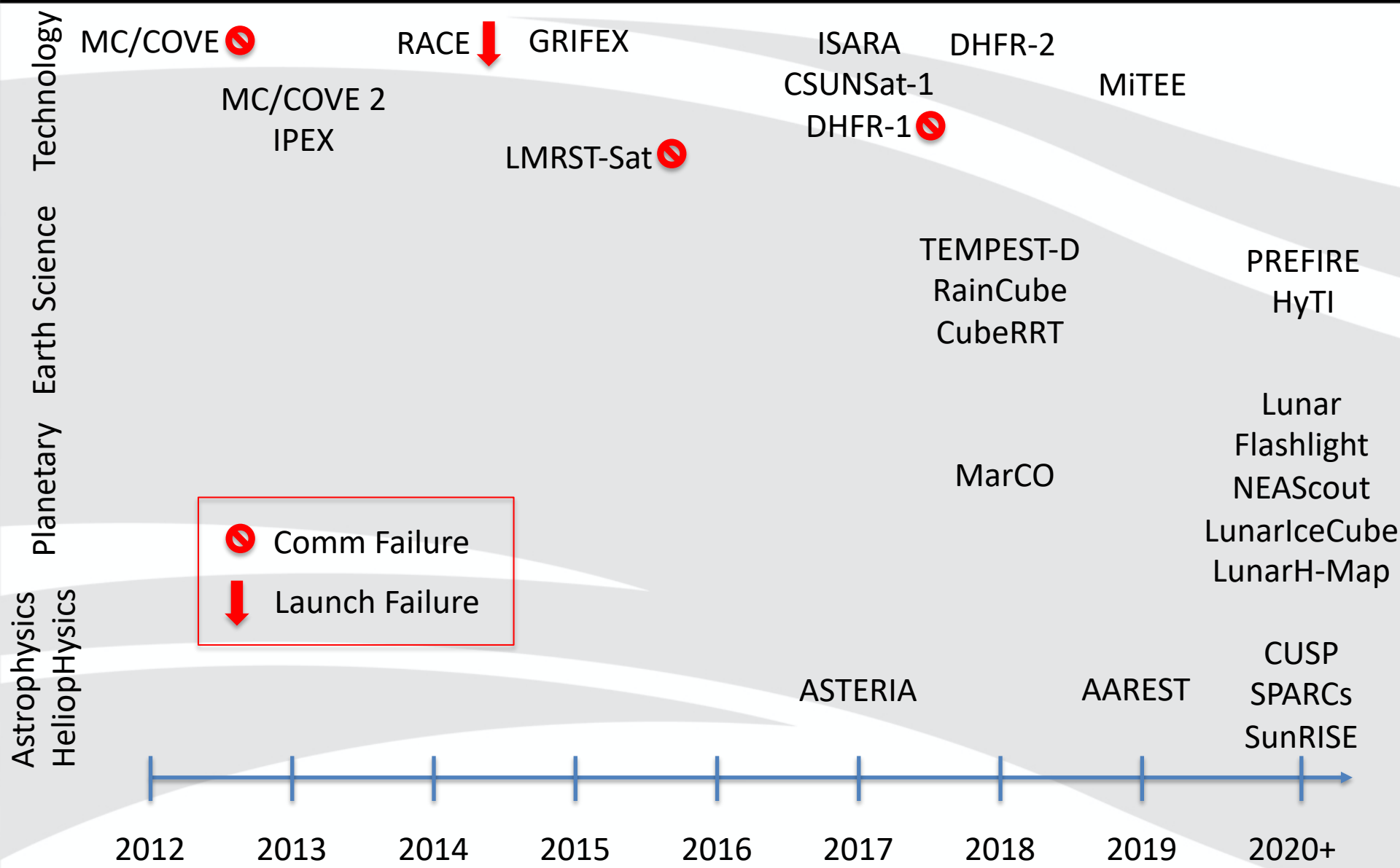
JPL-involved Cubesat Timeline



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Example RoadMap for Miniaturizing Instruments

Visible | *Infrared* | *Microwave* | *Radar* | *Gravity*

Miniature Dyson spectrometer

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

Dual-Frequency Feedhorn

MMIC Receiver including Detector

Radiometer Backend and Power Conditioning

Motor and Drive Electronics

Reflector

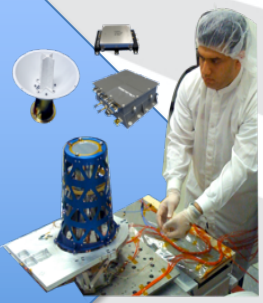
Command and Data Handling: Onboard FPGA

MASC

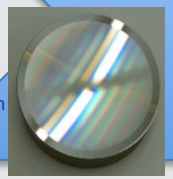
SSPA & Power Combiner

Up/Down Converter

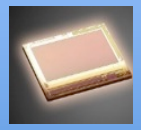
Processing (Pulse Compression and Modulation)

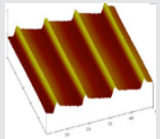


JPL e-beam grating



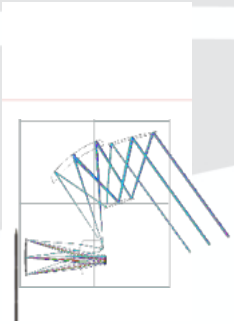
JPL BIRD MWIR Detectors



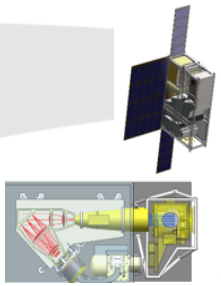


JPL Qualified Thales Cooler

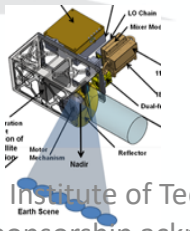
Snow and Water Imaging Spectrometer
Spatial: ±5°, 0.28 km
Spectral: 228 Bands, 350 nm – 1.65 µm
SWAP: 6U,, 9 kg, 15W, 5 Mbps



CubeSat Infrared Atmospheric Sounder (CIRAS)
Spatial: ±48.3°, 13.5 km
Spectral: 1000 Channels, 4.1-5.4 µm
SWAP: 6U, 20 kg, 30 W, 1 Mbps

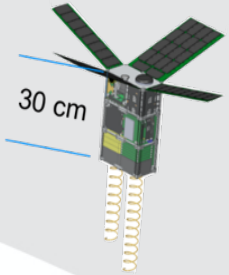


Microwave Atmospheric Sounder on CubeSat (MASC)
Spatial: ±45°, 15 km (183) – 20 km (118)
Spectral: 8 Channels: 118-183 GHz
SWAP: <0.01 m³, 3 kg, 7 W, 10 kbps



RainCube: Precipitation Profiler
Spatial: 5 km (Horiz) x 250m (Vert)
Spectral: 35.6 GHz
SWAP: 6U, 20 kg, 30 W, <1 Mbps

MicroGRACE Gravity Measurement
Spatial: 5 km (Horiz) x 250m (Vert)
Spectral: 35.6 GHz
SWAP: 6U, 20 kg, 30 W, <1 Mbps



Slide courtesy J. Hyon, JPL

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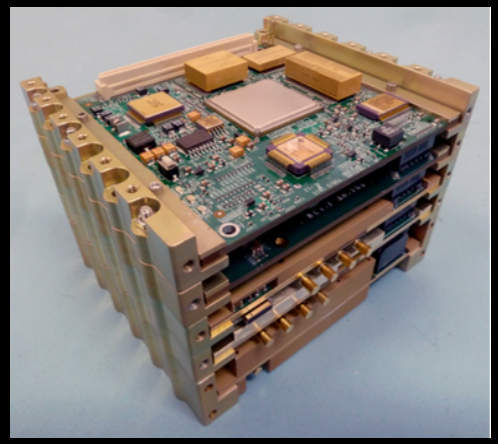
Cubesat-sized Instruments – 2012 and 2019

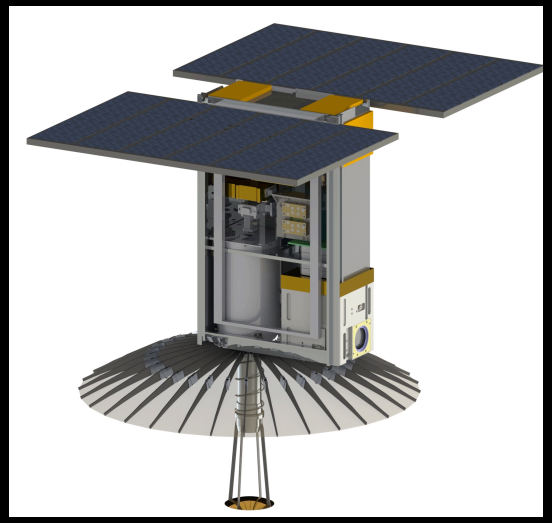
Technology	Selva* and Krejci, 2012	Freeman 2019	Justification
Atmospheric Chemistry Instruments	Problematic	Feasible	PICASSO, IR sounders
Atmos Temp and Humidity Sounders	Feasible	Feasible	CiRAS
Cloud Profile and rain radars	Infeasible	Feasible	RainCube
Earth Radiation Budget radiometers	Feasible	Feasible	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

Slide courtesy J. Levison, JPL

Jet Propulsion Laboratory

National Aeronautics and Space Administration

F′

F Prime: a flight-proven, multi-platform, *open source* flight software framework

https://github.com/nasa/fprime

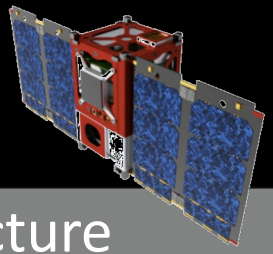
Flight Proven:

- RapidScat on ISS
- ASTERIA

Upcoming Flights:

- NEA Scout
- Lunar Flashlight

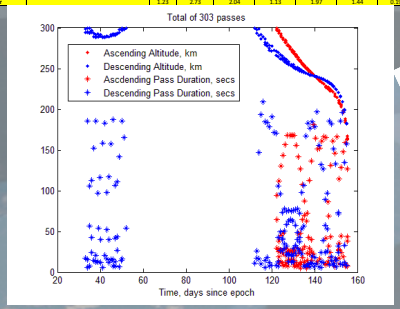
Fast Formulation - Team Xc

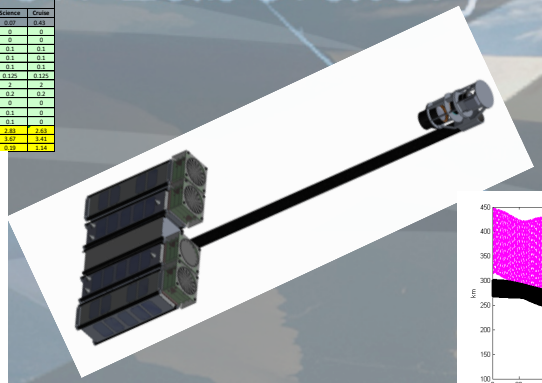


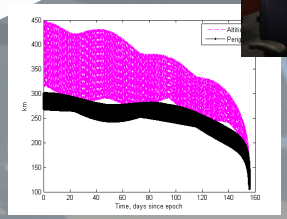
Agile, collaborative design team built on Team X infrastructure

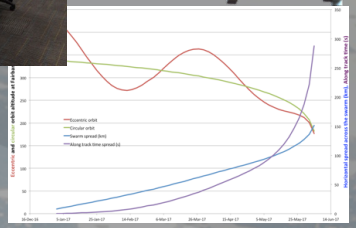
- Fast turnaround for mission concepts and studies (~2 weeks)
- Quickly assess feasibility, trade space, point designs, operations concept
- Cost Effective (Team X study cost/2)
- Products that plug directly into proposals
- Average 12 studies per year

ICSP Power Modes		Setup Phase			Day in life				
		Beacon	Stabilization	Deployment	GPS	Recharge	Downlink	Science	Cruise
	Mode Durations (hrs)	1.00	1.00	0.17	0.25	0.75	0.10	0.07	0.40
Mechanical	Antenna Deployment	0	0	2	0	0	0	0	0
	Solar Panel Deployment	0	0	9	0	0	0	0	0
Avionics	GomSpace Battery	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
	Michigan C&DH	0.1	0.1	0.1	0	0	0.1	0.1	0.1
	Novatel GPS	0.1	0.1	0.1	2	0.1	0.1	0.1	0.1
	GomSpace EPS	0.125	0.125	0.125	0.125	0.125	0.125	0.125	0.125
ACS	BCT XACT	0.5	2	0.5	2	2	2	2	2
Telecom	L3 Cadet S band	0.3	0.3	0.3	0.3	0.3	12	0.2	0.2
	Patch Antenn	0	0	0	0	0	0	0	0
Instruments	Faraday cup	0	0	0	0	0	0	0.1	0
	Magnetometer	0	0	0	0	0	0	0.1	0
Total W		3.23	2.73	12.23	4.53	2.63	14.43	2.83	2.63
Total W+Cont (30%)		1.59	3.54	15.89	5.88	3.41	18.75	3.67	3.41
Total W-hr		1.23	2.73	2.04	1.13	1.97	1.44	0.28	1.14









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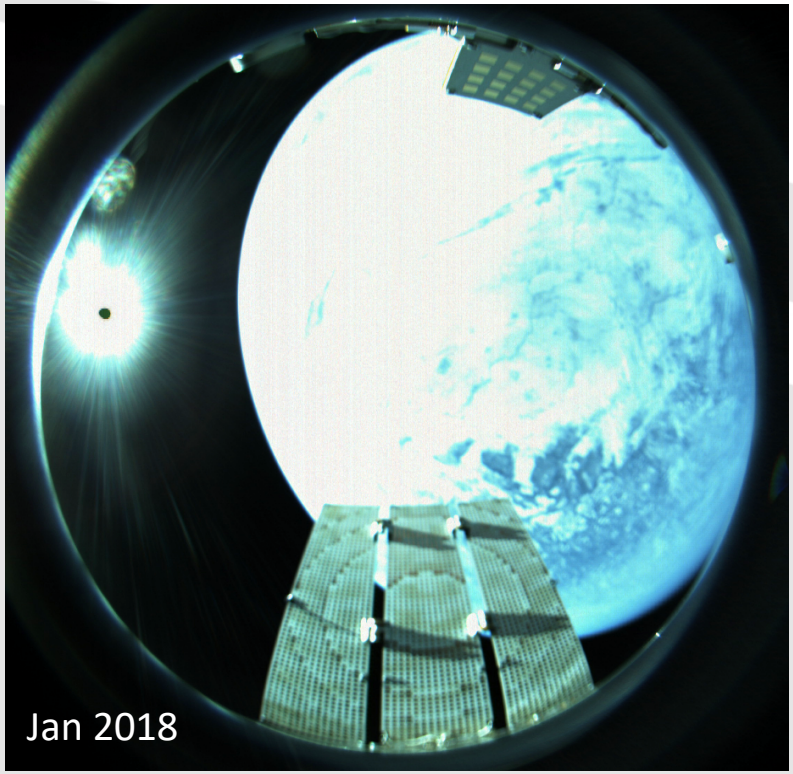
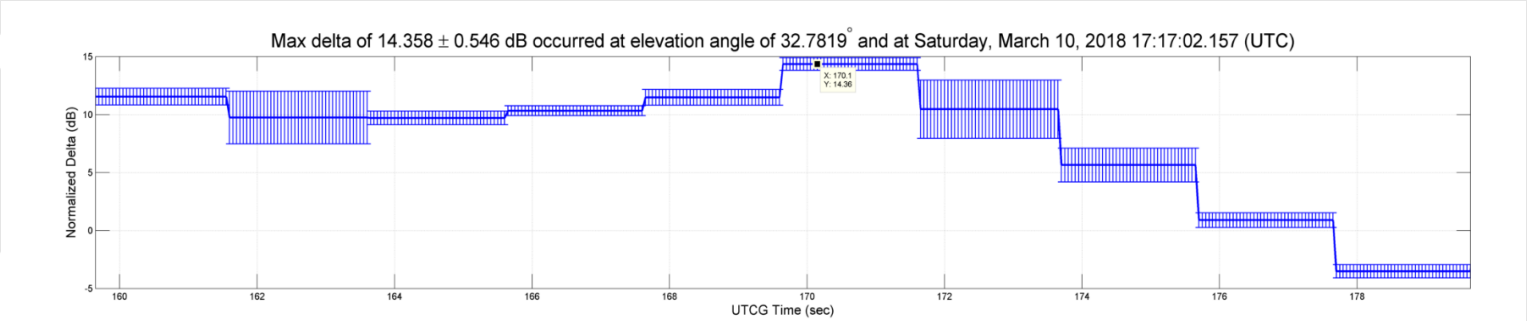
ISARA – 100 Mbps Downlink Capability

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



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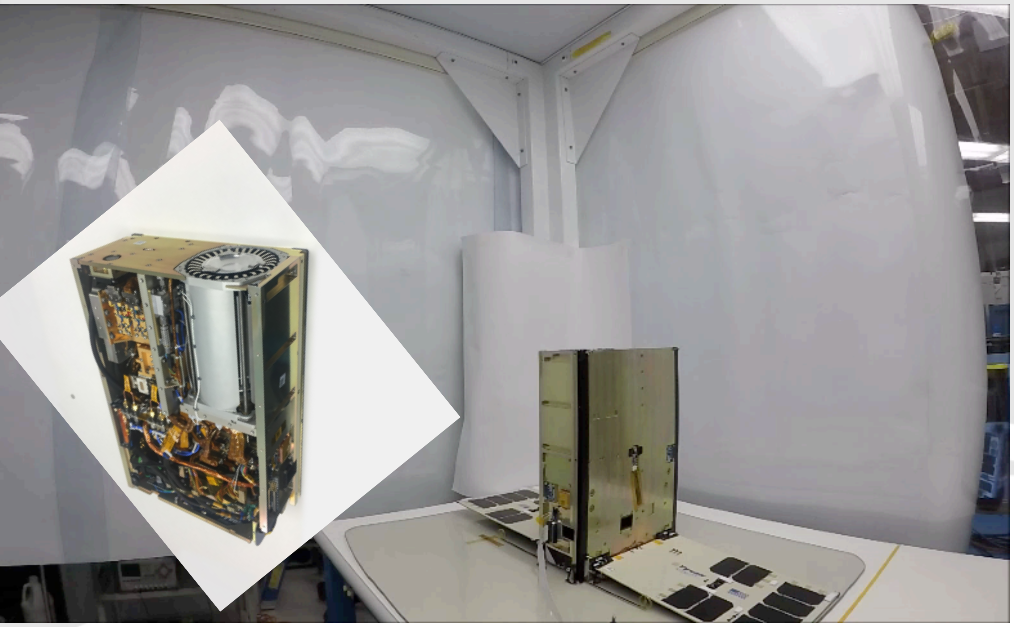
RainCube – first cubesat radar

Slide courtesy Eva Peral and the RainCube team

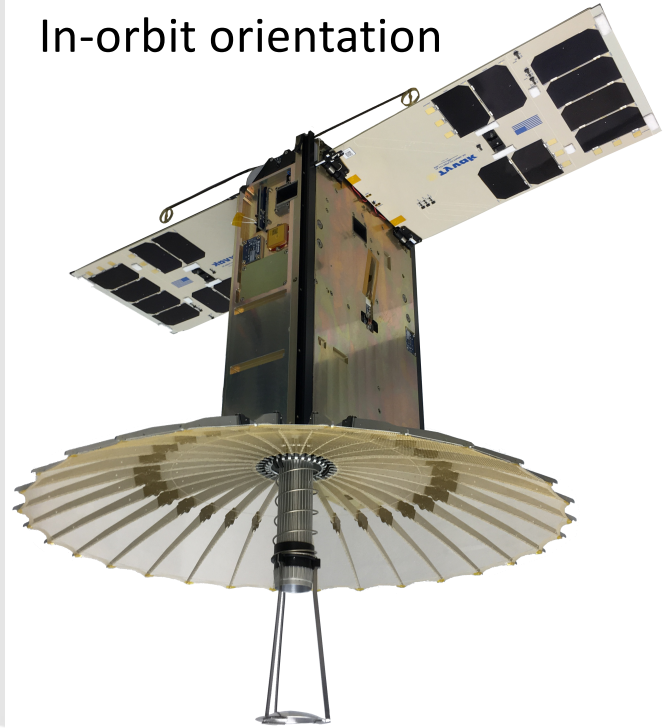
- ✓ First radar cubesat (6U)
- ✓ Vertically sounding, precipitation measurements
- ✓ 0.5 m diameter Ka-Band antenna (1.5U when stowed) – Tendeq license
- ✓ 2.5U radar electronics

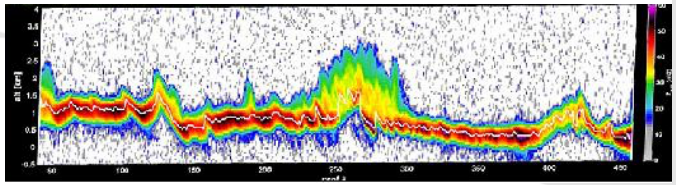
01/18: I&T



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

In-orbit orientation





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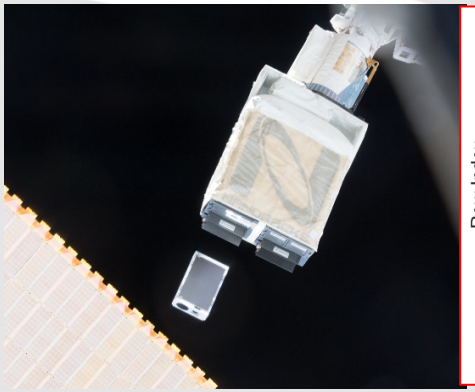
ASTERIA – hunting exoplanets one star at a time

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

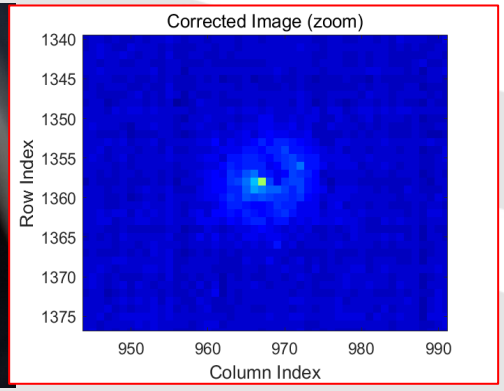
Arcsecond Space Telescope Enabling Research in Astrophysics (ASTERIA)

- ✓ 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

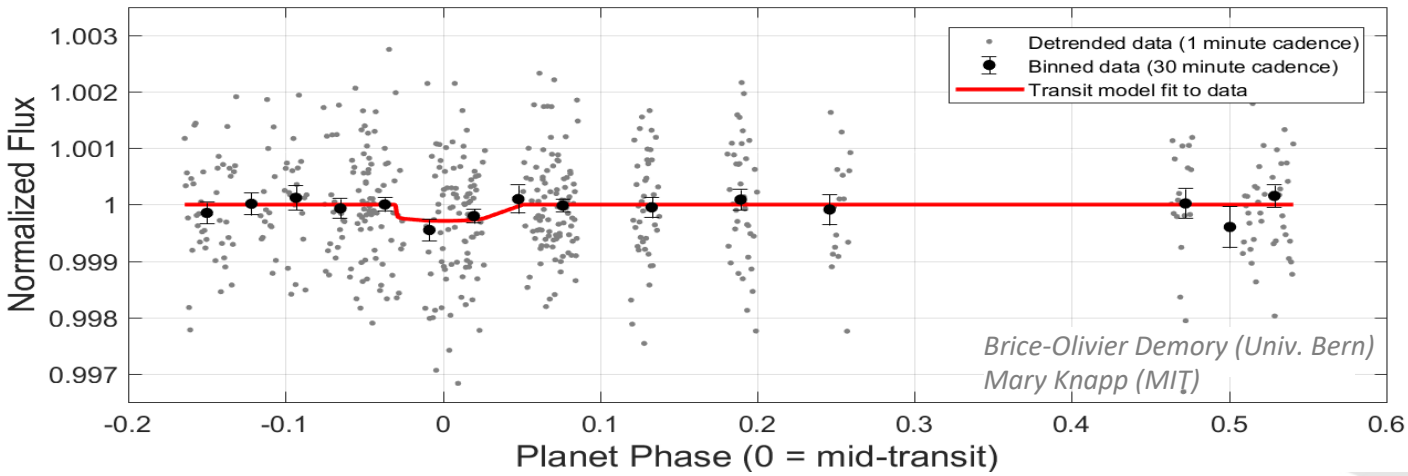
11/17: Deployed from ISS



12/17: First Image



ASTERIA 55 Cancri e Transit Light Curve



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

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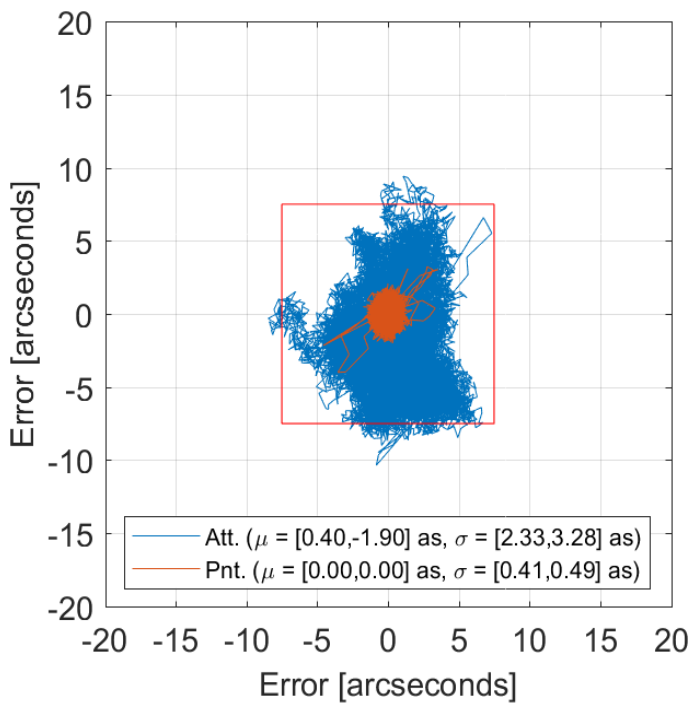
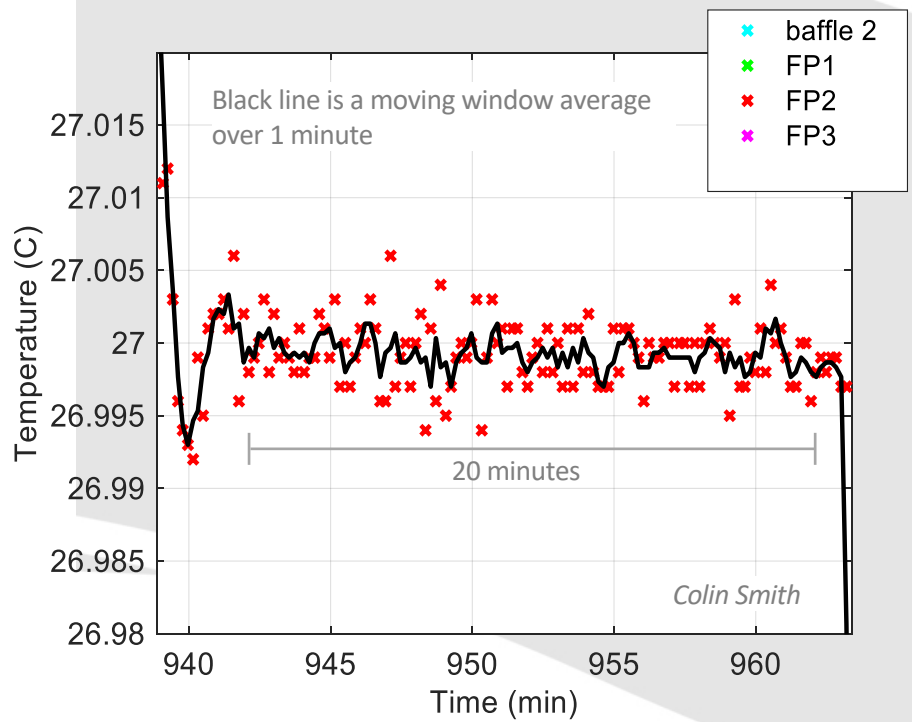
ASTERIA - Pointing and Thermal Control

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





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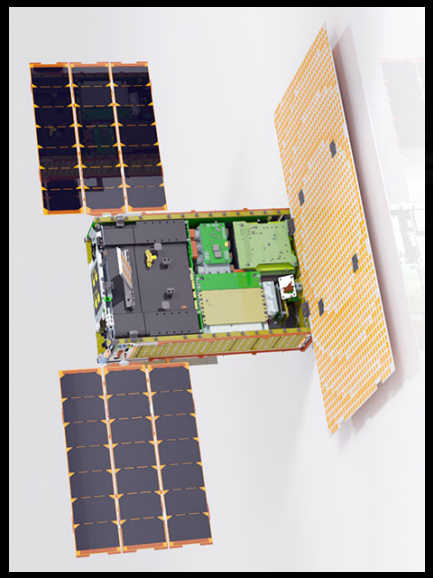
MarCO – the first Interplanetary Cubesats



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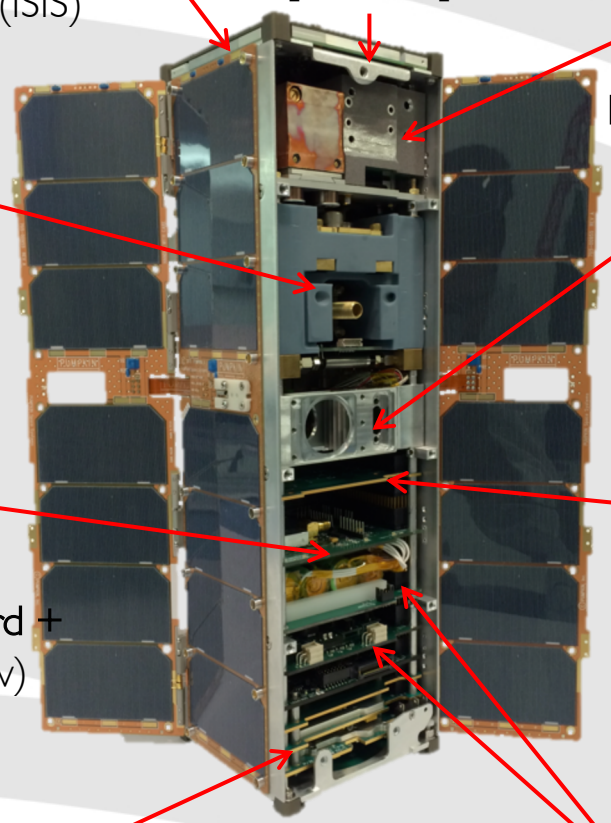
INSPIRE – Pathfinder for MarCO
[still on the shelf]

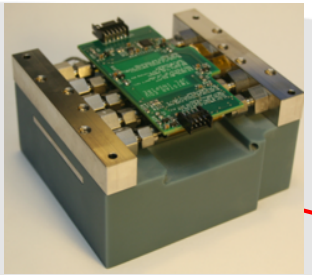
Ready for launch since 2014



UHF Antenna (ISIS)

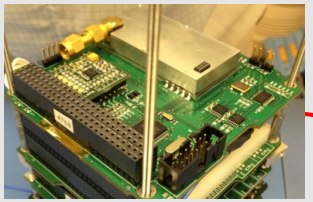
X-Band Patch Antennas (JPL) [two sets]

Magnetometer (JPL)



Cold-Gas ACS (U. Texas)

Star Tracker (Blue Canyon)

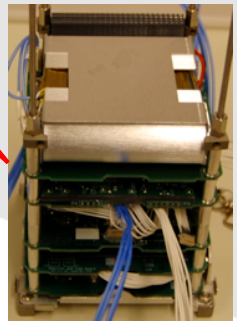


C&DH + Watchdog Board + Lithium UHF (AstroDev)

Processing Board (CalPoly / Tyvak)

Nav/Comm X-Band Radio (JPL)

Deployable Solar Panels (Pumpkin) Structure (JPL)



Electrical Power System + Battery Board (U. Michigan)

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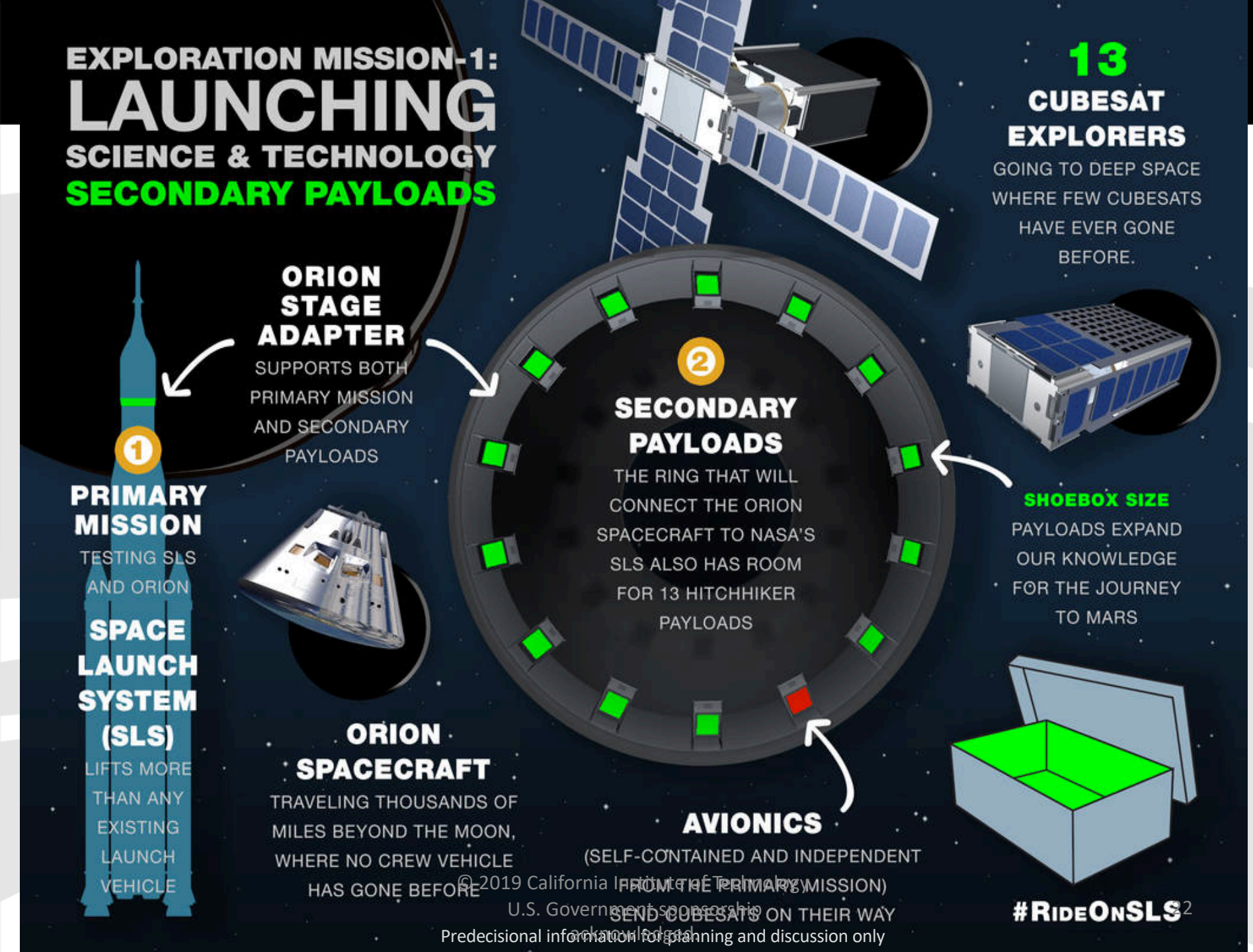

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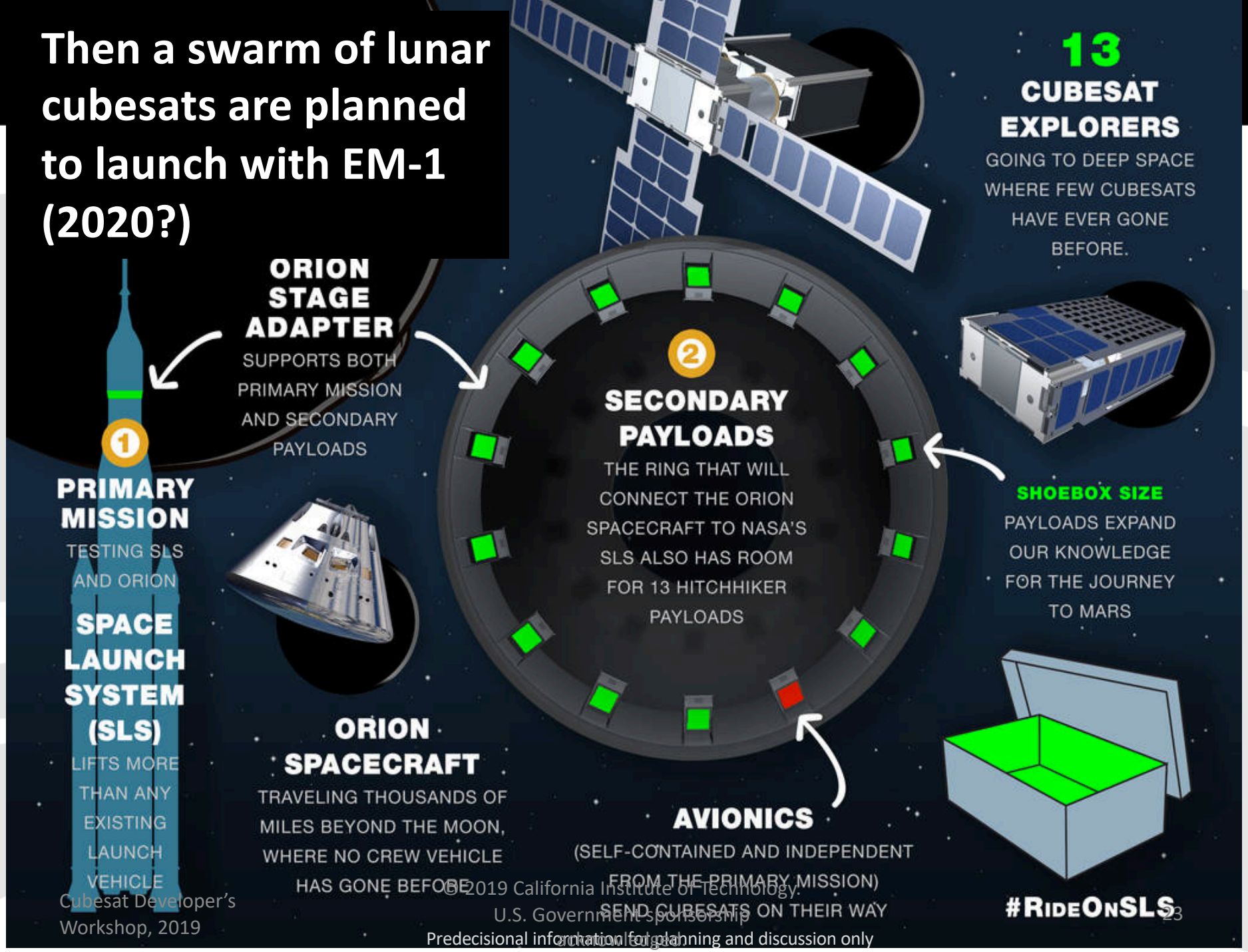
Then a swarm of lunar cubesats are planned to launch with EM-1 (2020?)



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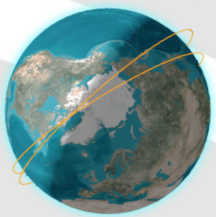
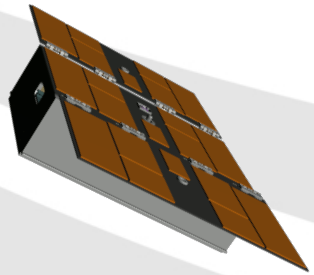
Predecisional information for planning and discussion only

PREFIRE - PolaR Energy in the Far InfraRed Experiment

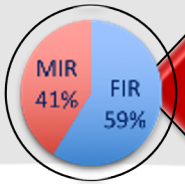
PI: Tristan L'Ecuyer, UWisc Slide courtesy Brian Drouin, JPL



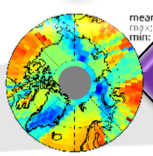


- ✓ Two 3-U CubeSats in asynchronous polar orbits
- ✓ Miniaturized IR spectrometer

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



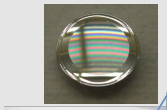
Nearly 60% of Arctic emission occurs at wavelengths > 15 μm (FIR) that have never been systematically measured.

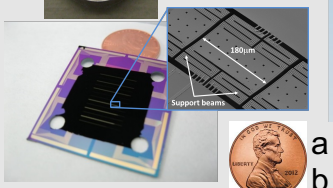


PREFIRE improves Arctic climate predictions by anchoring spectral FIR emission and atmospheric GHE

Planned launch in 2021

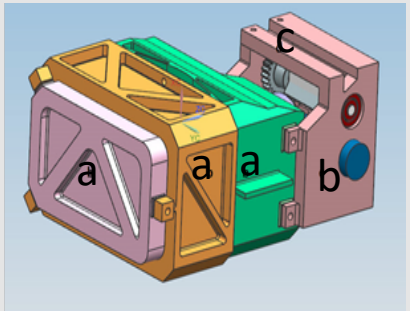
GRATING





THERMOPILE

2U Thermal IR Spectrometer



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

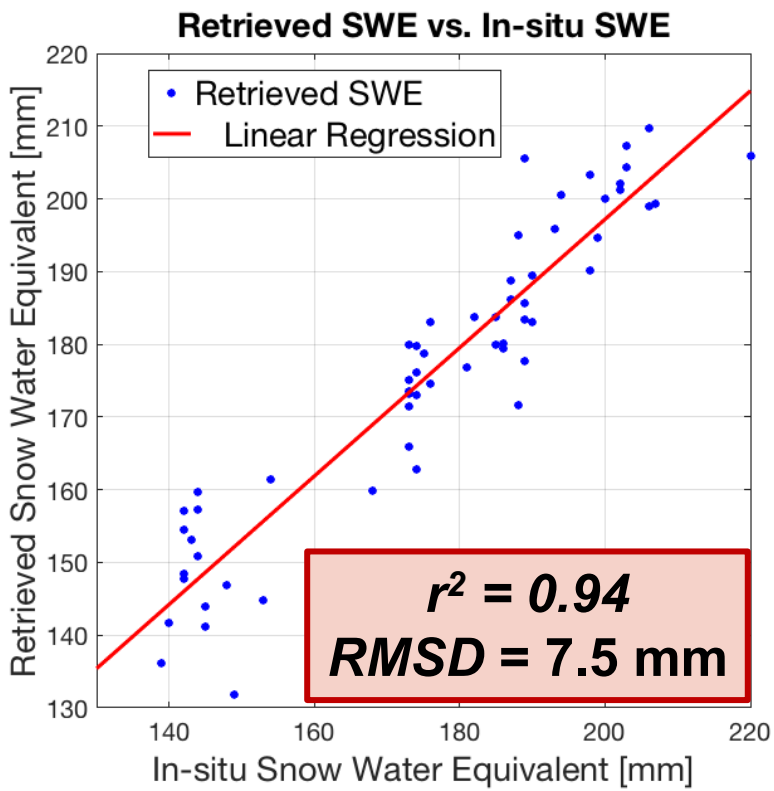
Thermopile array	Spectral resolution	Spatial coverage	Mass	Data rate	Power peak/avg
64 × 8 pixels	0.84 μm from 0–45 μm	8 cross-track pixels with 1.2° footprints	0.97 kg	35 kbps	6.74 / 1.74 W

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

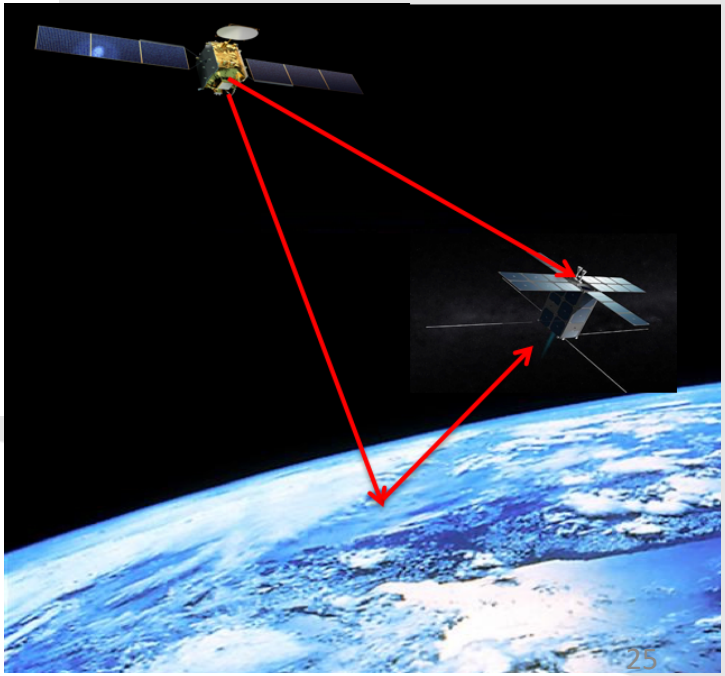
SNoOPI – SIGNALS OF OPPORTUNITY INVESTIGATION

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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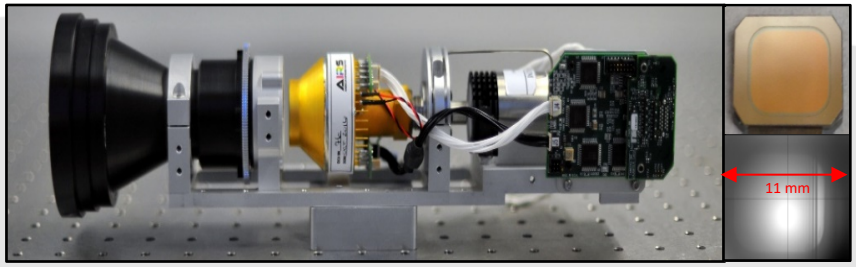
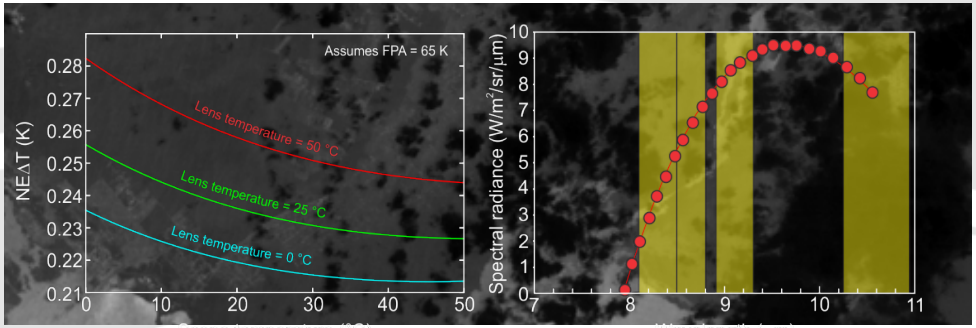
HYTI

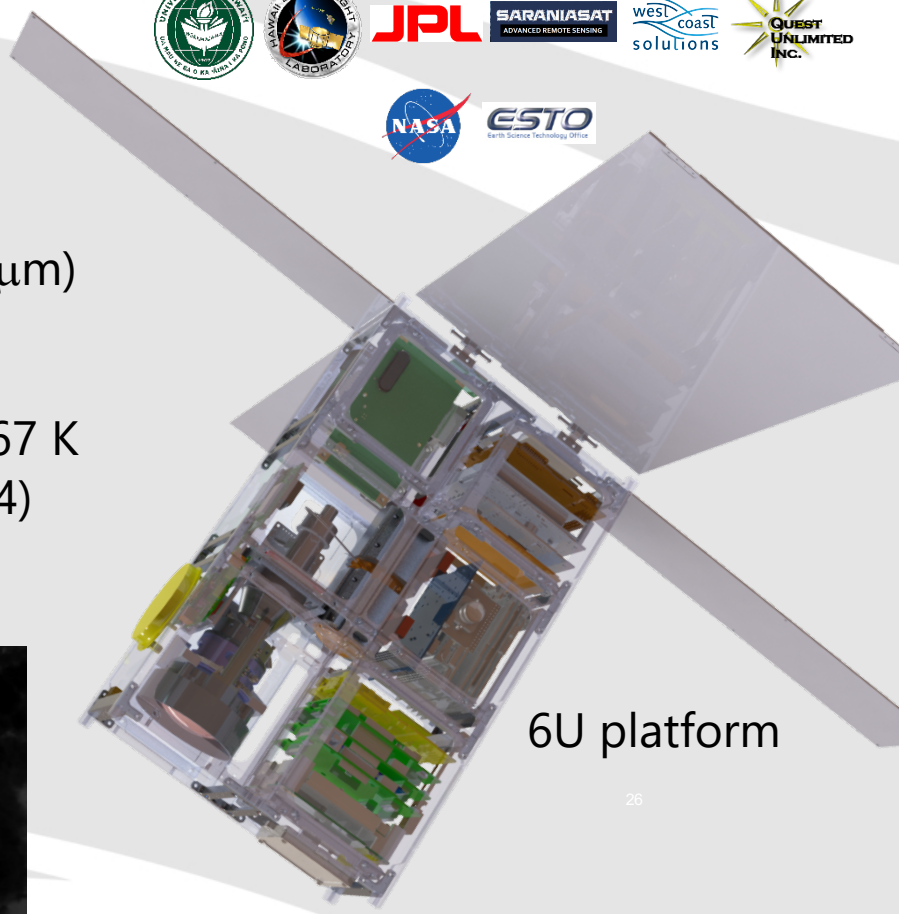
Hyperspectral Thermal Imager

Slide courtesy PI Rob Wright, UHI



- High spectral resolution (25 bands, 8-10.5 μm)
- 70 m spatial resolution; 30 km swath
- Fabry-Perot interferometer (inset, top)
- JPL's BIRD FPA inside the dewar, cooled to 67 K
- Single multi-element refractive lens (f#/3.44)
- Data acquired at 157 frames per second
- Delivery for launch Oct 2020





6U platform

Govt. Cubesat Forum, 2019

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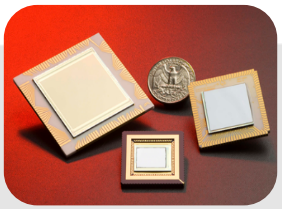
CubeSat IR Atmospheric Sounder (CIRAS) [canceled but back in the game]

Slide courtesy
Tom Pagano, JPL

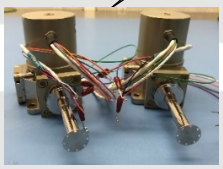
FPA HOTBIRD (JPL)

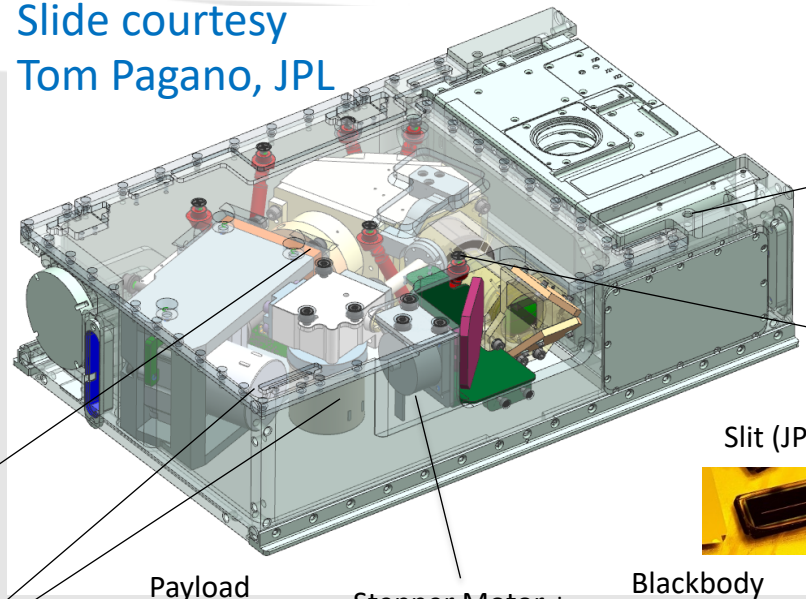


Camera Electronics (IR Cameras)

Dewar (IDCA) (IR Cameras)

Cryocoolers + Electronics (Ricor K508N)

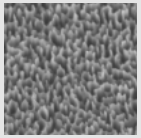




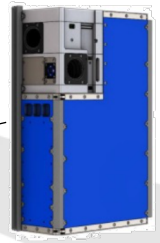
Payload Electronics

Stepper Motor + Mirror

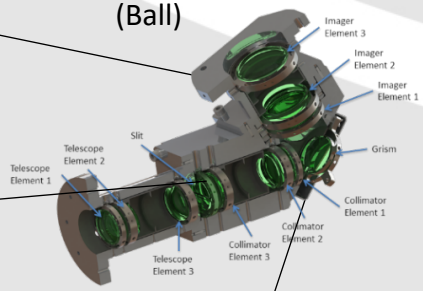
Blackbody Assembly Black Silicon



Spacecraft (BCT)

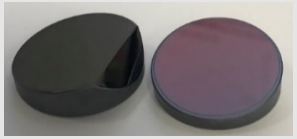


Optics Assembly (Ball)

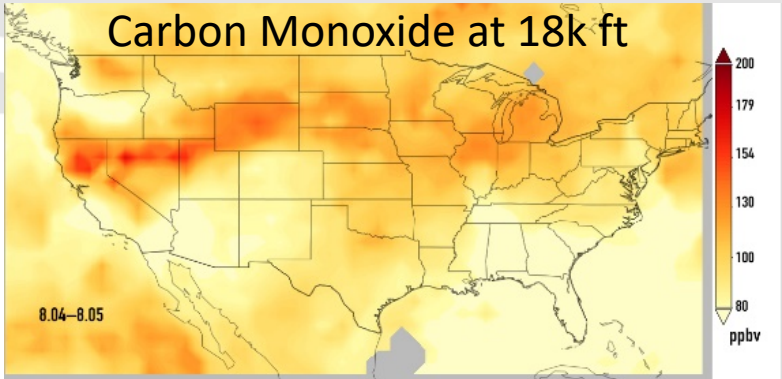


Slit (JPL)

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



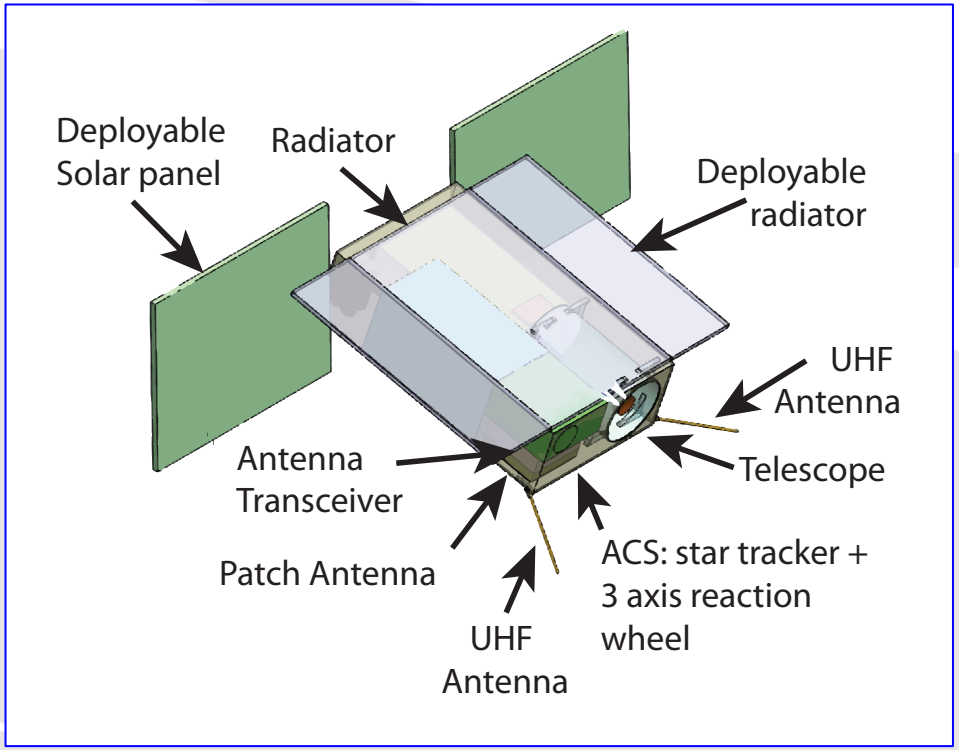
SPARCS 6U cubesat mission

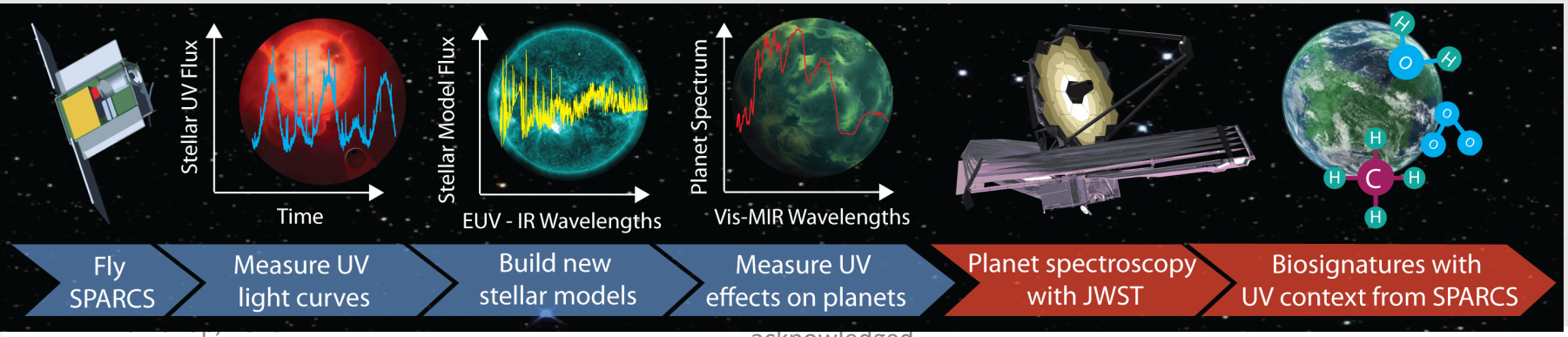
Study UV environment of exoplanets around M dwarf stars

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



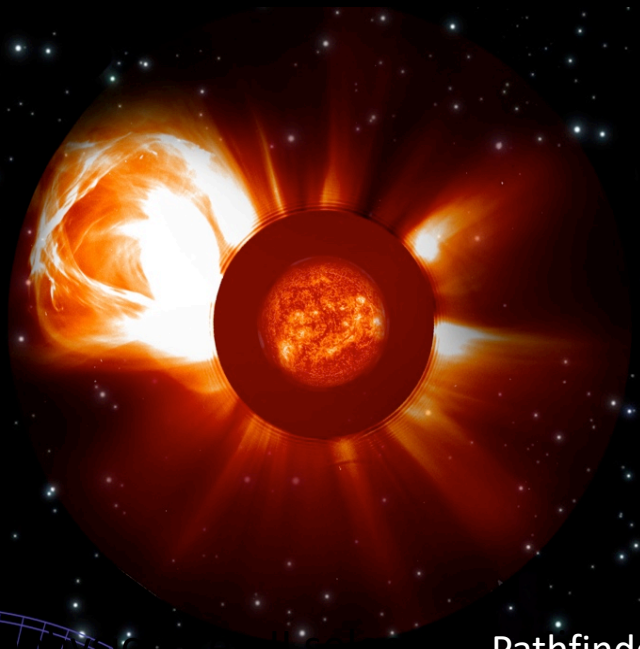


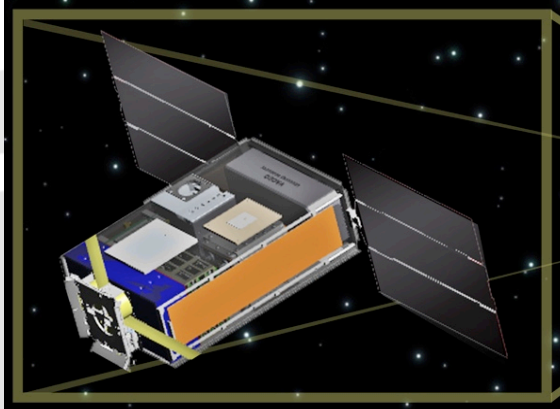
acknowledged.

SunRISE is in extended Phase A

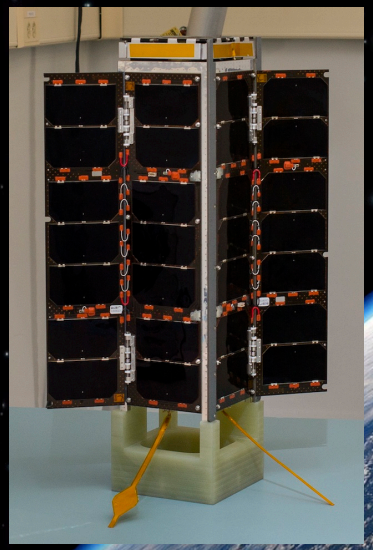
Sun Radio Imaging Space Experiment (SunRISE)

- ✓ 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)



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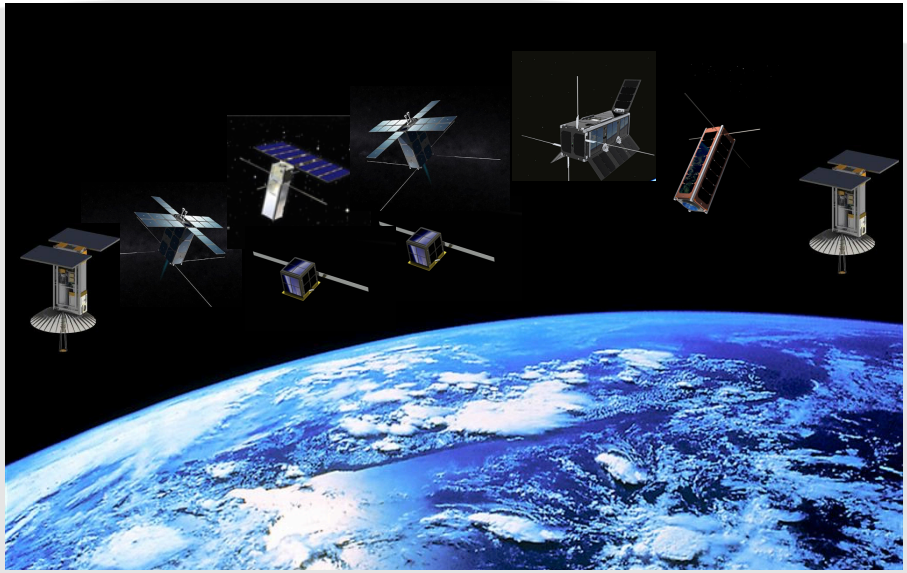
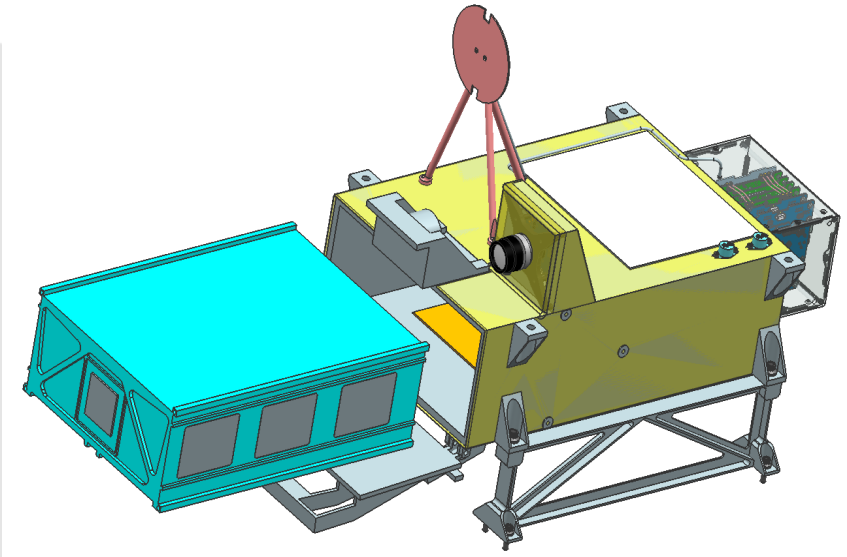
Pre-Decisional Information -- For Planning and Discussion Purposes Only

Looking at the Horizon

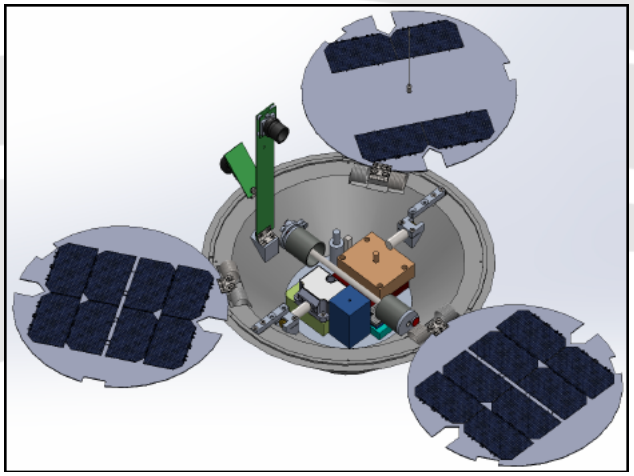
Cube-train Constellations for Earth Science



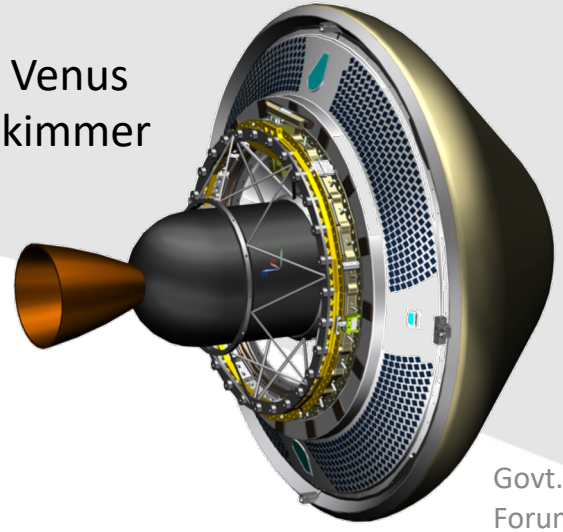
Deep Space P-Pod



MarsDrop Micro-lander



Cupid's Arrow Venus Atmosphere Skimmer



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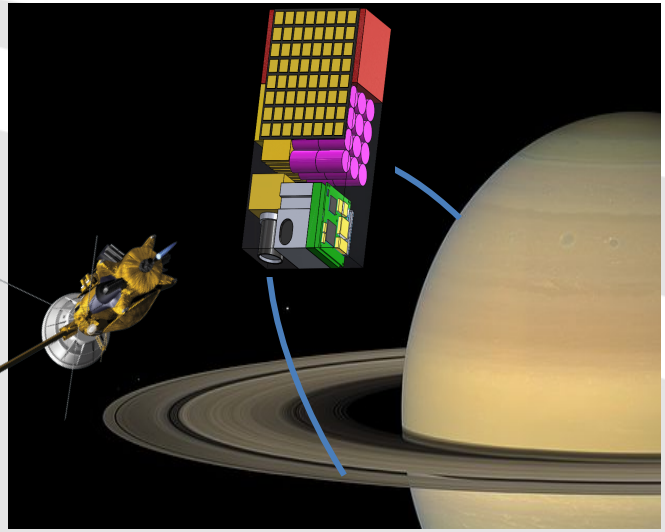
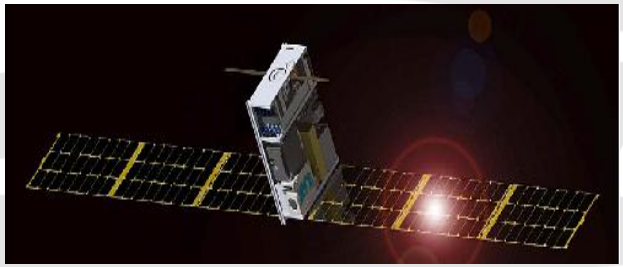
CubeSats at Saturn?

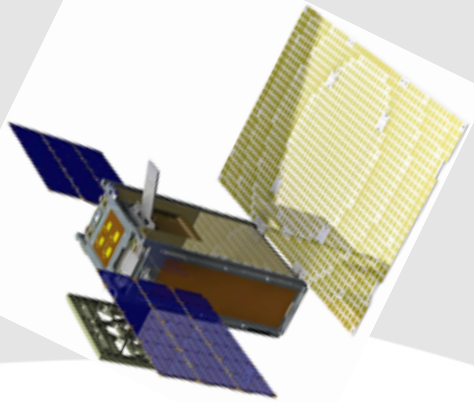
- ✓ Power – 11 days to fully charge a 200 Whr capacity battery with 1.2-2W solar power @ Saturn
- ✓ Control – need <0.003° pointing; >35°/sec slew rates
- ✓ X-Band Communications (relay to primary) with 28 dBi reflectarray
- ✓ Propulsion (chemical) – up to 250 m/s ΔV
- ✓ Thermal – compact RHUs

Saturn Ring Diver Concept





Lunar IceCube: 120 W @ Earth



MarCo 28 dBi reflectarray

1W; 40g RHU

Slide courtesy Andrew Bocher, Cal Poly SLO

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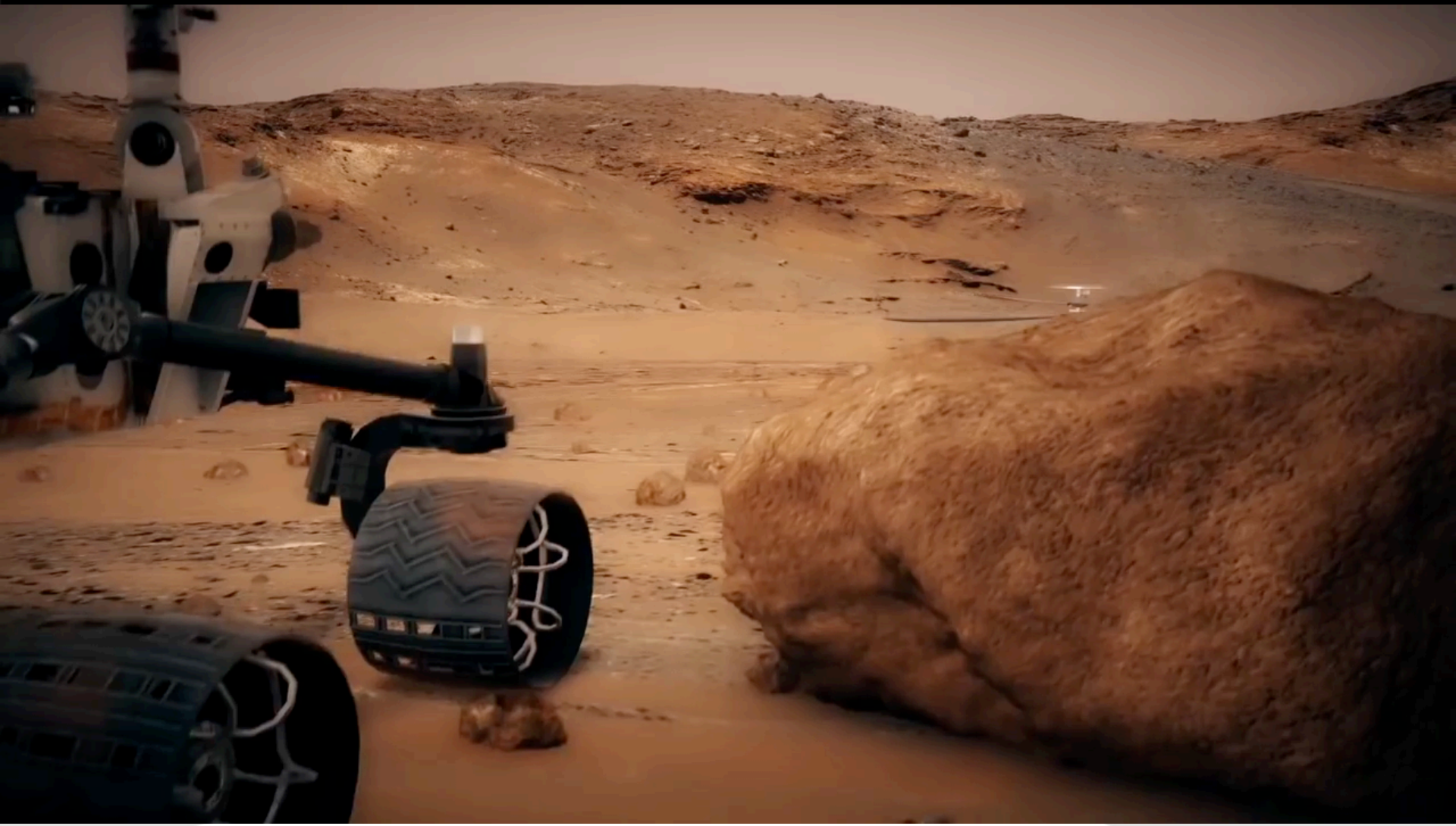
And in 2020 the Mars Helicopter…



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The CubeSat Era in Space

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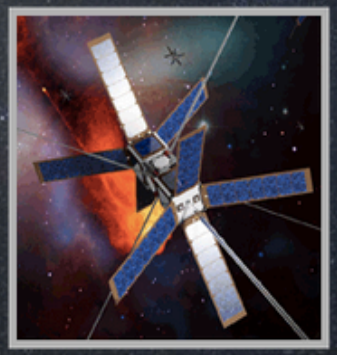

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