Jet Propulsion Laboratory
California Institute of Technology

CubeSats as a Disruptive Innovation in Exploration Science and Technology Development

Leon Alkalai, JPL Fellow

Rationale for CubeSat Development

Enable decadal-class focused science via new mission architectures including constellations and access to extreme environments

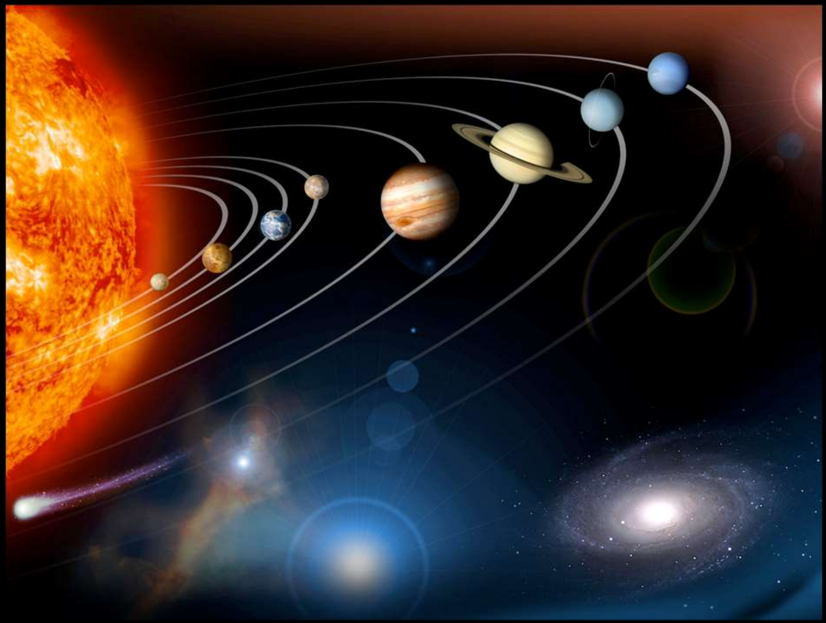
Advance new technologies to enhance the capabilities of future missions

Utilize CubeSats as a stepping-stone to more capable small satellite missions in all science areas

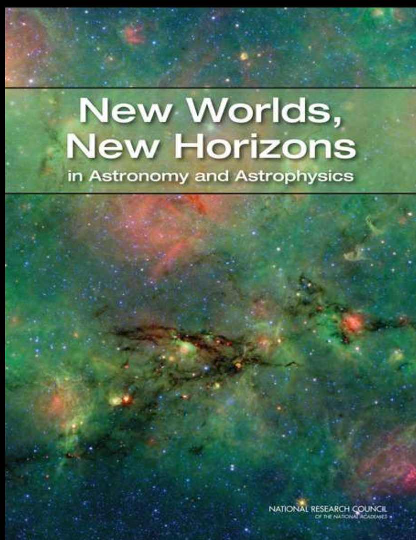
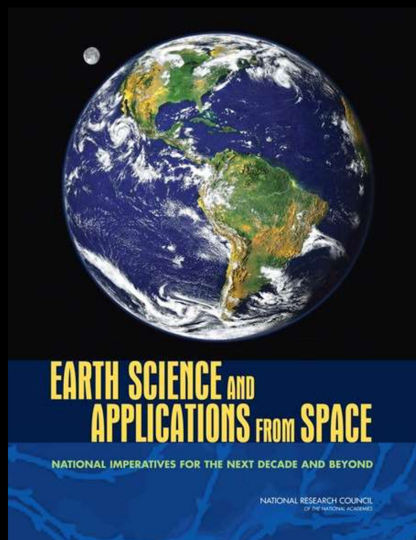
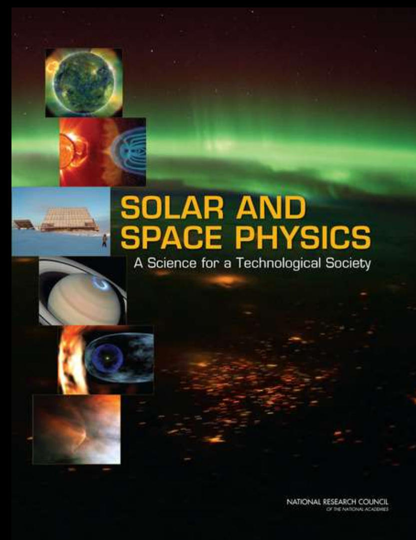
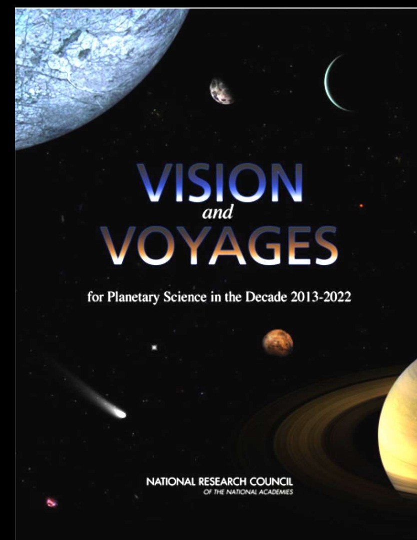
Develop the next generation of explorers and revitalize the existing ones

Increase the pace of scientific discovery and technology maturation within a constrained budget environment

Enhance the science return of future flagship missions



The Decadal Surveys

Astrophysics	Earth Science	Heliophysics	Planetary
			
2012 – 2021	2007 – 2016	2012 – 2021	2013 – 2022

Organized by the National Academies on behalf of NASA establishing USA national priorities for scientific observations, as identified by the community, within a 10-year time frame

Spectrum of Satellite Development

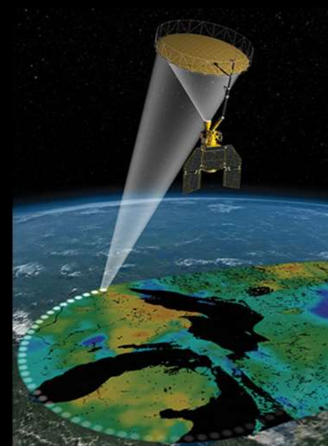
Small satellites are a growing component of space exploration

CubeSat / SmallSat

CP-6
10+ cm (linear)
1 – 180 kg
5 – 200 W

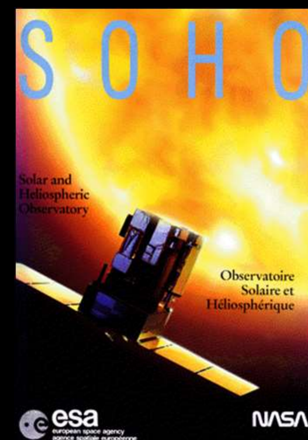
MiniSat / ESPA-Class

LCROSS
2 meters (linear)
585 kg (dry mass)
600 W



Medium-Class

SMAP
9.7 meters (linear)
944 kg
550 W (radar peak)



Large-Class

SOHO
4.3 meters (linear)
1850 kg
1,500 W

Flagship-Class

Aura
17.37 meters (linear)
2,967 kg
4,600 W

Potential of Small Satellite Measurements

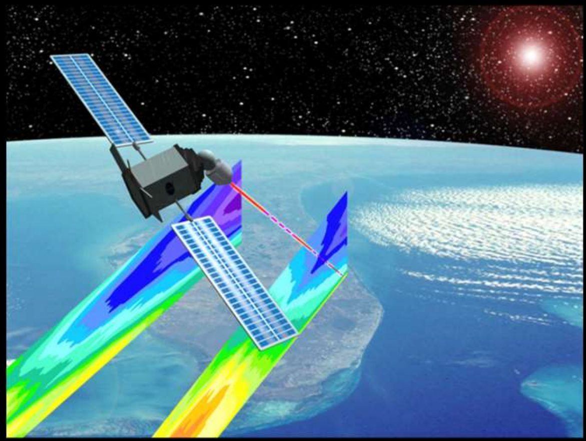
An alternative architecture to obtain global 3D wind measurements?

2007 NRC Decadal Survey identifies 3D tropospheric wind measurements as “transformational” for NWP

Significant challenges remain to deliver an operational global 3D Lidar winds mission at an acceptable cost

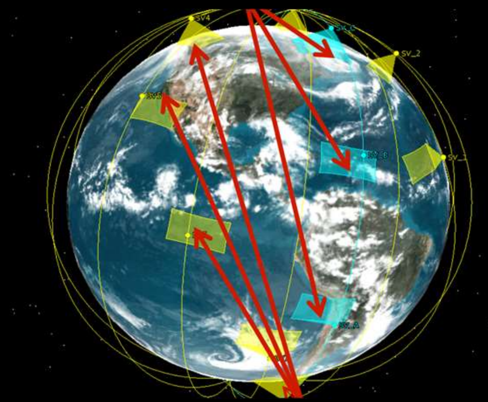
The proposed “MISTiC Winds” approach is to use a series of low-cost micro-satellites in a string of pearls constellation to provide global tropospheric IR profiles of temperature and humidity at high resolution

The rapid refresh rates from the constellation would enable global 3D winds from the troposphere



Recent Concept: Global Wind Observing Sounder (GWOS)

Would consist of a coherent aerosol Doppler receiver with a direct detection molecular Doppler receiver



Midwave IR Sounding of Temperature and Humidity in a Constellation (MISTiC) Winds

27U Instrument on ESPA Constellation in LEO may offer lower cost/risk than alternatives

PI: Kevin Maschoff (BAE Systems)

The NRC Achieving Science Goals With CubeSats Study

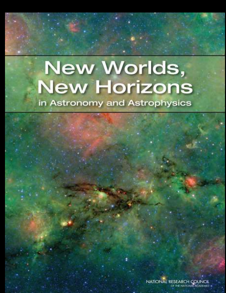
Key elements of charge to the committee

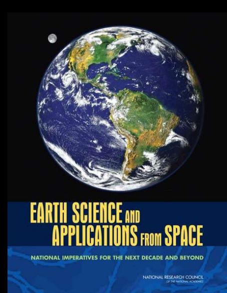
Review the current state of scientific potential and technological promise of CubeSats

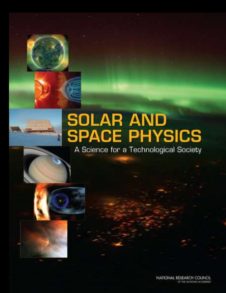
Review the potential of CubeSats as platforms for obtaining high-priority science data

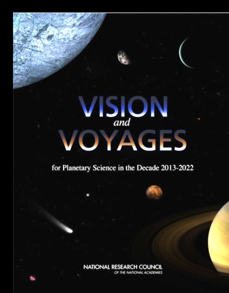
- From recent decadal surveys
- Science priorities from 2014 NASA science plan

Provide a set of recommendations on how to assure scientific return on future federal agency support of CubeSat programs









The NRC Achieving Science Goals With CubeSats Study

CubeSats as a Disruptive Innovation

"Process by which a product or service takes root initially in simple applications at the bottom of a market and then relentlessly moves up the market […]." Clayton Christensen, 1995

Describes many shifts in targeted markets of the economy:

- Emergence of laptops over desktop computers, but supercomputers still exist
- Smartphone cameras replace low-end camera, but high-end cameras still exist

CubeSat exemplify Disruptive Innovation:

- (Initially) poorer performance, lower cost, emerged from non-traditional sources, driven by enabling technologies, matured and developed in new ways.
- Need not replace mainstream technology
- The "end-state" and level of disruption remains unclear

The NRC Achieving Science Goals With CubeSats Study

NASA (57 Missions / 80 CubeSats) and NSF (15 Missions / 24 CubeSats) [2015]

	Funding Program	CubeSat Missions Launched	CubeSat Missions Planned	Launch Years
NASA	Heliophysics	MinXSS	CeREs, CuSP, ELFIN-STAR,[a] HeDI, SORTIE, TBEx	2015-2018+
NASA	Earth Science	GRIFEX, IPEX, MCubed/COVE (2)	CIRAS, CIRiS, CubeRRT, HARP, IceCube, LMPC, MiRaTa, RainCube, RAVAN, TEMPEST-D	2011-2018+
NASA	Planetary Science	O/OREOS	INSPIRE (2), LunaH-Map, MarCO (2), Q-PACE Technology Development Only: DAVID, HALO, MMO	2010-2018+
NASA	Astrophysics		HaloSat	2018
NASA	Advanced Exploration Systems and Human Exploration and Operations	GeneSat, PharmaSat, SporeSat (2)	BioSentinel, EcAMSat, Lunar Flashlight, Lunar IceCube, NEA Scout, Skyfire	2006-2018+
NASA	Space Technology	EDSN (8),[b] NODeS (2), OCSD-A, PhoneSat (5)	CPOD (2), CSUNSat-1, ISARA, iSAT, OCSD (2)	2013-2017
NASA	Centers (Internal)			2008-2018+
NASA	Ames Research Center	PreSat,[c] TechEdSat (3)	KickSat	
NASA	ARC and Marshall Space Flight Center	NanoSail-D (2)		
NASA	Goddard Space Flight Center		CANYVAL-X, Dellingr, ESCAPE, RBLE	
NASA	Jet Propulsion Laboratory	LMRST, RACE[d]	ASTERIA, MITEE	
NASA	Kennedy Space Center		Cryocube, StangSat	
NASA	NASA IV&V Facility		STF-1	
NSF	National Science Foundation	CADRE, CSSWE, CINEMA-1, DICE (2), ExoCube, FIREBIRD (4), Firefly, RAX (2)	ELFIN, ISX, IT-SPINS, LAICE, OPAL, QBUS/QB50 (4), TRYAD (2)	2010-2018+

a) ELFIN is now jointly funded by NASA/NSF as ELFIN-STAR, b) Super-Strypi launch failure, c) Falcon-1 launch failure, d) Antares launch failure

The NRC Achieving Science Goals With CubeSats Study

Sample Near-Term Science Opportunities

Earth Science

- Multi-point high temporal resolution of Earth processes
- Mitigation of data gaps and continuous monitoring

Solar and Space Physics (Heliophysics)

- Measurement of plasma processes in the magnetosphere-ionosphere system

Planetary Science

- In situ investigation of planetary surfaces or atmospheres

Astronomy and Astrophysics

- Low-frequency radio science and the search for extra-solar planets

Biological and Physical Sciences

- Survival and adaptation of organisms to space

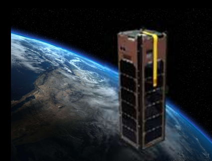
Portfolio of Missions with JPL

Externally-Led Mission

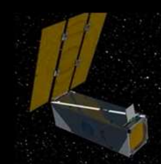
JPL-Led or with key JPL participation

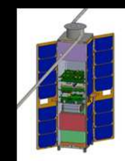

M-Cubed/COVE (2)


IPEX

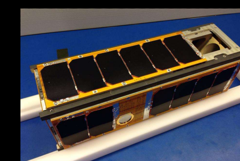

GRIFEX


CSUNSat-1


ISARA


DHFR


CuSP

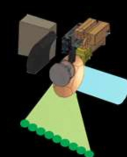

RACE

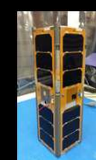

INSPIRE


CIRAS

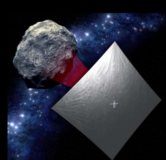

RainCube

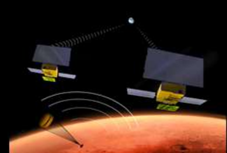

CubeRRT


TEMPEST-D


LMRST


ASTERIA


NEA Scout

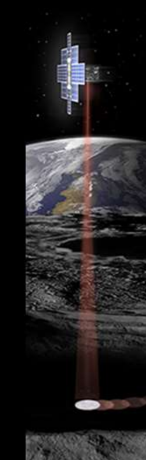

MarCO


Lunar IceCube


LunaH-Map


AAREST


MiTEE


Lunar Flashlight

RainCube

Ka-Band Precipitation Radar

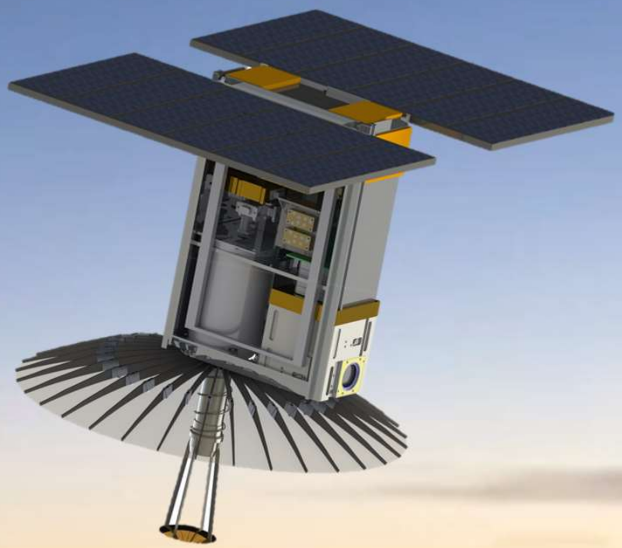
Design Capability

1st CubeSat radar capability at 20 dBZ or better

Spatial: 10km (Horiz) x 250m (Vert)
Spectral: 35.75 GHz
SWAP: 6U, <20 kg, <50W, <100 kbps

Key Technologies

Ka-Band deployable antenna, Offset IQ processing capability



Enables precipitation profiling down to the near-surface, at all latitudes, and at various sub-daily scales

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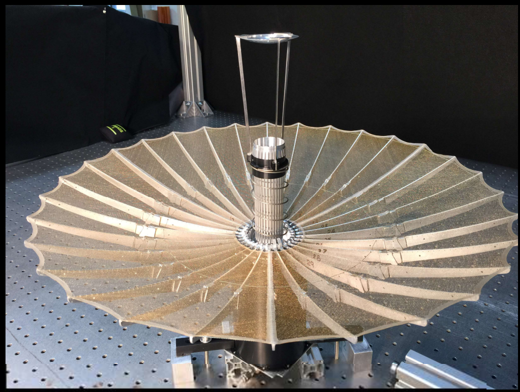
NASA

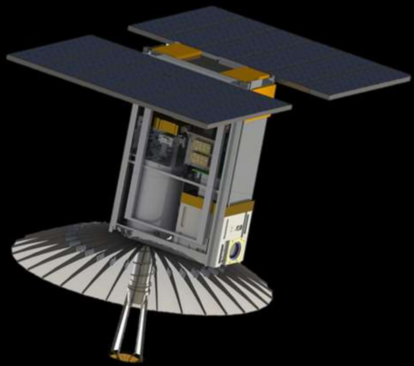
ESTO
Earth Science Technology Office

KaPDA Antenna Deployment

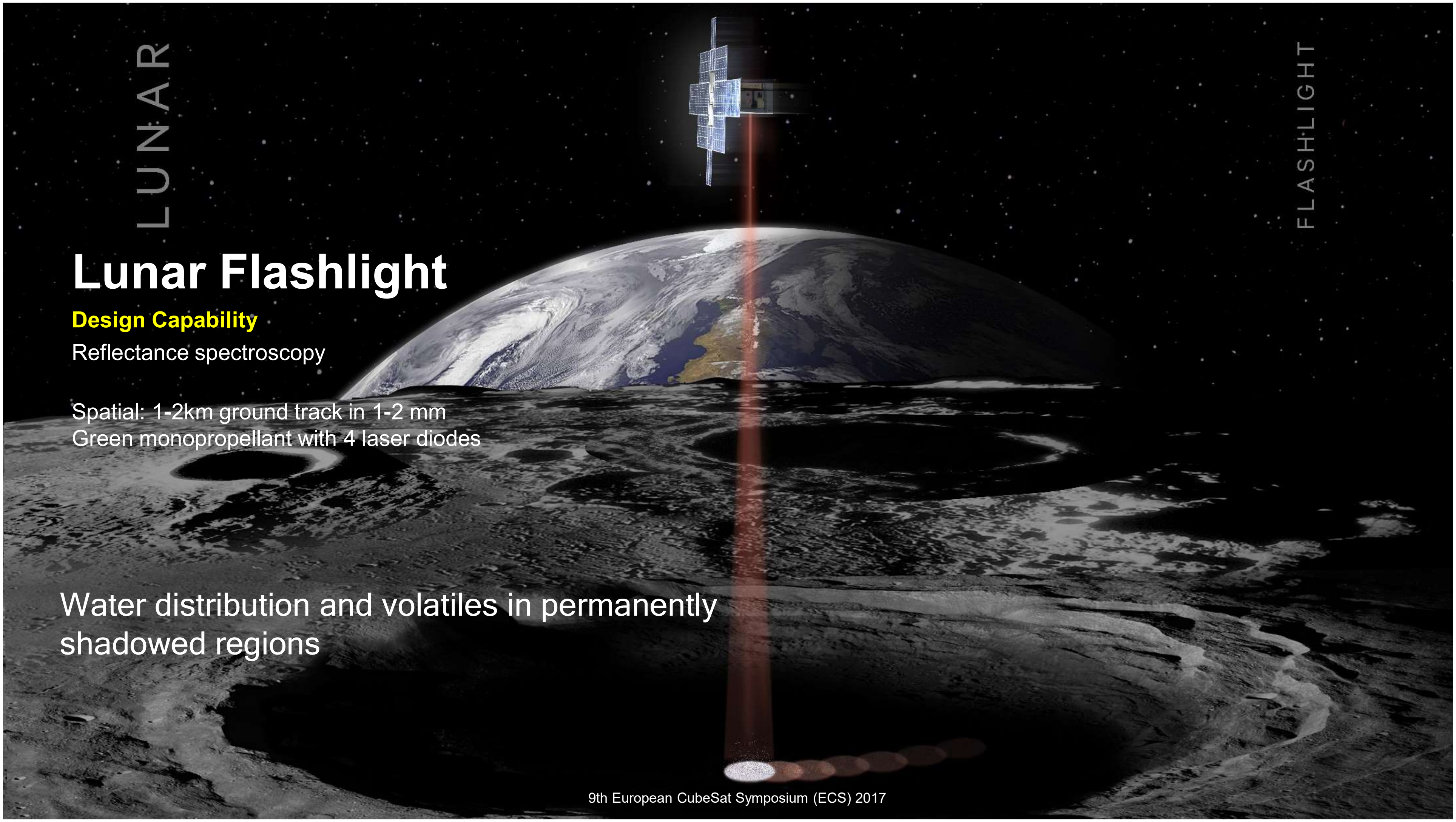
0.5 meter Ka-Band antenna development for RainCube

16x
speed





Courtesy: Jonathan Sauder, JPL


LUNAR
FLASHLIGHT
Lunar Flashlight
Design Capability
Reflectance spectroscopy
Spatial: 1-2km ground track in 1-2 mm
Green monopropellant with 4 laser diodes
Water distribution and volatiles in permanently shadowed regions
9th European CubeSat Symposium (ECS) 2017

Infrared Sounding

Captures severe weather events and improves operational forecasts

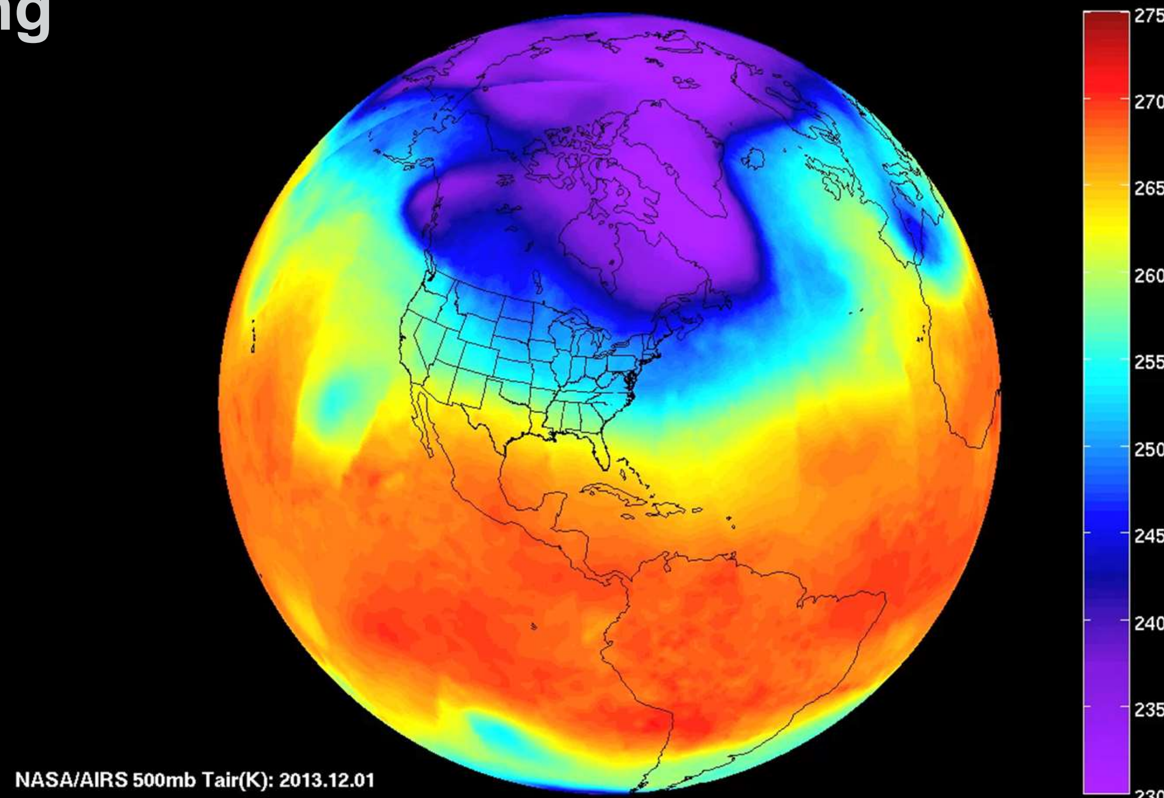
Polar vortex of 2013-2014

Dec 4, 2013: Denver weather: Temperature hits minus 13 — record low for the date

Dec 24, 2013: Record Low Tied at Cedar Rapids This Morning | Iowa Weather Blog

Jan 6, 2014: Chicago Record Low Temperature: City Hits -16 Mark

Jan 29, 2014: Atlanta, Georgia, historic weather for the past week



Courtesy: Tom Pagano, JPL

CIRAS

Infrared Atmospheric Sounder

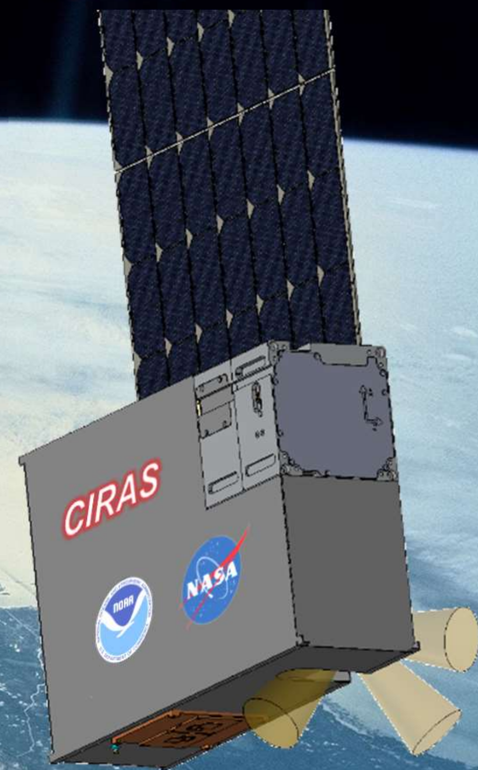
Design Capability

Accuracy comparable to legacy IR sounders, e.g. AIRS on AQUA and CrIS on JPSS, but only in the lower troposphere (< 300 mb)

Spatial: FOV: 15° , GSD: 13.5 km
Spectral: 625 Channels, 4.9-5.1 μm
SWAP: 6U, <14 kg, <50 W, <2 Mbps

Key Technologies

MWIR grating spectrometer, HOT-BIRD detectors, cryocoolers, black silicon IR blackbody



Enables capability to measure spectrum of upwelling infrared radiance from the Earth (temperature and water vapor profiles)

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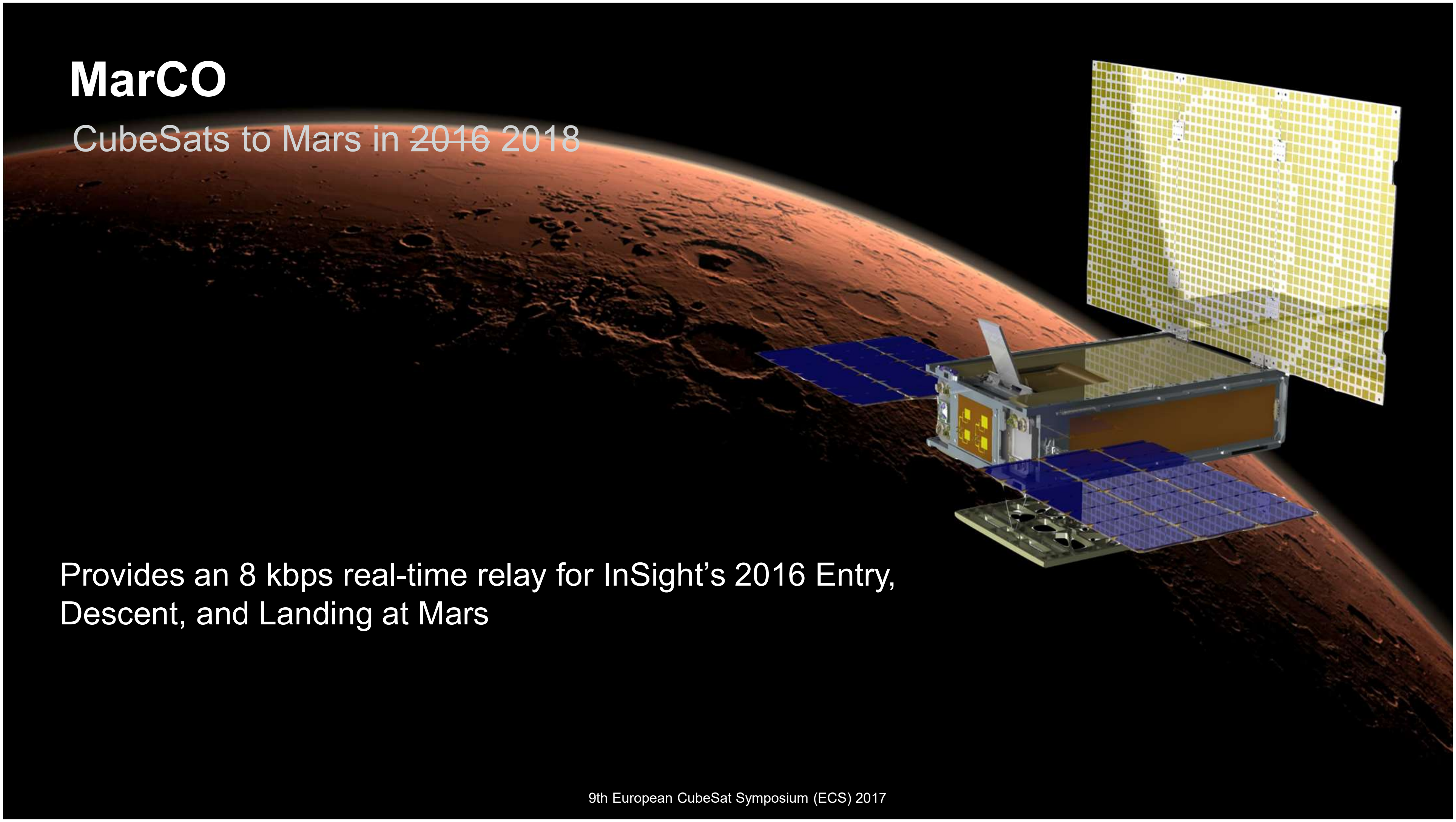
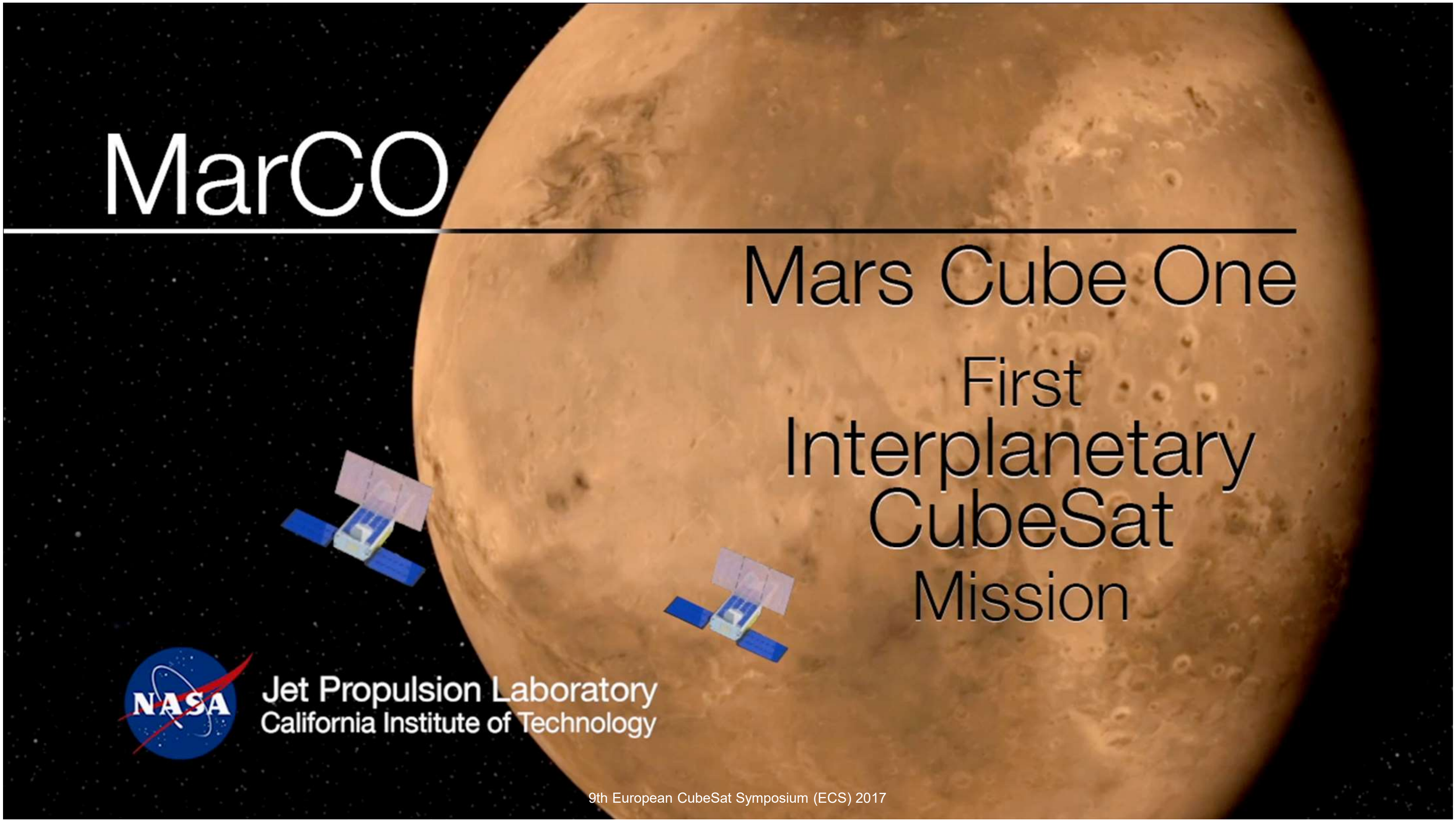
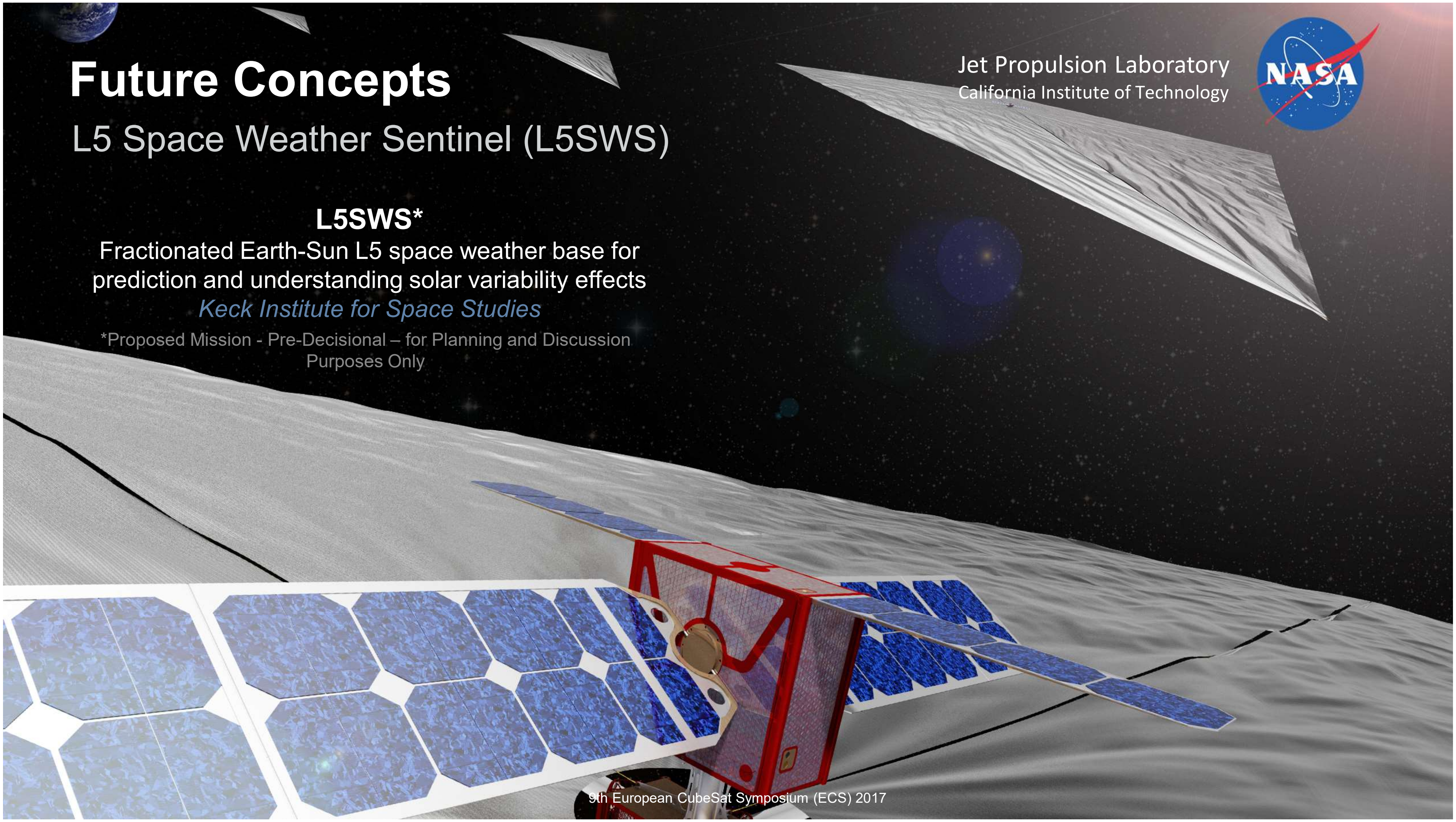
ESTO
Earth Science Technology Office

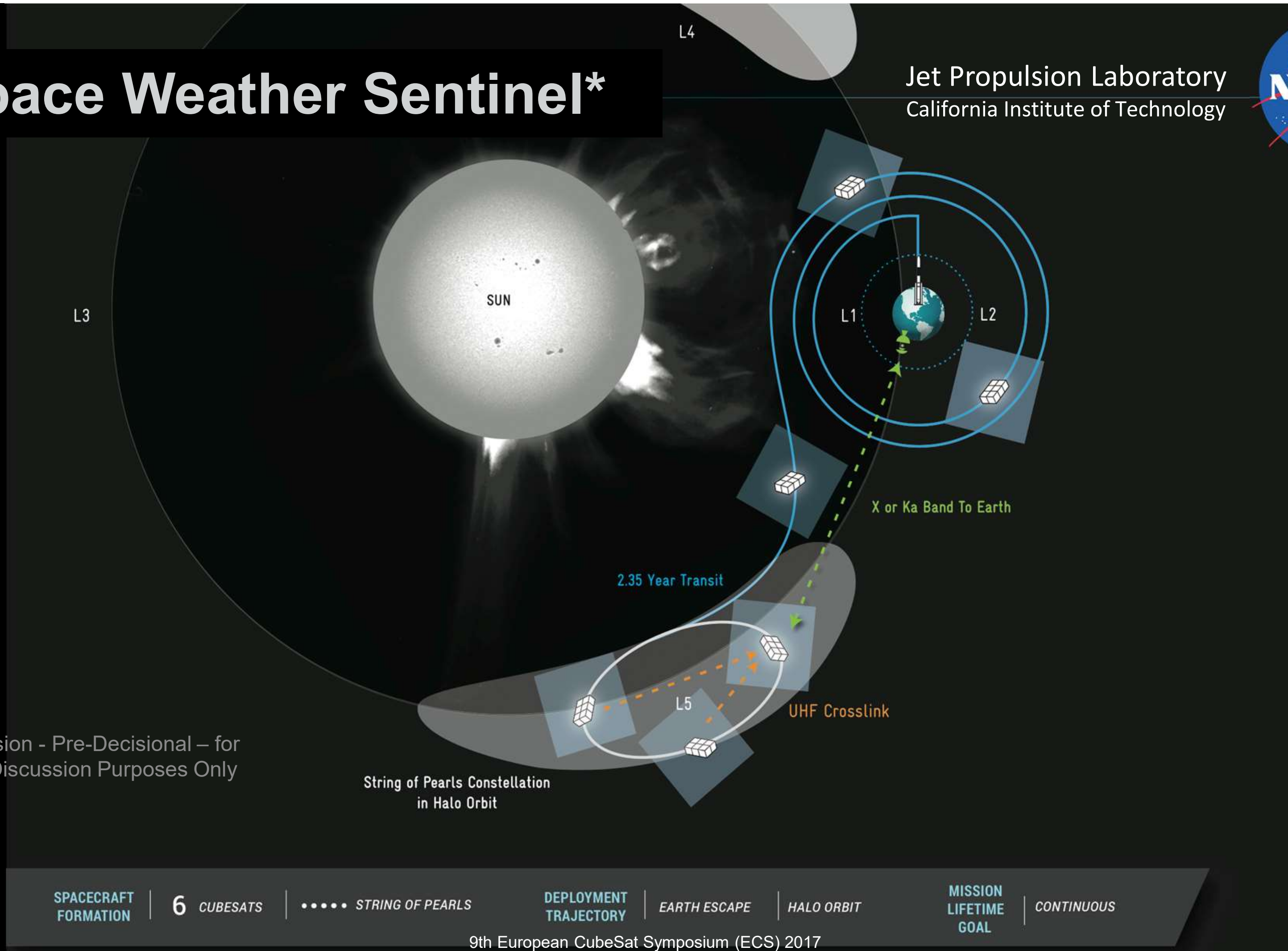

MarCO
CubeSats to Mars in ~~2016~~ 2018
Provides an 8 kbps real-time relay for InSight’s 2016 Entry, Descent, and Landing at Mars
9th European CubeSat Symposium (ECS) 2017


MarCO
Mars Cube One
First
Interplanetary
CubeSat
Mission
NASA
Jet Propulsion Laboratory
California Institute of Technology


Future Concepts
L5 Space Weather Sentinel (L5SWS)
Jet Propulsion Laboratory
California Institute of Technology
NASA
L5SWS*
Fractionated Earth-Sun L5 space weather base for prediction and understanding solar variability effects
Keck Institute for Space Studies
*Proposed Mission - Pre-Decisional – for Planning and Discussion Purposes Only
9th European CubeSat Symposium (ECS) 2017

L5 Space Weather Sentinel*

Jet Propulsion Laboratory
California Institute of Technology



*Proposed Mission - Pre-Decisional – for Planning and Discussion Purposes Only

Closing Comments

NASA's recent investments, such as TROPICS, show the potential of CubeSats as a disruptive technology

TROPICS – NASA EVI-3 Award (March 10, 2016)

PI: Bill Blackwell

MIT Lincoln Labs

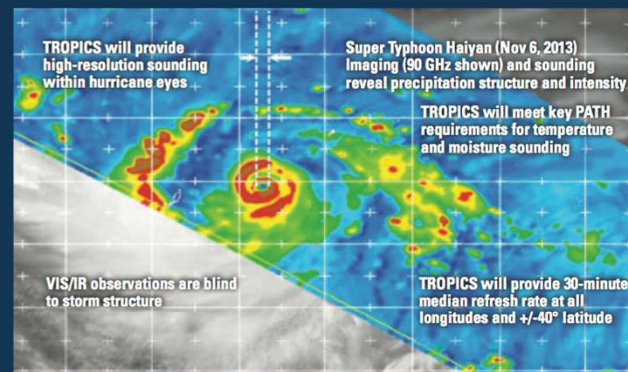
12 satellite constellation for Time Resolved Observations of Precipitation Structure and Storm Intensity

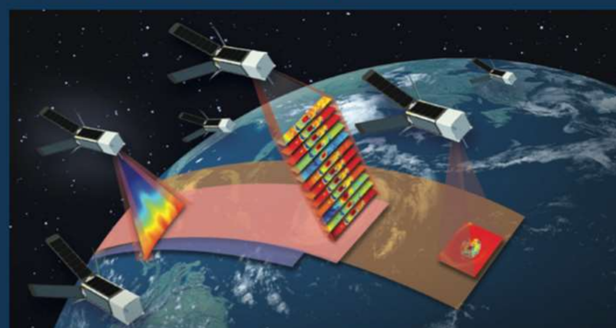
TROPICS

Time-Resolved Observations of Precipitation structure and storm Intensity with a Constellation of Smallsats

Science Objectives

- Relate precipitation structure evolution, including diurnal cycle, to the evolution of the upper-level warm core and associated intensity changes
- Relate the occurrence of intense precipitation cores (convective bursts) to storm intensity evolution
- Relate retrieved environmental moisture measurements to coincident measures of storm structure (including size) and intensity
- Assimilate microwave radiances and/or retrievals in mesoscale and global numerical weather prediction models to assess impacts on storm track and intensity





12 identical 3U CubeSats provide sounding (left CubeSat has a temperature profile of a simulated Tropical Cyclone (TC) from a Numerical Weather Prediction (NWP) model) and 12-channel radiometric imagery (center CubeSat has simulated radiances from NWP model and radiative transfer model and the near right CubeSat has a single channel radiance image of a TC) with 30-minute median revisit rate to meet most PATH requirements.

Significance to NASA

- First high-revisit microwave nearly global observations of precipitation, temperature, and humidity
- Fulfills most of PATH Decadal Survey mission objectives using a low-cost, easy-to-launch CubeSat constellation
- Complements GPM, CYGNSS, and GOES-R missions with high refresh, near-all-weather measurements of precipitation and thermodynamic structure
- Increases understanding of critical processes driving significant and rapid changes in storm structure/intensity

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jpl.nasa.gov