In Situ Data Collection Paving the Way for Human Mars Exploration with the MARS$_{DROP}$ Microlander

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Interplanetary Small Satellite Conference

Santa Clara, California

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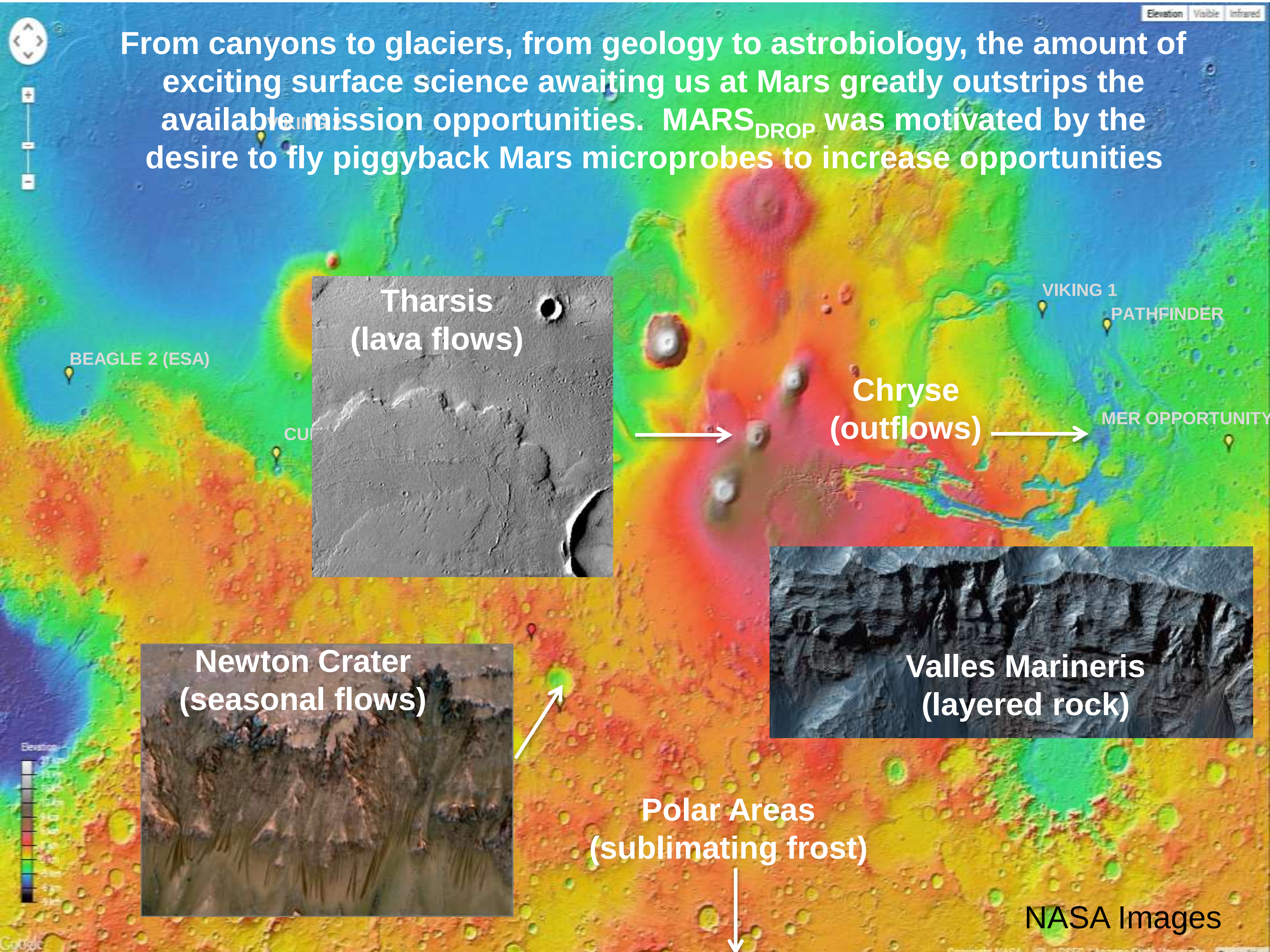
From canyons to glaciers, from geology to astrobiology, the amount of exciting surface science awaiting us at Mars greatly outstrips the available mission opportunities. $\text{MARS}_{\text{DROP}}$ was motivated by the desire to fly piggyback Mars microprobes to increase opportunities



Tharsis (lava flows)

Chryse (outflows)

Valles Marineris (layered rock)

Newton Crater (seasonal flows)

Polar Areas (sublimating frost)

NASA Images

Science Goals and Measurements

NASA's Mars Exploration Program Science Objectives

Goal 1: Determine whether life ever existed on Mars

Goal 2: Characterize the climate of Mars

Goal 3: Characterize the geology of Mars

Goal 4: Prepare for human exploration--mostly about biohazards and resource determination (mostly water availability)

	Proposed Payload Suites (each with multiple small instruments)	Organic detection	Ambient conditions & Dust Hazard	Mineralogy	Geology	Internal Structure	Total Mass
#	Goals	1,3	1,2,4	1,3	3	3	
1	Still camera, seismometer, multispectral imager, weather station		✓	✓	✓	✓	1 kg
2	Still camera, seismometer, aerosol sensor		✓		✓	✓	1.05 kg
3	Still camera, seismometer, deep UV fluorescence	✓			✓	✓	>1.5 kg
4	Video camera, tunable laser spectrometer (CH_4, H_2O, CO_2), T, P, RH	✓	✓		✓		1 kg

Developing a Landing Architecture for a Planetary Microprobe

Objectives/Motivation

The ability to land a small scientific package on Mars could unleash a wave of exciting exploration missions. Science on a global scale, at low cost, allowing for bold mission ideas that will augment and complement the flagship Mars programs.

Aerospace & JPL have flown 20 small satellites over the past 15 years, including reentry probes (REBR). The addition of a landing system to our reentry probes creates a new route for planetary research.

Project aims to architect & demonstrate a proof-of-concept landing system for a Mars microprobe, while preserving sufficient volume for a useful scientific payload.

Mars Microprobe Landing Architecture:

- Small hitchhiker payload riding with a host craft to Mars
- Aeroshell based on the REBR form factor, stability on entry
- Subsonic deployment of a lifting parawing - low sink rate
- Sized to land a miniature (3kg) probe at the highlands


NASA Parawing (courtesy NASA)

Approach

High altitude drop testing using weather balloons provides unmatched test fidelity for demonstrating the landing design.

100,000 feet above Earth is a Martian Atmosphere:

- It's quite cold (-50°C)
- It's a near vacuum (99%)
- High velocity, subsonic flow

Test in stages:

- Launch, tracking, & recovery
- Parawing deployment
- Backshell separation
- Full proof-of-concept demo

Collaborate with community to transition to mission proposals.


Lunar Lake Test Site

Significant Results

Internal research results…

- Detailed trade study defined a viable landing approach
- Technical interchanges amongst the technical community broader community at JPL to define potential missions
- Developed the ability to carry out high altitude tests, a useful capability that can benefit other projects
- Test and demonstration phase over several flights


Deployed Parawing at 100,000 feet

Impact

Landing architecture will pave the way for discussing new missions with planetary scientists:

- Missions to the never before visited highlands of Mars
- Bold high risk destinations, including the great canyons of Mars
- Atmospheric flyovers using long duration glides
- Distributed science simultaneously at multiple locations


Mars Talk at JPL with Dr. Williams

Summary/Bottom Line

A bold approach towards Mars exploration that seeks to enable new science on a global scale:

- Aiming for the first successful Mars microprobe lander
  - And the first flying vehicle on another planet
    - And the cheapest Mars vehicle

Landing Architecture

Entry Interface
100 km, V=7km/sec

T+1 min, Max Q
35 km, 15 g's

T+3 min, Backshell Sep.
6.5 km, Mach 0.85

T+3 min, Main Deploy
6.5 km, 200m/sec

T+3 min, Peak Inflation Load
6.5 km, 65 g's

T+10 min, Terminal Landing
3.0 km, Vertical < 7.5 m/sec

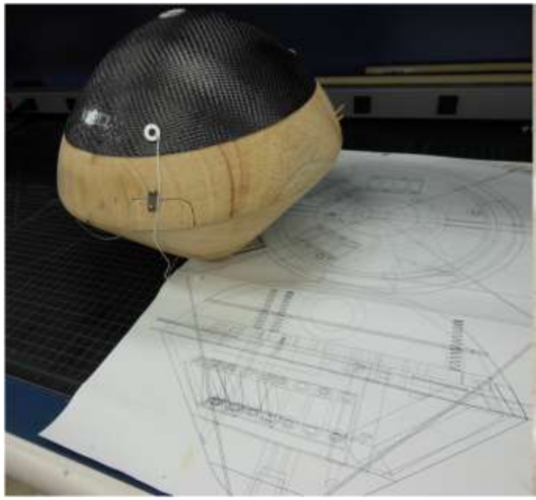
3-DOF Simulation
(Range, Height, Orientation)

Foreground Image Courtesy of NASA

Aerodynamic Decelerator Optimized for Volume, Scaled Down from a Gemini Parawing Design

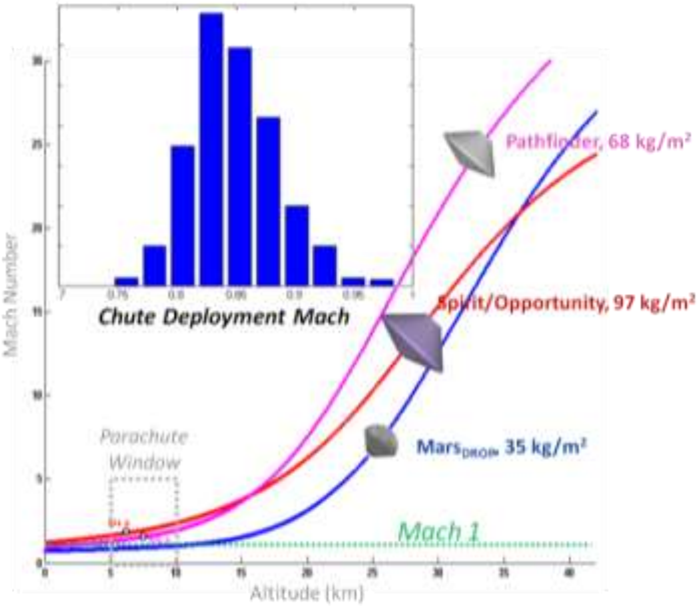
Concepts:	**Solid Circular Parachute** 	**Disk-Gap-Band Parachute** 	**Inflatable Decelerator** 	**Vortex Ring Parachute** 	**Parawing** ✓ 
Claim to Fame	"Standard" Round Solid Parachute	Used on all NASA Mars Landers	Targeted for future NASA Mars Landers	Highest Drag	Gliding Chute
Supersonic	No	Yes	Yes	Unreliable	No
Complexity	Low	Low	High	High (Swivel)	Medium
Prior Research	Extensive	Extensive	Moderate	Minimal	Moderate
Subsonic Drag	Moderate (C_D ~ 0.9)	Low (C_D ~ 0.6)	Moderate (C_D ~ 0.8)	Very High (C_D ~ 2.0)	Very Low (C_D ~ 0.3), but Lift
Mass / Volume for 7.5m/s vertical velocity (reference V)	🟨 1.1 kg / 2300 cm^3	🟥 1.7 kg / 3480 cm^3	🟥 2.5 kg / 5200 cm^3	0.5 kg / 1050 cm^3	🟩 0.2 kg / 200 cm^3
Notes / Landing Site Limitations		Poor subsonic drag prompts two-stage deceleration	Is attractive for much larger vehicles	🟨 Suspect Reliability	🟨 Horizontal velocity -could be good or bad

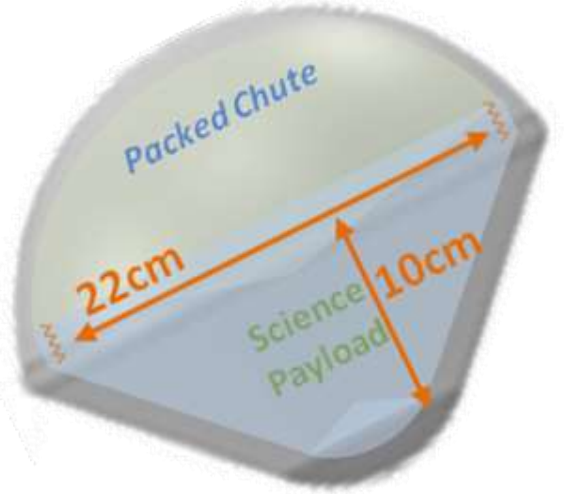

NASA Photo



Capability Summary

- 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 chute preserves a significant portion of the volume for a landed payload
- Parawing is potentially steerable, opening the way for targeted landing
  - *New missions enabled*
- Inexpensive, $20-50 million per mission
  - *Encourages high risk destinations, such as canyons*





Going to Mars on Earth

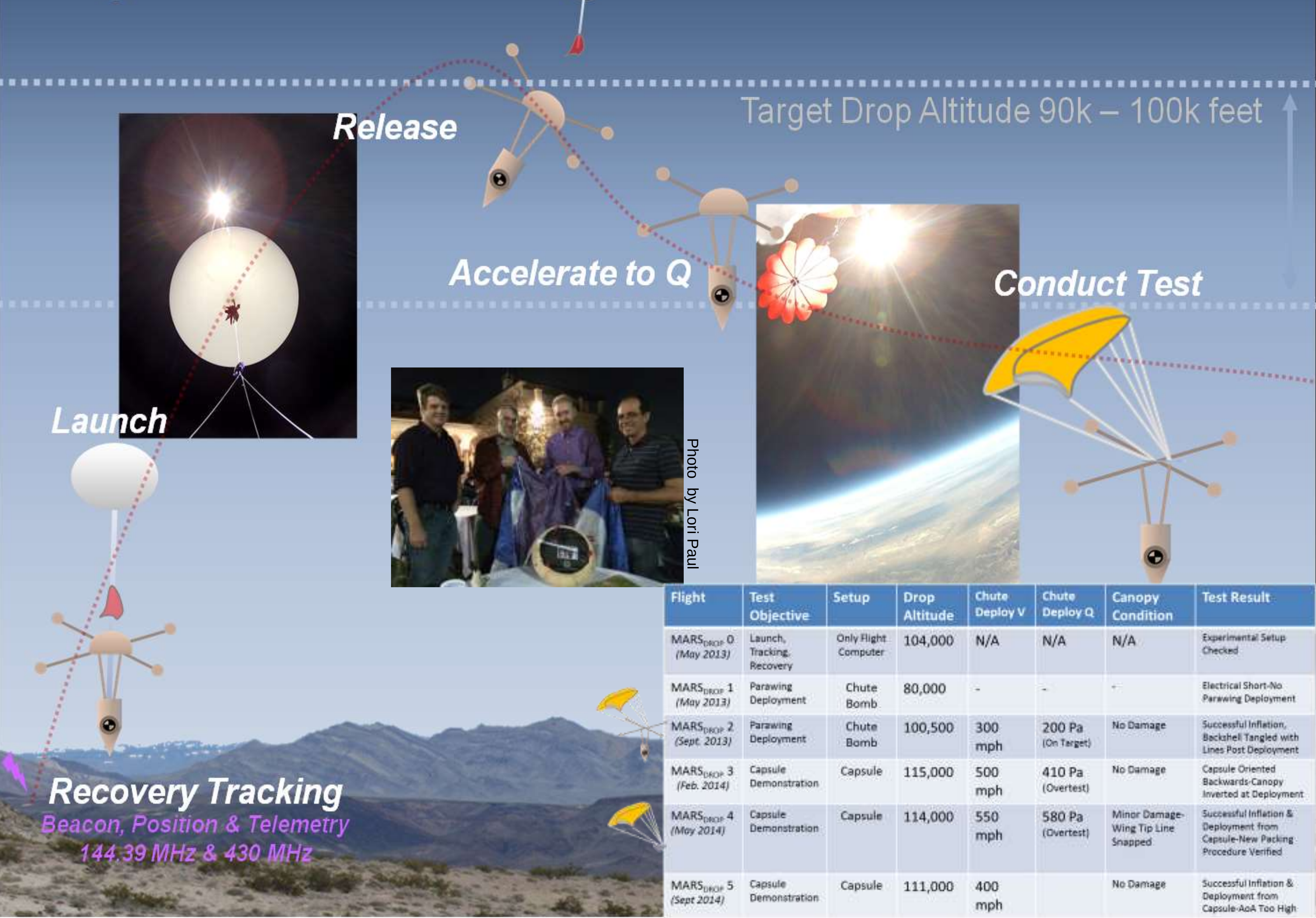
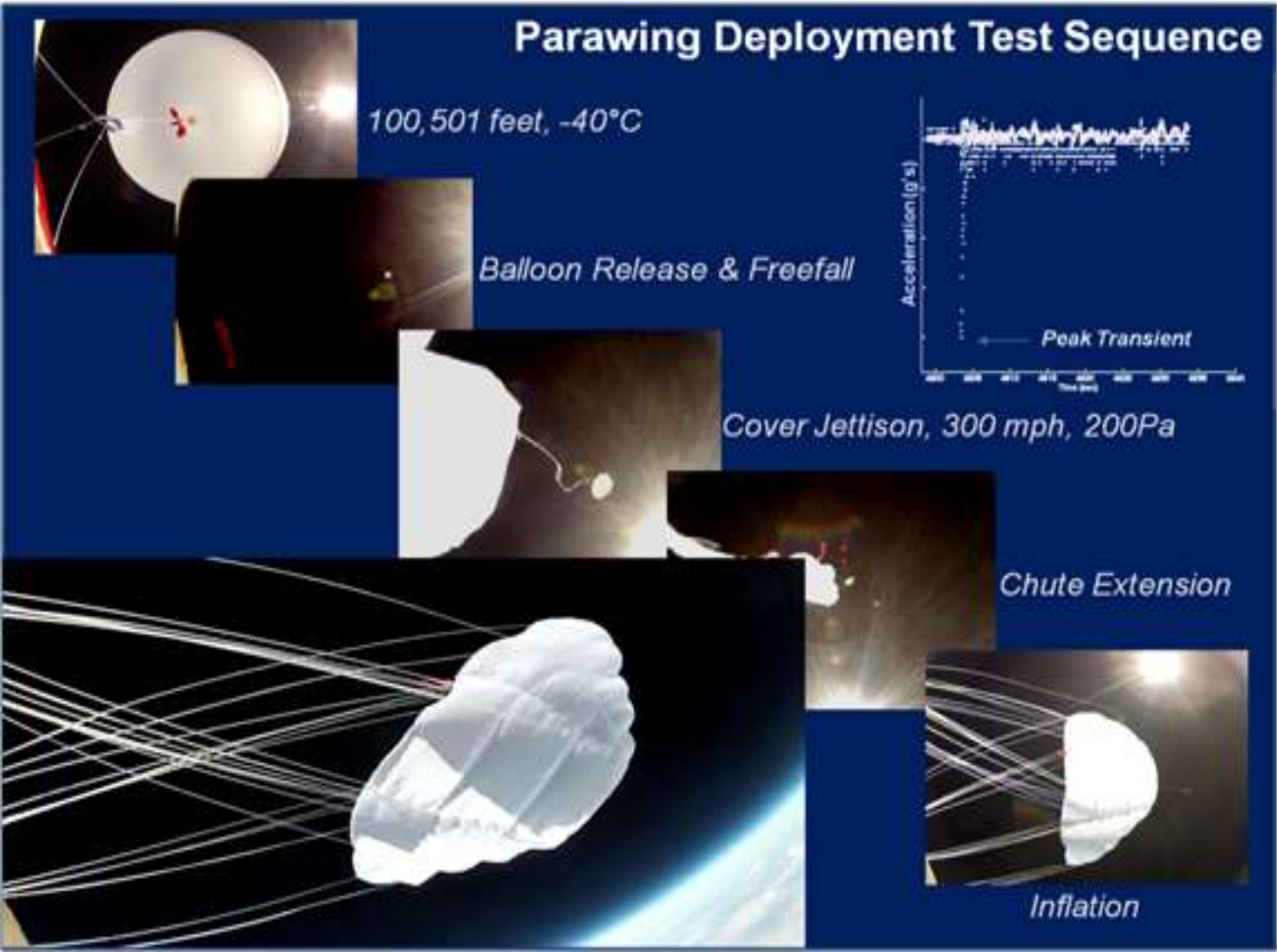


Photo by Lori Paul

Flight	Test Objective	Setup	Drop Altitude	Chute Deploy V	Chute Deploy Q	Canopy Condition	Test Result
$\text{MARS}_{\text{DROP}}$ 0 *(May 2013)*	Launch, Tracking, Recovery	Only Flight Computer	104,000	N/A	N/A	N/A	Experimental Setup Checked
$\text{MARS}_{\text{DROP}}$ 1 *(May 2013)*	Parawing Deployment	Chute Bomb	80,000	-	-	-	Electrical Short-No Parawing Deployment
$\text{MARS}_{\text{DROP}}$ 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
$\text{MARS}_{\text{DROP}}$ 3 *(Feb. 2014)*	Capsule Demonstration	Capsule	115,000	500 mph	410 Pa (Overtest)	No Damage	Capsule Oriented Backwards-Canopy Inverted at Deployment
$\text{MARS}_{\text{DROP}}$ 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
$\text{MARS}_{\text{DROP}}$ 5 *(Sept 2014)*	Capsule Demonstration	Capsule	111,000	400 mph		No Damage	Successful Inflation & Deployment from Capsule-AoA Too High

Parawing Deployment Test Sequence



100,501 feet, -40°C

Balloon Release & Freefall

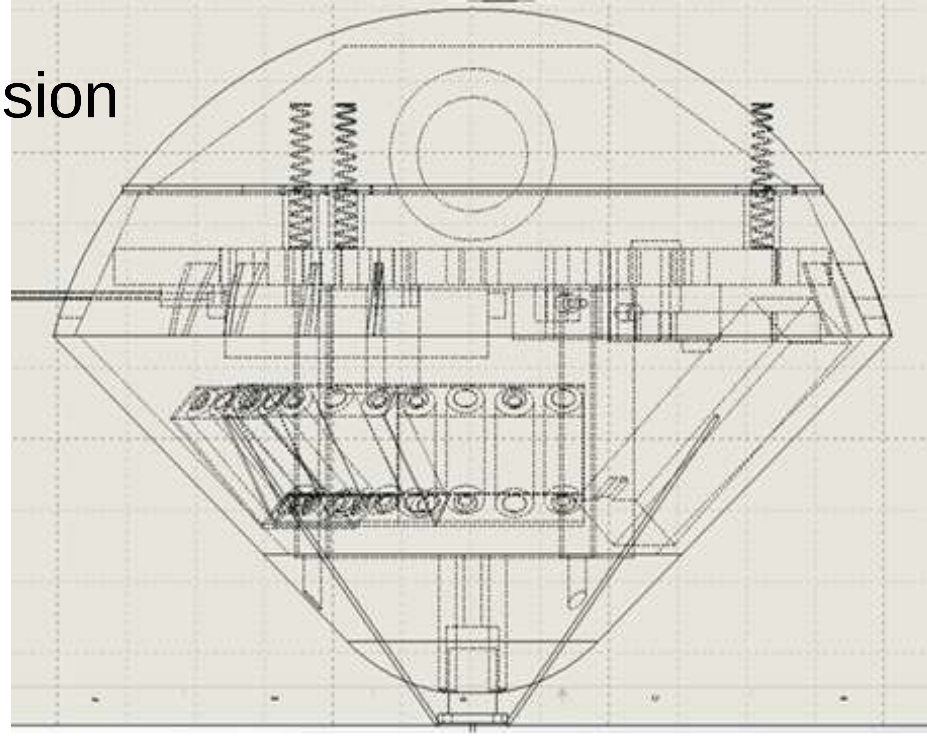
Cover Jettison, 300 mph, 200Pa

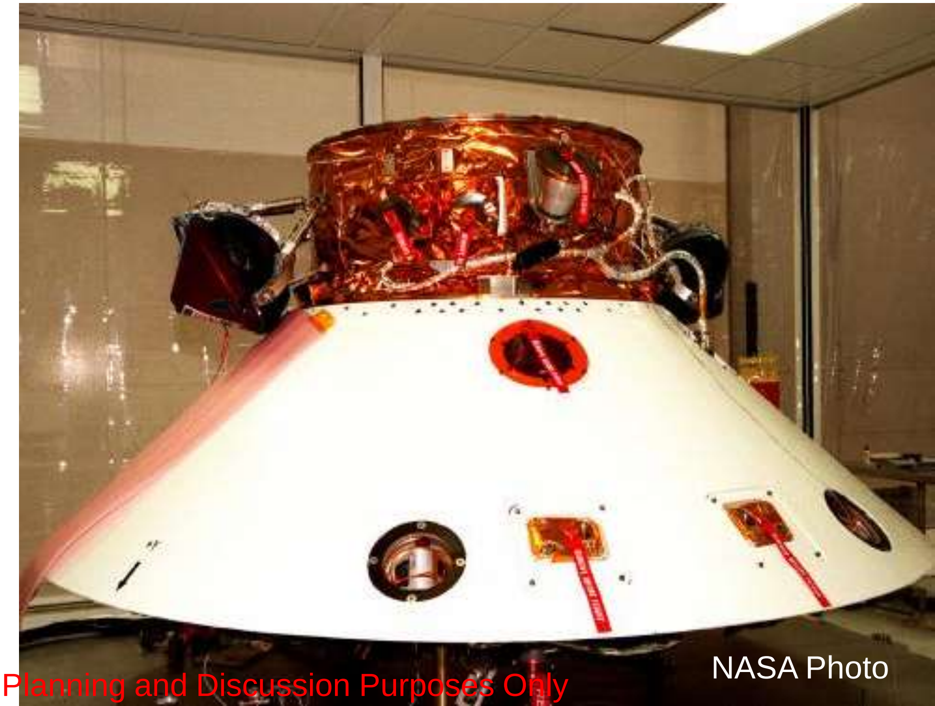
Chute Extension

Inflation

A Technology Demonstration Mission

- A low cost demonstration mission could be mounted in the near future based largely on existing elements:
  - *Cruise stage carrier brackets borrowed from Mars Polar Lander design.*
  - *Aeroshell derived from REBR/DSII.*
  - *Flight computer borrowed from Aerospace/JPL CubeSats.*
  - *Iris-based radio.*
  - *COTS imaging descent camera.*
- Once demonstrated, several piggyback probes can go with each Mars-bound craft at minimal added cost & mass.
  - *Instrument technology survey identified a wide range of plausible payloads.*





NASA Photo

Driving Performance Parameters

Performance Parameters	**Tech Demo (Initial Flight)**	**First science demo**	**“Operational” Capability Target**
Number of $\text{Mars}_{\text{DROP}}$ Landers	One	One+	2 - 10
Allowable payload mass	~~100 g~~	1 kg	1 kg, growing to 2+ kg
Spacecraft landing orientation control	~~50% chance of achieving desired orientation~~	90% chance of achieving desired orientation	90% chance of achieving desired orientation
Average Collected Solar Power	~~0.5 W~~	1 - 2 W	2 – 5 W
Battery Capacity	~~16 Whr~~	50 Whr	same or greater
Surface Survival Duration	~~1 sol~~	30 sols	1 Mars year
Data Volume Return	~~100 kbits~~	>10 MBytes	>100 MBytes
Host Support	~~position knowledge before deployment.~~	position knowledge before deployment.	add trickle charge, command & sw upload, checkout data download
Glide distance	10 km	10+ km	10+ km
Landing accuracy	1 km	100s m	10s m

Preliminary Mass/Equipment List

Subsystem	Components	Mass	Average Power	Heritage
Entry & Deceleration	Parawing, Aeroshell, Controls	1500 g	-	REBR/DSII
Payload	Instrument Allocation	<1000 g	<2 W	Variable
Power	Electrical Power System (EPS) & Battery Board	<100 g	<1 W	INSPRE
	Body-Mounted Solar Panel (3U)	135 g	-	INSPIRE
	Batteries (2x18650 Li Ions, ~16 Whr)	90 g	-	INSPIRE
Avionics	Flight Computer (C&DH)	<100 g	<1 W	INSPIRE
Telecom	UHF Proxy-1 Radio	<100 g	<3 W	TBD
	UHF Low Gain Antenna	<80 g	-	RAX-1/2
Navigation	GumSticks Camera	<50 g	<1 W	IPEX/COVE
	IMU (Gyro & Accelerometer)	<10 g	<0.1 W	MarCO
Mechanical	Structure & Harnessing	<150 g	-	TBD
Sterilization	Sterilization Bag	< 50 g	-	TBD
TOTAL	Total No Margin/ With 10% Margin	**<3.4 kg/ <3.7 kg**	Variable	-

Total mass (10% margin) just under maximum allowable allocation
Solar Panels expected to generate ~ 7.5 W max, ~2-3 W available continuously

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

Instrument Type	Mass (g)	Power (mW)	Max Dimension (mm)	Example	Modifications Required	Measurements & Remarks	POC/JPL Org
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**	**215**	**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 + dust 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.	(included above)	M. de la Torre Juarez
Multispectral Microscopic 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 Microscopic Imager VSWIR	**150**	**9000 (5 mins)**	**110**	MMI Mars 2020 proposal	Wider FOV ~ 30 x 30 cm. 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.	Organic 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
Iris 2+ Transponder	**700**	**12,000 (xmit)**	**100**	Iris on INSPIRE Cubesat	Reduce mass (perhaps UHF-only), cold temp	Data downlink 8 kbps X-band direct to DSN 70 m at 1 AU; higher rates by UHF to Mars orbiting relay assets.	C. Duncan

Example Camera System with Computation for Terrain Relative Navigation

Gumstix module (left) mounted on a programming board and connected via flex cable to a 1 MP Aptina MT9V032-based camera with M12 lens (right).

The TI AM3703 DSP could run a modified version of the Mars2020 Lander Vision System to provide Terrain Relative Navigation better than 1 meter knowledge at landing.

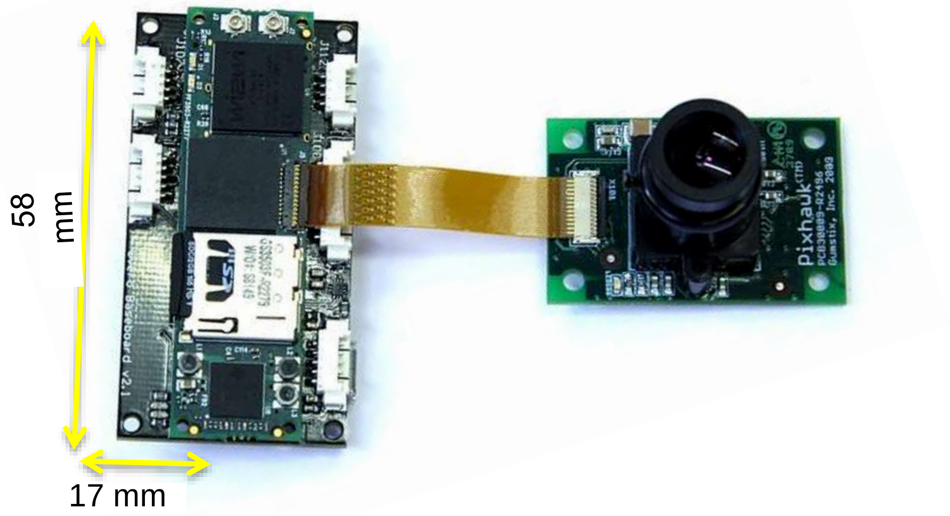


image source: https://pixhawk.ethz.ch/electronics/camera

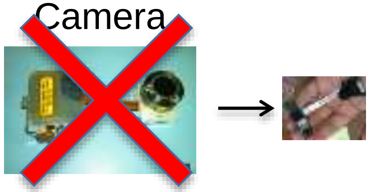
Parameter	Specification
Mass, Power, Volume	33 g, 475 mW, < 6 cc
FOV, iFOV, pixels	48˚, 1 milliradian, 1 MP
framerate	60 fps
lens	4-element glass, f/4, 6 mm
Computation	TI AM3703 DSP with 1GHz ARM CORTEX A8
IMU input for Lander Vision System	MEMS Altimeter & 3-axis MEMS accelerometer

- Modifications likely required:
  - Materials compatibility.
  - Modest rad tolerance (<~3 krad).
  - Thermal tolerance or heater.
  - Different pressure sensor?

Synergy with Mars Lander Vision System

Inertial Measurement Unit (IMU)

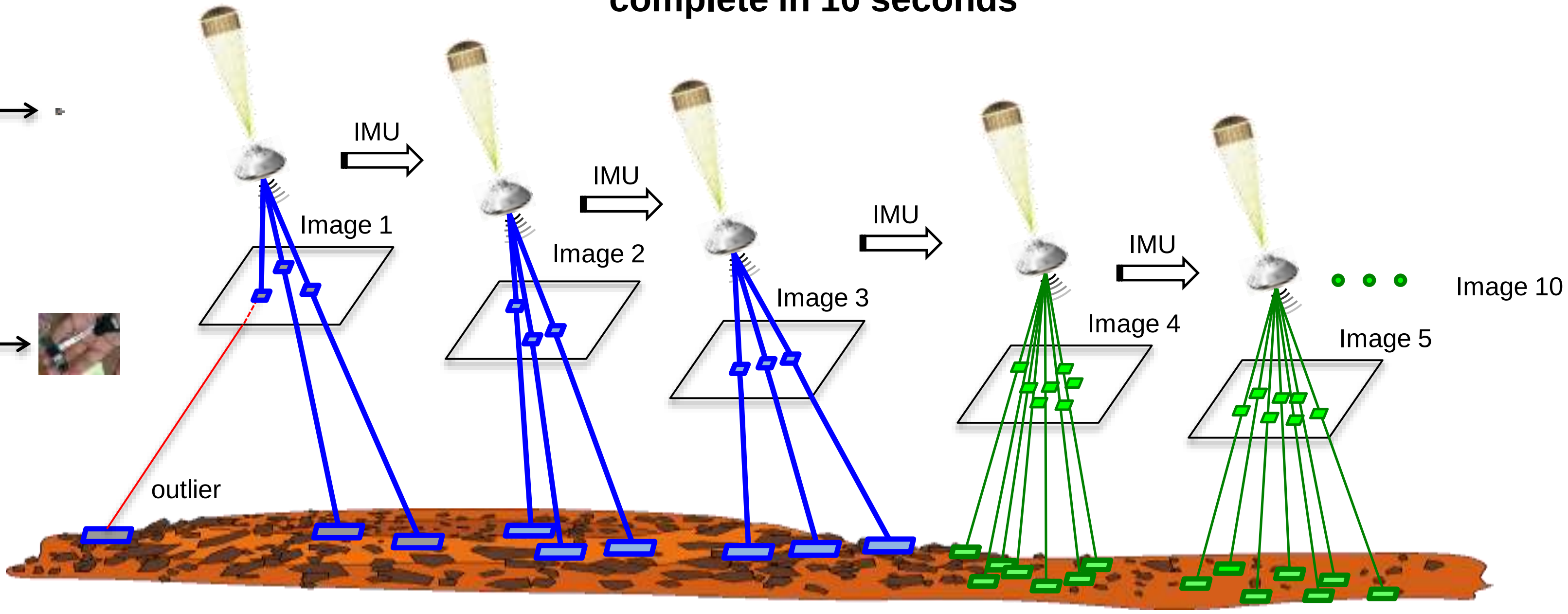
Camera



Map

State Estimation

Fuse inertial measurements from IMU with landmarks from 1024x1024 images and complete in 10 seconds



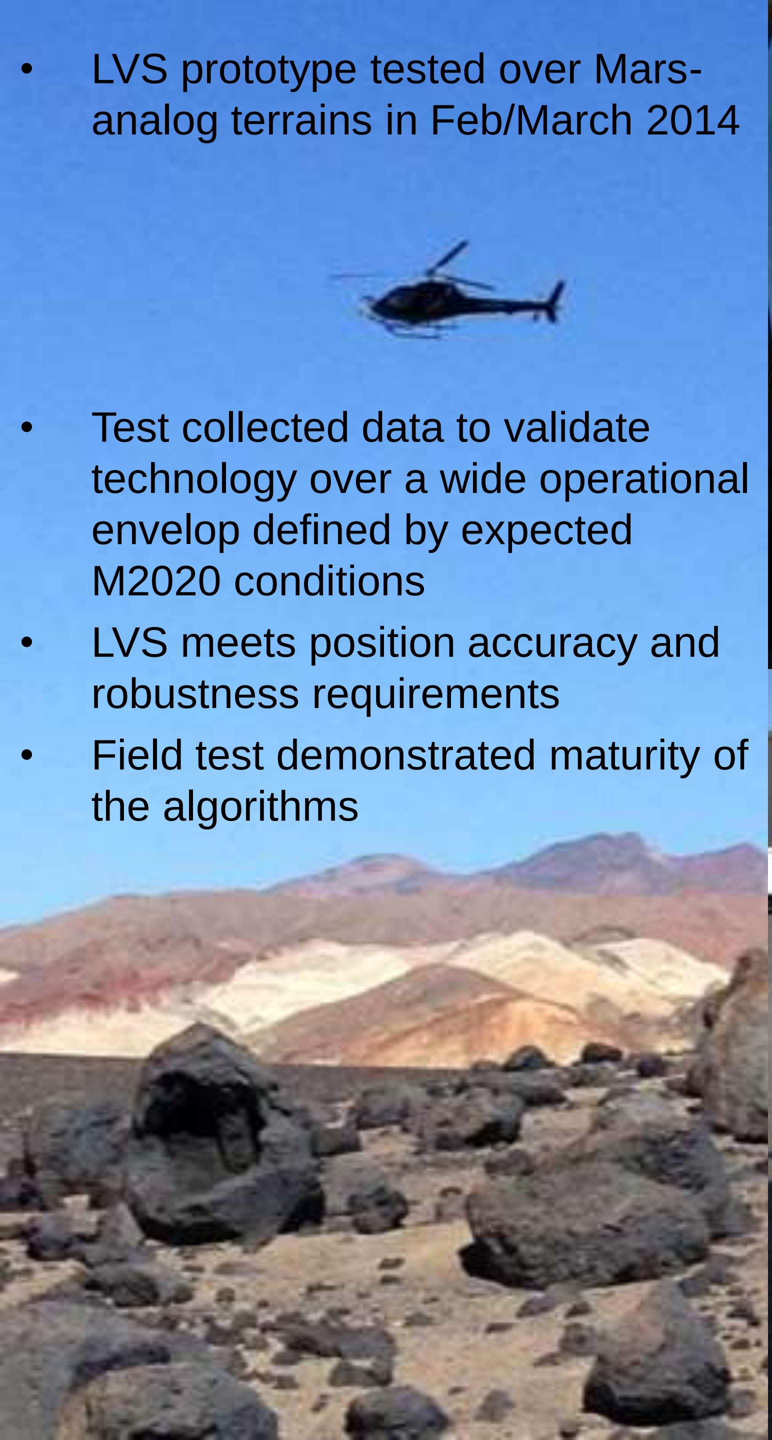
Coarse Landmark Matching

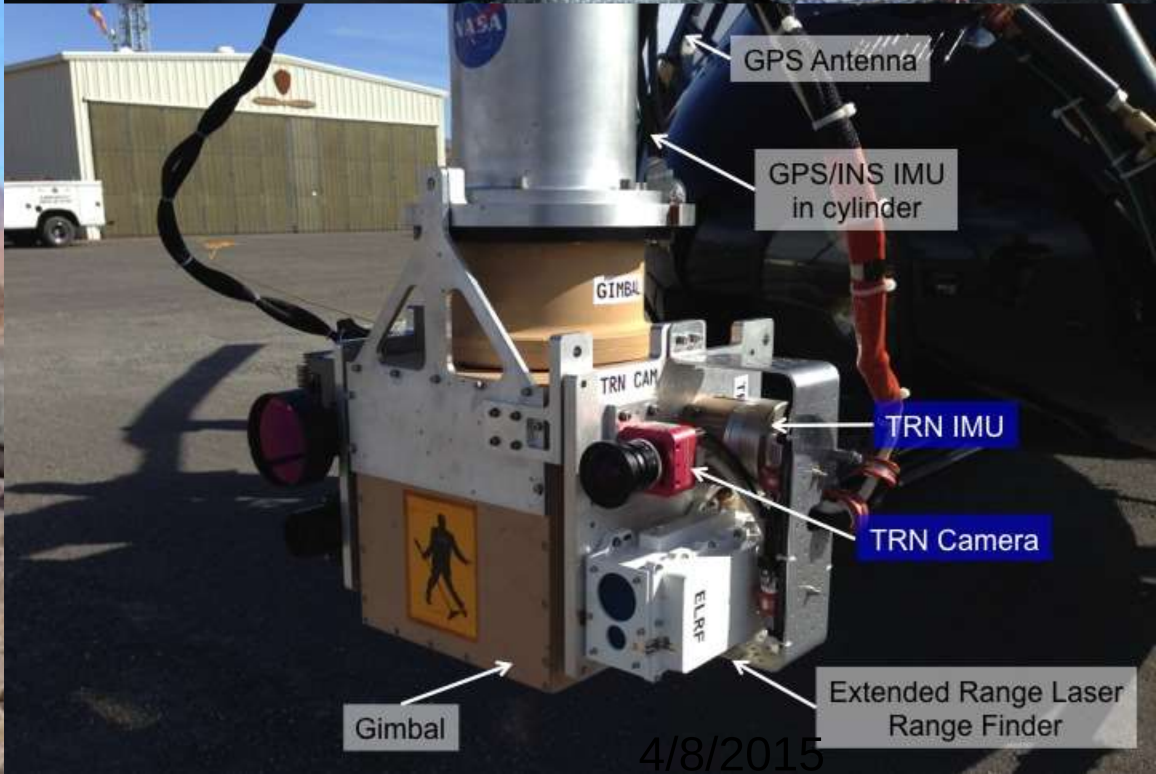
Remove Position Error (3km 3-σ)

Fine Landmark Matching

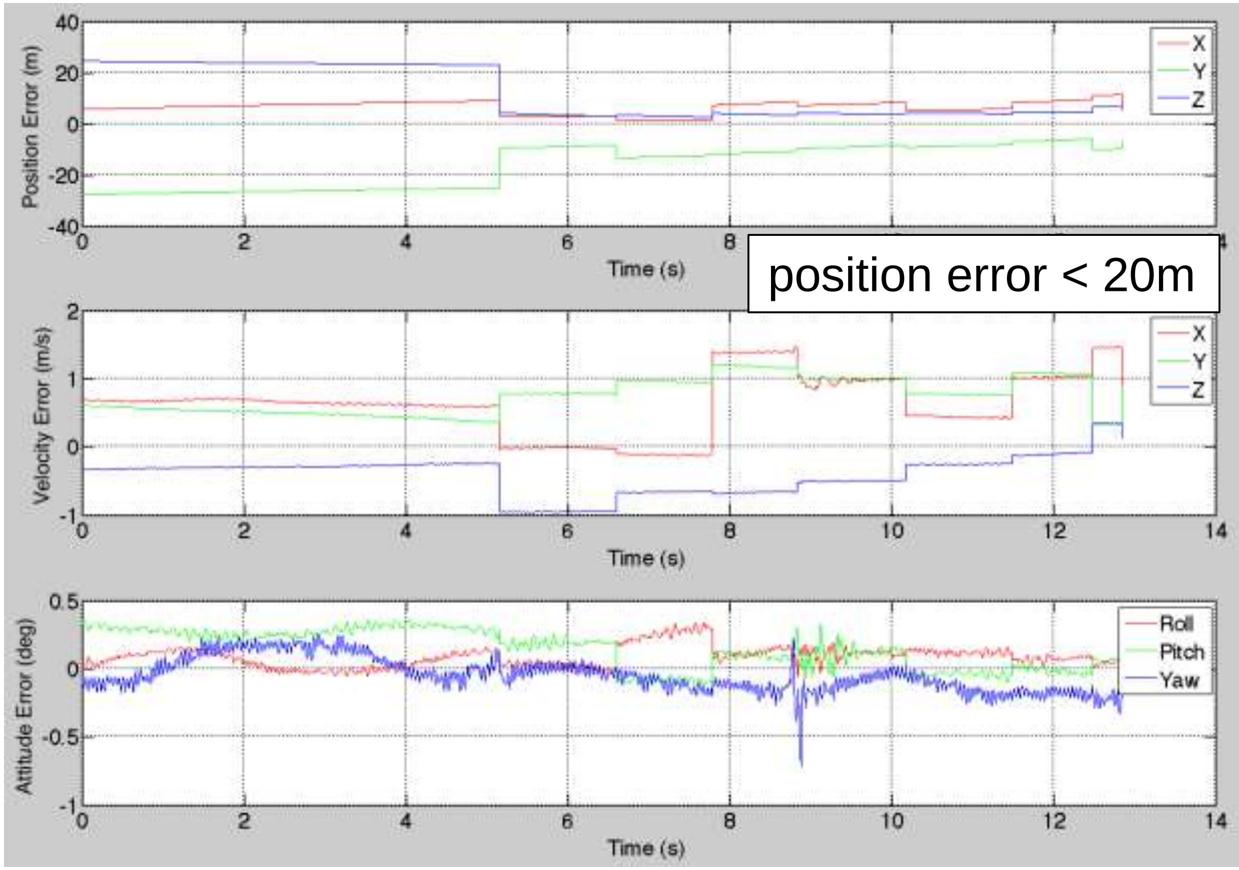
Improve Accuracy (40m 3-σ)

- LVS prototype tested over Mars-analog terrains in Feb/March 2014
- Test collected data to validate technology over a wide operational envelop defined by expected M2020 conditions
- LVS meets position accuracy and robustness requirements
- Field test demonstrated maturity of the algorithms



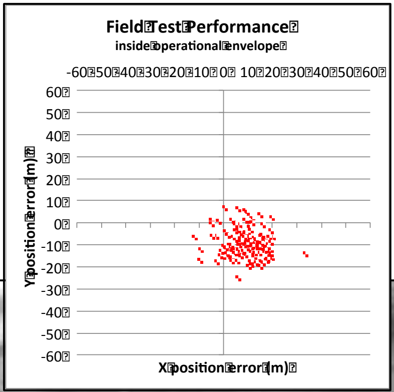


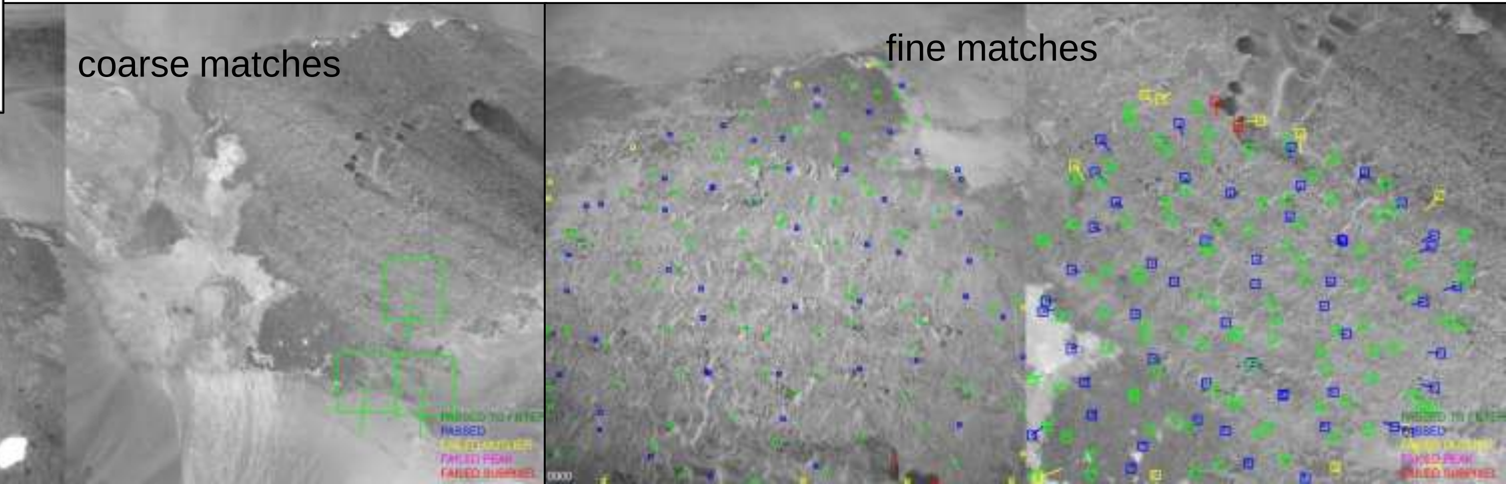
LVS Helicopter Test
March 2014



position error < 20m

- LVS prototype tested over Mars-analog terrains in Feb/March 2014
- Estimates position, velocity and attitude
- takes out 3km position error
- 40m 3 sigma position error at 2km altitude
- 1s TRN updates
- 20Hz state updates

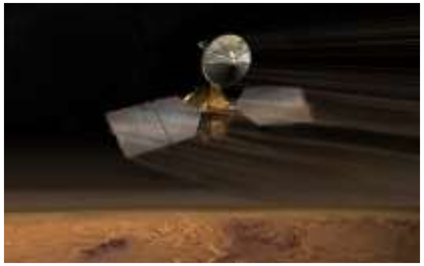




Planetary atmospheric studies

By analogy with Earth, methane gas is a potential indicator of biological activity on Mars, possibly from sub-surface microbes.

Mars Reconnaissance Orbiter launched in 2005 observed methane in the Martian atmosphere

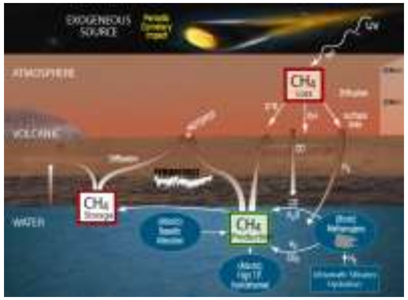


MRO spacecraft

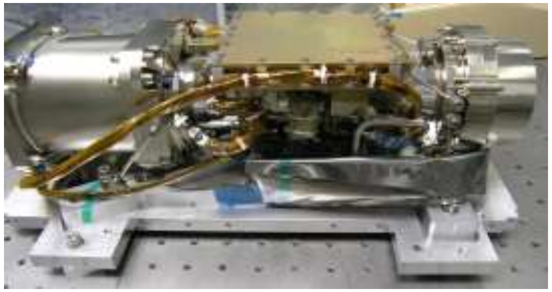
Curiosity Rover landed on Mars Aug.5th,2012

POC: Lance Christensen/JPL

What is the source of methane generation on Mars ? Does life exist on Mars?

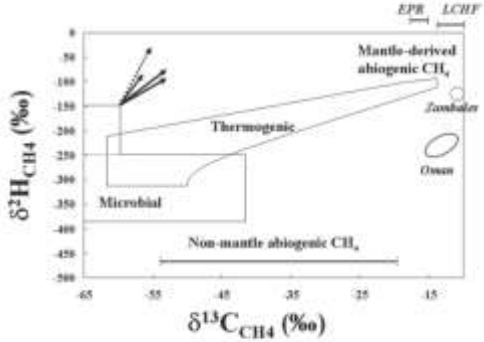


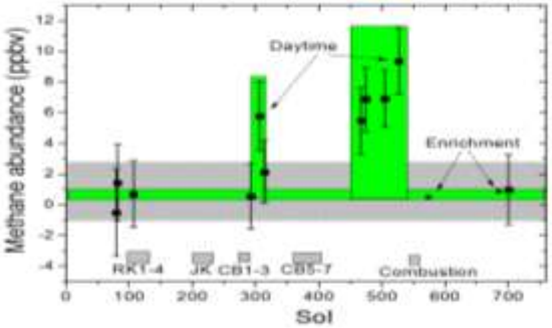
Mars Methane Cycle



TLS instrument PI: (C. Webster)

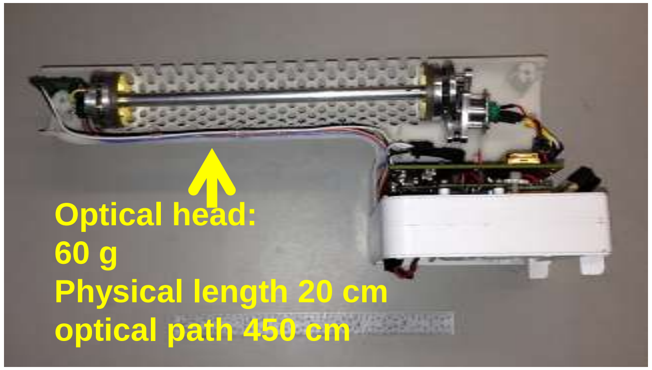
Measurement of isotopic ratio of $^{13}C/^{12}C$ could answer the origin of methane on Mars





TLS-SAM-MSL has detected methane on Mars in two distinct regimes:
At background levels of 0.7 ppbv generated by UV degradation of infalling meteorites
In bursts of methane at 7 ppbv – ten times above background- that rapidly come and go

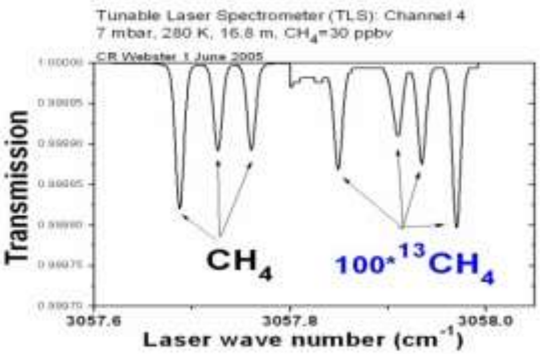
Example Instrument: Tunable Laser Spectrometer (300 g, 2W for continuous measurement) could measure gases such as Methane (CH_4), Water (H_2O) and isotope ratios within these gases: D/H, $^{13}C/^{12}C$, $^{18}O/^{17}O/^{16}O$ in a descent (DROP) profile or on-surface sampling.



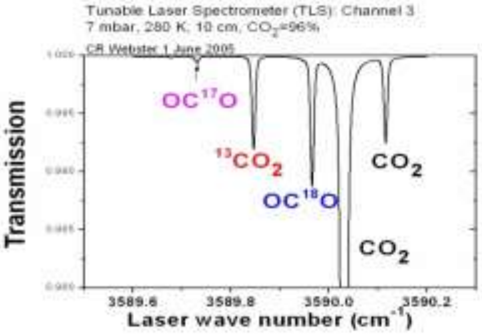
JPL + industry has invested in miniature methane sniffers for public safety and reducing fugitive emissions

- *Precision* is 100's ppt s^{-1} ambient Earth conditions
- Mars pressure << Earth; Expect few ppb s^{-1} sensitivity with same miniature configuration

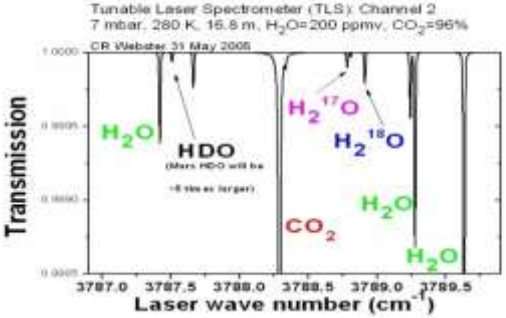
Capability:



Methane Isotope Ratios at 3.27 μm



Carbon Dioxide Isotope Ratios at 2.78 μm



Water isotope ratios at 2.64 μm

Example Instrument: Deep UV Fluorescence

Trace Organics/Biosignature Detection

- Deep UV (excitation <250 nm) spectroscopy is an active spectroscopic method that *enables* detection and characterization of organics and astrobiologically relevant minerals.
- Integrated visible imaging CCD context camera.
- NASA- & DARPA-supported development >15 yrs.
- ~700 g, <15W for Fluorescence-only.

Deep UV laser induced native fluorescence

- Enables detection and differentiation of organics
  - both abiotic and biotic organics
  - Organics in meteorites (wide range of thermal maturity), and potential biosignatures.
- Maps organic distribution over 1cm^2
- Sensitivity at ppb.

Deep UV *resonance* Raman

- Enables detection and characterization of a wider range of organics relevant to biosignatures and alteration processes.
- Presently too large for MarsDrop microlander capability.

Current Status

- Mars 2020 – SHERLOC instrument under development;
- 3+ kg.; miniaturizing in progress.
- TRL advancements for next generation sub-250 nm deep UV sources to be developed to reduce overall size.

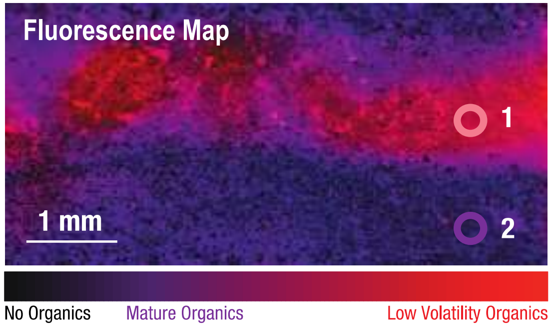
(POC: Roh Bhartia rbhartia@jpl.nasa.gov/
Luther Beegle, lbeegle@jpl.nasa.gov)

Deep UV Fluorescence/Raman Instr.

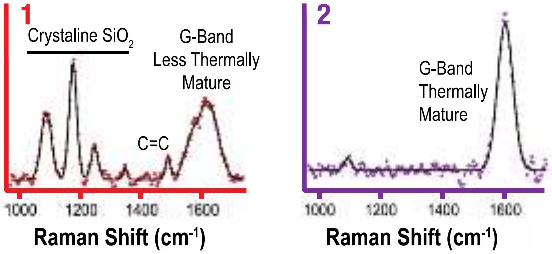
SHERLOC-Mars 2020 Prototype

Example Data Product

Macroscopic Image



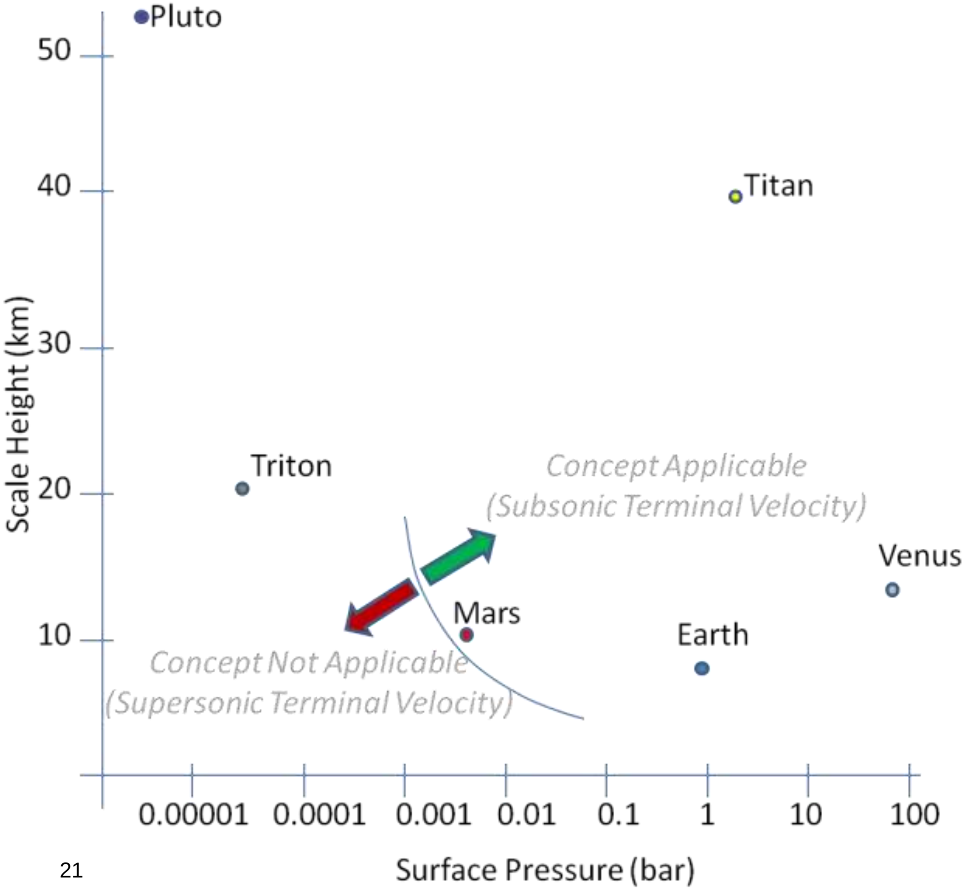
DUV Fluor: Organic Detection, Classification, & Distribution



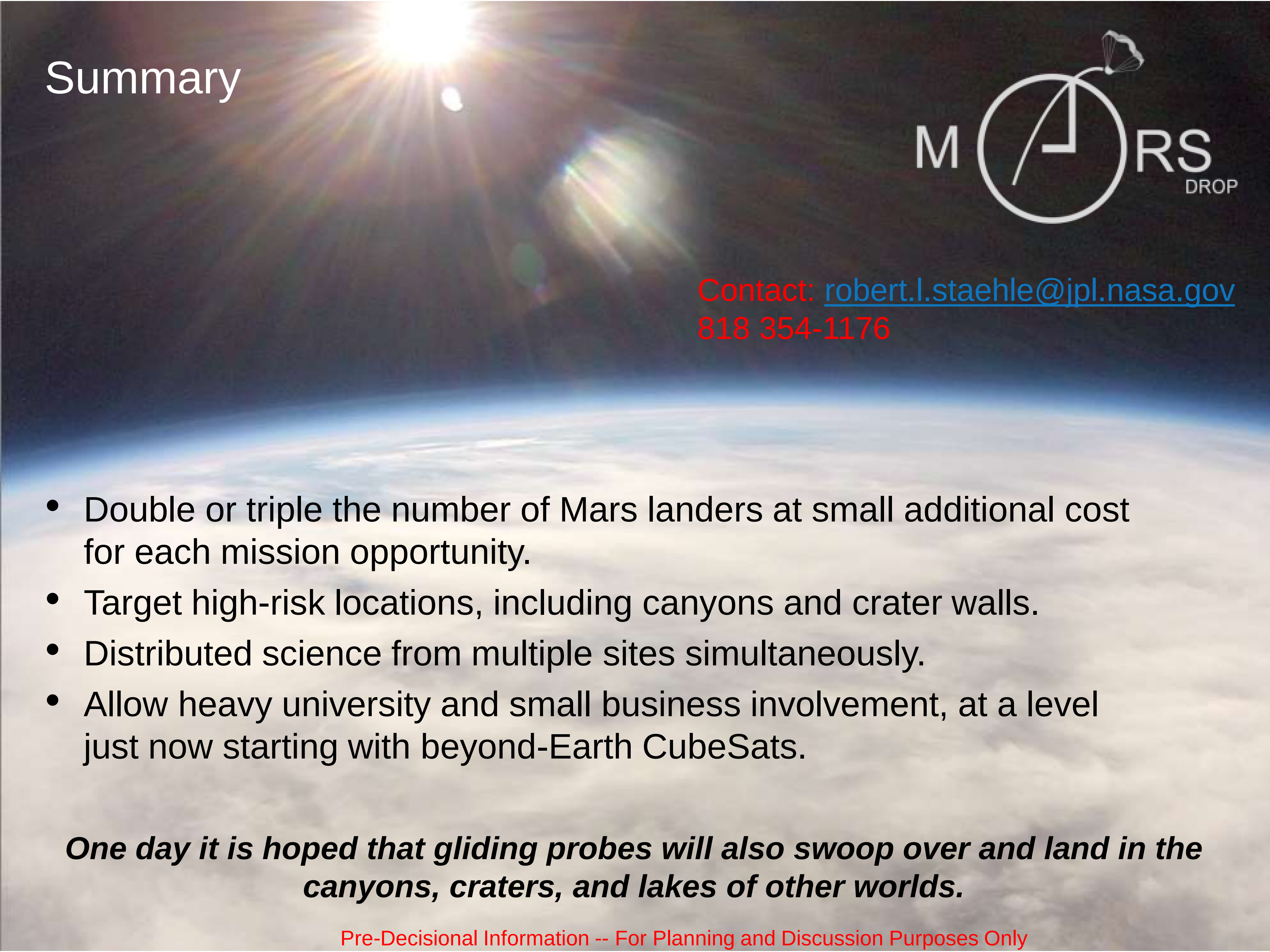
DUV Raman: Organic analysis & mineralogy

Beyond Mars

- Concept equally applicable to planetary atmospheres thicker than Mars: Earth, Titan, Venus
  - *Titan, in particular, has a variety of terrain, lakes, and potentially rivers; ability to send multiple probes to different sites is attractive.*



Summary



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- Double or triple the number of Mars landers at small additional cost for each mission opportunity.
- Target high-risk locations, including canyons and crater walls.
- Distributed science from multiple sites simultaneously.
- Allow heavy university and small business involvement, at a level just now starting with beyond-Earth CubeSats.

One day it is hoped that gliding probes will also swoop over and land in the canyons, craters, and lakes of other worlds.