JPL's Advanced Interplanetary CubeSat Concepts for Science and Technology Demonstrations

ISSC 2015

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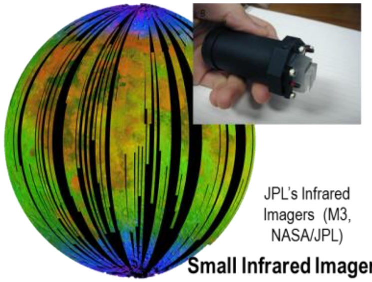
Motivation for Planetary Small Spacecraft

Planetary small spacecraft (e.g. CubeSats) that fly as secondaries and are deployed at destinations to perform missions and communicate via mothership or direct to Earth

- Planetary Science and Exploration Value:
  - Enhance primary's science objectives
  - Enable new science and exploration in new, potentially dangerous environments
- Novel Technology Demonstrations:
  - Enable testing new instruments or measurements in deep space
  - Mature technologies (hardware/software/architectures) for small and large sats

- Leverages:
  - CubeSat community hardware/software heritage, experience
  - Miniaturized instrumentation (imagers, sensors, etc.)
  - Autonomous operations and telecommunication relays



JPL's Infrared Imagers (M3, NASA/JPL)

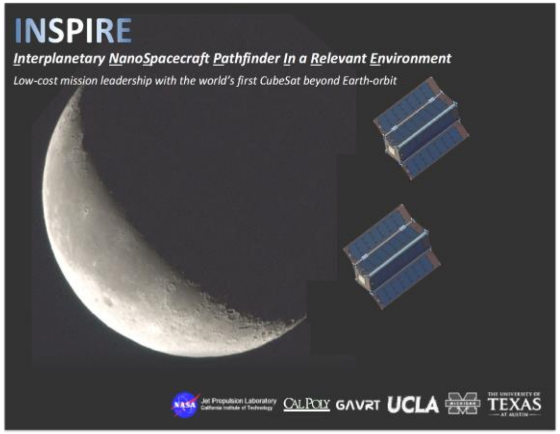
Small Infrared Imager

- Advantages of Planetary Small Spacecraft:
  - Accept higher risk by exploring dangerous/unknown environments
  - Relatively low cost ($10-$25M, < 5-10% of primary mission costs)
  - Low additive mass (5-20 kg with deployer, <10% of primary mission)

INSPIRE CubeSat
(Interplanetary)
EPS, Star Tracker

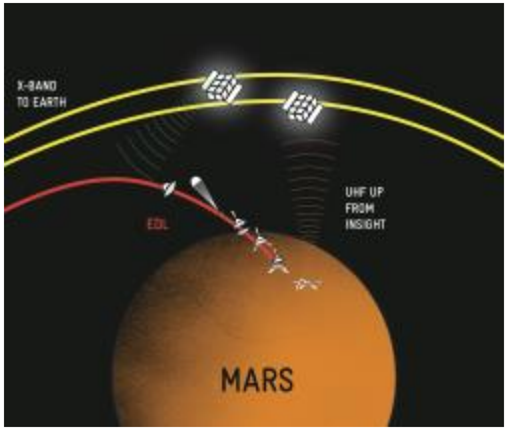
IPEX CubeSat (LEO)
On-Board Science Decision and Planning
(IPEX, NASA/JPL/CalPoly)

Active Interplanetary CubeSat Projects Provide Heritage

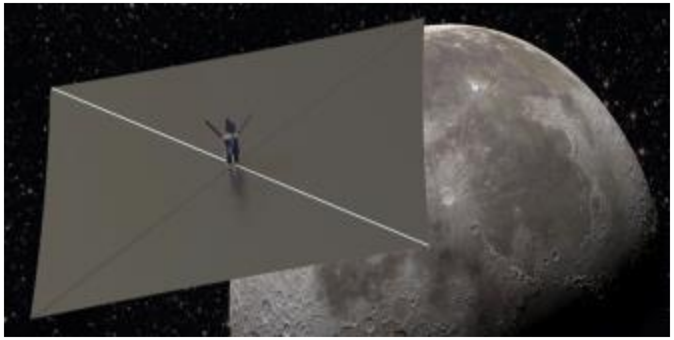


INSPIRE (JPL)[1]
Navigation demonstration with the IRIS radio beyond the Moon

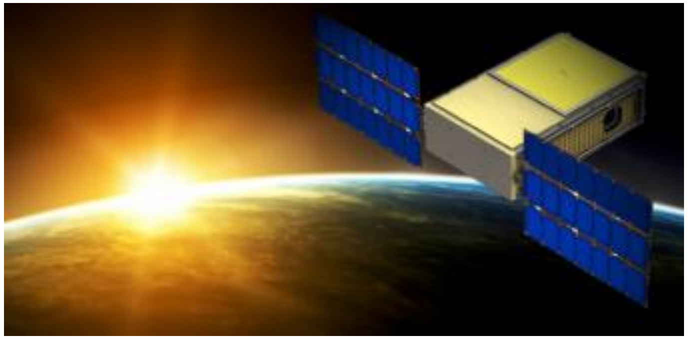
NEA Scout (MSFC/JPL) [2,3]
Asteroid characterization mission [EM-1]



MarCO (JPL)[2]
InSight insertion real-time Mars relay



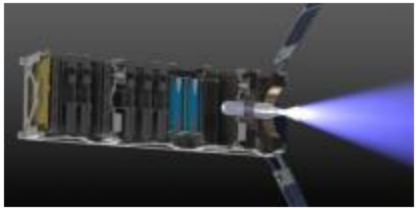
Lunar Flashlight (JPL/MSFC) [2,3]
Lunar orbiter to search for ice in lunar craters [EM-1]



BioSentinel (Ames) [2,3]
Biosensor to study impact of radiation on living organisms [EM-1]

[1]JPL/NASA Planetary Science Division, [2]JPL, [3]NASA's Advanced Exploration Systems (AES)

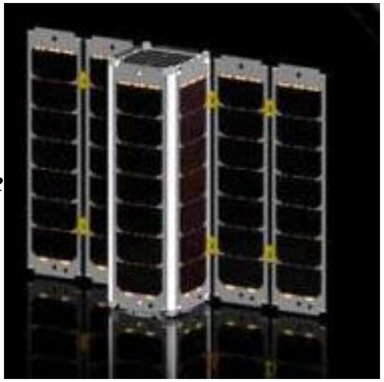
Emerging Enabling Small Spacecraft Technologies



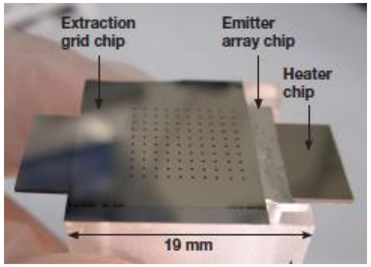
CAT Thruster

- Telecommunication and Navigation systems
  - Iris Transponder (JPL) and high gain antennas
  - High-rate S/Ka-Band radios (50+ Mbps dld from LEO)
- CubeSat Propulsion systems (ΔV>3 km/sec in 3U)
  - VACCO Cold Gas Systems (low ΔV for TCMs/ de-sats)
  - NASA-funded MEP (MIT- S-iEPS, JPL- MEP, Busek- HARPs)
  - CubeSat Ambipolar Thruster (CAT), Busek CHAMP, Chemical Thruster
- High-accuracy attitude control technology
  - Blue Canyon's XB1: 7.2 arcsec accuracy, 1 arcsec stability, <2.5 kg, ~1 U, <2.5 W
- Solar arrays that are deployed and are gimbaled for Sun-tracking
  - Deployable Solar Arrays (Clyde Space, MMA up to 130 W/kg)
- Integrated bus architectures and radiation-tolerant components
  - Blue Canyon XB1 Bus (GNC, C&DH, Telecom, Power, ACS)
  - Companies offering buses like Tyvak, Blue Canyon, etc.
- Standard deployers (JPL's PDCS, Planetary System's CSD, Tyvak's Deployers)

Clyde Space Double Deploye 2-Sided 30 W Solar Panels



Blue Canyon XB1 Bus



JPL's MEP Thruster

Image Credit: Clyde Space, ISIS, Blue Canyon, PEPL

Unique Challenges Faced by Interplanetary CubeSats

Areas	Challenges	Solution(s)
Power	-Solar collection at >>1 AU -Energy storage: mass, volume, thermal limits, lifetime	-Low-power components -Power cycling components -Charge batteries in cruise
Telecom *JPL's Iris Transponder* 	-Relay direct-to-Earth (DTE) hard! -Mother-daughtership can cause disruptions to primary mission	-On-board data compression -Low rate communication -Dedicated deployer telecom system
Orbit & Attitude Control	-Limited available mass, volume, power for wheels, propulsion, etc.	-Small reaction wheels -Small cold gas thrusters
Autonomy	-Must operate without direct link at large distances for long durations	-Onboard autonomous operations -Agile science algorithms
Lifetime	-Long duration cruises in deep space	-Shielding during cruise -Short mission durations
Programmatic	-Potential risk to primary	-Standard deployer, ΔV tip-off

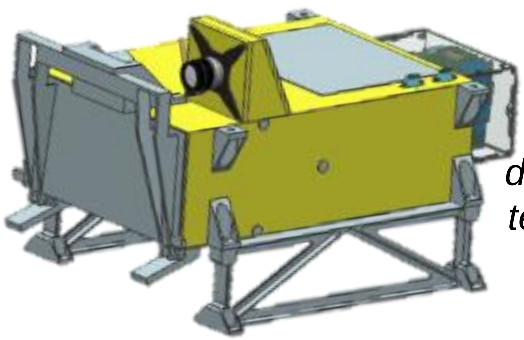
Conventional design approaches are not applicable!

- Cannot carry more propellant, make structure walls thicker (radiation), etc.
- Creativity, minimizing mass/power and component integration is critical

Technology Infusion Across the Portfolio

Deep Space Deployable Payloads Architecture & Disruption Tolerant Network
Provides common housing (heating, power, data), telecom relay at target

Standard Deployment (PDCS)



Standard deployment and telecom system

Disruption Tolerant Network (DTN)

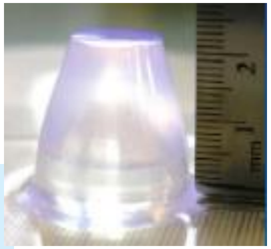
Improved communication with store and forward via relay stations

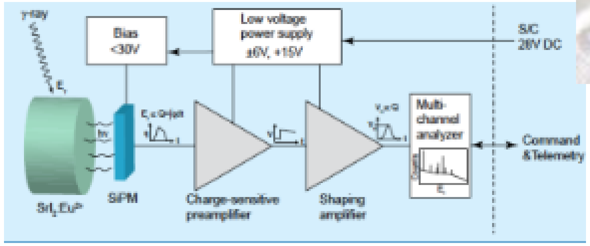
IntelliCam

Modular intelligent camera (Justin Boland, JPL)

New Miniaturized SrI2 Gamma Ray Spectrometer

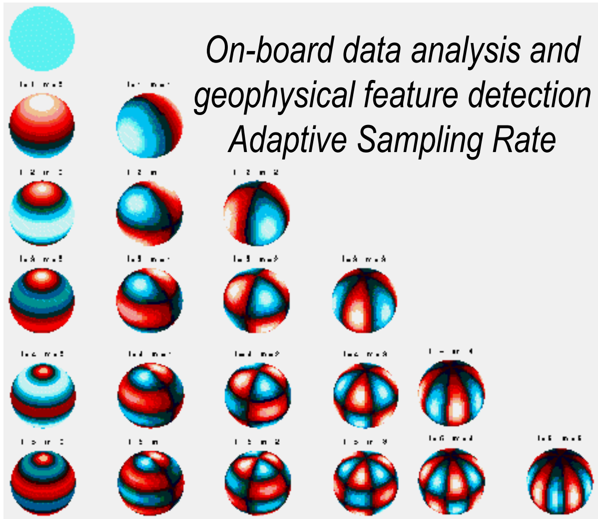
(PSI/Fisk U/ JPL)





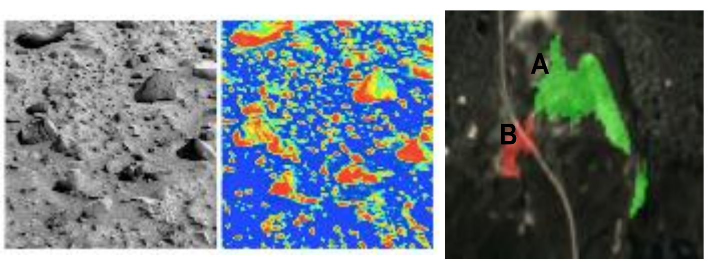
Technology Infusion for Science-Driven Missions

Agile Science Software enables autonomously maximizing science return



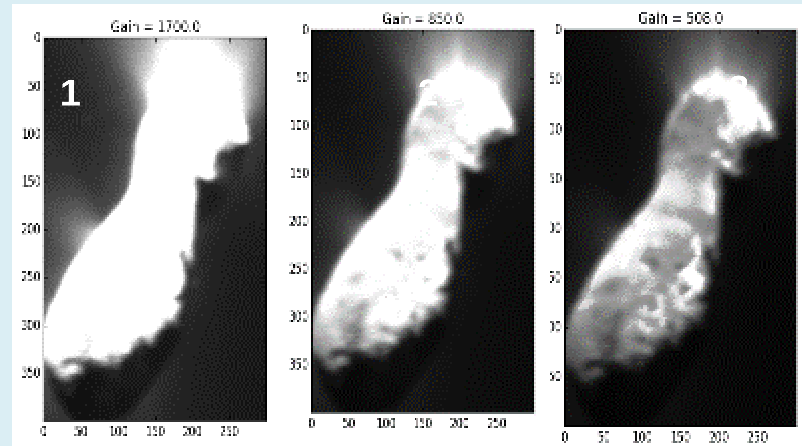
On-board data analysis and geophysical feature detection Adaptive Sampling Rate

Rapid Feature Extraction
(EO-1, NASA/JPL)



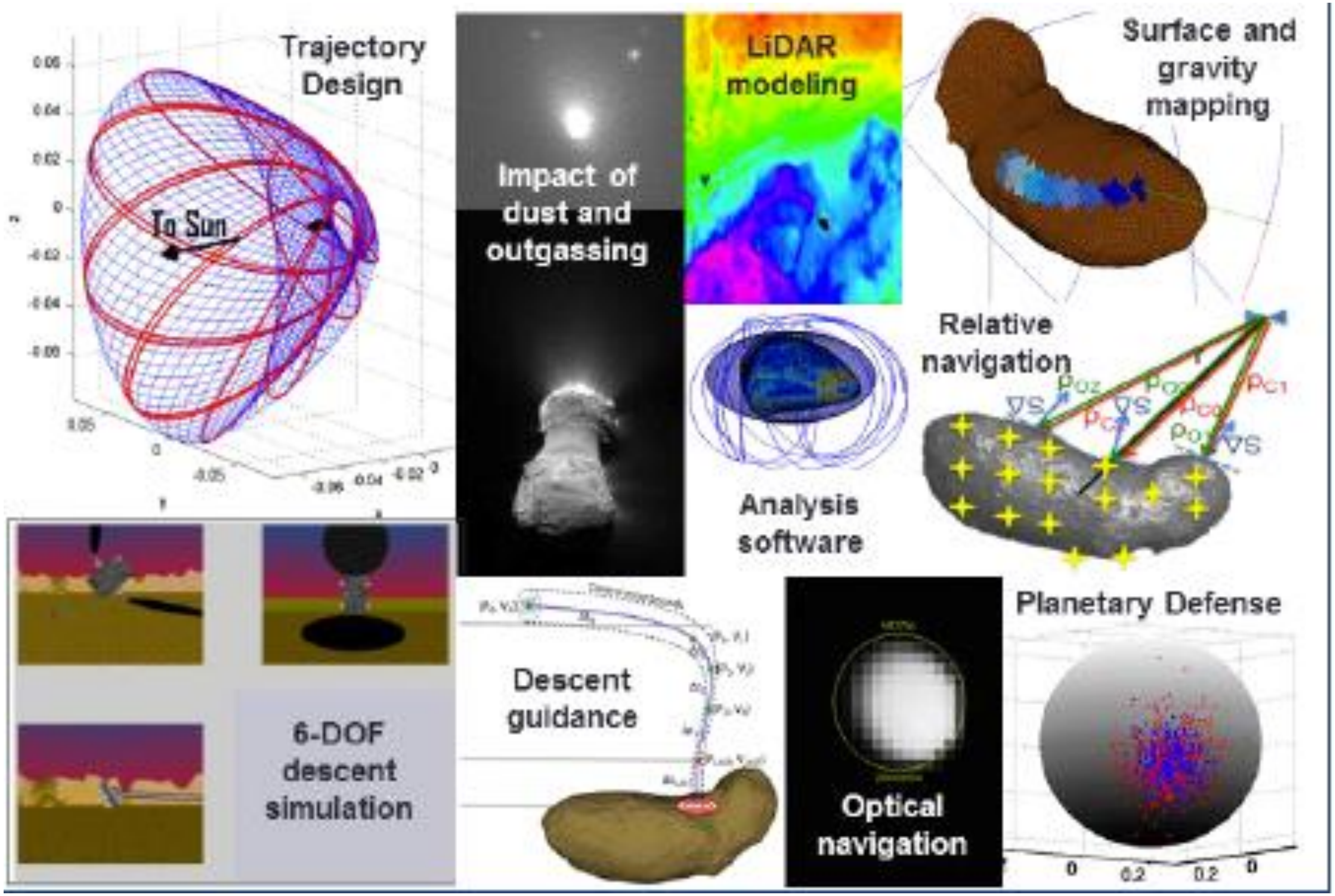
Autonomous Feature Detection (TextureCam, NASA ASTID)

Dynamic Gain Setting, Autonomous Dust Detection, Data Downlink Prioritization



Technology Infusion for Small Bodies Missions

Primitive Bodies and Terrain-Relative Navigation



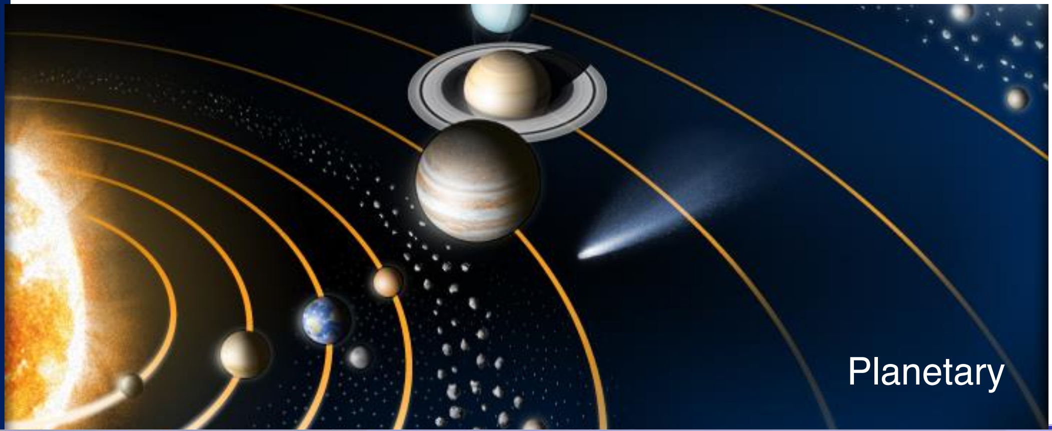
Planetary CubeSat Portfolio Overview

Standard Components: Rad-hard LEON processor, UHF radio or Iris transponder (DTE), BCT attitude control unit (reaction wheels, IMU), cold gas thrusters, solar arrays, primary/secondary batteries, 6U Al CubeSat structure

Technology Demonstrations: mothership-daughtership telecommunication architectures, autonomous navigation and operations, miniaturized instrumentation, and software for on-board processing of science data.

Science Applications/Instruments:

- Measuring magnetic fields, high-resolution images at low altitudes
- Searching for volatiles and water ice (mini spectrometer)
- Acquiring acceleration profile optimized with agile science algorithms
- Measuring elemental composition of landing site
- Performing controlled dust adhesion investigation (SKGs)
- Sampling atmosphere and measure noble gasses (ion-trap mass spectrometer)

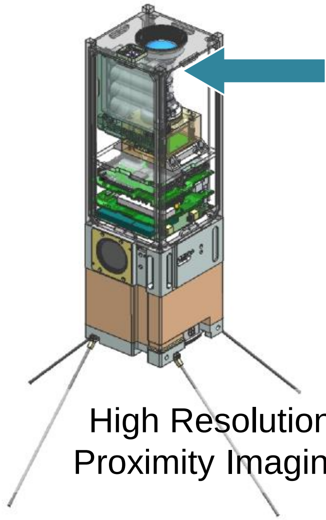


Dormant cruise Duration: 100-2200 days
Mission Duration: Most 1-7 days, one 30 days, one 10000 days
Sun Range: 0.75-3 AU at destination

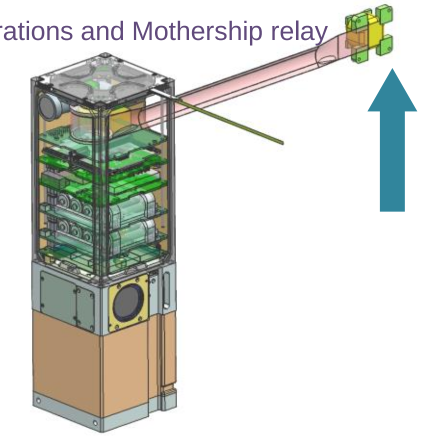
Planetary CubeSat Portfolio “Family Portrait”

Secondary Orbiter/Flyby Constellations

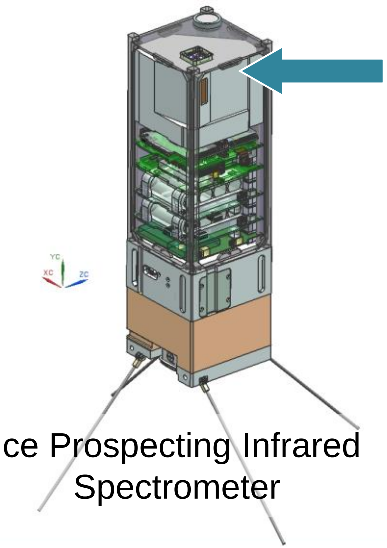
~48-72 hour operations with (semi-)autonomous operations and Mothership relay



High Resolution Proximity Imaging



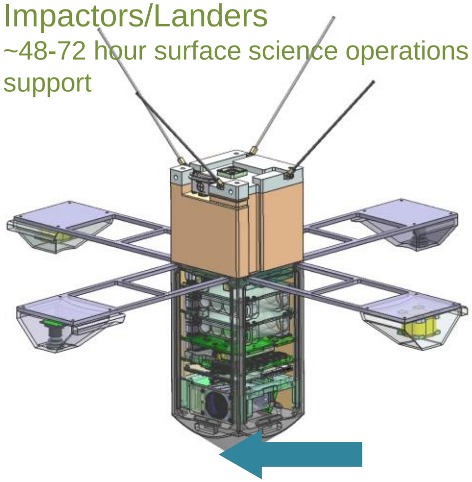
Distributed, Simultaneous Particles & Fields Measurements



Ice Prospecting Infrared Spectrometer

Impactors/Landers

~48-72 hour surface science operations with mothership localization and relay support

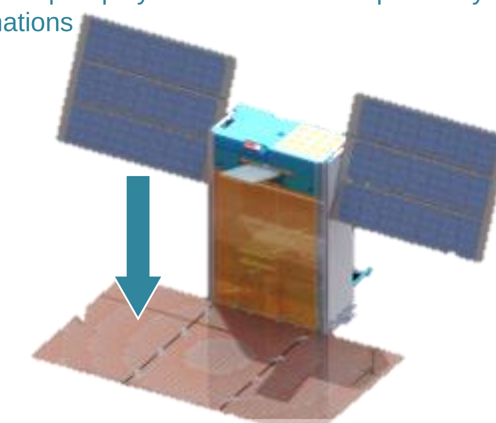


Asteroid/Comet Instrumented Surface Penetrator

Phobos Surface Landing w/ Gamma Ray Spectrometer

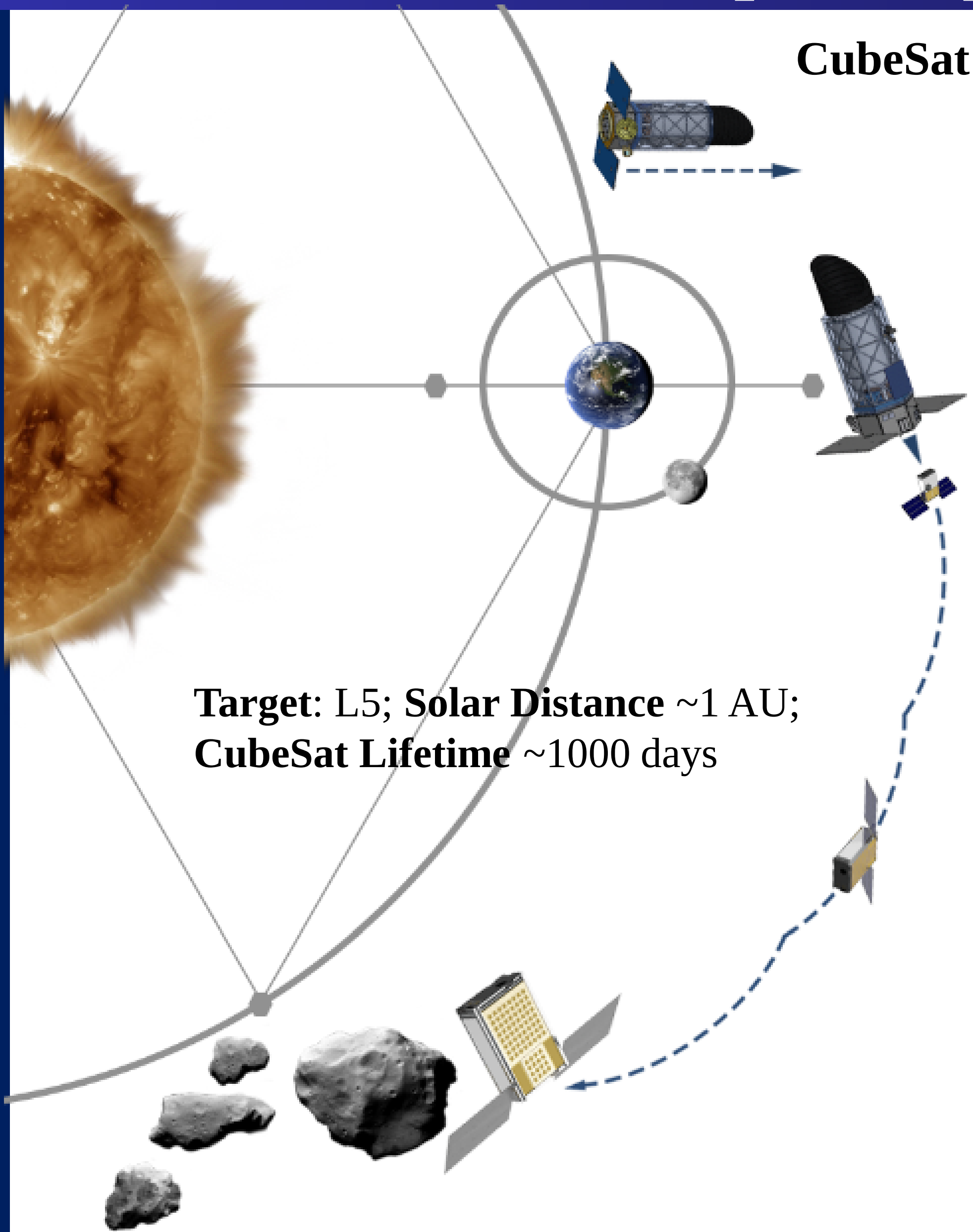
Hitchhiking Deep Space Nano-Satellite

Mothership-deployed s/c to other interplanetary destinations



Deep Space Navigation & Radio Science Demonstrations

Representative Mission Concept: Kuiper



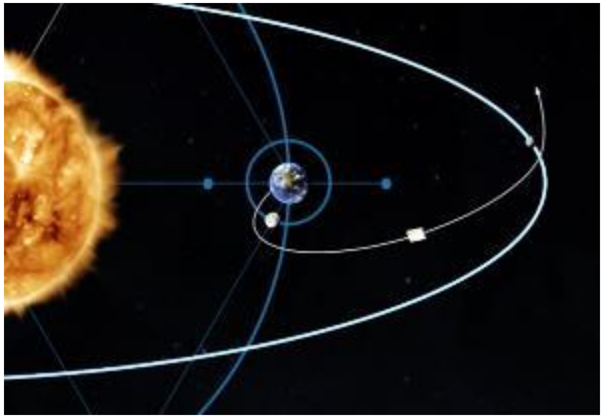
CubeSat (6U) AutoNav Demonstration

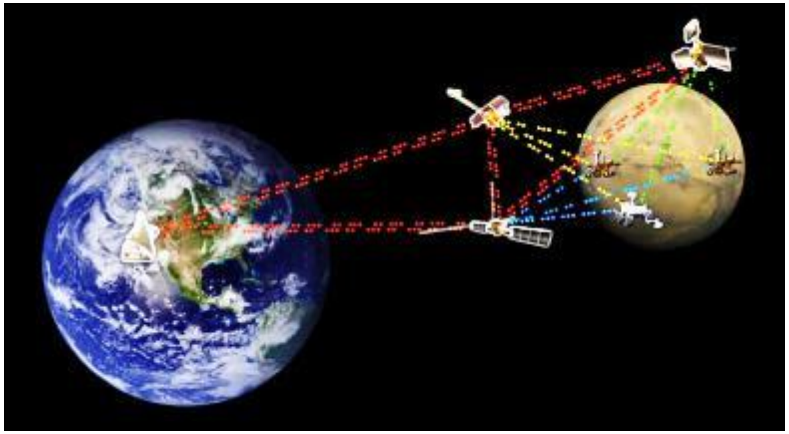
- Hitches ride to Earth-Sun L1 on Discovery-class mission
- Demonstrates orbit determination on 6U CubeSat to avoid expensive (time, power) tracking to the DSN.
- Paves the way to operations cost reduction for future small interplanetary CubeSats.
- Introduces the IntelliCam, tailored to reference target acquisition.
- JPL's new CubeSat C&DH supplies processing performance needed for orbit determination and autonomous maneuver planning and execution.

Image Credit: Lucy Burton

Future Impact of Science-Driven Small Spacecraft

- ***Performing significant ΔV and high-precision attitude control enables:***
  - Escaping Earth-orbit, transferring to Moon, Mars, asteroids
  - Creating and maintaining formation flight/constellations (*e.g.* large apertures)
- ***Autonomous Operations enabling:***
  - Autonomous navigation by imaging asteroids (*e.g.* DS1)
  - Agile Science for on-board autonomy to locate Earth, detect objects (*e.g.* plumes)
  - Dynamic observation planning, disruption-tolerant networking (DTN)
- ***Future potential to accomplish SMEX/Discovery-class science:***
  - Multi-spacecraft architectures: constellations, mother-daughtership, swarms, formation flying to perform distributed temporal/spatial measurements
  - Pre-cursor missions to explore dirty/dangerous/unknown environments (*e.g.* comets, asteroids, Earth-Sun Lagrange points) or support surveys (*e.g.* NEOs)





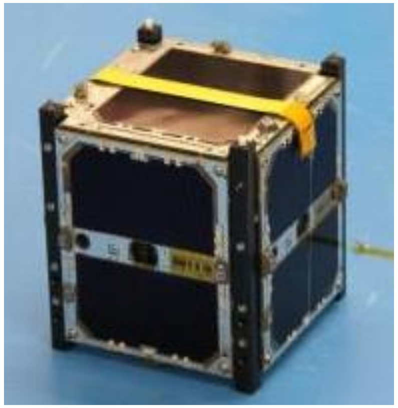
Agile Science Reference: D. R. Thompson, S. A. Chien, J. C. Castillo-Rogez

Acknowledgments

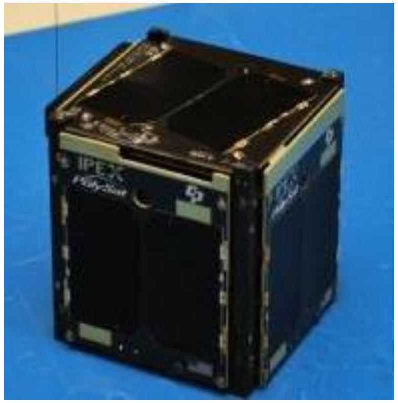
- Ross Jones, Susan Jones, Kim Reh for study definition and management
- Lucy Barton for proposal artwork
- Gregory Lantoine and Damon Landau for trajectory support
- Steve Chien, David Thompson, and Jay Wyatt for agile science expertise
- Courtney Duncan for telecom support
- Murray Darrach, Rob Staehle, Justin Boland, Lee Johnson, Tom Prettyman (PSI) and Carlos Calle et al. (KSC)for instrument support
- Shyam Bhaskaran for AutoNav support
- Blue Canyon Technologies for their support
- JPL scientists and PIs for their support

Backup

Active Low Earth Orbit (LEO) CubeSat Projects

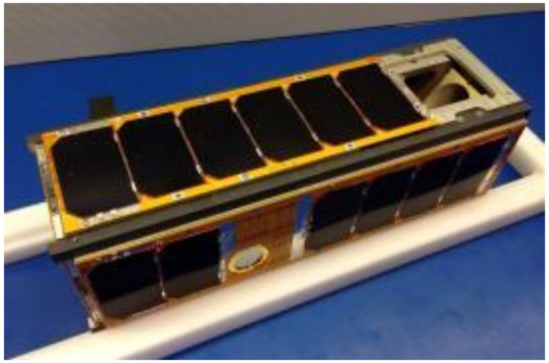


M-Cubed/COVE-2 (NASA ESTO)
High data-rate on-board processing
P. Pingree: JPL, U. Michigan
Launched VAFB: Dec. 5, 2013 (NASA CLI)

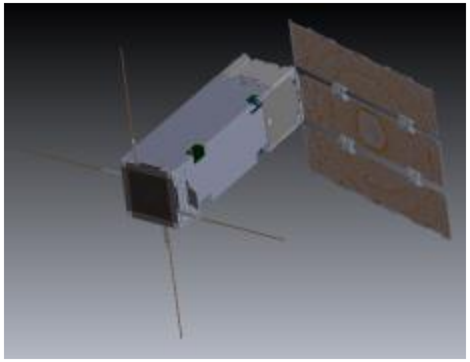


IPEX/CP-8 (NASA ESTO)
Autonomous low-latency product generation
S. Chien: JPL, GSFC, Cal Poly SLO, Tyvak
Launched VAFB: Dec. 5, 2013 (NASA CLI)

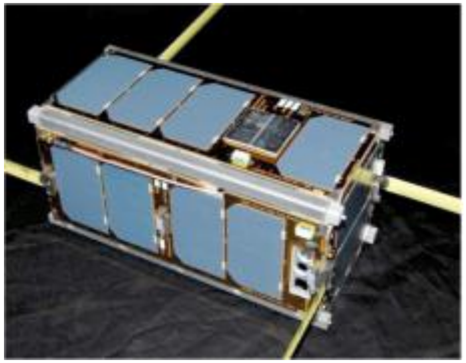
GRIFEX (NASA ESTO)
Unprecedented frame-rate ROIC/FPA
D: Rider JPL, U. Michigan
Launched VAFB: Jan. 31, 2015 (NASA CLI)



RACE
Hydrometric Atmospheric Radiometer
B. Lim: JPL, UT Austin
Launch Failure WFF: Oct. 2014 (NASA CLI)

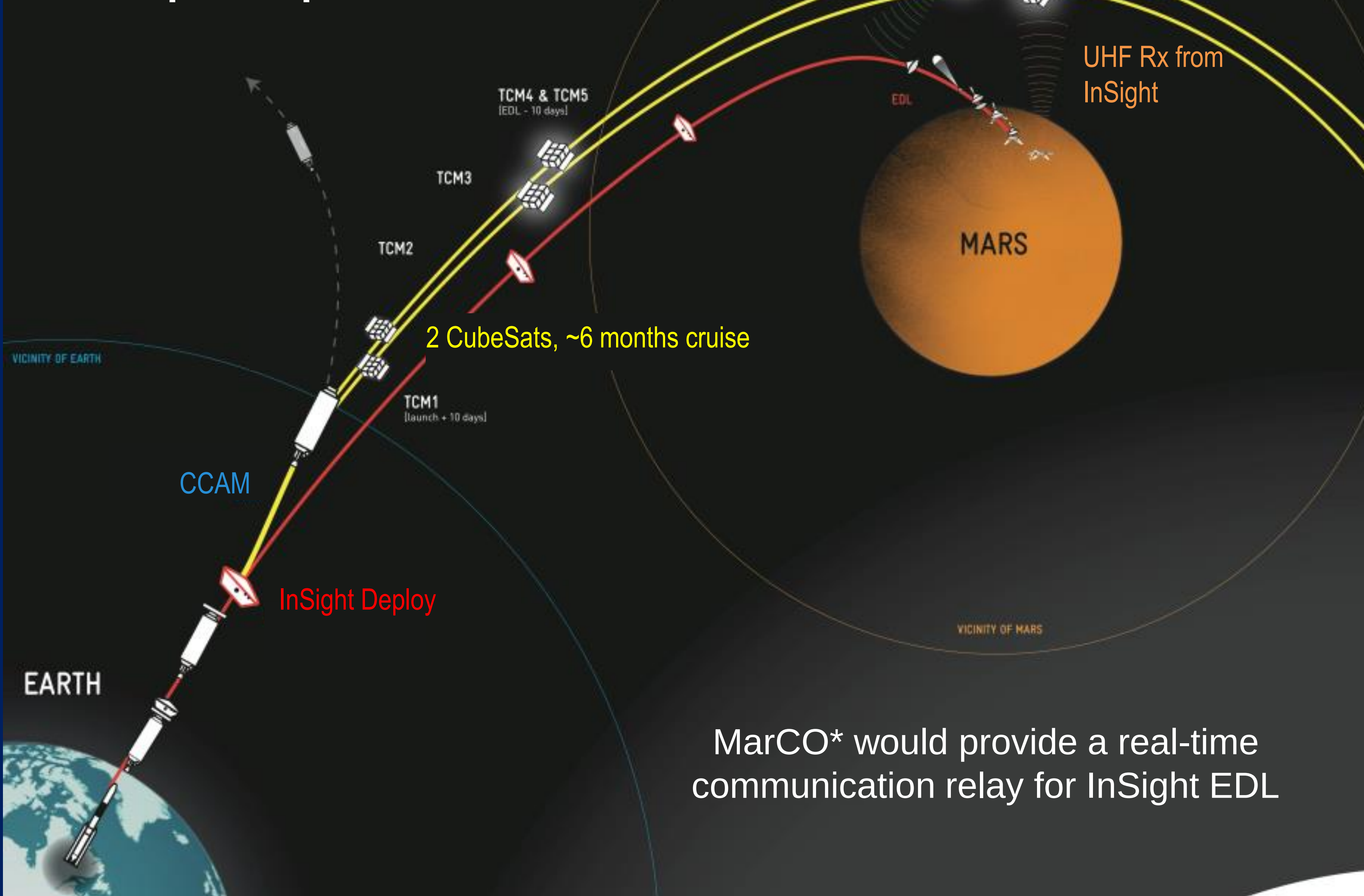


ISARA (EDISON)
Integrated Solar Array & Reflectarray Antenna
R. Hodges: JPL, Aerospace Corp., Pumpkin Inc.
Launch Manifest: Aug. 2015 (NASA CLI)



LMRST
Low Mass Radio Transponder
C. Duncan: JPL, Stanford
Launch Manifest: 2015 (NASA CLI)

Concept of Operations

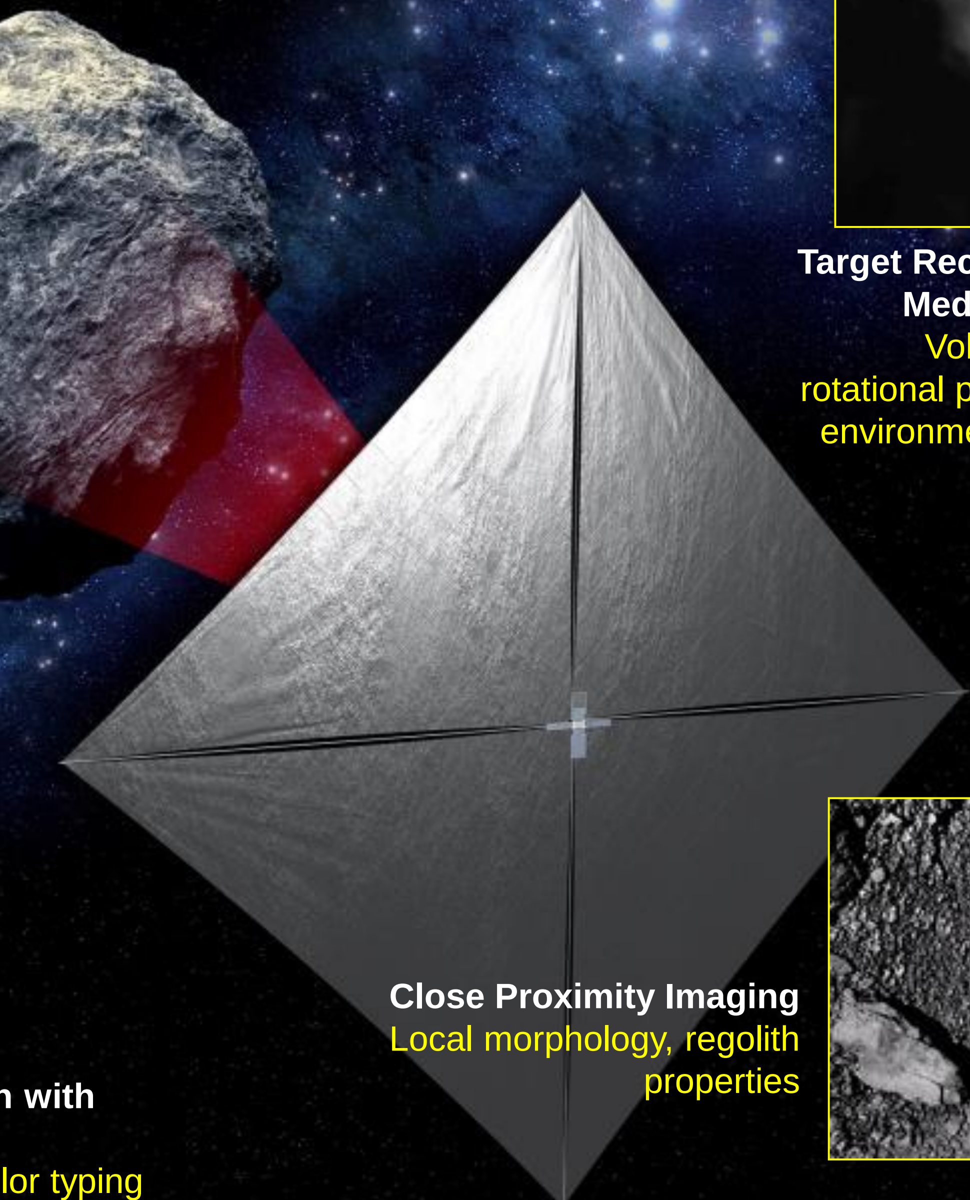


MarCO* would provide a real-time communication relay for InSight EDL

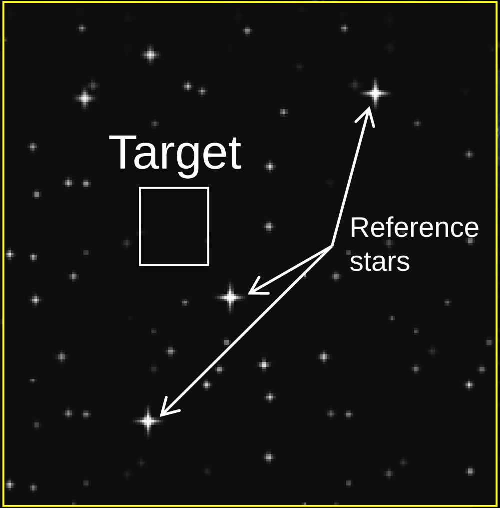
*Mission Concept - Pre-Decisional – for Planning and Discussion Purposes Only

NEA Scout (MSFC/JPL)

Near Earth asteroid reconnaissance via imaging

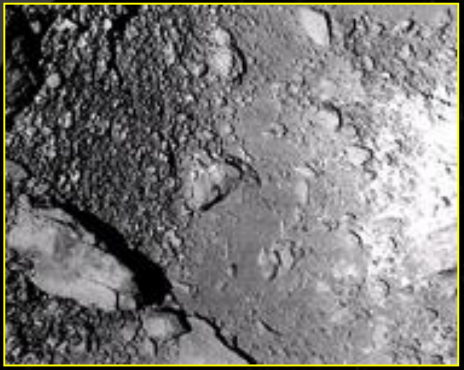


Target Reconnaissance with Medium Field Imaging
Volume, global shape, rotational properties, and local environment characterization



Target Detection and Approach with Wide-Field Imaging
Ephemeris determination and color typing

Close Proximity Imaging
Local morphology, regolith properties



Lunar Flashlight*

A CubeSat with a solar sail to “shine light” on the distribution of water and other volatiles in the Moon’s permanently shadowed regions

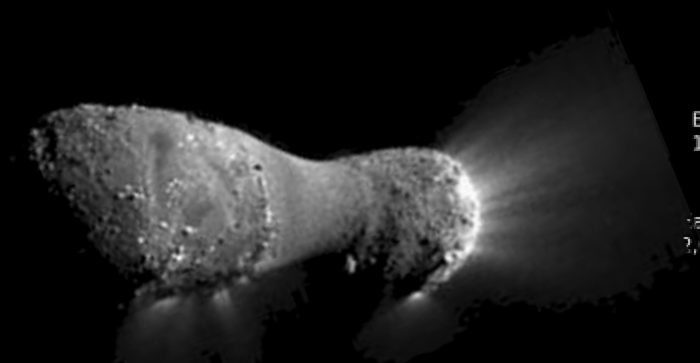
*Mission Concept - Pre-Decisional – for Planning and Discussion Purposes Only

IPEX Future Impact on Beyond LEO Exploration

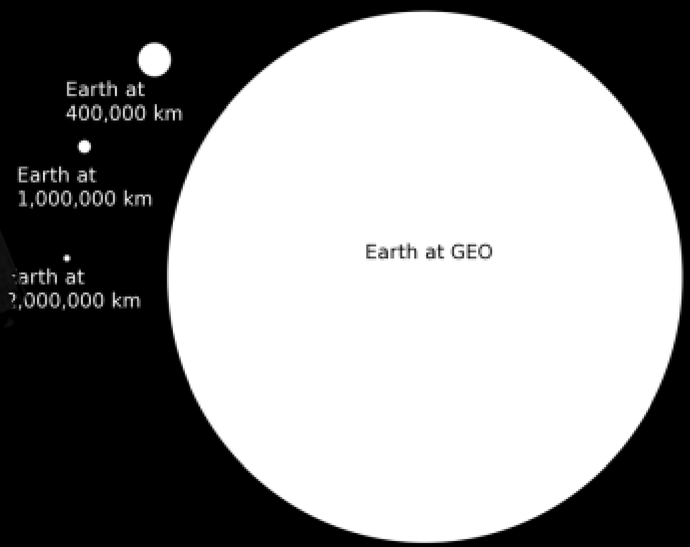
Jet Propulsion Laboratory
California Institute of Technology

INSPIRE: On-Board Autonomy to Locate Earth in Star Field

For further information see
S. Chien, J. Doubleday, D. R. Thompson, or J. Castillo-Rogez



OCCAM (SIMPLEx concept): Rapid Science Re-Planning Following Plume

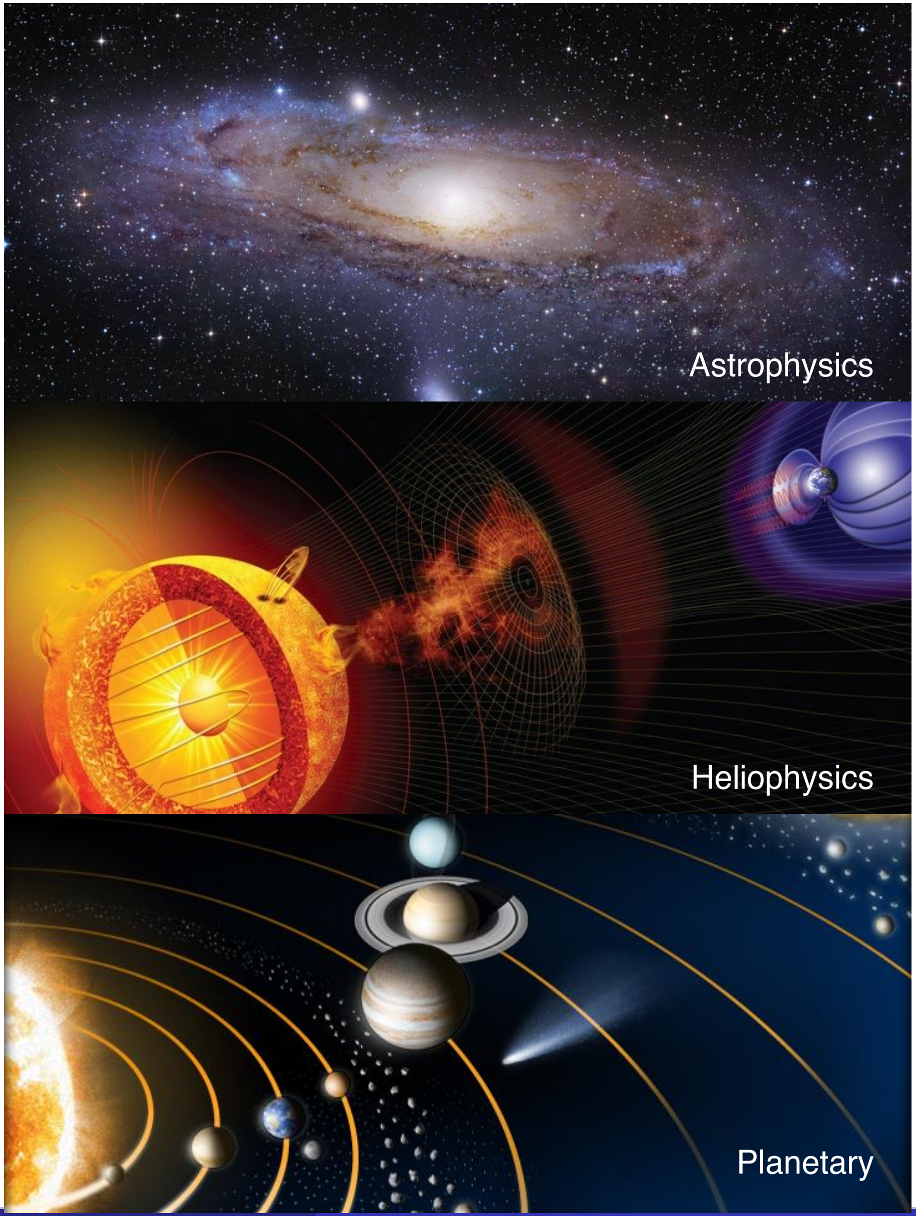


Apparent size of Earth in camera frame
Shown for different mission phases

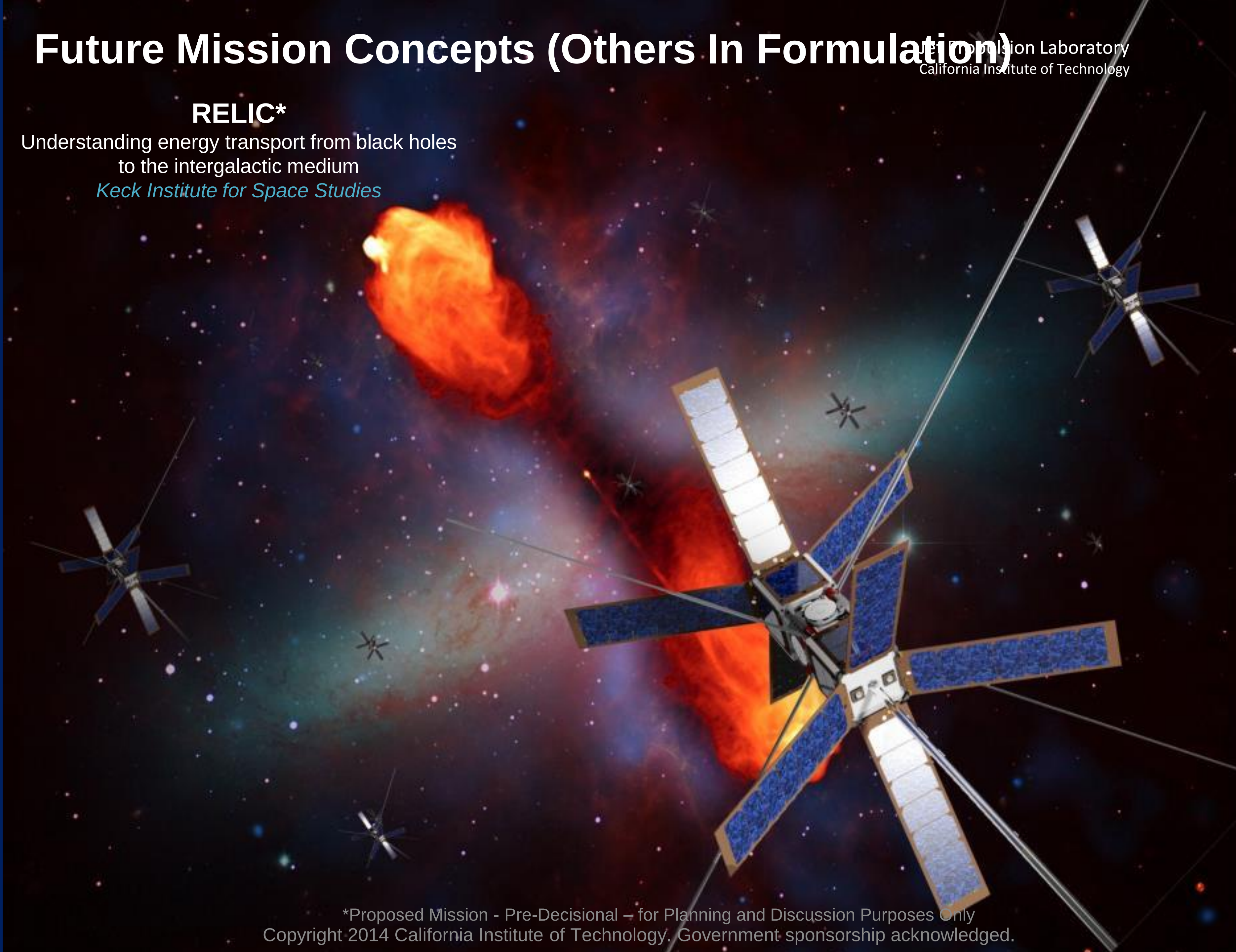
Keck Institute for Space Studies Final Report

www.kiss.caltech .edu/study/smallsat

Jet Propulsion Laboratory
California Institute of Technology



Future Mission Concepts (Others In Formulation)



RELIC*

Understanding energy transport from black holes
to the intergalactic medium

Keck Institute for Space Studies

Future Mission Concepts (Others In Formulation)

L5SWS*

Fractionated Earth-Sun L5 space weather base for prediction and understanding solar variability effects

Keck Institute for Space Studies