Will Smallsats and CubeSats Revolutionize Solar System Exploration?

Robert L. Staehle
Jet Propulsion Laboratory, California Institute of Technology

2016 November 2

composite simulation, & L. Paul

- Skylab
- Pluto-Kuiper Express
- Interplanetary CubeSats
- Lunar Flashlight, Near-Earth Asteroid-Scout
- Global Wildland Fire Monitoring
- MarsDrop Microlanders

© 2016 California Institute of Technology. Government sponsorship acknowledged

Success and speculation have many authors.

In this slide package, anything that is wrong is the fault of the integrator/presenter:

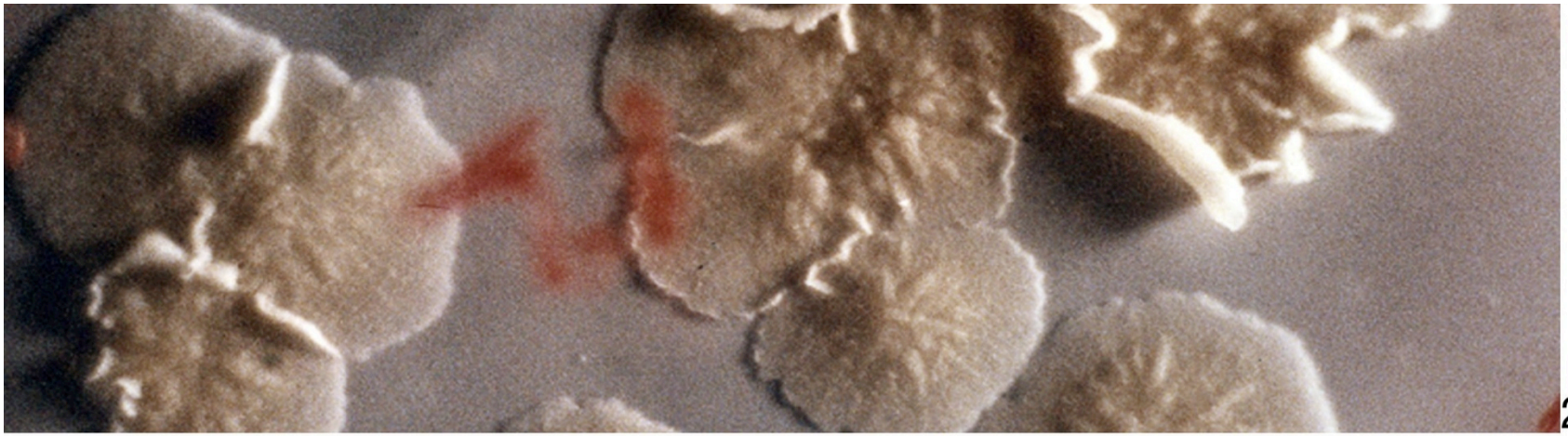
Robert L. Staehle

Much of the credit goes to many more people than named here, but these are some of the leaders:

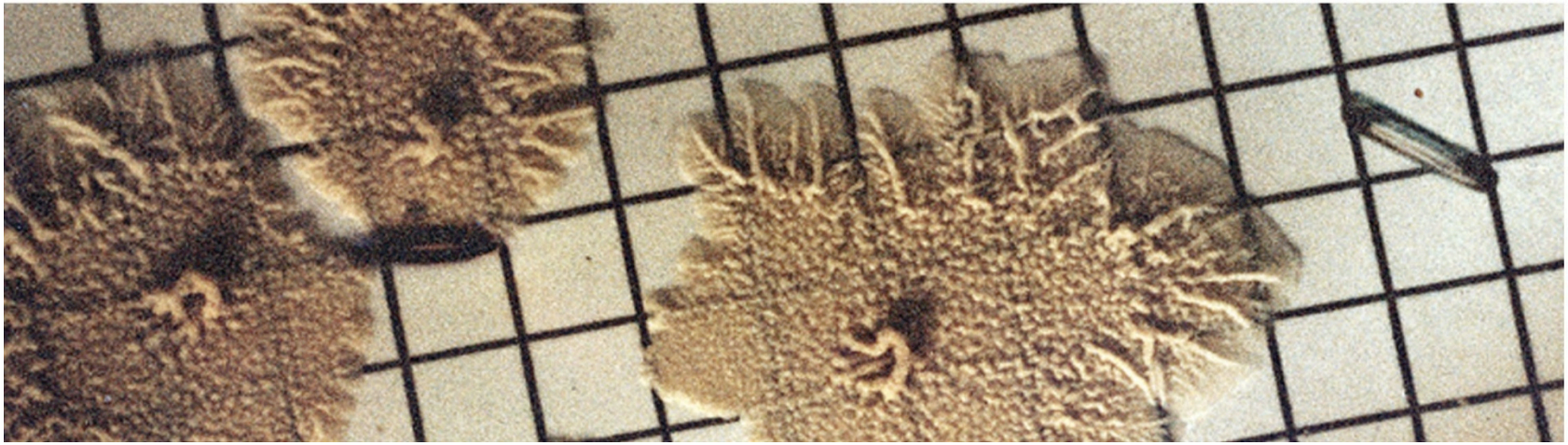
- Skylab: Henry Floyd, Jack Waite, Stephen B. Hall/MSFC
- Pluto-Kuiper Express: Stacy Weinstein, Richard J. Terrile, Chris Salvo, Hoppy Price, Candida Nunez, Rich Zitola, Bob Miyake, Marty Herman, Richard Caputo, John Carraway, Jay Wyatt, Richard Doyle, Leon Alkalai, and the rest of the early JPL Pluto Team; Elaine Hansen/University of Colorado-Boulder; Alan Stern and the SwRI + APL New Horizons Mission Team
- Interplanetary CubeSats: Robert L. Staehle, Diana Blaney, Hamid Hemmati, Dayton Jones, Andrew Klesh, Paulett Liewer, Joseph Lazio, Martin Wen-Yu Lo, Pantazis Mouroulis, Neil Murphy, Paula J. Pingree, Thor Wilson, Chen-Wan Yen/JPL; Brian Anderson & C. Channing Chow II/USC; Bruce Betts & Louis Friedman/The Planetary Society; Jordi Puig-Suari & Austin Williams/CalPoly-San Luis Obispo; and Tomas Svitek/Stellar Exploration
- Lunar Flashlight, Near-Earth Asteroid-Scout: Benny Toomarian, Paul Hayne, R. Glenn Sellar, Martin W. Lo, Peter Kahn, John Baker/JPL; Barbara Cohen, Jason Wagoner, Amy Walden/MSFC; Benjamin Malphrus & Robert Twiggs/Morehead State Univ.; David Paige/UCLA; and other members of the LF & NEAScout Teams
- Global Wildland Fire Detection & Monitoring: David R. Thompson, William Johnson, Michael Mercury/JPL
- MarsDrop Microlanders: Sara Spangelo, Marc S. Lane, Kim M. Aaron, Rohit Bhartia, Justin S. Boland, Lance E. Christiansen, Siamak Forouhar, Manuel de la Torre Juarez, Nikolas Trawny, Chris R. Webster/JPL; Matthew Eby, Jared Lang, Jeffrey Lang/The Aerospace Corporation; David A. Paige/UCLA; Rebecca M. E. Williams/Planetary Science Institute

1973

Bacillus subtilis bacteria from high school to orbit

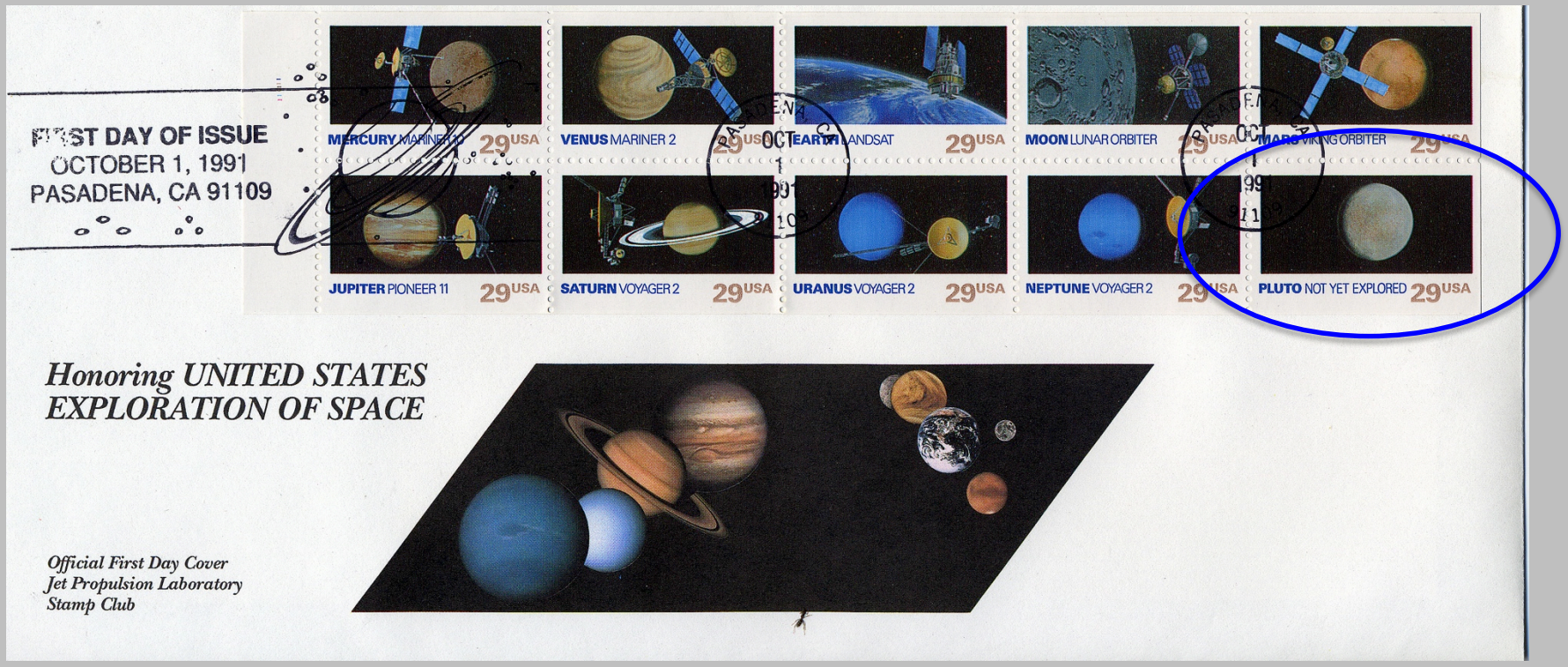


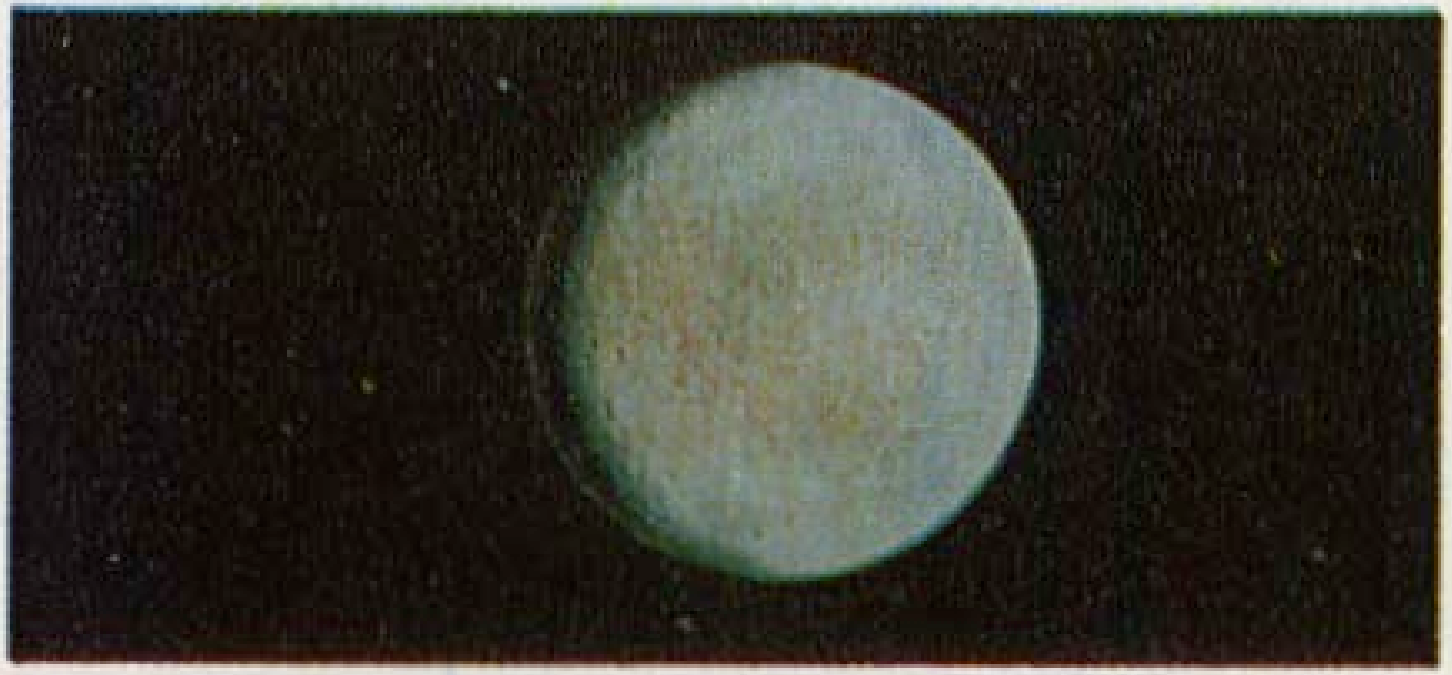
2



A Taunt to Explore Pluto?

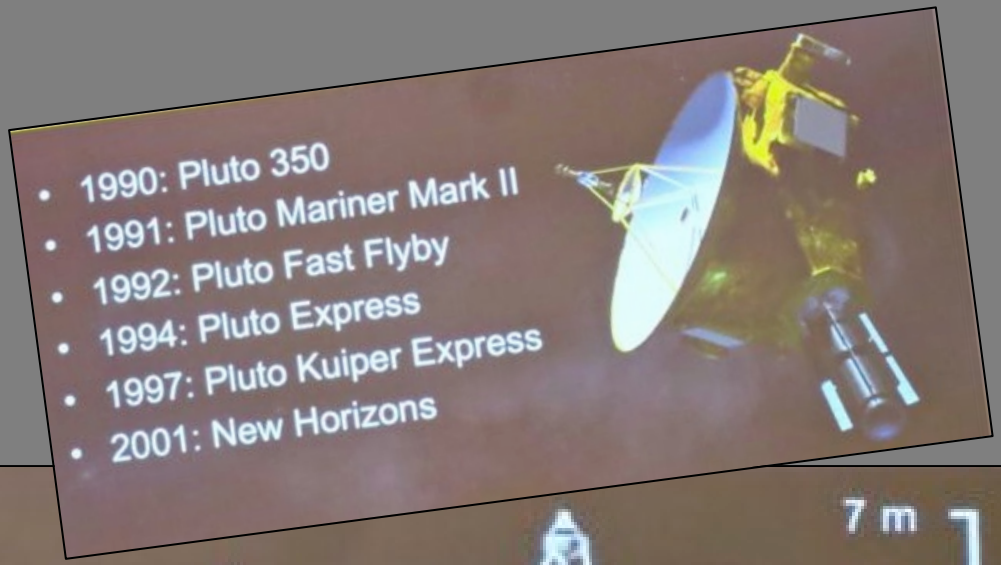
Hear the full story via podcast at:
http://www.audiomatic.in/show/the-journey-to-pluto-it-all-began-with-a-postage-stamp/

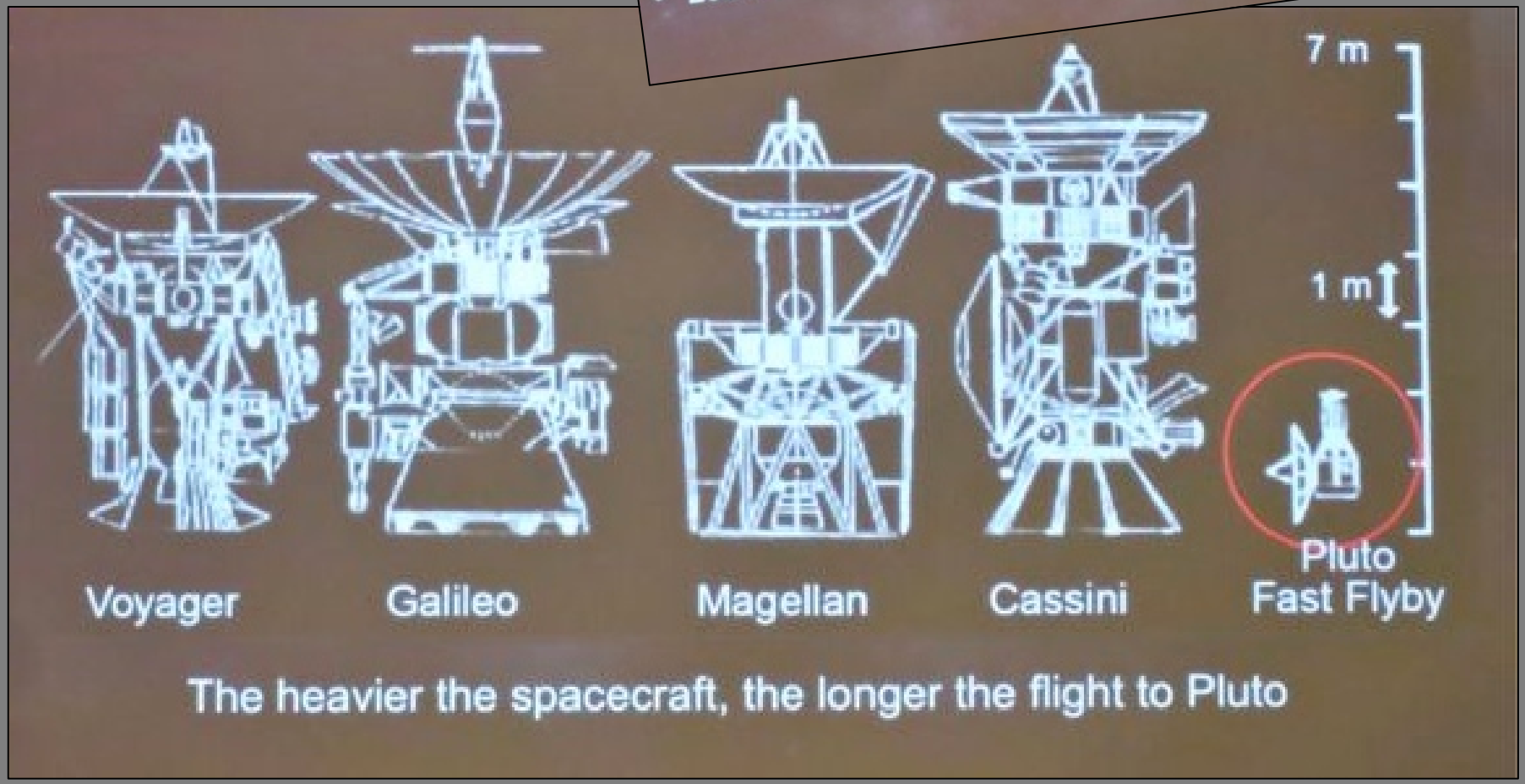




PLUTO NOT YET EXPLORED 29 USA

We broke the paradigm…





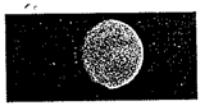
Used by permission from Alan Stern/SwRI

1992

eproduced from the Unclassified / Declassified Holdings of the National Archives

Jet Propulsion Laboratory
California Institute of Technology
4800 Oak Grove Drive
Pasadena, California 91109
(818) 354-4321

JPL



PLUTO NOT YET EXPLORED 29 USA

May 28, 1992

Refer to: 311-RS:amc

Daniel Goldin, Administrator
National Aeronautics and
Space Administration
Washington, DC 20546

Dear Mr. Goldin:

I enjoyed meeting you yesterday on the occasion of the Oscar return ceremony at the Motion Picture Academy of Arts and Sciences. Thank you for taking the time to discuss our Pluto Mission Development activity, and for offering to read our "mid-term" review package which I gave you.

To respond more fully to your question about timing, when I began creating our Pluto Team in December I told people I wanted to launch the Pluto Fast Flyby mission in 1997, though many said this would be impossible. I have been offered the following "advice" about launch year: 1) our radioisotope launch approval people (a representative of whom I recruited to our team) told us we couldn't secure White House and National Environmental Policy Act approval before 1998, if we start the process right now; 2) our Headquarters sponsor is telling me they won't entertain the possibility of a launch before 1999, and probably later, because they can't ask for a new start before 1997; and 3) many members of the science working group which advises our sponsor say they feel a more fully-instrumented, and therefore heavier spacecraft, is required to cover the breadth and depth of science they feel is necessary to justify a Pluto mission. A significantly heavier spacecraft in turn means an 11+ year flight time on the largest launch vehicle, or if an Atlas or Delta are used, then the flight time is still 11+ years with departure not before 2000, 2001 or later to obtain the necessary alignment with Jupiter and Pluto. This latter scenario is the basis of the "Pluto 350" mission concept described in the package I left you.

In short, I still want to go in 1997, but we will need your help to do so.

The new spirit you have brought to the top of the Agency is a long overdue inspiration, for which many of us at all levels of JPL have been grateful. While many people cite "the good old days" of the Sixties, we have done a few fast, inexpensive missions more recently--Solar Mesosphere Explorer (SME) being an example. In that spirit, and in response to discouragement about the slowing pace of planetary exploration, we have proposed to "finish the job" of the first reconnaissance of the known planets by flying a small, relatively inexpensive mission to Pluto, launching as soon as we can get the powers-that-be to agree.

Dear Bob
Thanks for taking the time to explain your exciting mission concept to Pluto. Ideas such as this are the future of NASA. We don't have to spend billions to get good science. I am very supportive of your ideas. Please keep up the good work. Please work with Ed Stone, Lou Fisk and the appropriate people to figure out how to fund your mission. I am real pleased by your efforts. If there is a special area where I can be of help please contact me.
C.C. Ed Stone
Lou Fisk
priorities this mission vs. Mars, Jupiter, asteroid flyby. What are the next steps.

RG255, E110, Goldin Coll., FRC Box 60
file 71441 "Pluto"

1992

DG - Read

JPL

May 28, 1992

Refer to: 311-RS:amc

Dear Bob

Thanks for taking the time to explain your exciting mission concept to Pluto. Ideas such as this are the future of NASA. We don't have to spend billions to get good science. I am very supportive of your ideas. ~~and have~~ Please keep up the good work. ~~what are the next steps~~ where does the science. commu

prioritize this mission v.s. Mesur, Junior orbiter, asteroid flyby. what are the next step

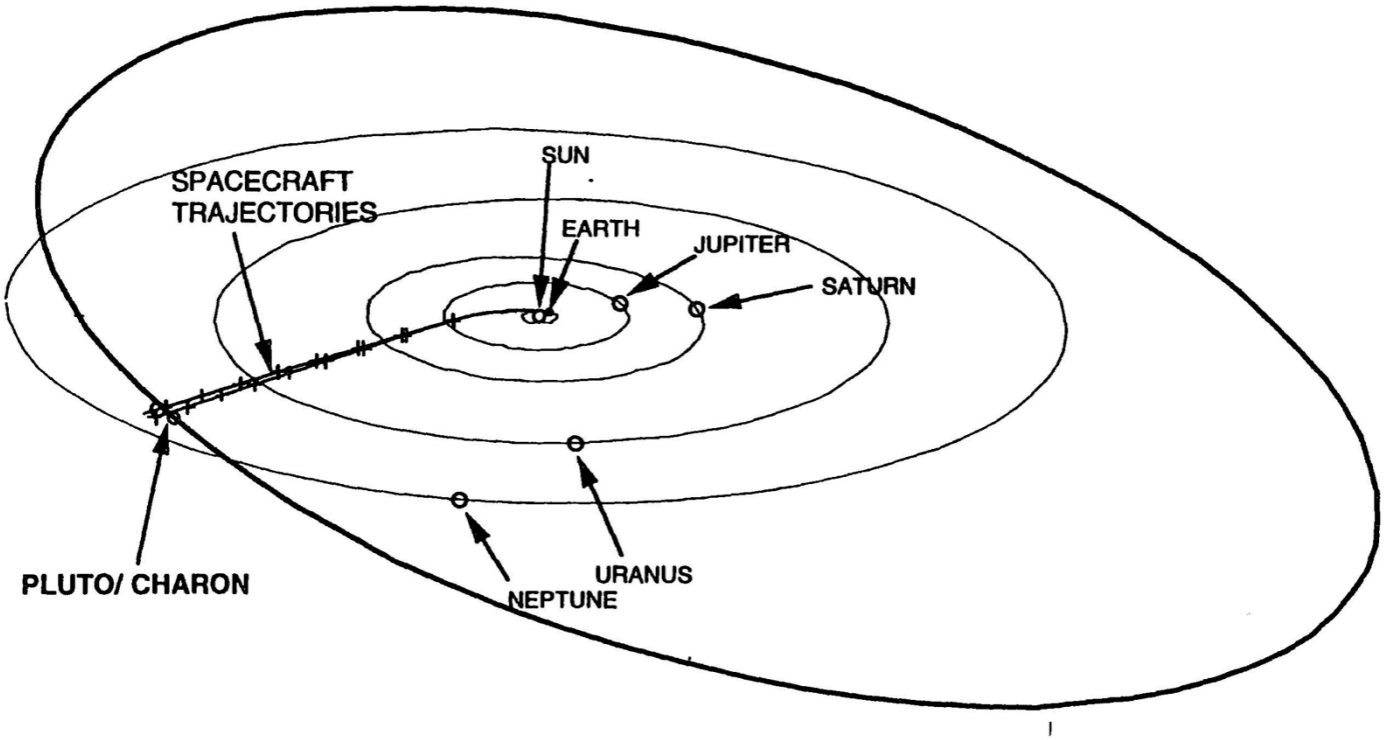
... the occasion of the Oscar return ceremony at the

Courtesy of the JPL Archives. D-65909, 1412_3-04

CL# 13-4036, Pages have been redacted.

1994

PLUTO FAST FLYBY
INTERPLANETARY TRAJECTORIES



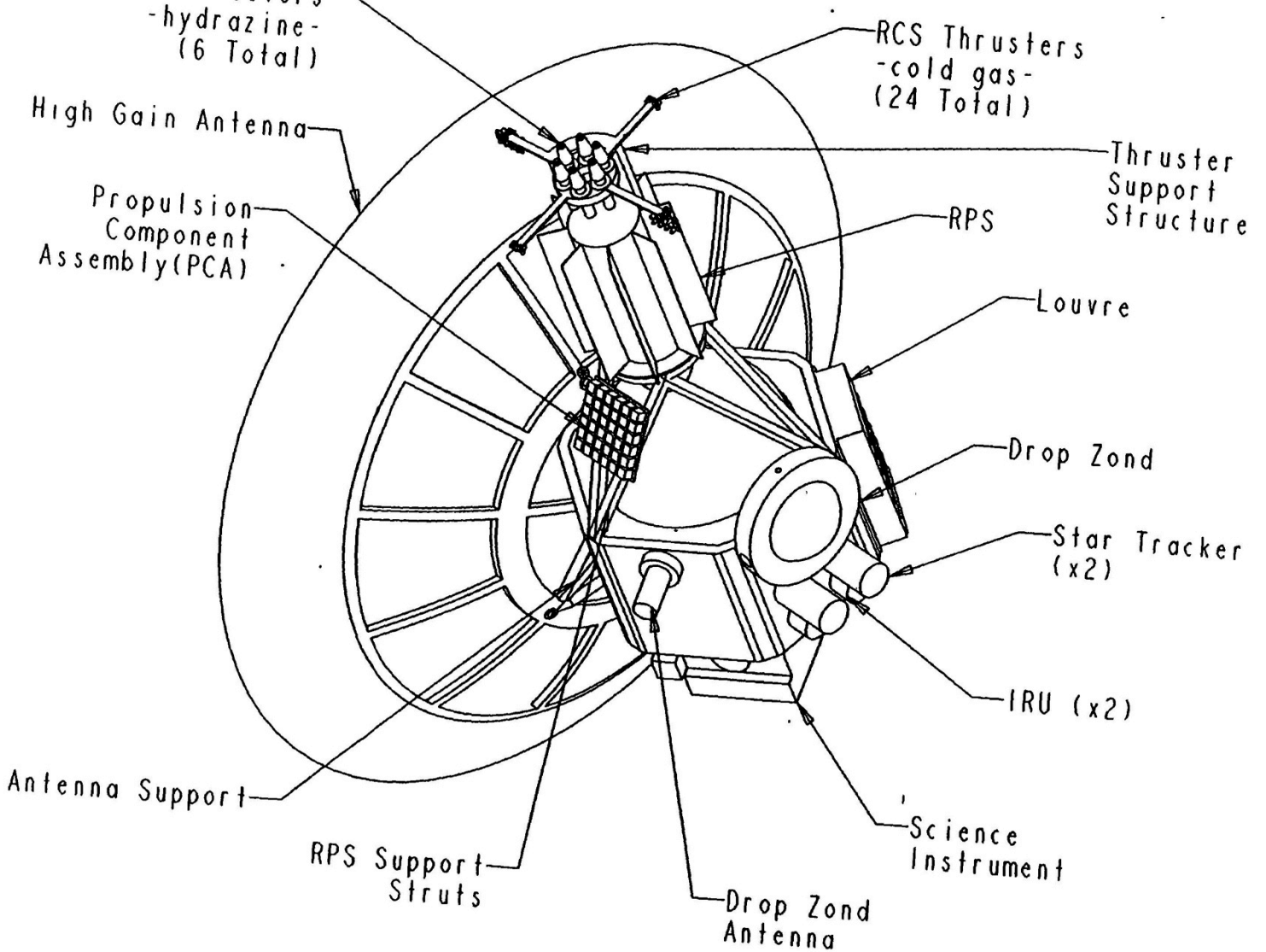
SSW
5/11/94

Courtesy of the JPL Archives. D-65909, 1412_3-04

CL# 13-4036, Pages have been redacted.

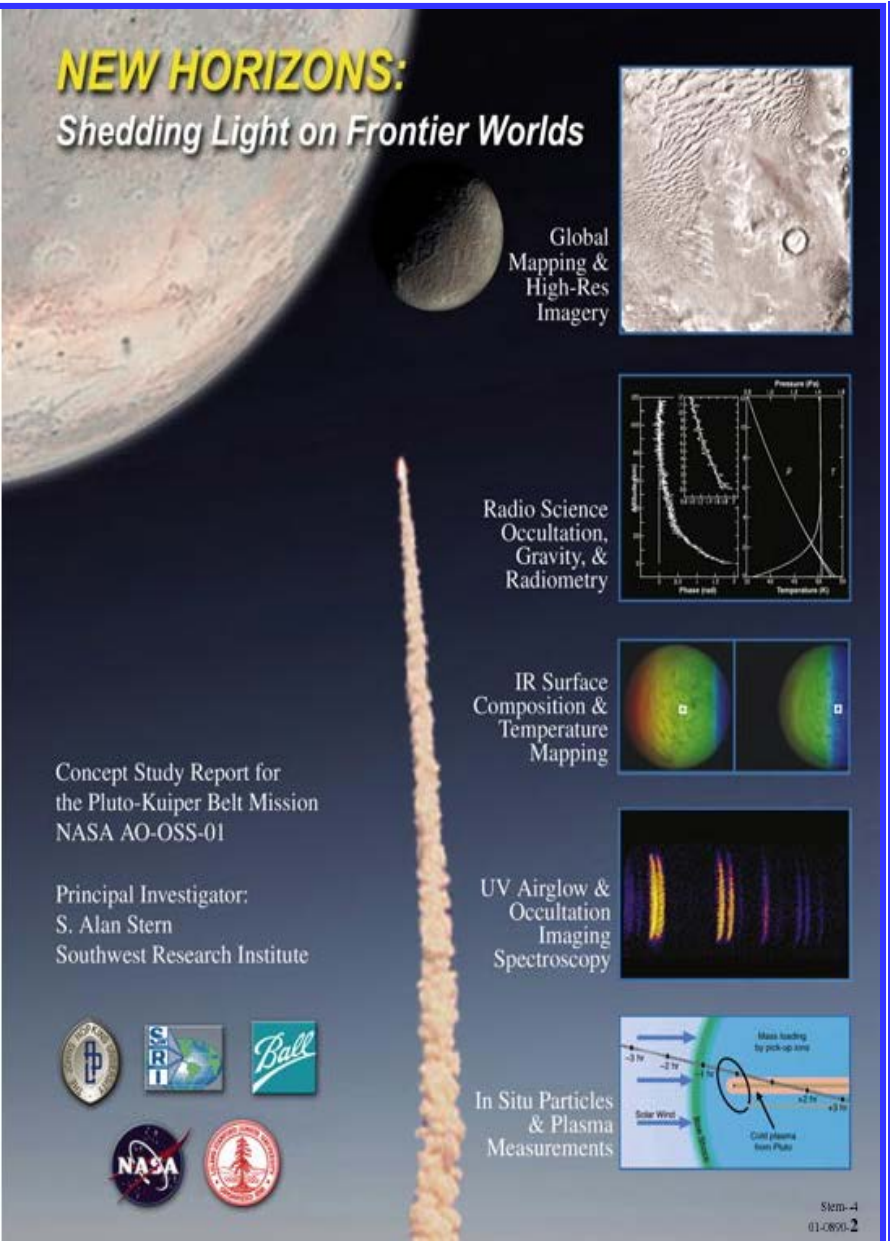
Pluto Spacecraft

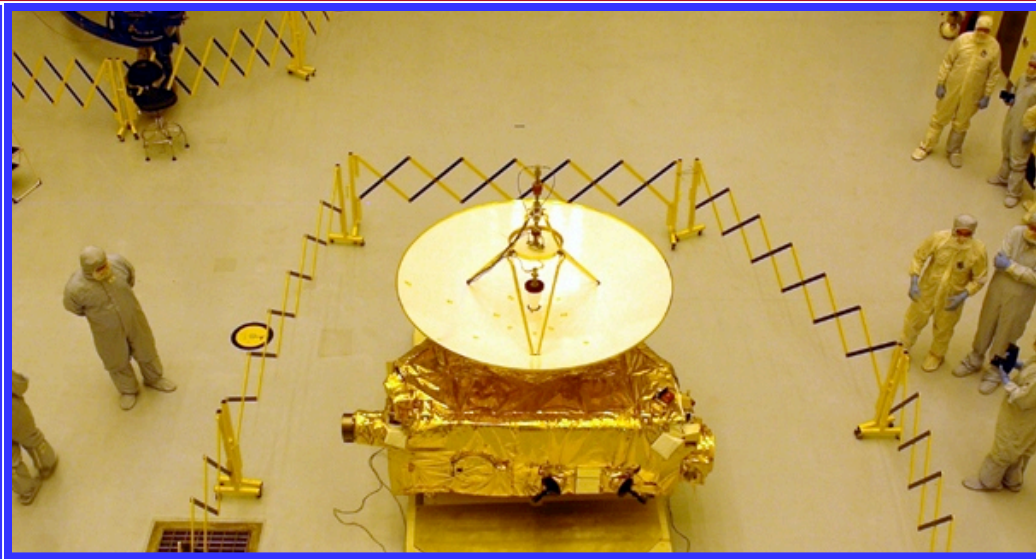
8/2/94 (0.08 Scale)

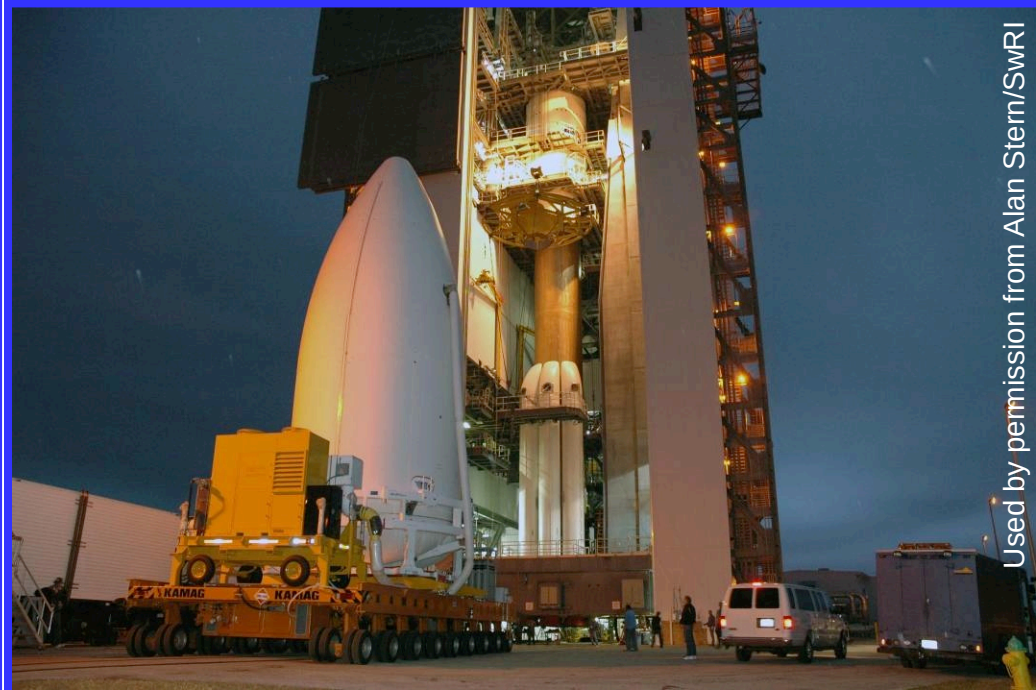


Pluto Fast Flyby mission concept c. 1994

2002-2005: DESIGN, BUILD, TEST

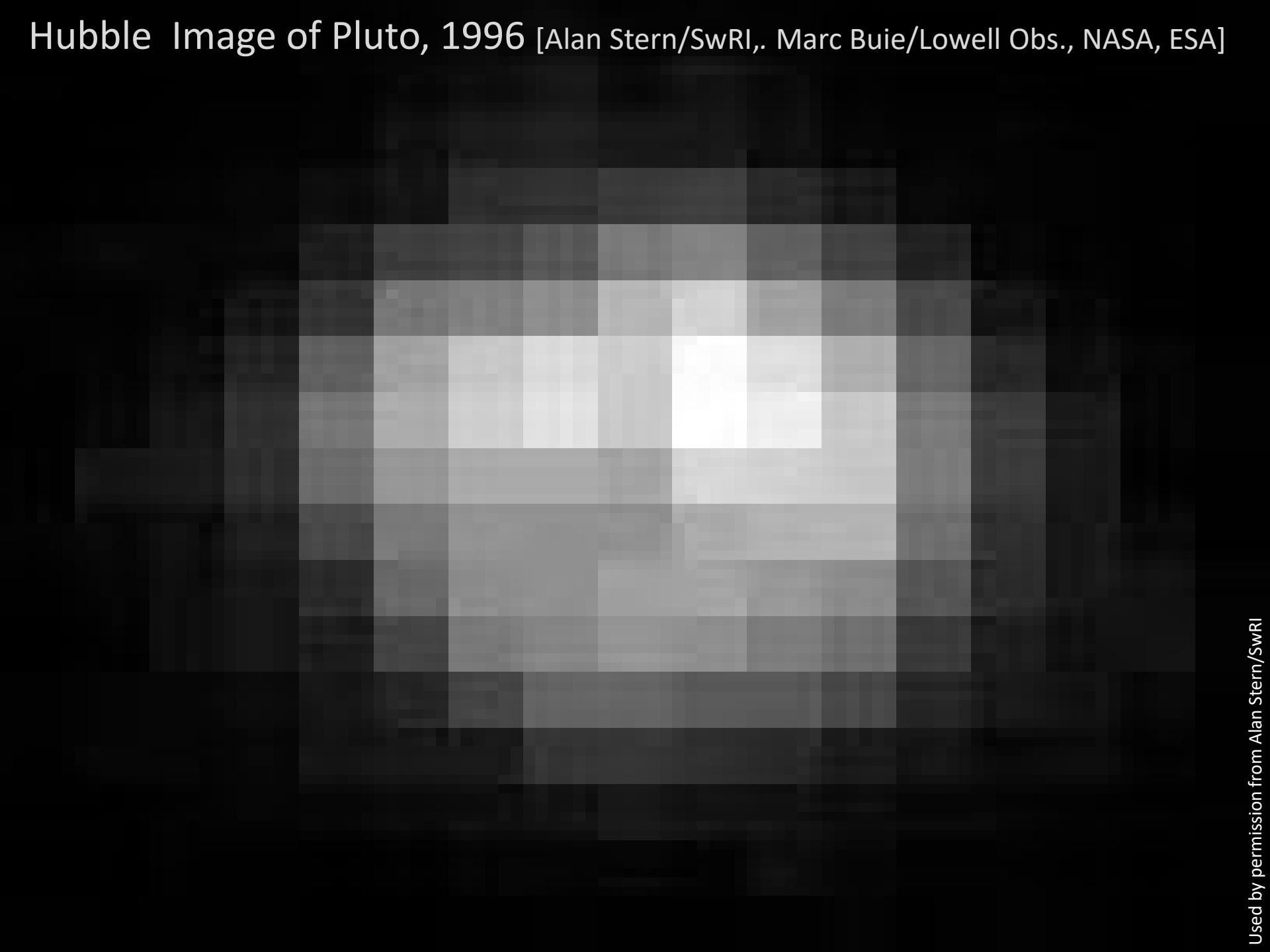






Used by permission from Alan Stern/SwRI

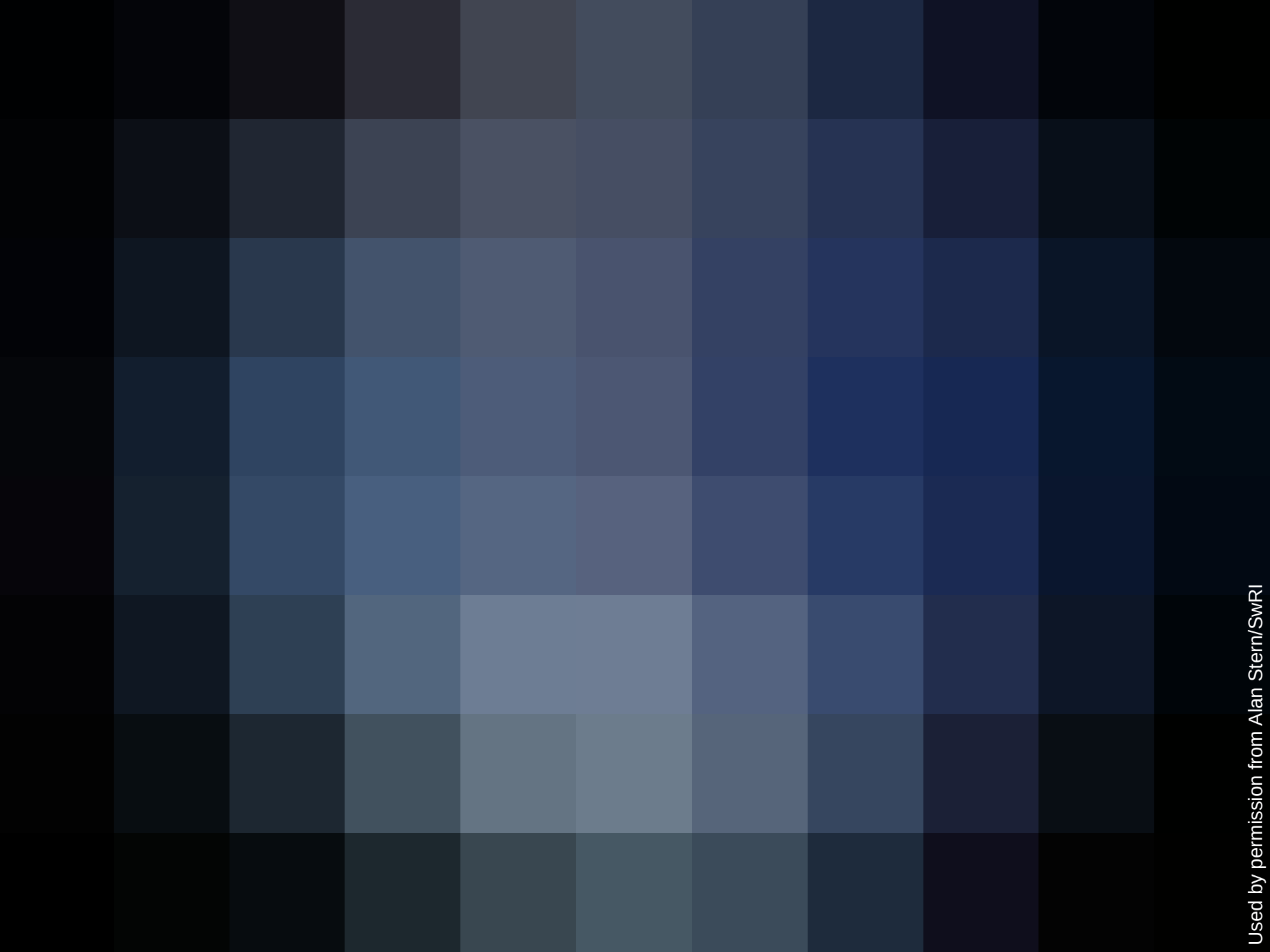
Hubble Image of Pluto, 1996 [Alan Stern/SwRI,. Marc Buie/Lowell Obs., NASA, ESA]



Used by permission from Alan Stern/SwRI

Used by permission from Alan Stern/SwRI

Used by permission from Alan Stern/SwRI



Used by permission from Alan Stern/SwRI

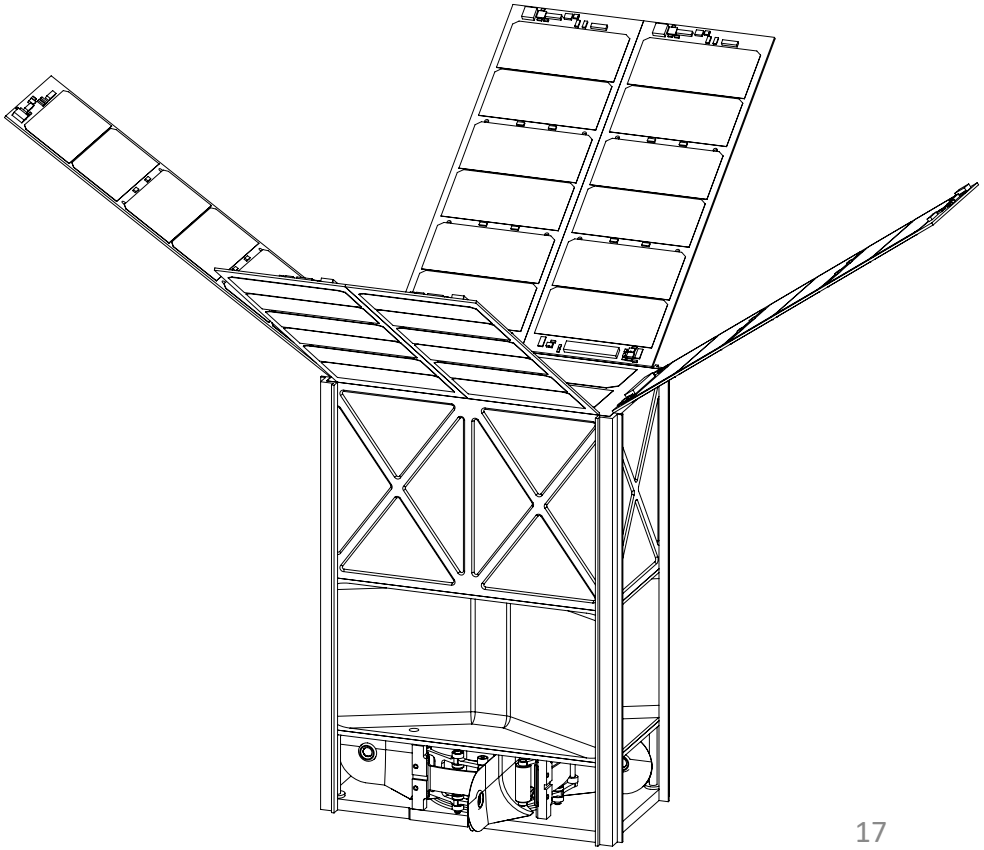
Inside the Box:

Generic CubeSat Configuration (6U):

10 x 20 x 30 cm

Fits inside "standard" box for launch

Minimizes risk to launcher or primary payload



Pre-decisional – for planning and discussion purposes only

Interplanetary CubeSats: Some Missions Feasible Sooner than Expected

First Interplanetary CubeSat Workshop
2012 May 29
Massachusetts Institute of Technology, Cambridge

Robert L. Staehle, Diana Blaney, Hamid Hemmati, Dayton Jones, Andrew Klesh, Joseph Lazio, Paulett Liewer, Martin Wen-Yu Lo, Pantazis Mouroulis, Neil Murphy, Paula J. Pingree, Thor Wilson, Chen-Wan Yen
Jet Propulsion Laboratory, California Institute of Technology

Jordi Puig-Suari, Austin Williams
California Polytechnic University, San Luis Obispo

Bruce Betts, Louis Friedman
The Planetary Society

Tomas Svitek
Stellar Exploration

Brian Anderson, Channing Chow
University of Southern California

Partial progress report:
The NASA Innovative Advanced Concepts (NIAC) task on which this report is based is still in progress. No mission described herein has been approved or funded.

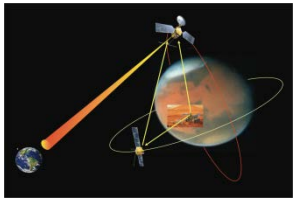
© 2012. All rights reserved. U.S. Government sponsorship acknowledged.

Pre-decisional – for planning and discussion purposes only

Getting to Interplanetary CubeSats

Six Technology Challenges

1. Interplanetary environment

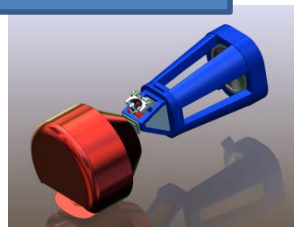


2. Telecommunications

3. Propulsion (where needed)

4. Navigation

5.Instruments



6. Maximizing downlink info content

Taxonomy

- Launch off C_3>0 ~ballistic traj
  - Cruiser
- Depart from "Mothership", 10s to 100s m/sec
  - Companion
  - Orbiter
  - Lander
  - Impactor
- Self-propelled

  1 – 10 km/sec/yr
  - *Electric*
  - *Solar Sail*

Pre-decisional – for planning and discussion purposes only

2011 *INTERPLANETARY CUBESATS* PROPOSAL INTO NASA INNOVATIVE ADVANCED CONCEPTS (NIAC) COMPETITION

"We intend to demonstrate feasibility and techniques…enabling a new class of missions beyond low Earth orbit, where this class is defined by mass < 10 kg, cost < $30M (potentially << $30M), and durations up to 5 years."

"Six technologies combine to enable a new architecture, yielding many exciting missions:

1. ***CubeSat electronics and subsystems*** extended to operate in the interplanetary environment (esp. radiation and duration of operation).
2. ***Optical telecommunications*** to enable very small, low power uplink/downlink over interplanetar y distances.
3. ***Solar sail propulsion*** to enable rendezvous with multiple targets using no propellant.
4. ***Navigation of the Interplanetary Superhighway*** to enable multiple destinations over reasonabl e mission durations and achievable deltaV.
5. ***Small, highly capable instrumentation*** (with a miniature imaging spectrometer example) enabl ing acquisition of high-quality scientific and exploration information.
6. ***Onboard storage and processing*** of raw instrument data and navigation information to enable maximum utility of uplink and downlink telecom capacity, and minimal operations staffing.

New Architecture: Mutual trades among all these technologies will create a new mission architecture enabling meaningful, modest and frequent Solar System exploration missions at <10% the cost of more ambitious missions today."

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

Outcome from NIAC Interplanetary CubeSats Investigation

- 7 NASA-funded missions in development (2 ready for launch now) to:
- Deep space ❖ Moon ❖ Mars ❖ Asteroid destinations
- All summed together for <$100 M
  - *Interplanetary NanoSpacecraft Pathfinder In a Relevant Environment (*INSPIRE; JPL)
  - *Lunar Flashlight* (JPL + MSFC + Morehead State Univ.)
  - *Near-Earth Asteroid Scout* (NEA Scout; MSFC + JPL)
  - *BioSentinel* (Ames Research Center)
  - *Mars CubeSat One* (MarCO; JPL)
  - *Lunar IceCube* (Morehead State Univ. + GSFC + JPL)
  - *LunaH-Map* (Arizona State Univ. + JPL)

DESIGN OVERVIEW: INSPIRE

Interplanetary NanoSpacecraft Pathfinder In a Relevant Environment

CubeSat Overview:

Volume: 3U (10x10x30cm)

Mass: 4.0 kg

Power Generation:

3 Axis Stabilized: 20 W

Tumbling: 13 W

Data Rate: 62-256000 bps

Software:

Developed in-house (*protos)*

I&T:

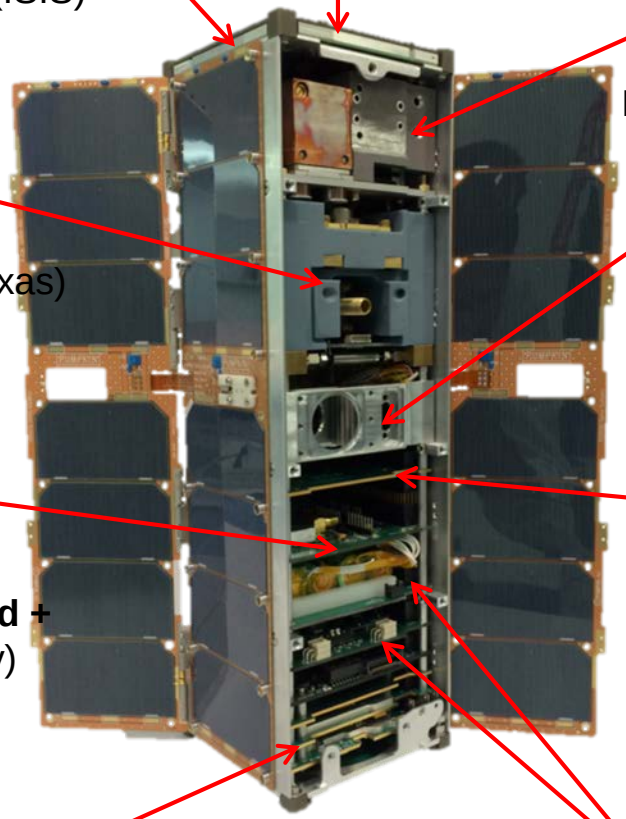
In-house S/C I&T, external environmental testing, NASA CLI P-Pod/Launch Integration

Operations:

Primary: DSN

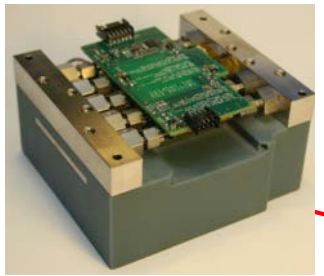
Secondary (Receive only): DSS-28 (GAVRT), & Secondary Stations, ex: Medicina Mountain

S/C components provide ***the basis for future high-capability, lower cost-risk missions*** beyond Earth, expanding and ***provide NASA leadership in an emergent domain***

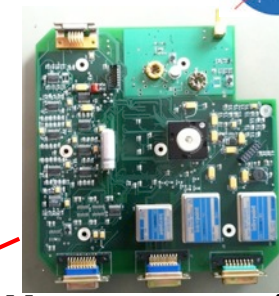


X-Band Patch Antennas (JPL) [two sets]

UHF Antenna (ISIS)

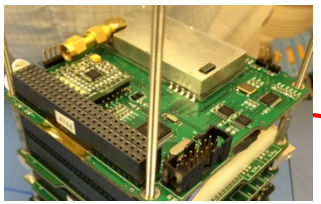


Cold-Gas ACS (U. Texas)



Magnetometer (JPL)

Star Tracker (Blue Canyon)



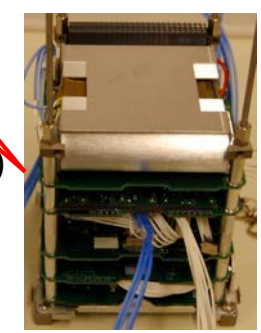
C&DH + Watchdog Board + Lithium UHF (AstroDev)

Processing Board (CalPoly / Tyvak)

Nav/Comm X-Band Radio (JPL)

Deployable Solar Panels (Pumpkin)

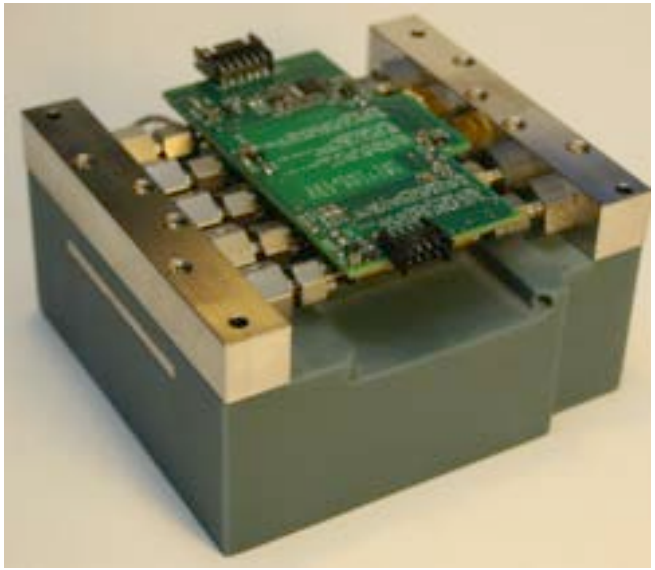
Structure (JPL)



Electrical Power System + Battery Board (U. Michigan

*Model is from Mechanical Fit Check on Feb 3, 2014

Minimizing Cost Through Flexibility



3D-Printed Attitude Control System

- Enables rapid & flexible implementation
  - **Minimizes detailed manufacturing** – prints as a single piece, including nozzles, fuel lines & tanks.
  - **Maximizes capability** as mission evolves
- Partnerships with small-businesses & universities for design and manufacturing.

Iris: Software-defined X-band Transponder

- Fully **Deep Space Network** compatible, yet supports secondary groundstations
- **Flexible in operations** – 62.5 bps to 2 Mbps
- **Low-cost & lightweight** - 0.4 kg in 4x10x10 cm
  - Enables focused CubeSat missions
  - Provides a low-cost backup for larger missions

INSPIRE *Interplanetary NanoSpacecraft Pathfinder In a Relevant Environment*

Jet Propulsion Laboratory
California Institute of Technology
CALPOLY GAVRT UCLA MICHIGAN THE UNIVERSITY OF TEXAS AT AUSTIN

INSPIRE Flight Spacecraft Completed On-Cost / On-Schedule

INSPIRE

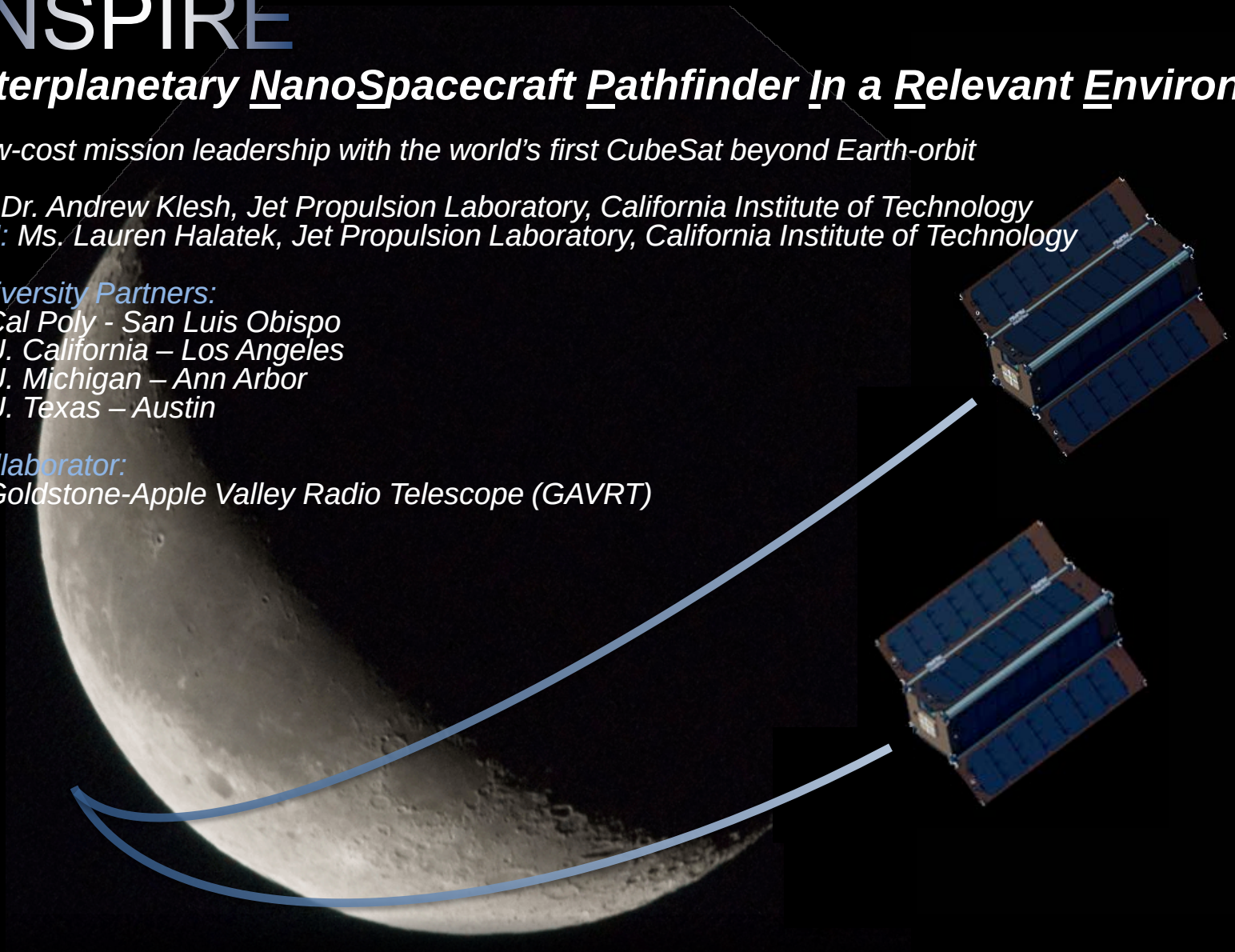
Interplanetary NanoSpacecraft Pathfinder In a Relevant Environment

Low-cost mission leadership with the world's first CubeSat beyond Earth-orbit

PI: Dr. Andrew Klesh, Jet Propulsion Laboratory, California Institute of Technology
PM: Ms. Lauren Halatek, Jet Propulsion Laboratory, California Institute of Technology

University Partners:
- *Cal Poly - San Luis Obispo*
- *U. California – Los Angeles*
- *U. Michigan – Ann Arbor*
- *U. Texas – Austin*

Collaborator:
- *Goldstone-Apple Valley Radio Telescope (GAVRT)*

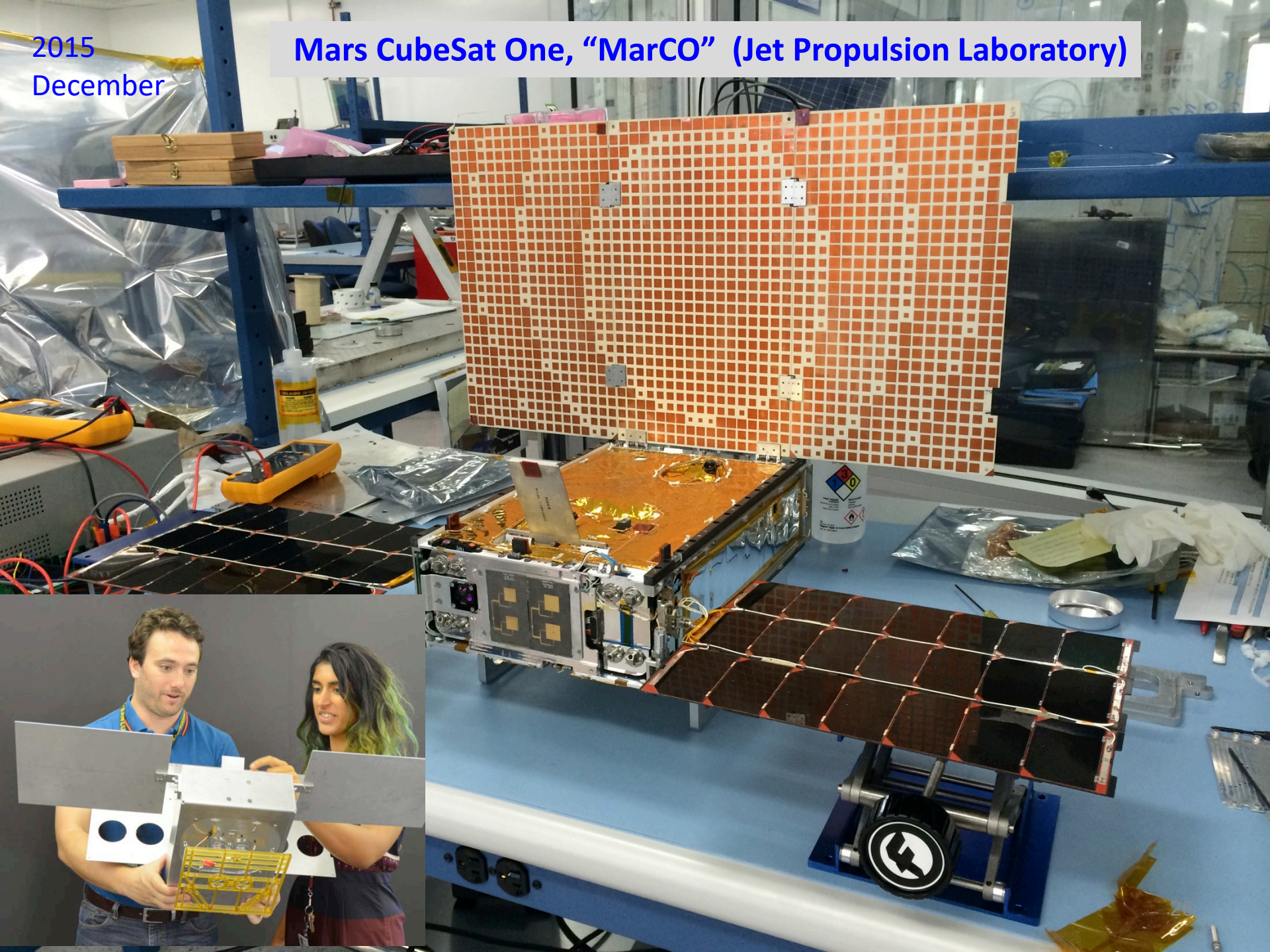


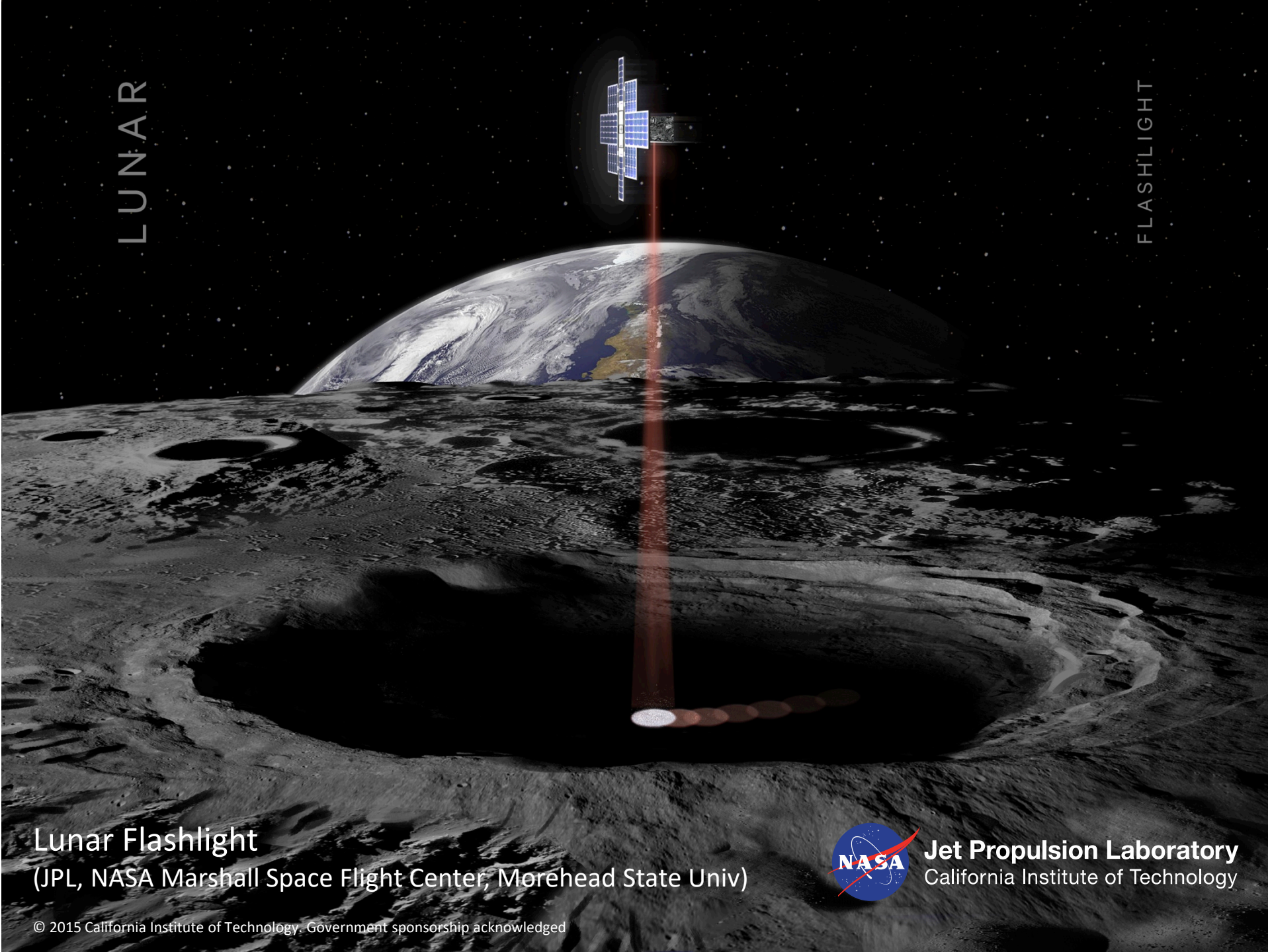
Jet Propulsion Laboratory
California Institute of Technology

Copyright 2014 California Institute of Technology. Government sponsorship acknowledged.

2015
December

Mars CubeSat One, “MarCO” (Jet Propulsion Laboratory)





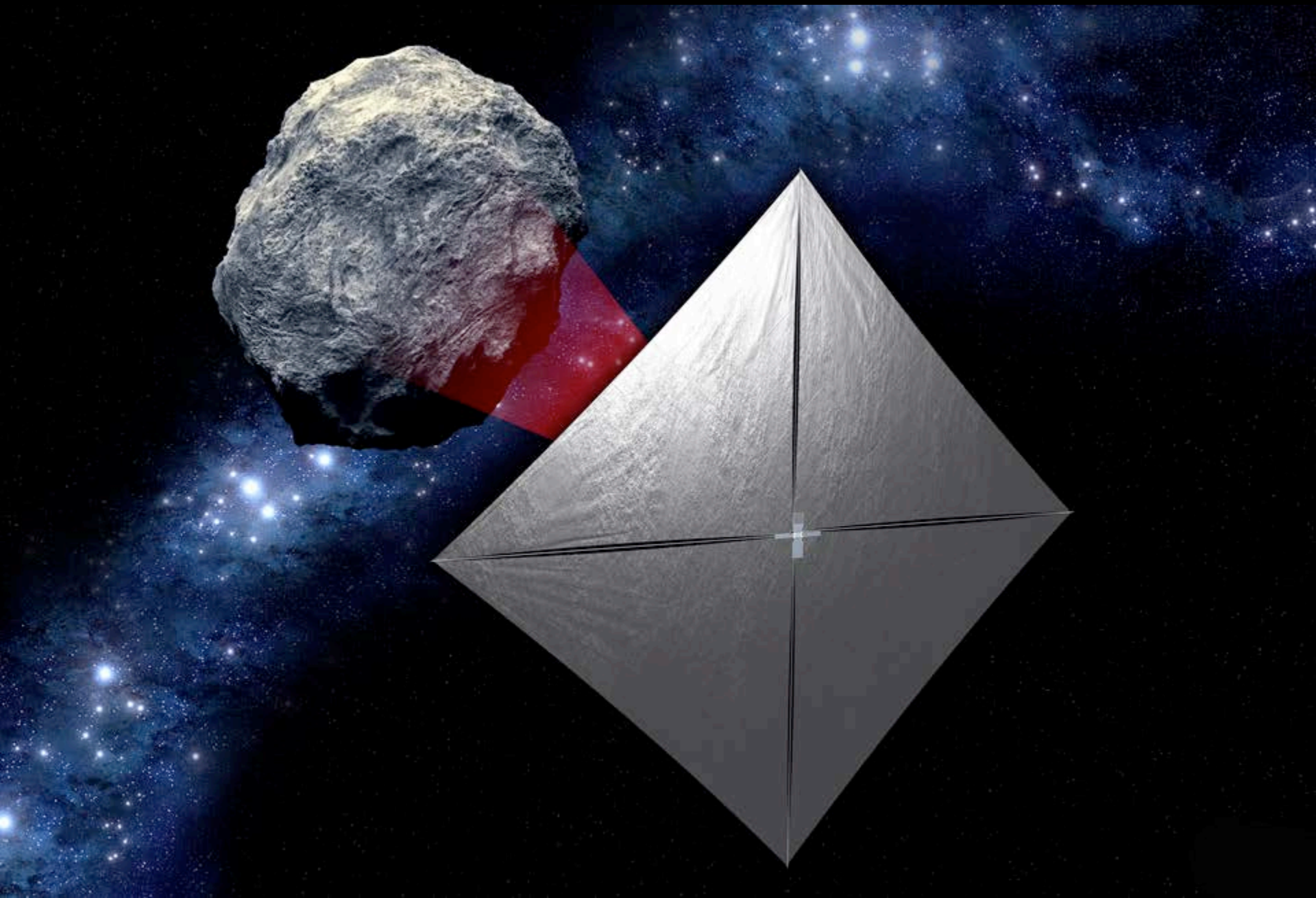
Lunar Flashlight

(JPL, NASA Marshall Space Flight Center, Morehead State Univ)

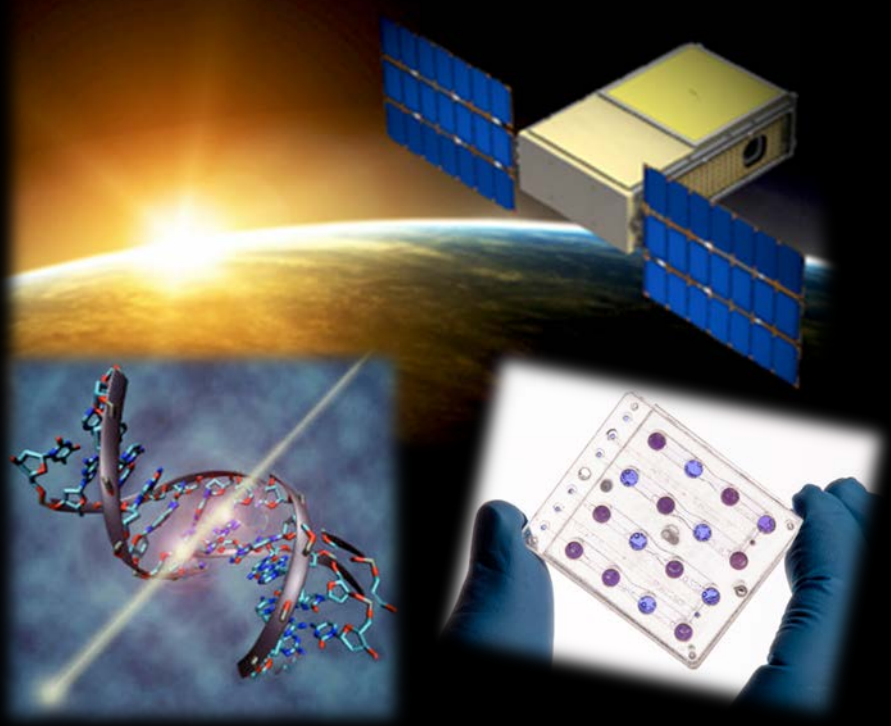
Jet Propulsion Laboratory
California Institute of Technology

© 2015 California Institute of Technology. Government sponsorship acknowledged

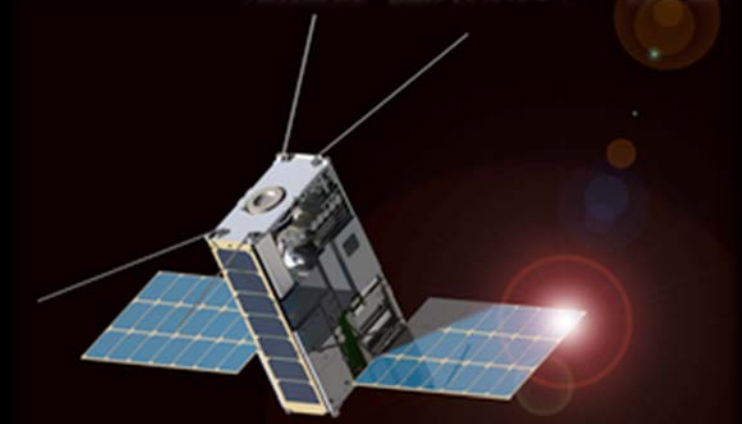
Near Earth Asteroid Scout (NASA Marshall Space Flight Center, JPL)



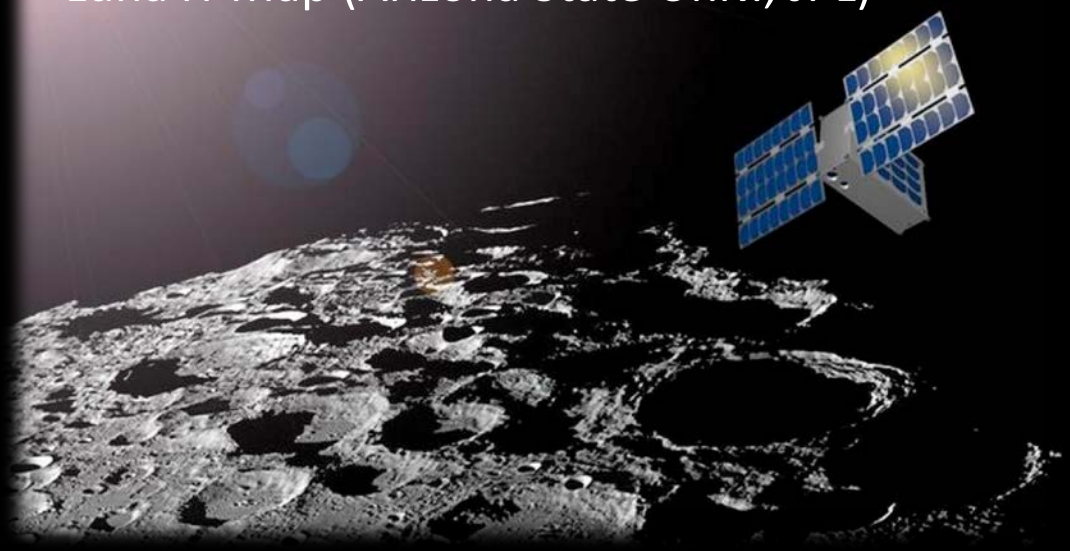
BioSentinel (NASA Ames Research Ctr)



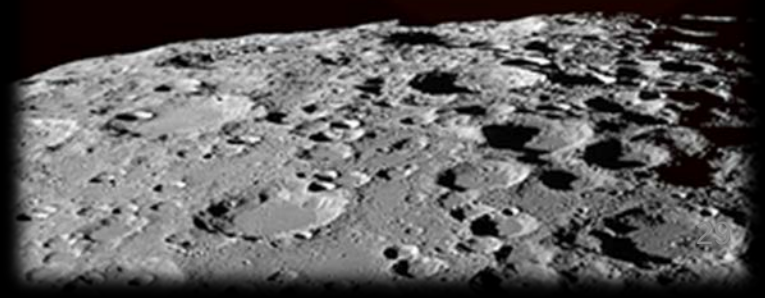
SkyFire (Lockheed Martin Corp.)



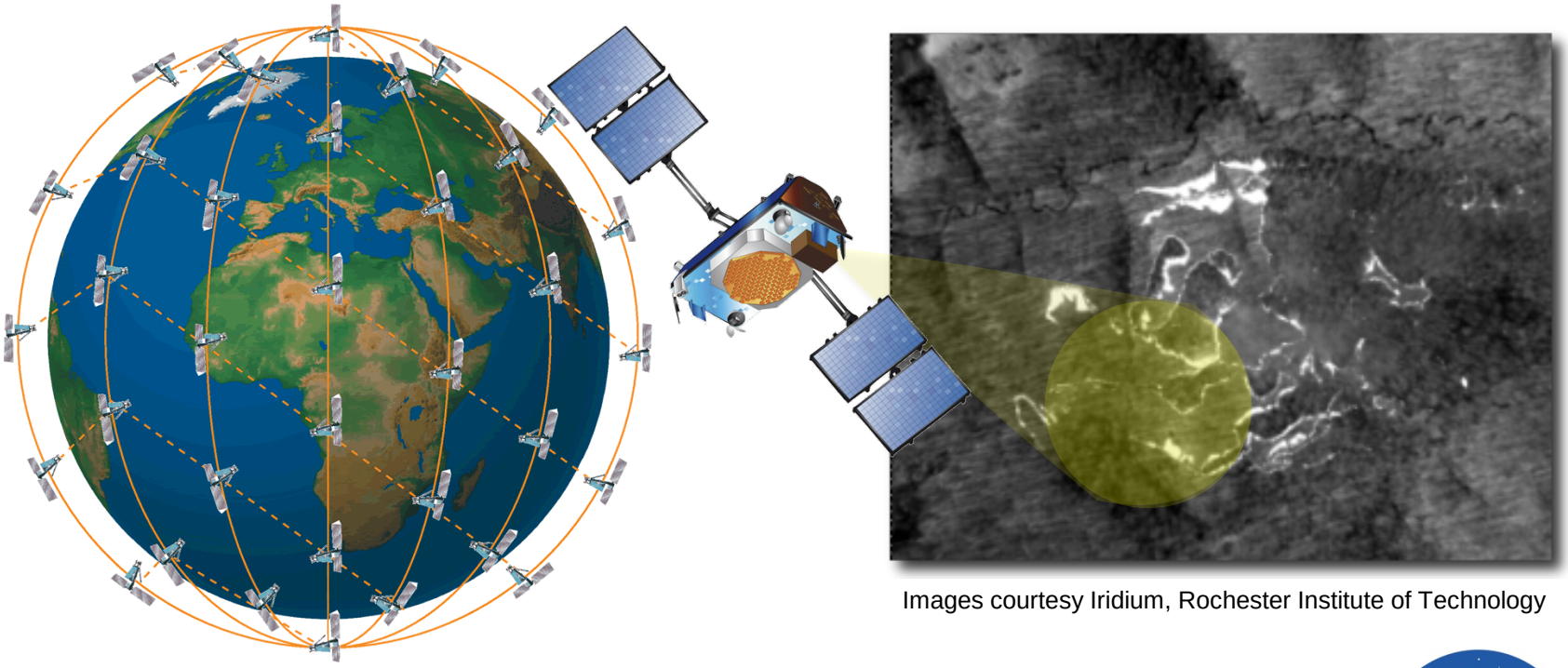
Luna H-Map (Arizona State Univ., JPL)



Lunar IceCube
(Morehead State University,
NASA Goddard Space Flight Center, JPL)



For: **Tactical Fire Remote Sensing Advisory Committee (TFRSAC)** 2011 October 27



Images courtesy Iridium, Rochester Institute of Technology

Fire Detection Constellation Concept:

Iridium Backcountry Wildfire Detection Network

David R. Thompson (388E), William Johnson (389G), Michael Mercury (312E)

Presented by: **Robert Staehle**, Instruments & Science Data Systems Division (380)

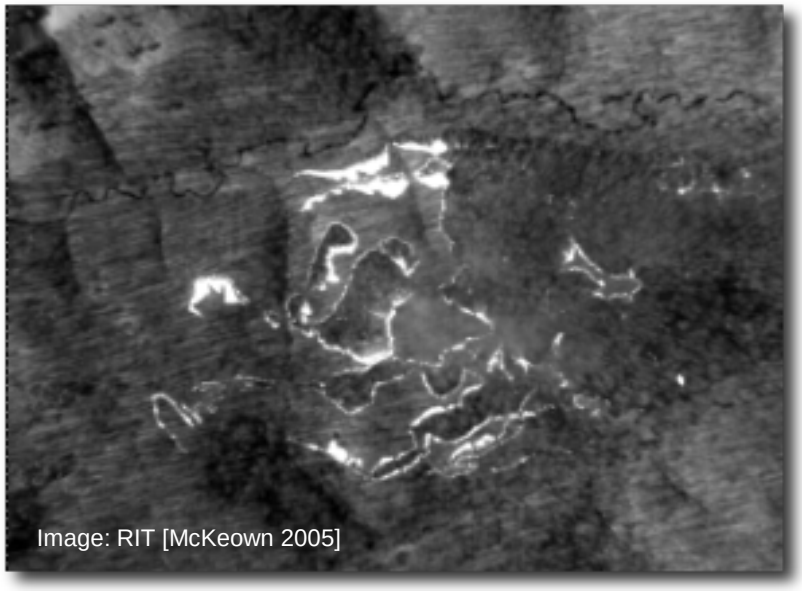
Jet Propulsion Laboratory, California Institute of Technology

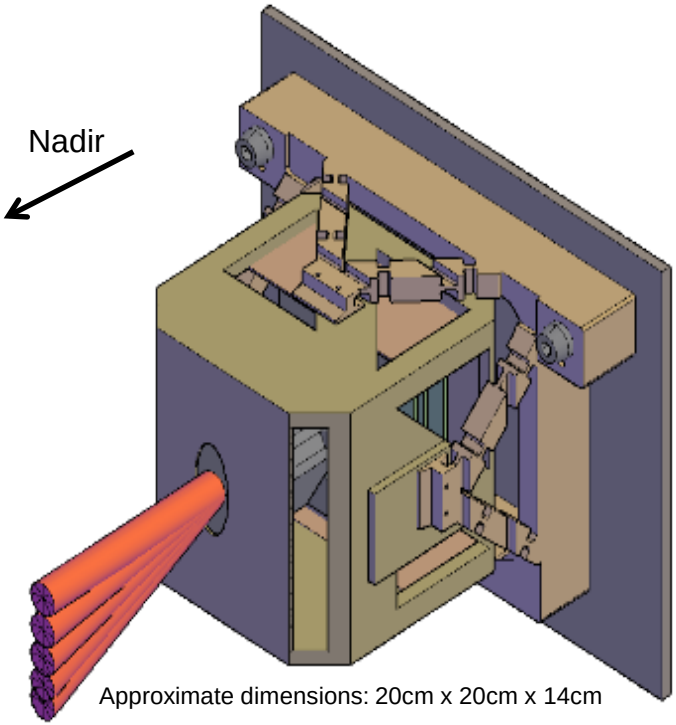
Copyright 2011 California Institute of Technology, except where noted. Government sponsorship acknowledged.

POC: *robert.l.staehle@jpl.nasa.gov, 818 354-1176*

A 4µm CAMERA POINT DESIGN

- Extrapolation from airborne MWIR images suggests that subpixel fires can be detected – as small as 15x15 m^2
- Detection is straightforward and can be accomplished with a small-scale instrument





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

Multiplying Mars Lander Opportunities with $MARS_{DROP}$ Microlander

2015 June 11

IAA Low Cost Planetary Missions Conference

Berlin, Germany

Robert L. Staehle/Jet Propulsion Laboratory-California Institute of Technology
Matthew A. Eby/Aerospace Corp., Rebecca M. E. Williams/Planetary Science Institute
Sara Spangelo, Kim Aaron, Rohit Bhartia, Justin Boland, Lance Christensen,
Siamak Forouhar, Marc Lane, Manuel de la Torre Juarez, Nikolas Trawny,
Chris Webster/JPL-Caltech
David Paige/University of California-Los Angeles

Copyright 2015. All rights reserved.

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

Planetary Science Institute

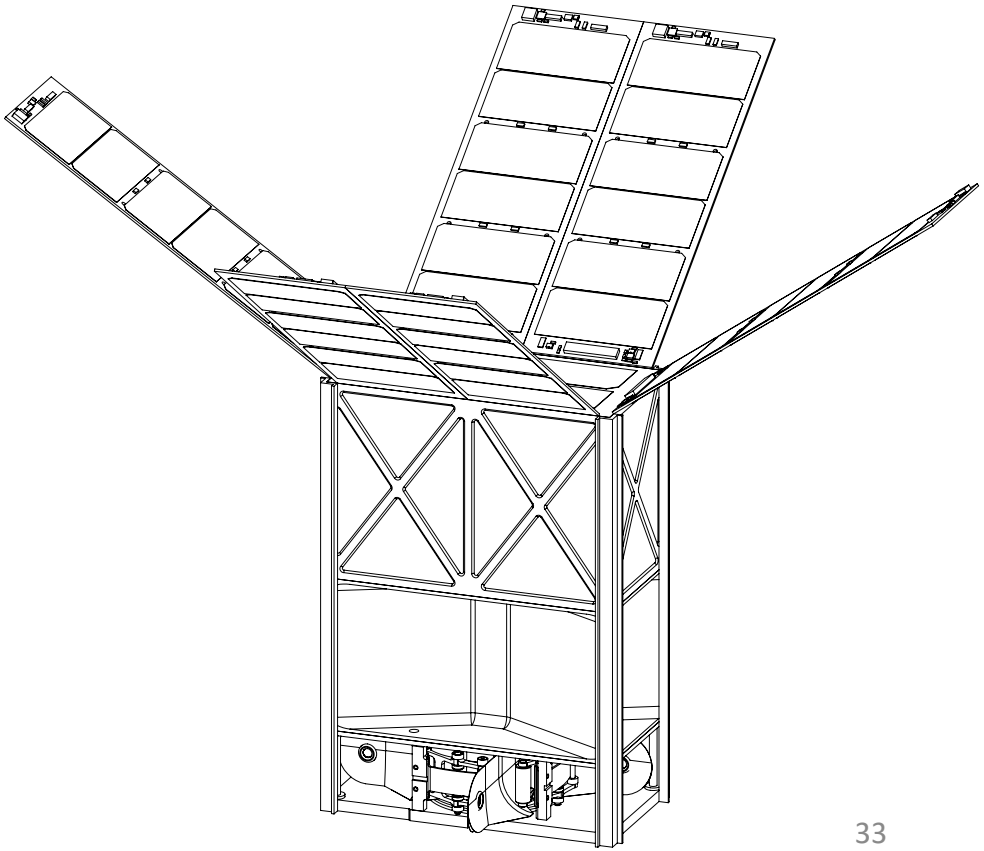
Inside the Box:

Generic CubeSat Configuration (6U):

10 x 20 x 30 cm

Fits inside "standard" box for launch

Minimizes risk to launcher or primary payload



Pre-decisional – for planning and discussion purposes only

Outside the Box:

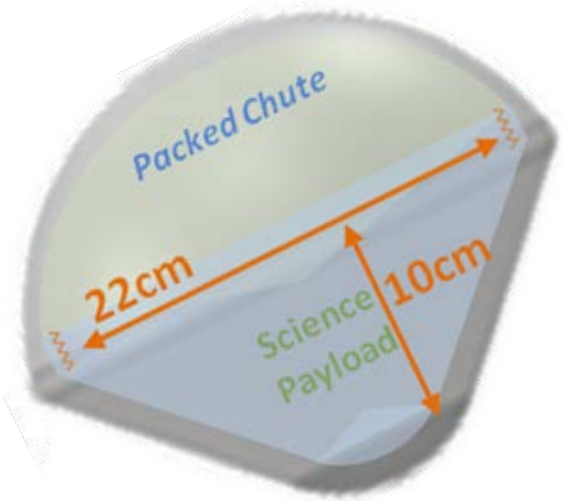
~~Generic CubeSat Configuration (6U~~) Unlimited configuration:

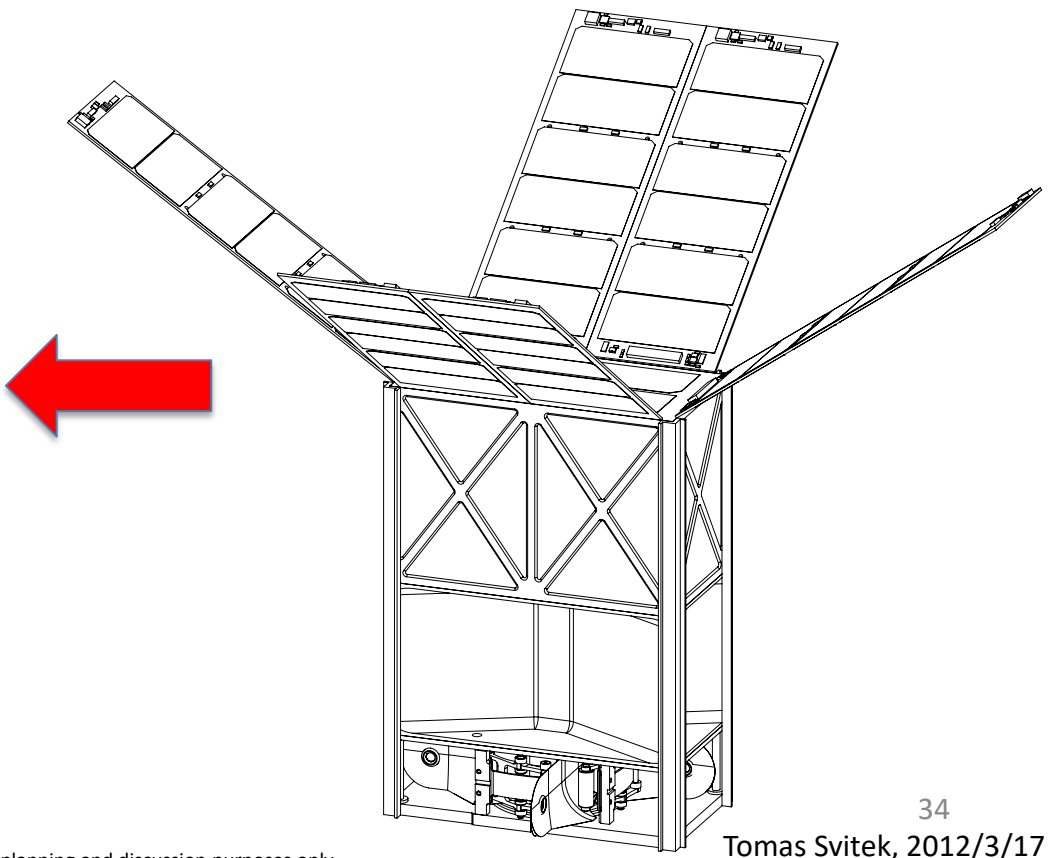
~~10 x 20 x 30 cm~~ <50 x 50 x 75 cm maximum.

Fits inside ~~"standard" box~~ for launch.

Fits inside "extra volume" aboard launch vehicle.

Extra effort required to minimize risk to launcher or primary payload.





Artist's Concept

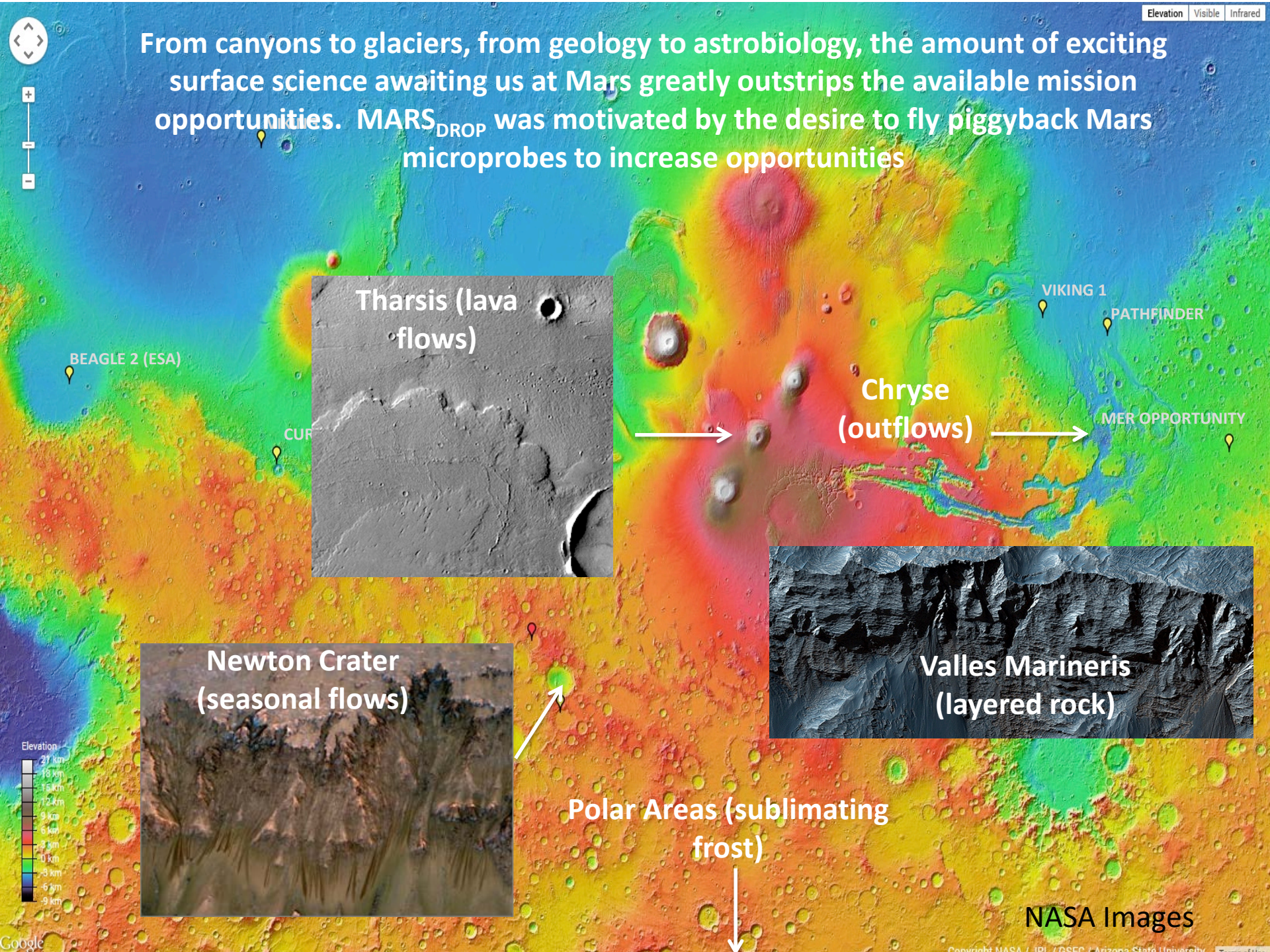
Robert Staehle, 2016/8/28

Tomas Svitek, 2012/3/17

Pre-decisional – for planning and discussion purposes only

AVIATION WEEK

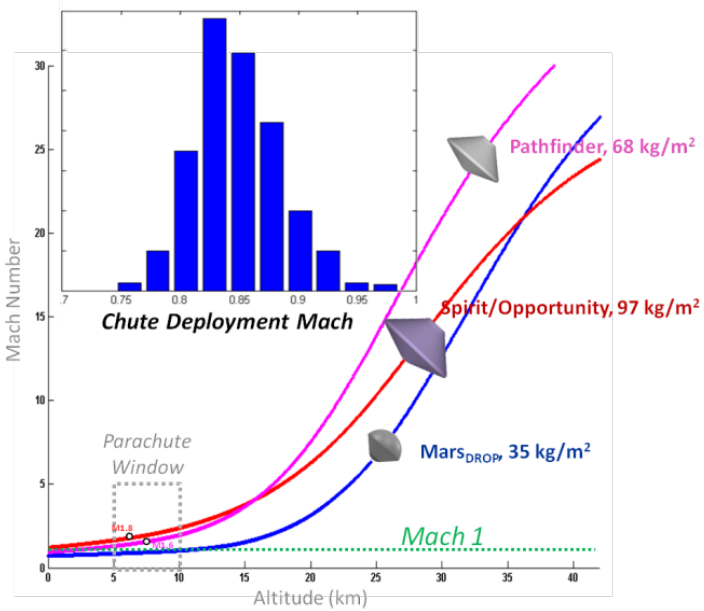
From canyons to glaciers, from geology to astrobiology, the amount of exciting surface science awaiting us at Mars greatly outstrips the available mission opportunities. $MARS_{DROP}$ was motivated by the desire to fly piggyback Mars microprobes to increase opportunities

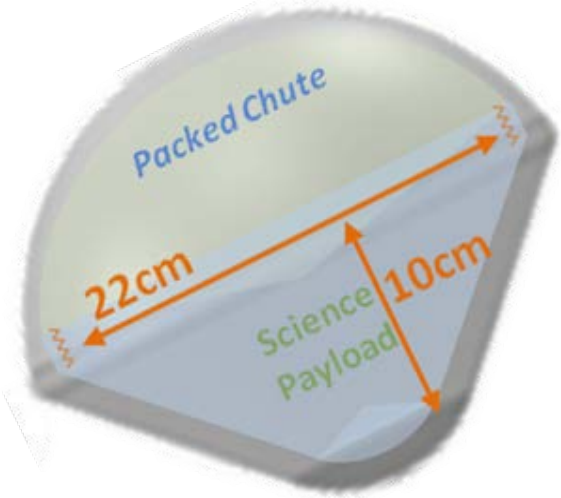


NASA Images

Capability Summary (conceptual)

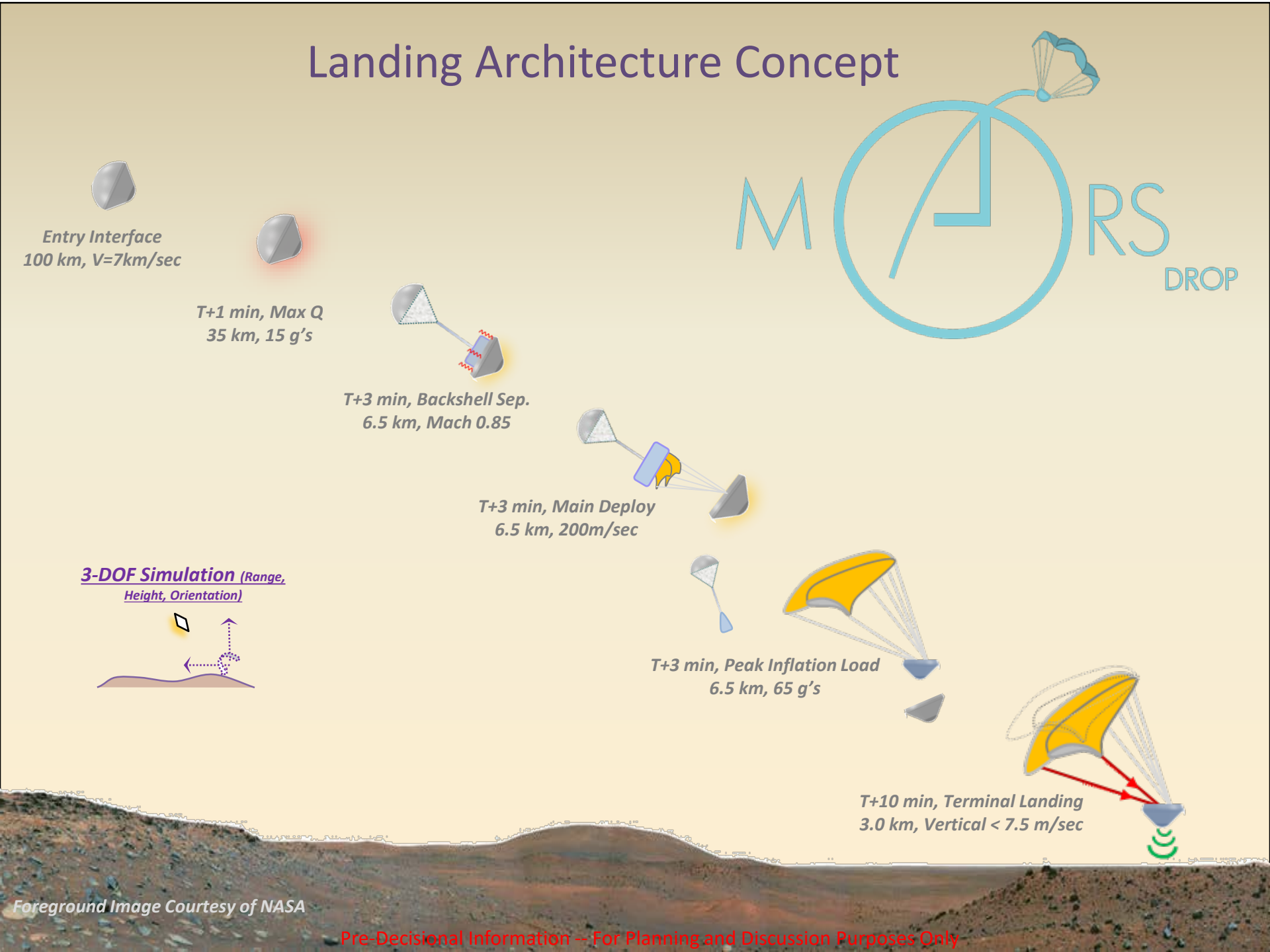
- Probe is largely inert ballast from the host standpoint, added burden of 10 kg per probe.
- Probe shape derived from REBR/DSII, provides passive entry stability.
- Entry mass limited by the need to provide a subsonic parachute deployment
  - *3-4 kg probe entry mass*
  - *Accommodates a ~1 kg science payload*
- Packed parawing preserves a significant portion of the volume for a landed payload.
- Parawing is steerable, opening the way for targeted landing.
- Inexpensive, ~~$20 M for <u>1st mission</u>
  - *<$10 M next mission; <<$10 M for copies*
  - *Encourages high risk destinations, such as canyons*





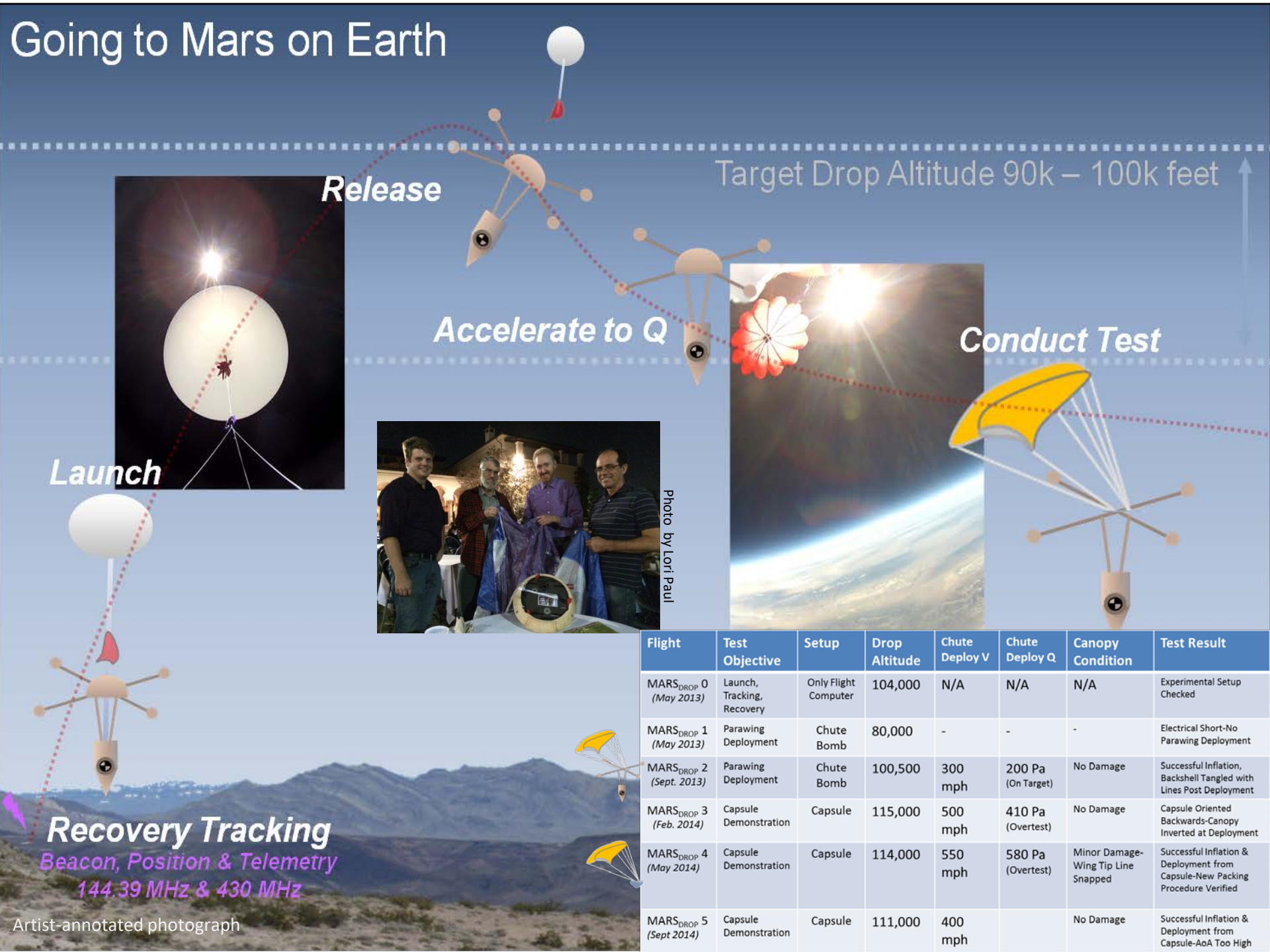
Pre-Decisional Information -- For Planning and Discussion Purposes Only

Landing Architecture Concept



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

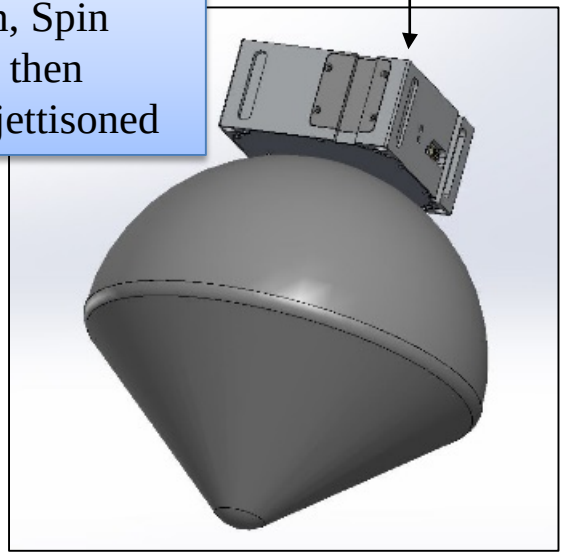
Going to Mars on Earth



Flight	Test Objective	Setup	Drop Altitude	Chute Deploy V	Chute Deploy Q	Canopy Condition	Test Result
$MARS_{DROP}$ 0 *(May 2013)*	Launch, Tracking, Recovery	Only Flight Computer	104,000	N/A	N/A	N/A	Experimental Setup Checked
$MARS_{DROP}$ 1 *(May 2013)*	Parawing Deployment	Chute Bomb	80,000	-	-	-	Electrical Short-No Parawing Deployment
$MARS_{DROP}$ 2 *(Sept. 2013)*	Parawing Deployment	Chute Bomb	100,500	300 mph	200 Pa (On Target)	No Damage	Successful Inflation, Backshell Tangled with Lines Post Deployment
$MARS_{DROP}$ 3 *(Feb. 2014)*	Capsule Demonstration	Capsule	115,000	500 mph	410 Pa (Overtest)	No Damage	Capsule Oriented Backwards-Canopy Inverted at Deployment
$MARS_{DROP}$ 4 *(May 2014)*	Capsule Demonstration	Capsule	114,000	550 mph	580 Pa (Overtest)	Minor Damage-Wing Tip Line Snapped	Successful Inflation & Deployment from Capsule-New Packing Procedure Verified
$MARS_{DROP}$ 5 *(Sept 2014)*	Capsule Demonstration	Capsule	111,000	400 mph		No Damage	Successful Inflation & Deployment from Capsule-AoA Too High

Phases & Configuration (conceptual)

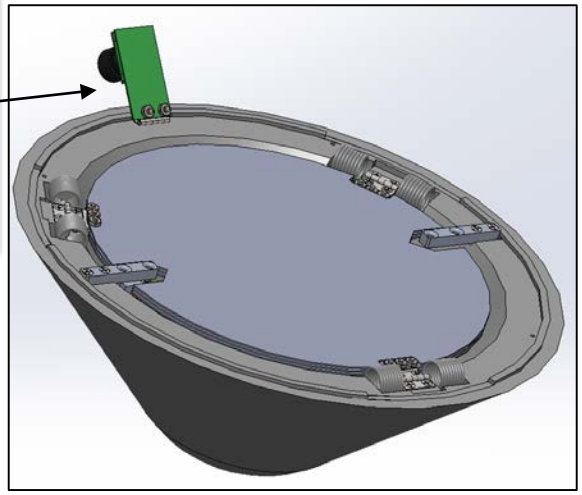
1) Deployment, Orientation, Spin Initialized, then Backpack jettisoned



1) **Deployment:** *Backpack Unit* is 0.5 U XACT BCT (includes batteries) module to sense & control attitude, then impart spin (~2 rpm) required for stability through entry; jettisoned at entry interface

2) Entry: Maximum deceleration ~12 g's and heating ~150 W/cm^2 at ~40 km altitude from Mars surface

2) Entry, jettison Backshell, then Parawing & Descent Camera deployed



(lines to parawing not shown)

Representative descent characteristics for Mars Microprobe (Mars$_{DROP}$ is very similar with β=36.4 kg/m^2 with Current Best Estimate mass)

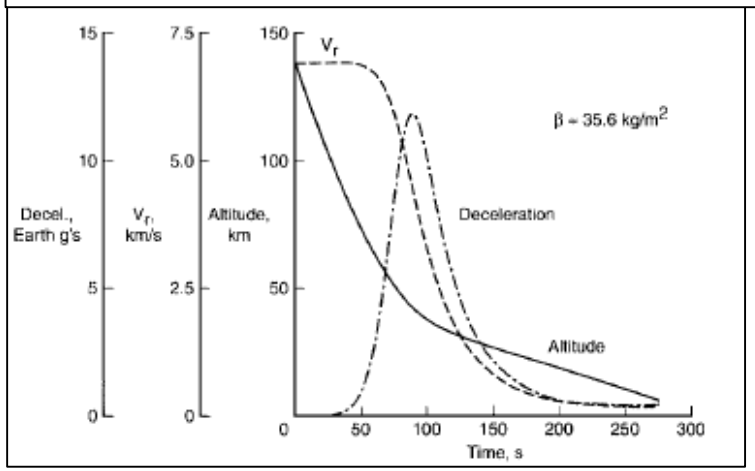


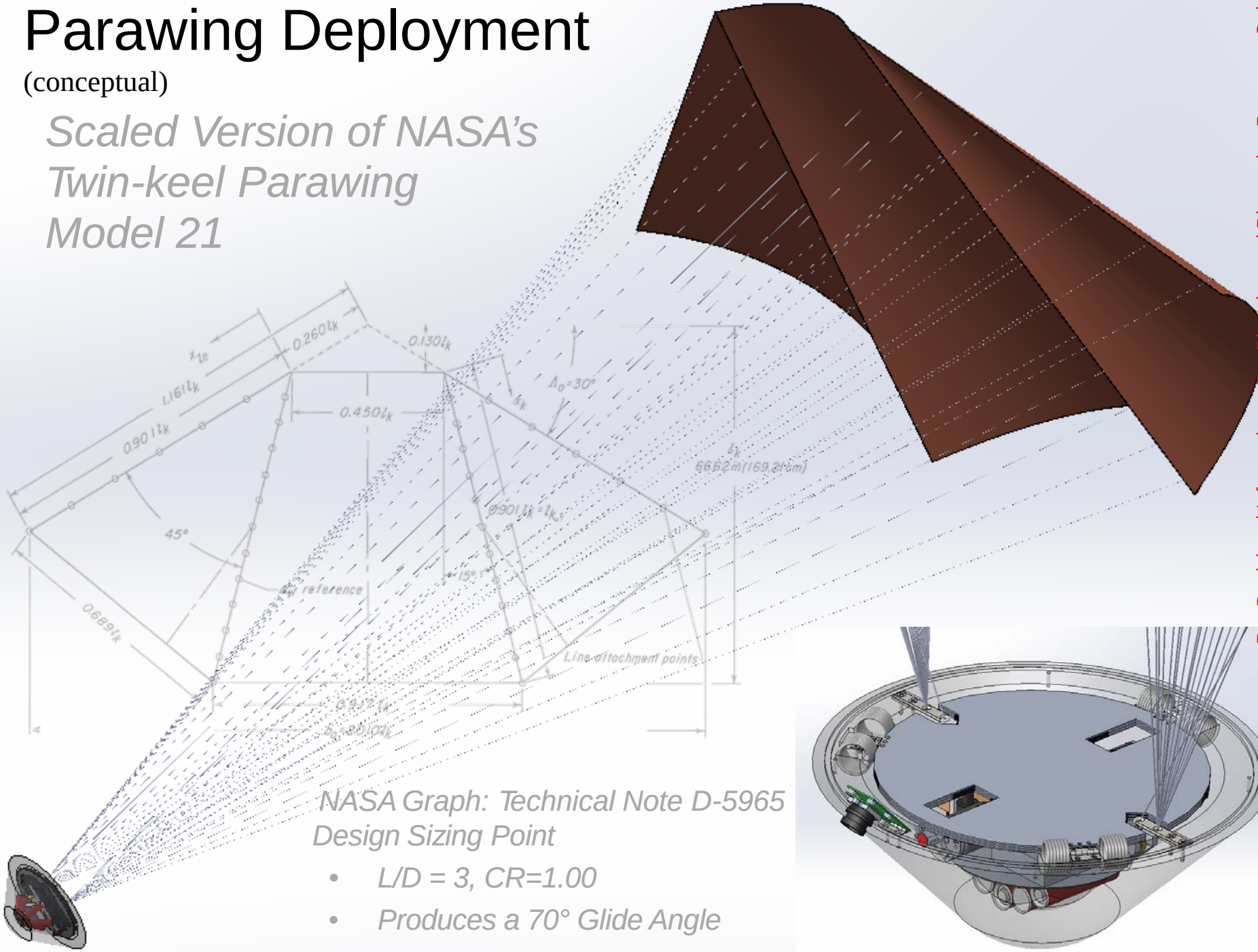
Figure reference: R. Braun et al., "Mars Microprobe Entry-to-Impact Analysis", JSR, 1999.

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

Parawing Deployment

(conceptual)

Scaled Version of NASA's Twin-keel Parawing Model 21



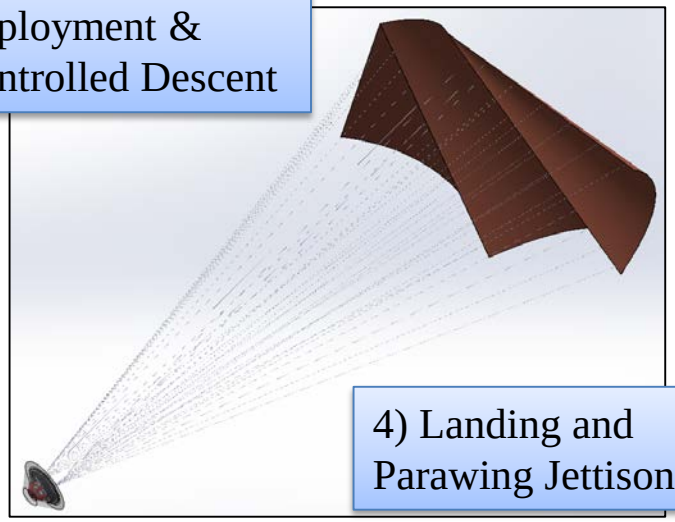
NASA Graph: Technical Note D-5965

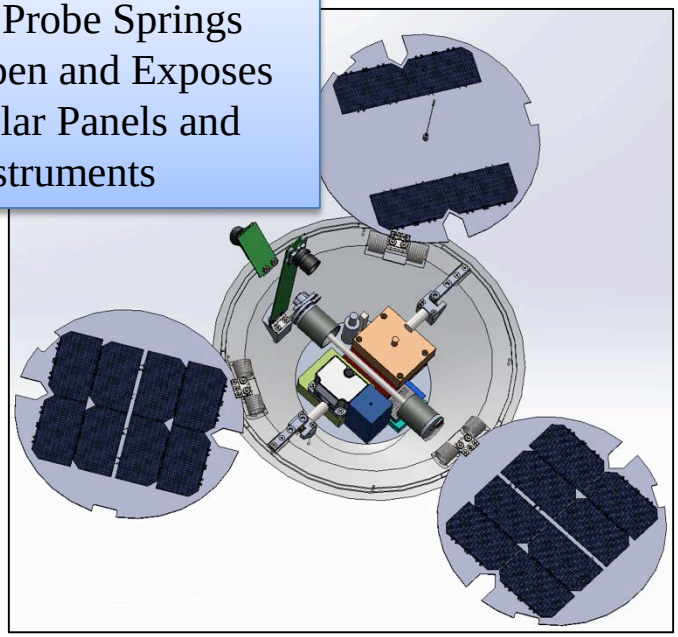
Design Sizing Point

- *L/D = 3, CR=1.00*
- *Produces a 70° Glide Angle*

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

Phases & Configuration (conceptual)





3) Parawing Deployed: Parawing released to enable gliding and controlled descent.

Controlled Descent: Camera pointed at ground/ horizon for position/altitude determination.

On-board navigation algorithms control actuators that pull on wingtips to turn (one wingtip) or change glide angle (both wingtips).

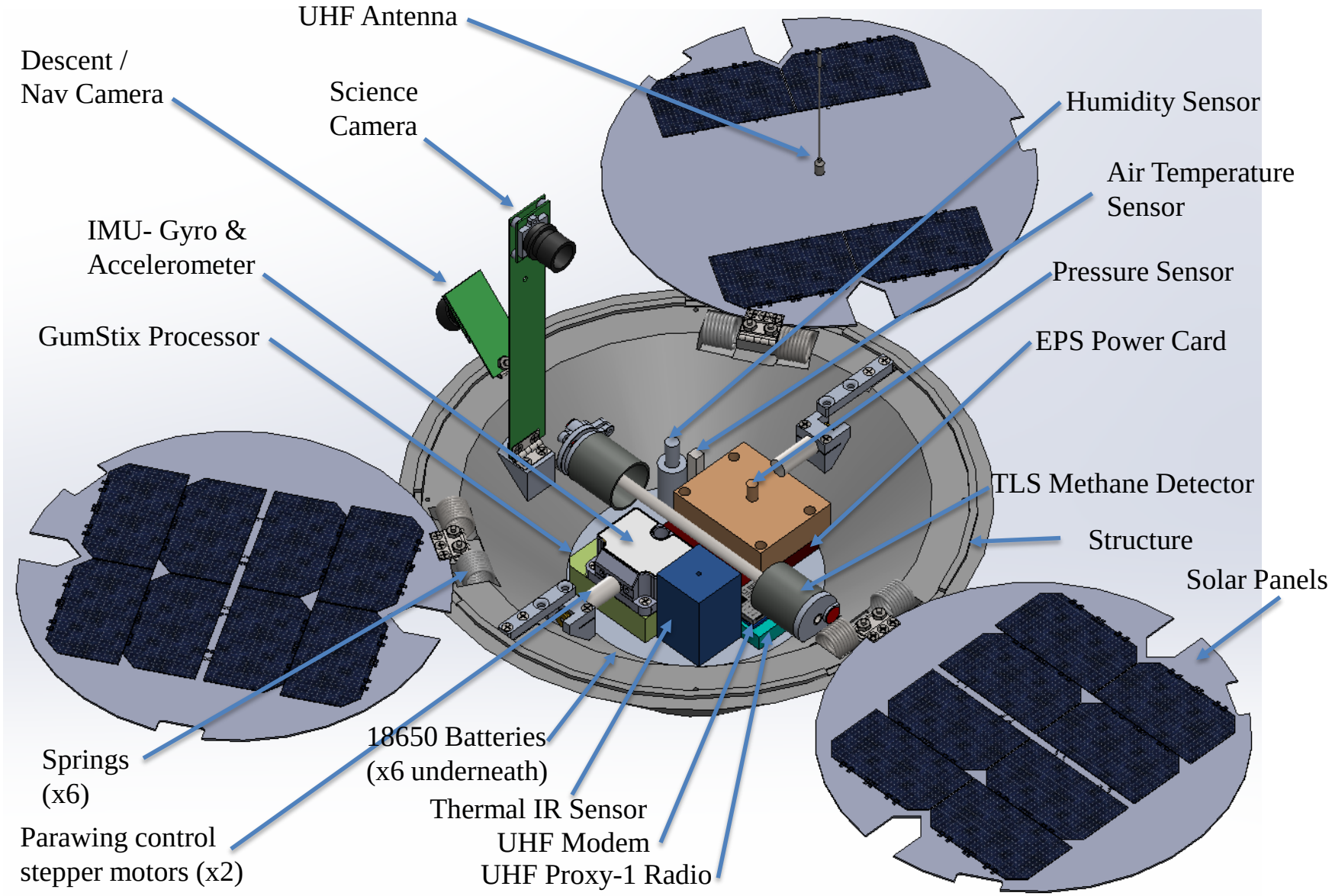
Nominally a ~3:1 glide ratio is achieved. The navigation system helps probe slide to pre-selected landing sites.

4) Landing: Expected speeds ~20 m/sec total, ~7 m/sec vertical, 18.7 m/sec horizontal, flare possible. Rolling expected and probe designed for expected impact forces (~300-500 g's).

5) Opening: Springs are powerful enough to "right" spacecraft regardless of landing orientation and expose "platters" to sky.

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

Configuration Overview (conceptual)



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

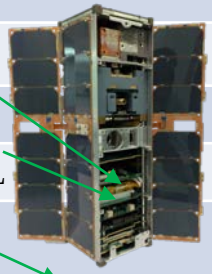
Survey: A Variety of Plausible Instrumentation, Serving a Span of Science, Can Be Accommodated

Instrument Type	Mass (g)	Power (mW)	Max Dimension (mm)	Example	Modification Required	Measurements & Remarks	JPL POC
Video Camera	**74**	**600-1900**	**60**	GoPro Hero3	Rad tolerance; modify for external control	720p, 960p, 1080p video with 3 FOVs up to ~150 deg. 5, 7, 10 MP pictures with 3 -10 fps.	T. Imken/ T. Goodsall
Legacy still camera	**220**	**210**	**67**	MER/MSL Hazcam & Navcam	Lander to provide input voltages and camera control	High heritage; scientific quality CCD still images up to every 5 sec. >20 units to Mars.	M. Walch
SmartCam	**<100**	**<1600**	**58**	PIXHAWK	Low op temp, Rad tolerance.	Machine vision camera and processing to support glide-to-target guidance.	J. Boland
uSeismometer	**200**	**100**	**30**	JPL Microdevices		Performance comparable to conventional terrestrial seismometer.	R. Williams/ PSI
Weather Monitor	**≤1930**	**12,750 (peak)**	**140**	REMS/MSL, Twins/InSIGHT	Adapt to the desired envelope.	Configuration is flexible and sensors can be added or subtracted/replaced + aerosol monitoring sensor via a dedicated camera.	M. de la Torre Juarez
Aerosol Properties Sensor	**630**	**4300 (peak)**	**70**	REMS/MSL, Twins/InSIGHT	Adapt to the desired envelope.	Camera from above + set of photodiodes; from Mars 2020	M. de la Torre Juarez
Multispectral Micrscopic Imager VNIR	**240**	**3000 (60 sec.)**	**67**	MER-MI Rosetta ROLIS Phoenix RAC	Wider FOV	Infer mineral grain composition at <1 mm scale. Operates day (panchromatic) or night (multispectral 0.4 to 1.0 microns).	R. Glenn Sellar
Multispectral Micrscopic Imager VSWIR	**150**	**9000 (5 mins)**	**110**	MIMI Mars 2020 proposal	Wider FOV ~30 x 30 xm. Consider COTS InGaAs camera	Infer mineral grain composition at <1 mm scale. Passively-cooled HgCdte - operates at night (multispectral 0.45 to 2.45 microns).	R. Glenn Sellar
Deep UV Fluorescence Imager	**700**	**3000 (peak)**	**150**	Lab demo	Communication/power from vehicle.	Orgranic detection. Small UV light sources dependent on current DARPA efforts.	R. Bhartia
Deep UV Fluorescence / Raman Imager	**3000**	**15000 (peak)**	**250**	SHERLOC/ Mars 2020	Reduce mass, comm/power from vehicle	Organic detection, astrobiological-relevant minerals, Ops short burst laser source high TRL.	R. Bhartia
Tunable Laser Spectrometer	**400**	**400**	**100**	CH_4 sniffer for PG&E	Miniaturized cell, electronics, low power laser packages.	CH_4 to 1 ppbv. Heritage from TLS-MSL and quadcopter versions.	L. Christensen/S. Forouhar

Master Equipment List (preliminary)

Suppliers shown only for proof-of-concept; no selection is represented.

Subsystem	Components	Mass	Power	Heritage / Supplier
Entry & Descent	Aeroshield (1,200 g), Parawing (400 g), Stepper motors (2 x 10 g)	1,620 g	-	REBR/Aerospace Corp.
Payload	Methane Detector (Tunable Laser Spectrom-TLS)	100 g	0.67 W	MSL/ JPL
	Pressure, Air Temperature, and Humidity Sensors	113 g	0.43 W	MSL/ JPL, various
Payload/Navigation	Descent/Geology Camera (2 x 40g)	80 g	1 W	None*/ Aptina
Navigation	IMU (Gyro & Accelerometer)	10 g	0.1 W	Variable/ Blue Canyon Tech.
Power	Body-Mounted Solar Panels (20 x UJT Cells)	40 g	-	Variable/ Spectrolab
	Batteries (6x18650 Li Ions, ~16 W-hr each max)	270 g	-	INSPIRE/ Panasonic
	Electric Power System & Battery Board	80 g	-	RAX & INSPIRE/ JPL
Computing & Data Handling	Gumstix Flight Computer & Storage	10 g	0.5 W	IPEX/ Gumstix
Telecom	UHF Proxy-1 Radio	50 g	2 W	Variable/ JPL
	UHF Low Gain Antenna (Whip)	5 g	-	Variable/ JPL
Mechanical & Others	Shelf (68 g), Brackets (26 g), Wing Actuator (19 g), Springs (48 g), Hinges (7 g), Fasteners (20 g), Harnessing (50 g), and others (20 g)	256 g	-	Variable/ JPL
Thermal	Heaters (3 x 50 g), Aerogel (10 g)	160 g	2 W	Variable/ JPL
Sterilization	Sterilization Bag	100 g	-	Variable/ JPL
TOTAL	Total No Margin/ With 20% Margin	**2.9 kg/ 3.5 kg**	~3 W (avg)	-

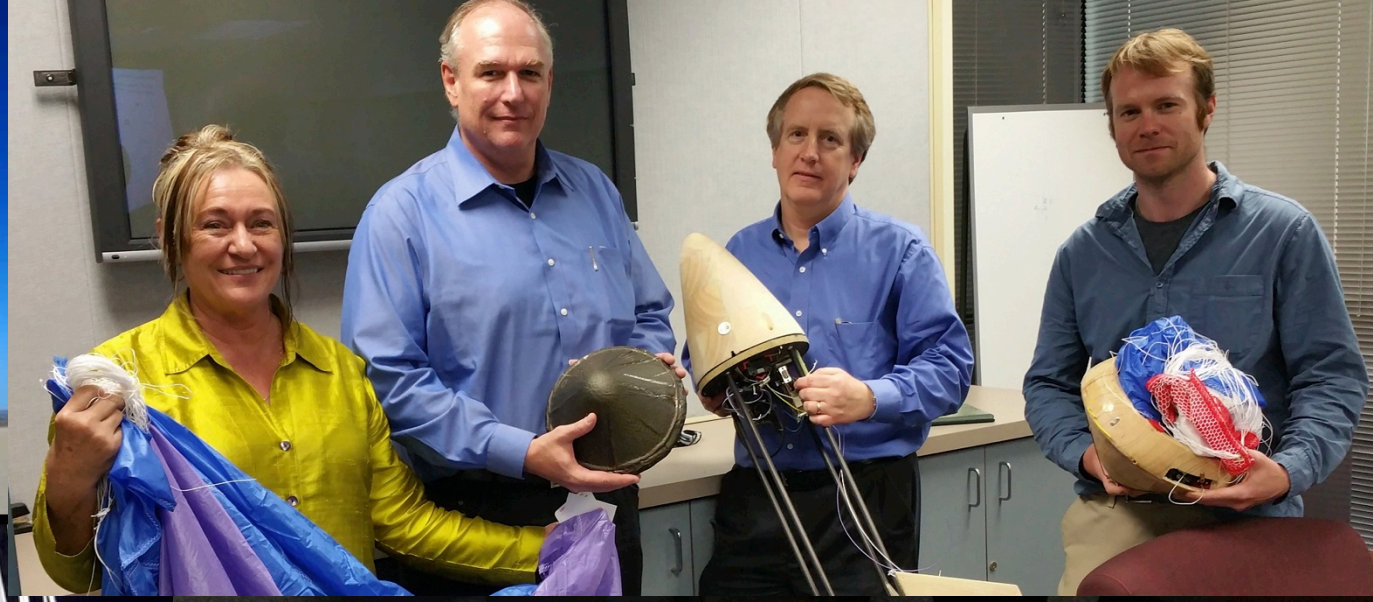


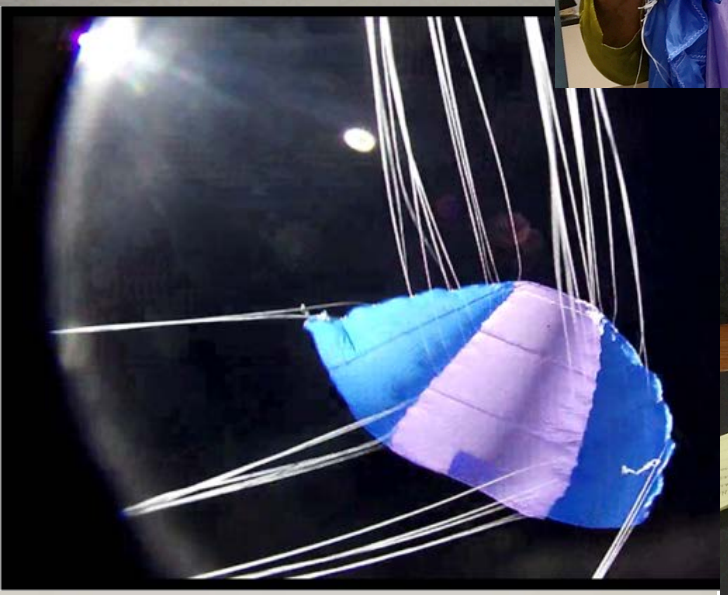
*Radiation (~3.5 krad) and thermal testing will be performed to ensure reliability

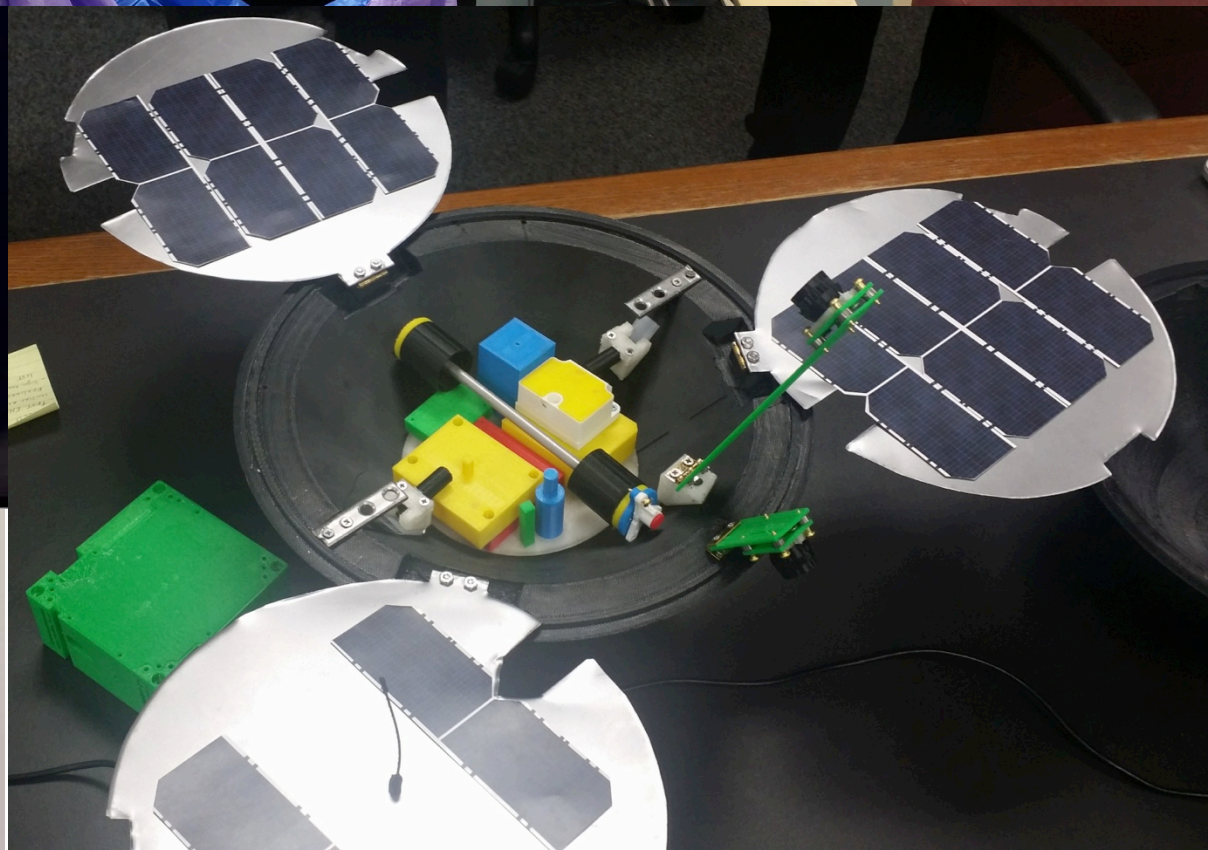
Entry mass (3.5 kg) consistent w/ mass from Aerospace Corp. REBR flights from Earth orbit.

Note: the Backpack (ACS & mechanical interfaces, spring for jettison) is an additional 0.7 kg/ 0.9 kg (30% margin).

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







Terrestrial lab model

Where will you go with “small”?

robert.l.staehle @jpl.nasa.gov
818 354-1176