Mars$_{DROP}$ for Getting Small Payloads to Mars' Surface: *How many would you like, and where would you like them to help resolve questions about methane on Mars?*

Adopted from:

Multiplying Mars Lander Opportunities with MARS$_{DROP}$ Microlander

2015 August 13 Utah State/AIAA Small Satellite Conference
Logan, Utah

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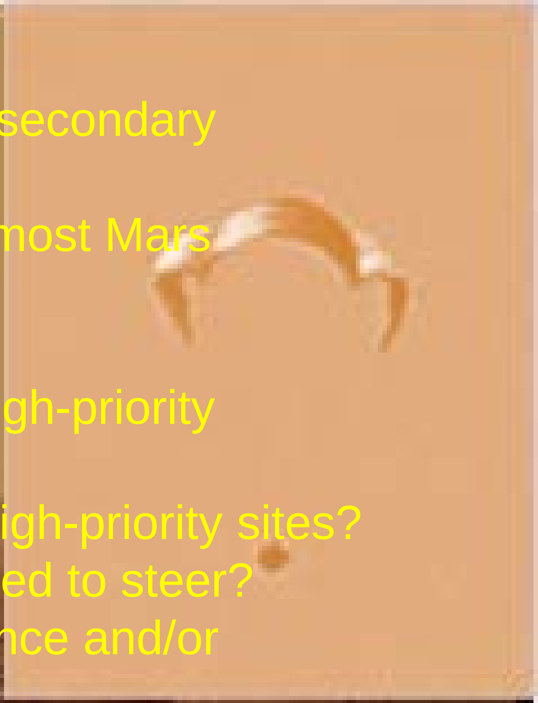
What if we could…?

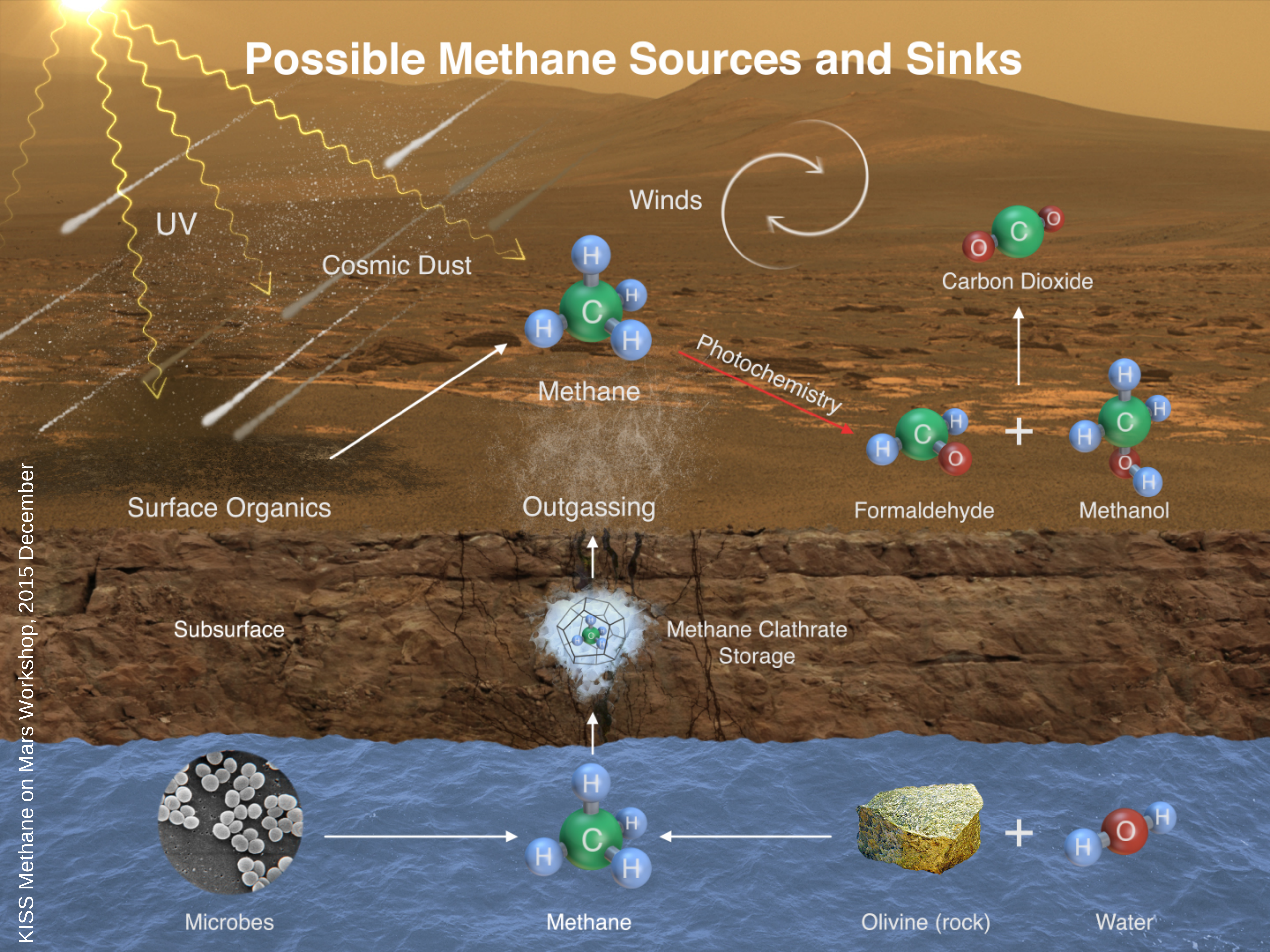


- Utilize excess cruise stage or orbiter mass capability to carry secondary payloads to Mars?
- Make a lander small enough that a few could be carried with most Mars missions?
- Have the ability to target the entry of the lander?
- After entry, have the ability to select among pre-determined high-priority landing points within uncertainty ellipse?
- Steer to landing within ~100 meters of one or more of those high-priority sites?
- Record and play back an awesome video from the camera used to steer?
- Carry instruments gathering information of high value for science and/or human exploration?
- Survive weeks to a year on the surface, relaying data via orbiting assets?

- All for adding 1 – 5% to the typical host mission cost?

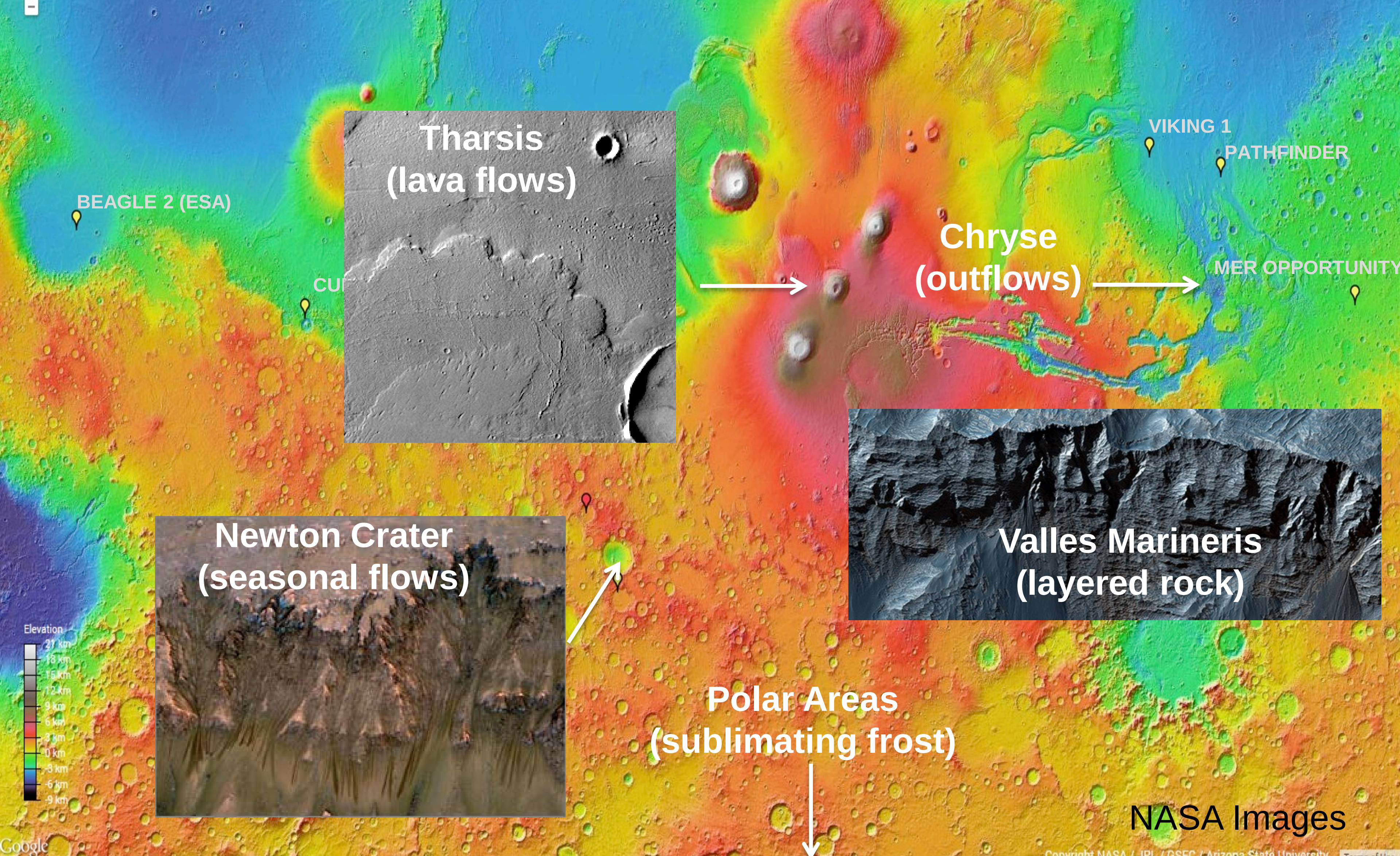
…we are developing this capability.

composite simulation, & L. Paul

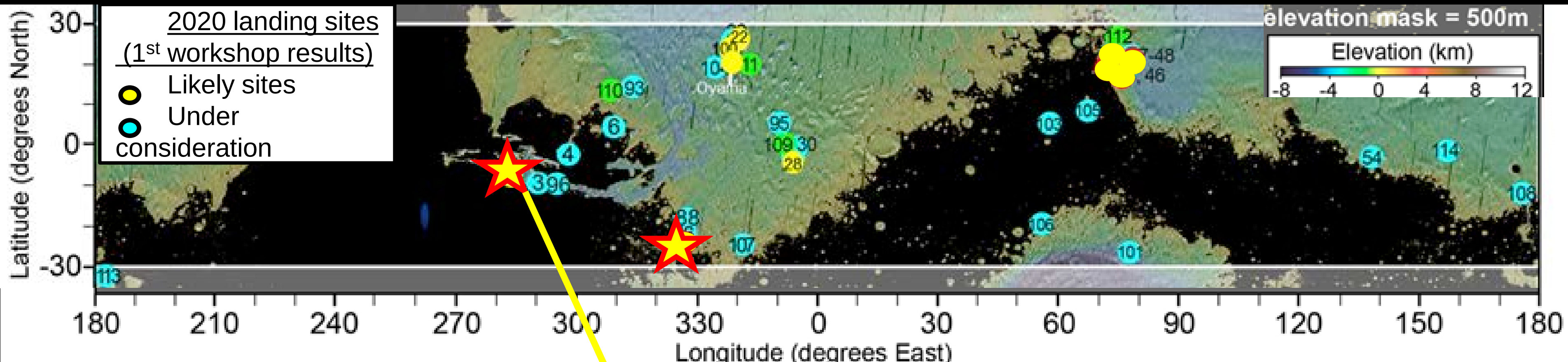


Possible Methane Sources and Sinks
UV
Cosmic Dust
Winds
Carbon Dioxide
Methane
Photochemistry
Surface Organics
Outgassing
Formaldehyde
Methanol
Subsurface
Methane Clathrate Storage
Microbes
Methane
Olivine (rock)
Water
KISS Methane on Mars Workshop, 2015 December

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



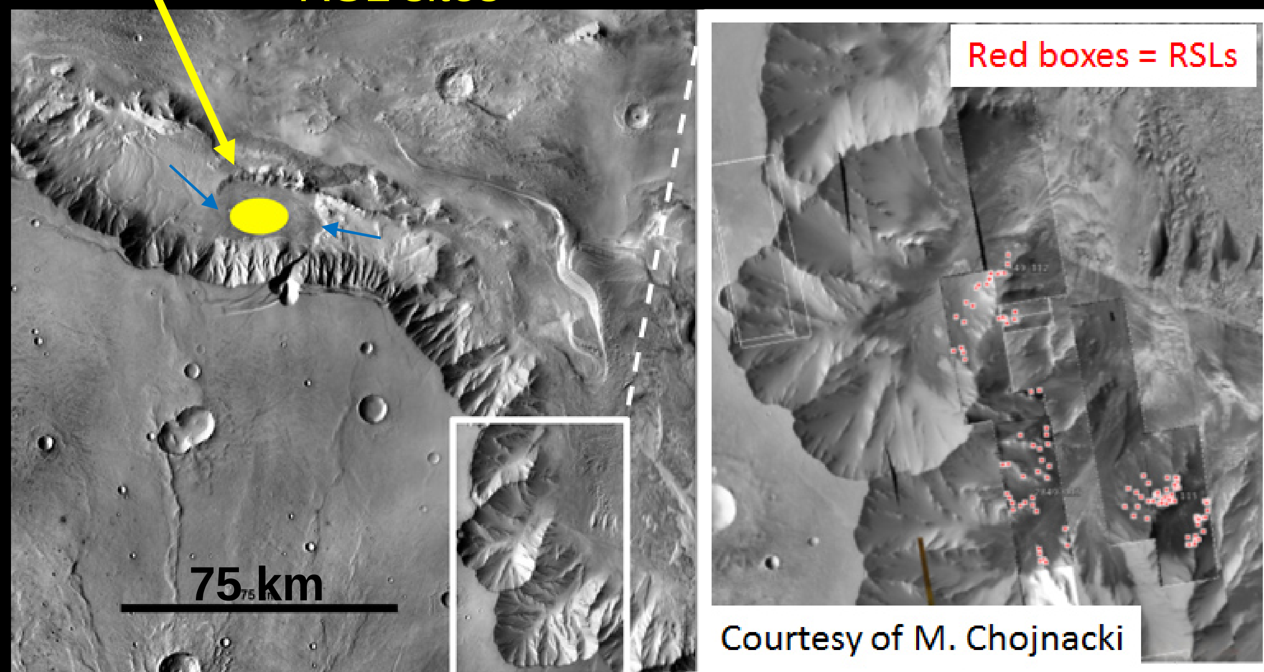
Equatorial Landing Zone



two candidate Mars 2020 landing sites near RSL sites

Example 2: SW Melas

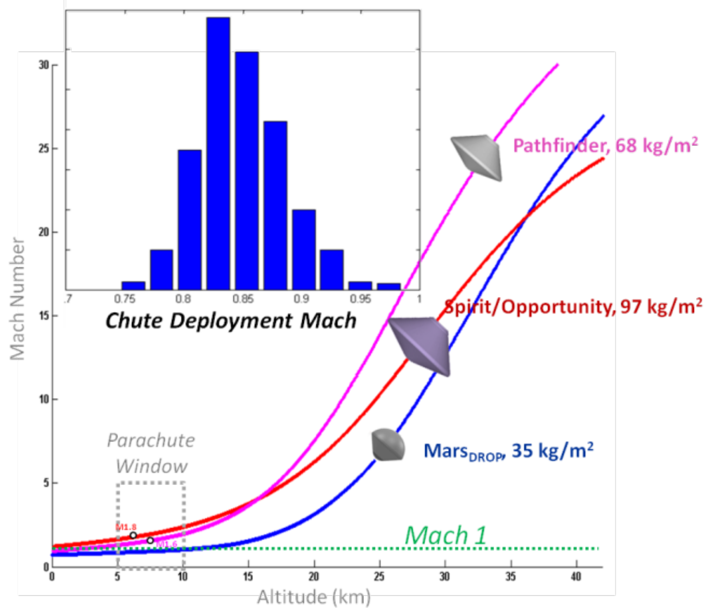
- Geologic context of primary landing site
- Valles Marineris wall rocks
- Temporal monitoring of Recurring Slope Linea (RSLs)
- Water-transported sediment

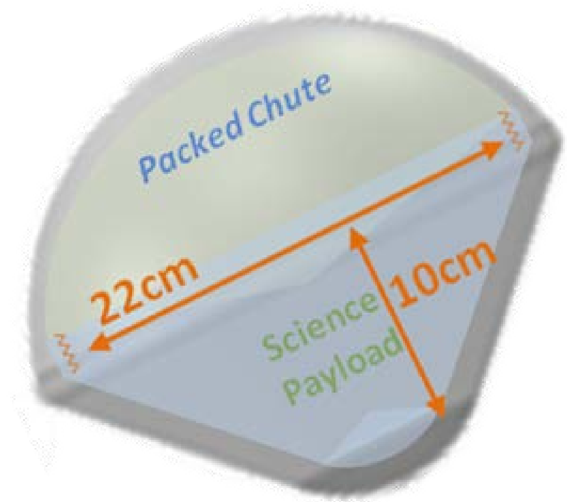


(Williams et al., 2014)

Capability Summary (conceptual)

- Probe is largely inert ballast from the host standpoint, added burden of 10 kg per probe.
- Probe shape derived from REBR/DS2, 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*

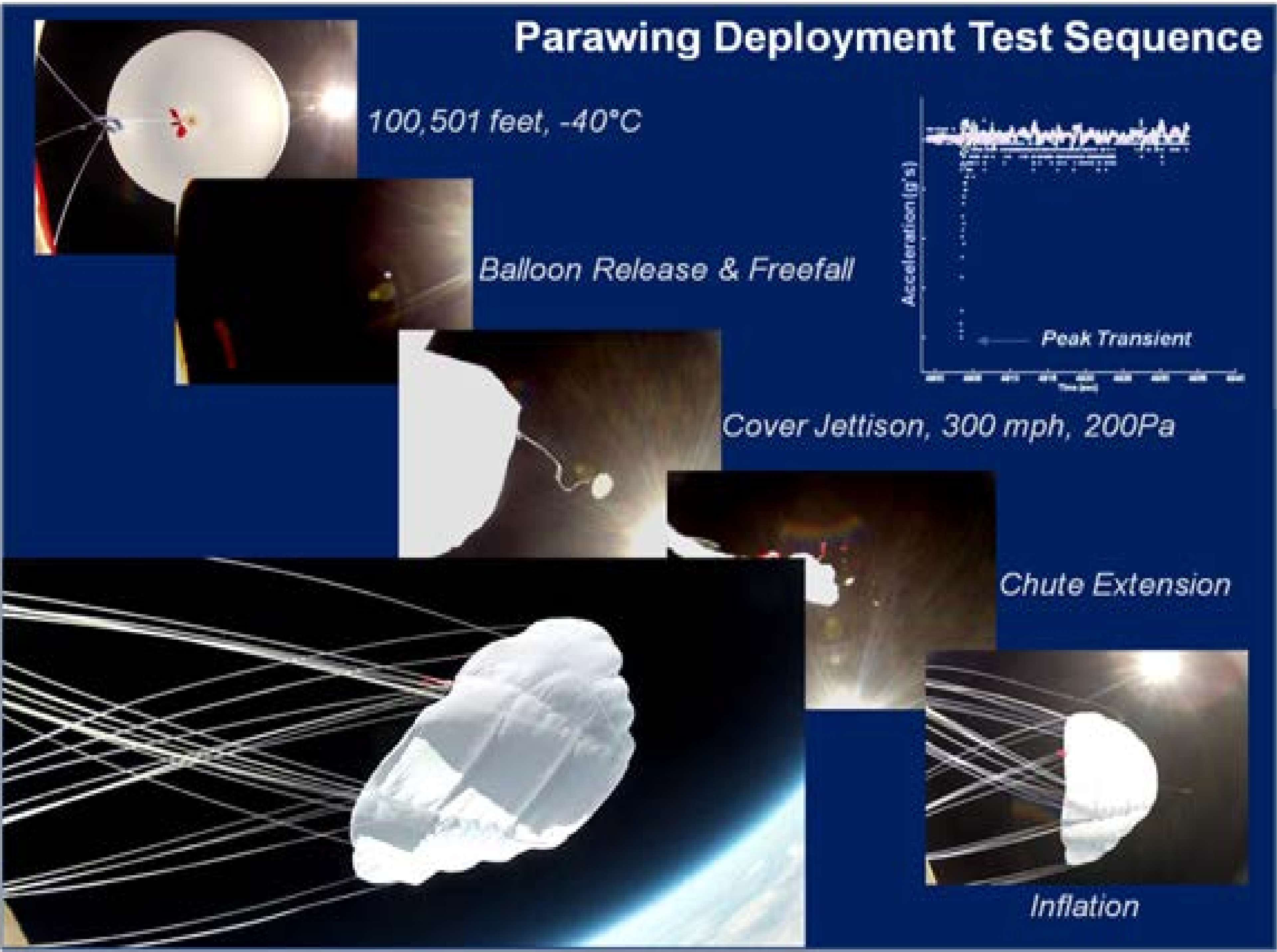




Landing Architecture

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


Parawing Deployment Test Sequence
100,501 feet, -40°C
Balloon Release & Freefall
Acceleration (g's)
Peak Transient
Cover Jettison, 300 mph, 200Pa
Chute Extension
Inflation

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

Driving Performance Desirements

Performance Parameters	Tech Demo (Initial Flight)	First science demo	“Operational” Capability Target
Number of Mars$_{DROP}$ 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 (sunlit)	0.5 W	~10 W	>10 W
Battery Capacity	16 Whr	70 Whr	same or greater
Surface Survival Duration	1 sol	90 sols	1 Mars year
Data Volume Return	100 kbits	>20 MBytes	>100 MBytes
Host Support	position knowledge before deployment.	position knowledge at deployment.	add trickle charge, command & sw upload, checkout data download
Glide distance	10 km	10+ km	10+ km
Landing accuracy to one of available sites across uncertainty ellipse	1 km	100s m	10s m

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

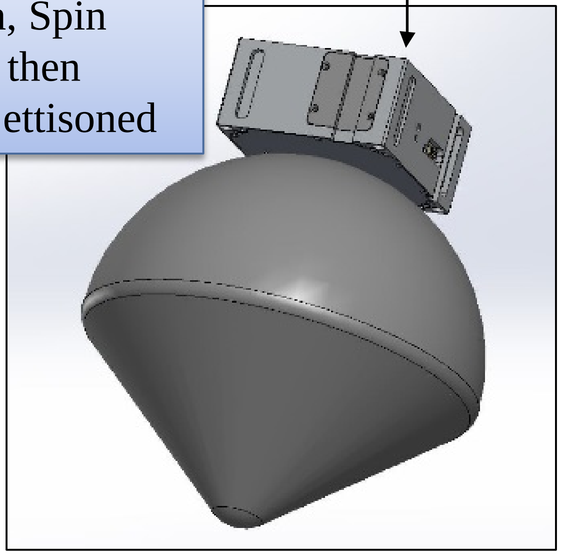
Goal 3: Characterize the geology of Mars

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	
A	Still camera, seismometer, multispectral imager, weather station		✓	✓	✓	✓	1 kg
B	Still camera, seismometer, aerosol sensor		✓		✓	✓	1.05 kg
C	Still camera, seismometer, deep UV fluorescence	✓			✓	✓	>1.5 kg
D	Video camera, tunable laser spectrometer (CH_4, H_2O, CO_2), T, P, RH	✓	✓		✓		<1 kg

Phases & Configuration (conceptual)

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

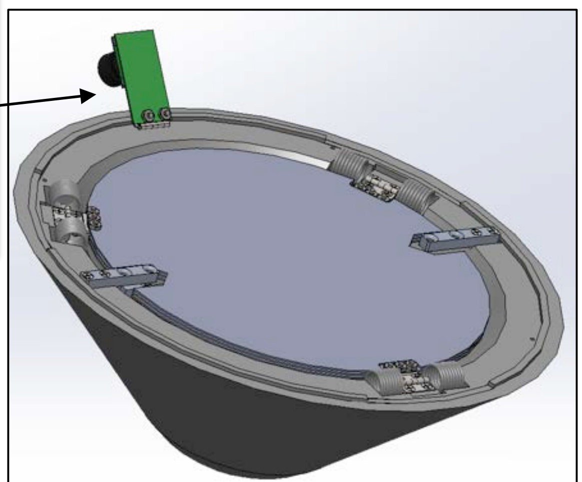


1) **Deployment:** *Backpack Unit* is 0.5 U XACT BCT (includes batteries) module to sense & control attitude, then impart spin (~2 rpm) required for stability through entry; jettisoned at entry interface

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)

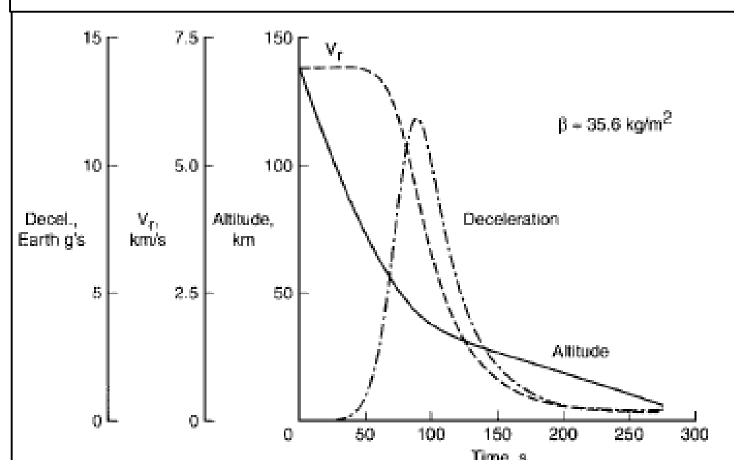
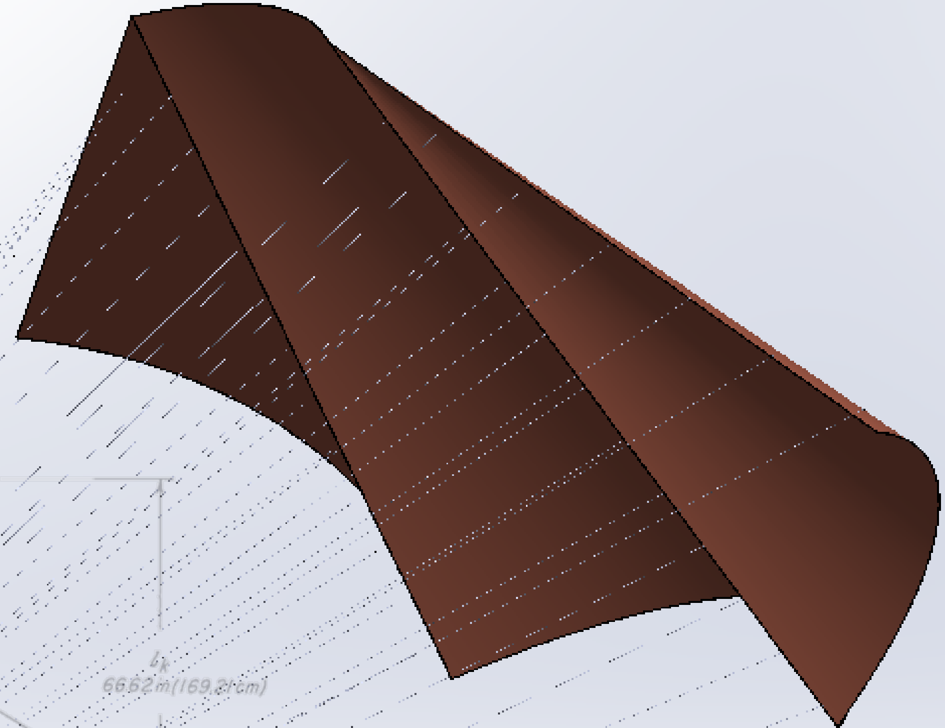
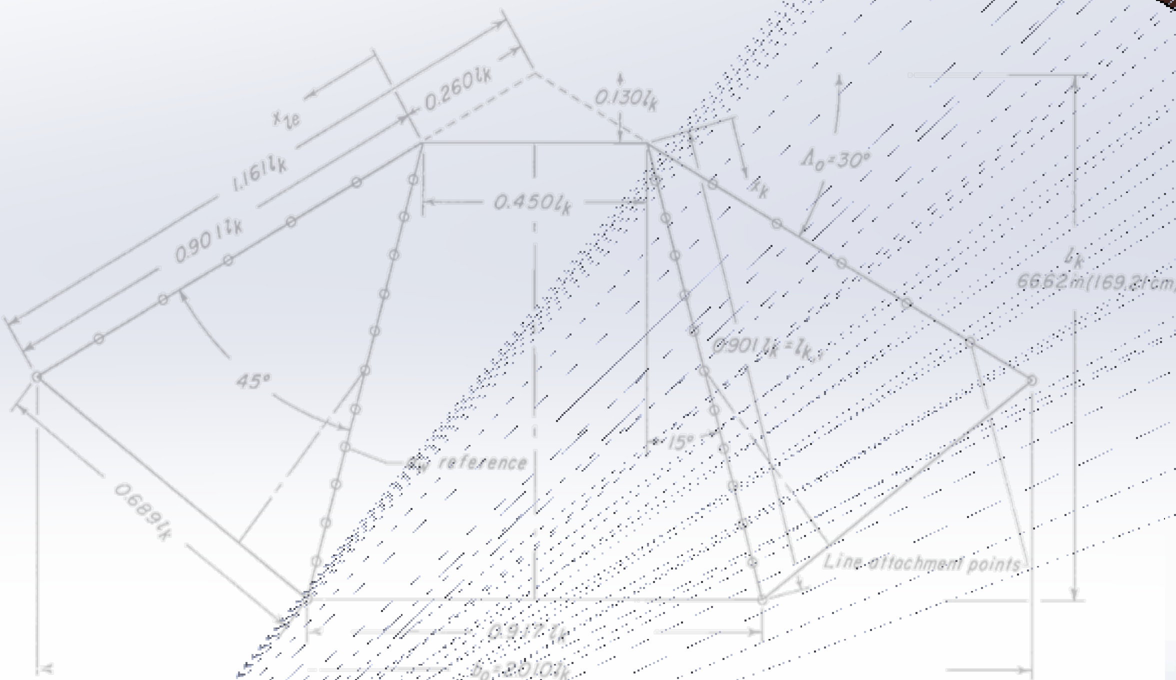


Figure reference: R. Braun et al., "Mars Microprobe Entry-to-Impact Analysis", JSR, 1999.

Parawing Deployment

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

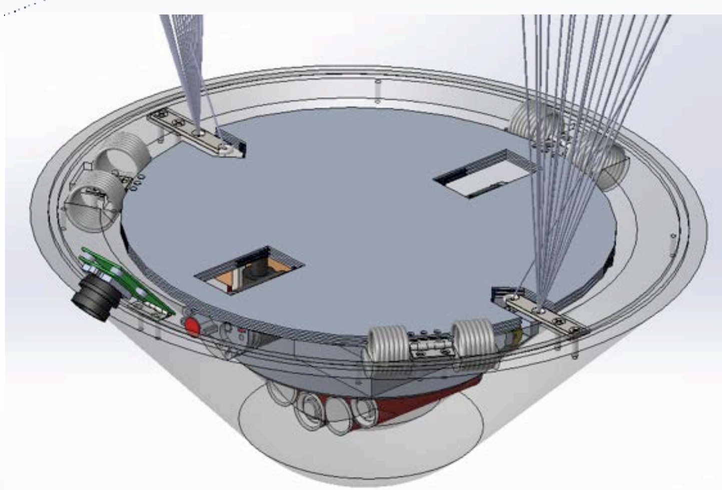




NASA Graph: Technical Note D-5965

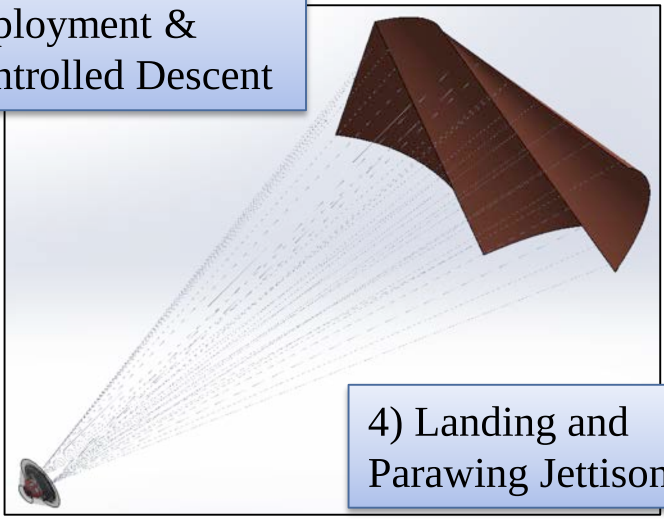
Design Sizing Point

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



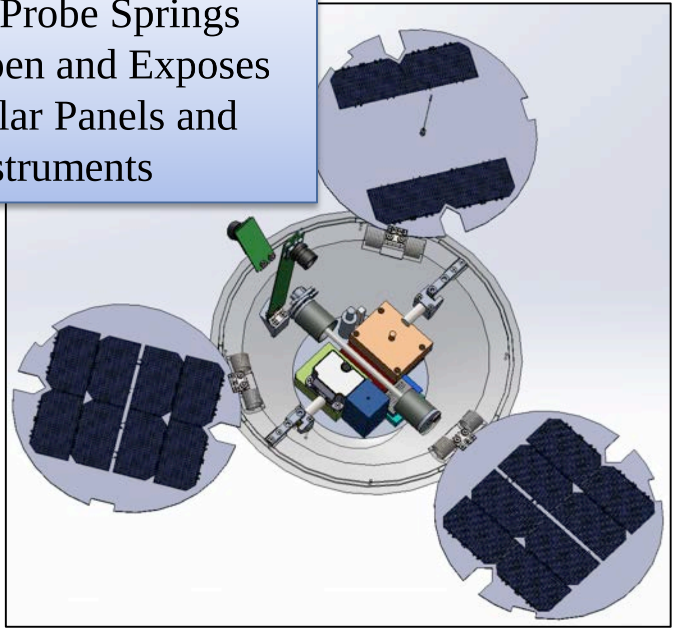
Phases & Configuration (conceptual)

3) Parawing Deployment & Controlled Descent



4) Landing and Parawing Jettisoned

5) Probe Springs Open and Exposes Solar Panels and Instruments



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.

Configuration Overview

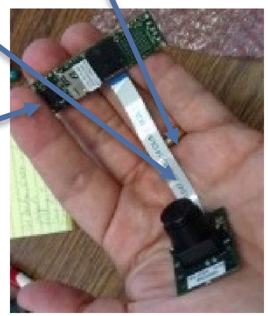
Suppliers shown only for proof-of-concept; no selection is represented.

UHF Antenna

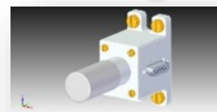
Descent / Nav Camera

Science Camera

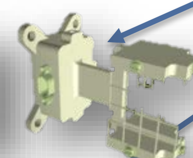
Gumstix Processor



Humidity Sensor



Air Temperature Sensor

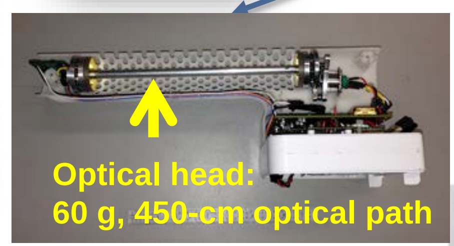


Pressure Sensor

Most hardware elements physically exist and many have flight heritage on previous Mars missions or CubeSats.

18650 Batteries (x6 underneath)

TLS Methane Detector

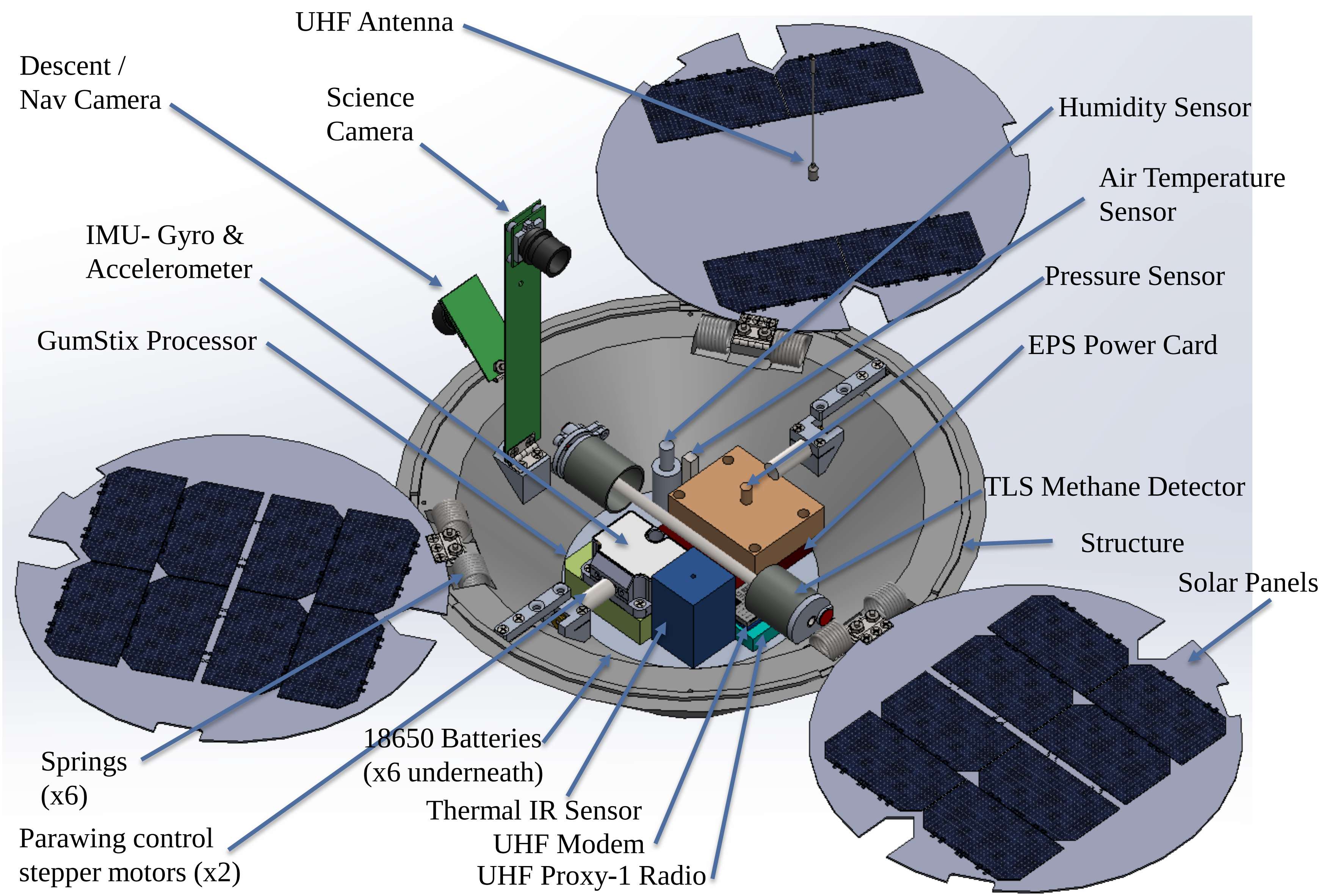


Solar Panels (x3)

UHF Modem
UHF Proxy-1 Radio

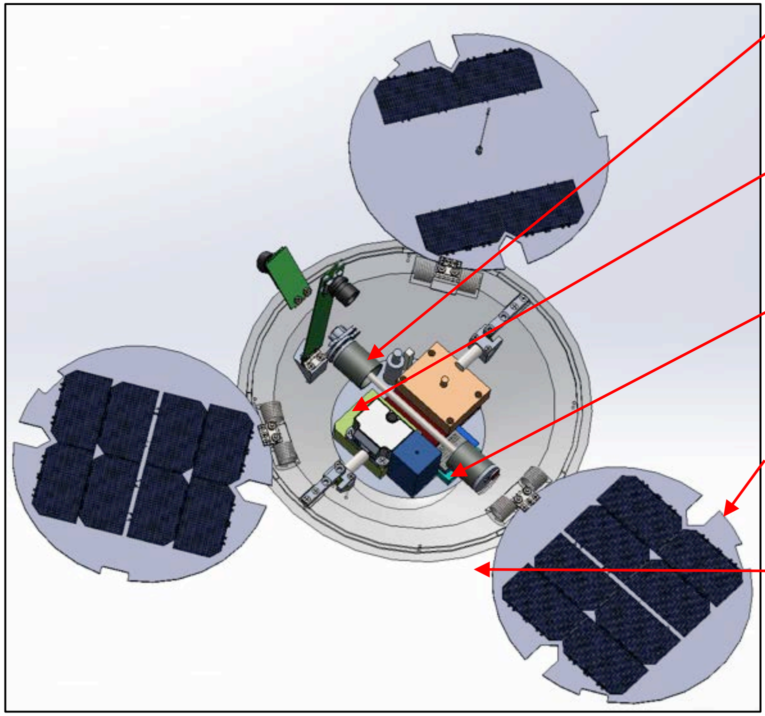
Equipment shown only for proof-of-concept. No vendor selection is represented.

Configuration Overview



System Overview

- Small spacecraft design philosophy and architecture (lean, multi-functional, low-cost)
- Leverage high-heritage components used for LEO CubeSats, INSPIRE, MarCO, Lunar Flashlight, NEAScout, etc. and short lifetime (3 months baseline)



Payload: Methane-detecting TLS, weather sensors, and surface geology (camera) <0.3 kg

Computing: Gumstix does all data management, storage, processing, control, interfaces

Telecom: UHF Proxy-1 link to Mars Orbiter at ~ 16 kbps (~1 W) to return ~ 1 MB/sol

Power: ~10 W total, store 72 Whr, require avg ~3W

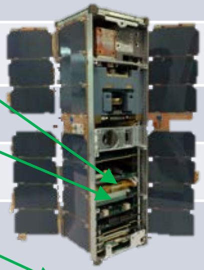
Thermal: 2 W heater to maintain instruments/batteries at survivable/operable temps during Mars night (>-40^{o}C)

Structural: impact-absorbing outer 0.5 – 2 cm. Current CG is aft (47% of probe's axial length), therefore spin stabilized with backpack for entry.

Master Equipment List

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).

Data Volume & Upload Strategy

Initial Data: collected during descent and first 6 sols on Mars (uploaded in first 6 sols):

Data Source	Type	Data Volume (MB)
Descent Video	VGA Time Lapse Thumbnail	4.39
Geology Image	VGA Thumbnail (8 cameras)	1.17
Weather Data	Temperature, Humidity, Pressure (300 bits/min, 7 sols)	0.16
Total	Including 1% Housekeeping/ Engineering Data	**5.85** (uploaded in 6 passes)

Regular data: collected continuously on Mars and uploaded over first 3 months:

- *Over time upload high resolution video and geology in regions of interest*
- *Methane data from the TLS (~4 kbits/spectrum, ~1 spectrum/week for calibration)*
- *Weather data (~100 bits/min; rate is highly flexible +/-100x within available resource)*

Data Source	Type	Data Volume (MB)
Descent Video	Full resolution VGA Video (1/4th of video)	65.92
Geology Image	Full resolution (1 camera)	3.00
Weather Data	Temperature, Humidity, Pressure (300 bits/min, 80 sols)	2.16
TLS	Methane Spectrum Data (4 kbits/7 sols, 80 sols)	0.006
Total	Including 1% Housekeeping/ Engineering Data	**71.80** (uploaded in <80 passes)

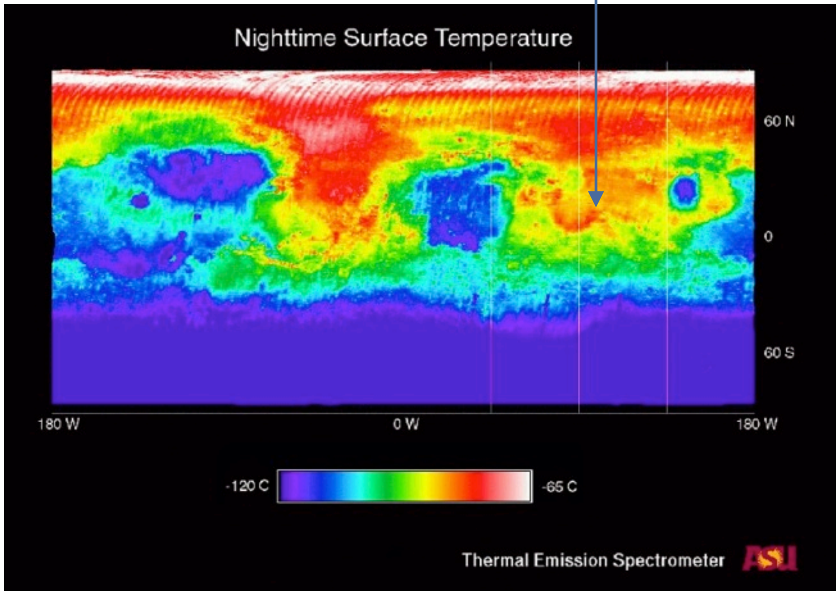
Data management and upload strategy highly flexible given opportunities events:

If methane detected (or spectrum changes), instrument data rate will increase, and methane data will displace video playback data within transmit allocation.

Results based on detailed data rate and volume analysis and 2x lossless compression [Justin Boland]

Thermal

- Driving thermal requirement is during night to maintain:
  - *TLS (methane detector) > -60º C (survival)*
  - *18650 Batteries > -40º C (operational as require energy during night)*
- Mars surface temperatures drop to -120 C in expected landing zone (-/-30º latitude)
- *Preliminary nighttime thermal analysis includes modeling all thermal gains/losses*
  - Aerogel Insulation (5 mm thickness inside heatshield)
  - Radiation loss through vapor deposited gold tape (ε=0.03) to 0 K environment
  - Convection loss to surrounding air (-100ºC)
  - Surface conduction loss to surface (-120ºC)
  - Design includes 2 W heater (require ~1.2 W)
  - Thermal equilibrium at +17º C
    - *20% margin on -40º C requirement, margin computed based on ºK*



Surviving Landing Impact

- Landing: ~7 m/sec vertical, 18.7 m/sec horizontal; with ~2.5 cm crushable aeroshell
- Flare may be possible (reducing loads) and lander expected to roll upon impact before stopping
- Structure and crushable material designed to minimize impact felt by internal components
  - *Current expected forces on probe <300 g’s (based on impact analysis below)*
- $Mars_{DROP}$ instrument and components are expected to survive ~500 g’s

$E = \frac{1}{2} m v^2$

$E = Fd$

$F = ma$

$a = v^2/2d$

E= Impact Energy
m = object mass
v = impact velocity

F= Deceleration Force
d = displacement
a = acceleration

Note acceleration does not directly depend on mass

Assumptions:

- Perfect conservation of energy
- Impact and displacement are vertical
- Force is applied evenly across displacement

Parameter	Symbol	MarsDROP	Units
Mass	m	3.5	kg
Vertical Velocity at Impact	v	7	m/sec
Impact Energy	E	85.75	J
Crushable Thickness		2	cm
Crushed Ratio (strain)		0.5	
Displacement	d	1	cm
Force	F	8575	N
Impact Acceleration	a	2450	m/s^2
Impact g’s	a	249.7	g's

Example Camera System with Computation for Terrain Relative Navigation

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.

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).

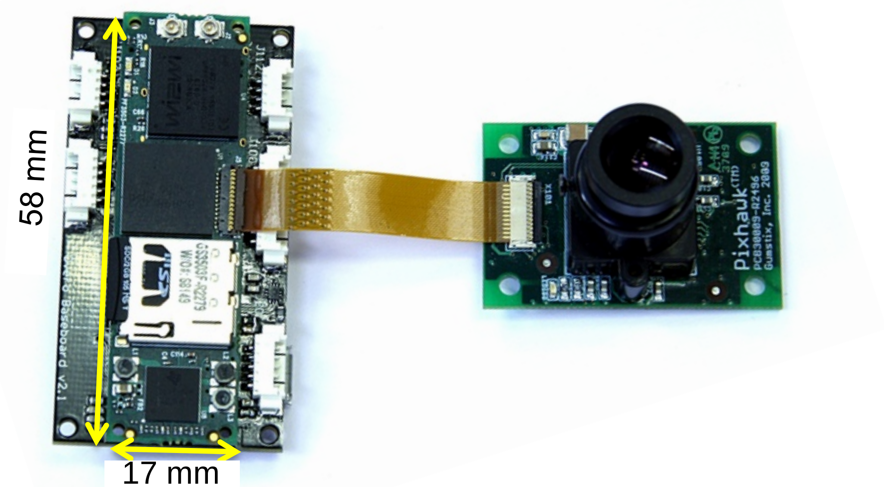


image source: https://pixhawk.ethz.ch/electronics/camera

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
Radiation tested	3.2 krad (RDF = 8)
Computation	TI AM3703 DSP with 1GHz ARM CORTEX A8

Modifications likely required:

- Materials compatibility.
- Thermal tolerance or heater.
- Add pressure sensor and MEMS gyro.

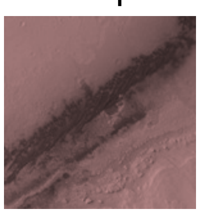
Synergy with Mars Lander Vision System (LVS)

State Estimation

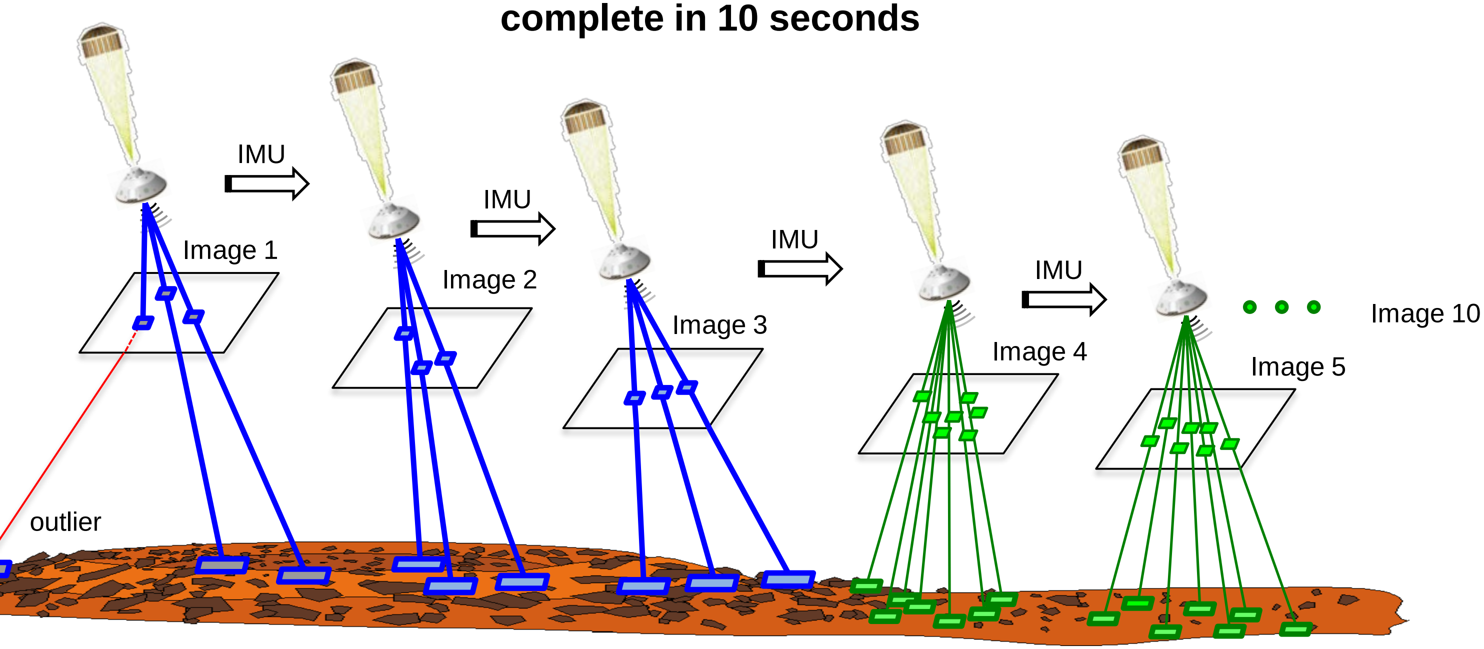
Inertial Measurement Unit (IMU)

Camera

Map



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



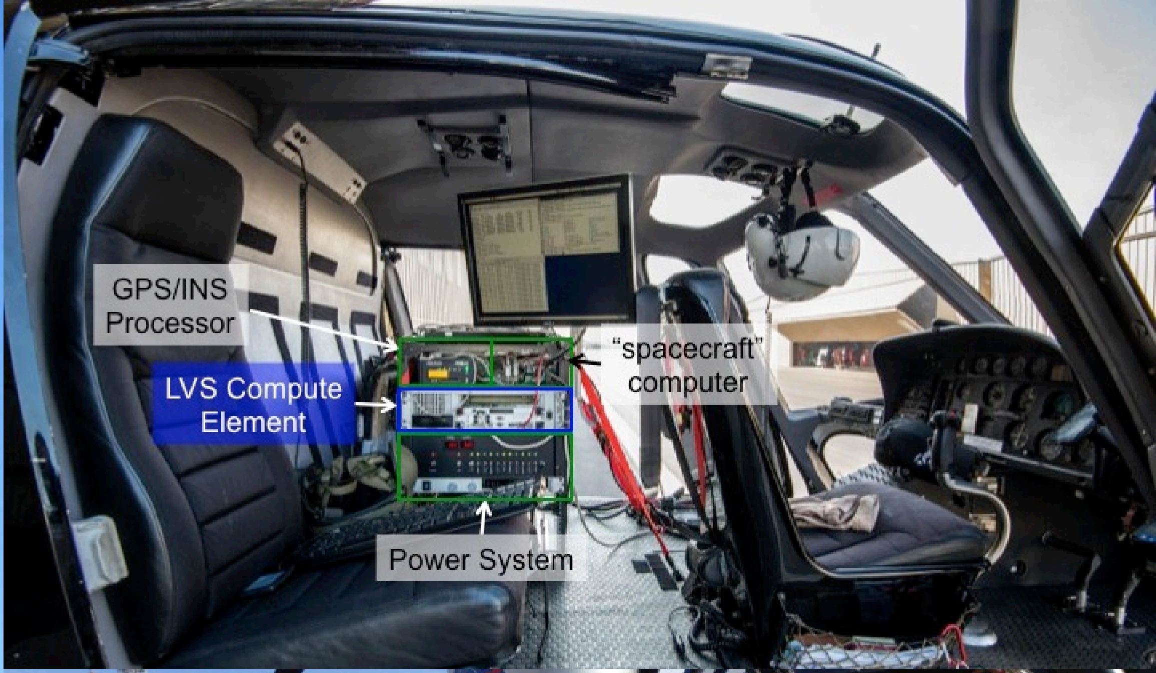
Coarse Landmark Matching

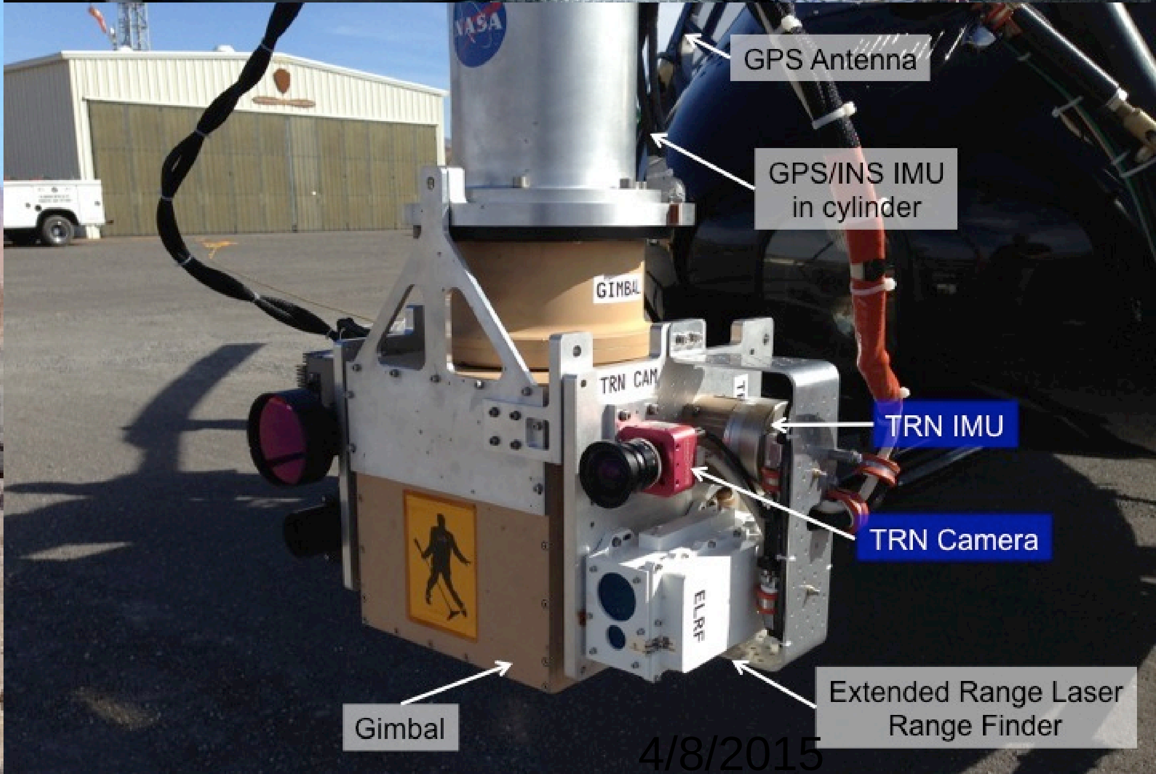
Remove Position Error (3km 3-σ)

Fine Landmark Matching

Improve Accuracy (40m 3-σ)

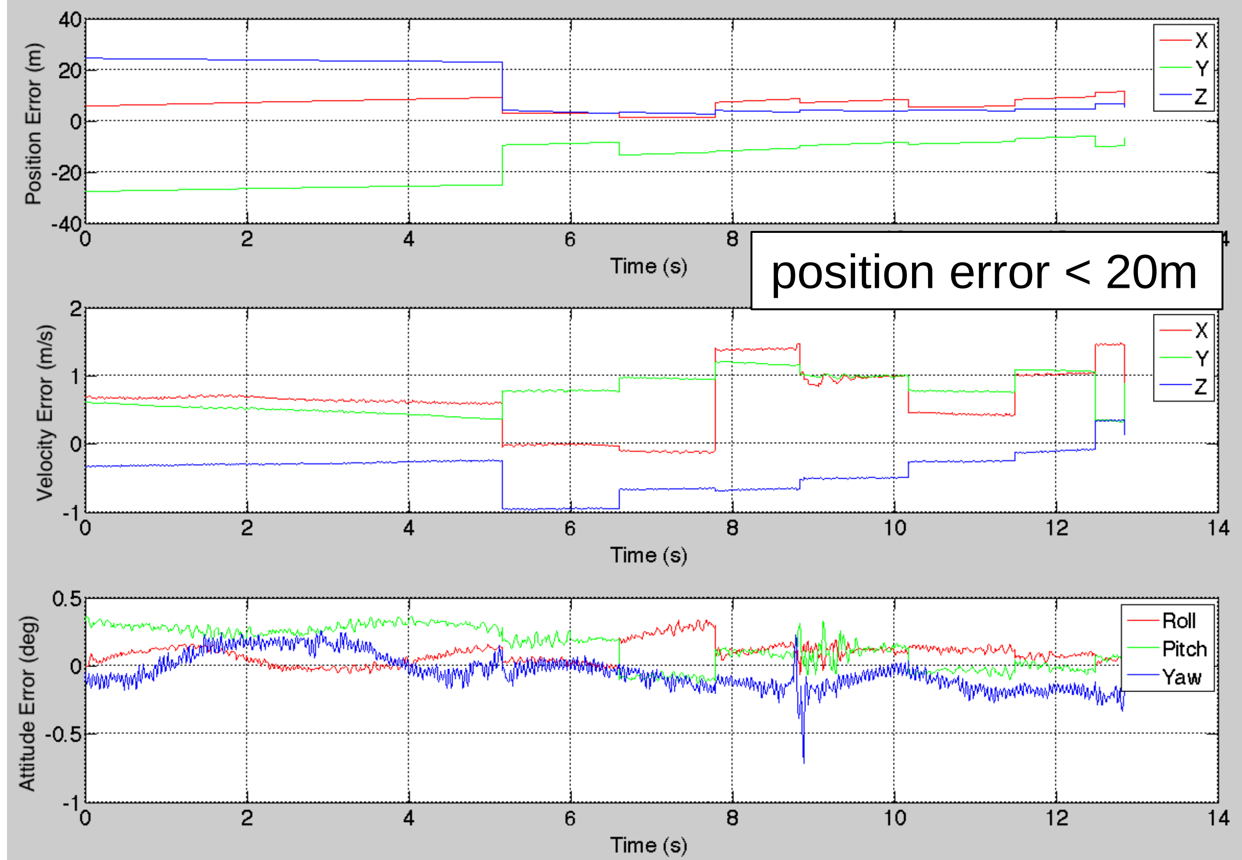
- LVS prototype tested over Mars-analog terrains in Feb/March 2014
- Test collected data to validate technology over a wide operational envelop defined by expected M2020 conditions
- LVS meets position accuracy and robustness requirements
- Field test demonstrated maturity of the algorithms

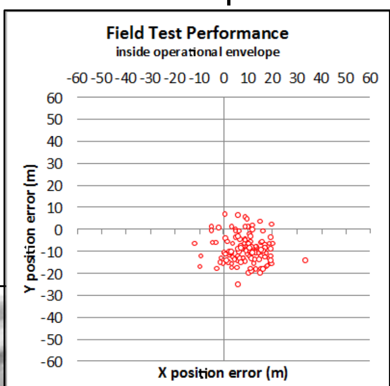


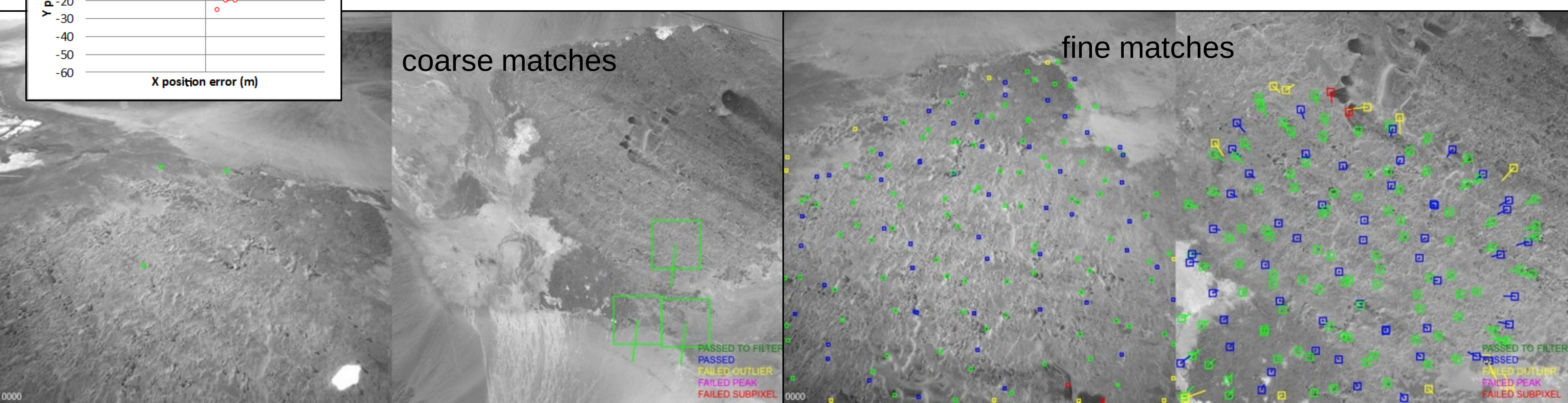


LVS Helicopter Test March 2014

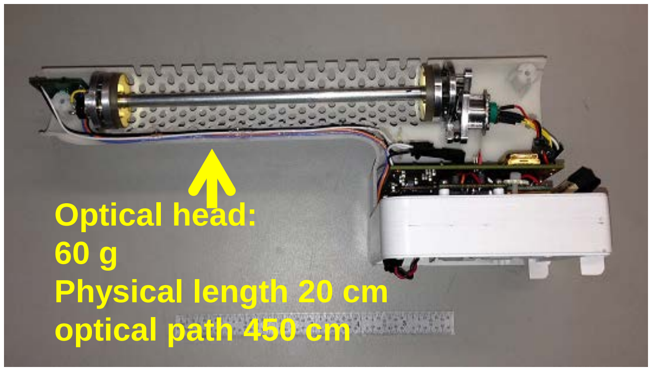
- LVS prototype tested over Mars-analog terrains in Feb/March 2014
- Estimates position, velocity and attitude
- takes out 3 km position error
- 40 m 3 sigma position error at 2 km altitude
- 1s TRN updates
- 20Hz state updates







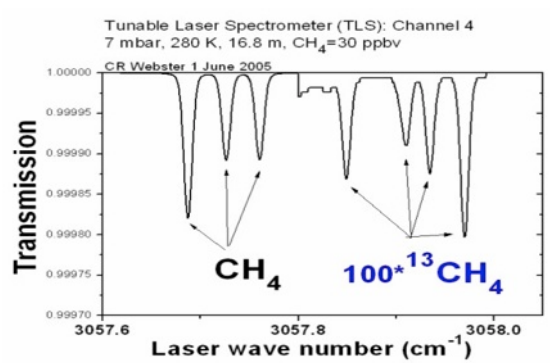
Example Instrument: Tunable Laser Spectrometer (300 g, 2W for continuous measurement) could measure gases such as Methane (CH_4), Water (H_2O) and isotope ratios within these gases: D/H, $^{13}C/^{12}C$, $^{18}O/^{17}O/^{16}O$ in a descent (DROP) profile or on-surface sampling.



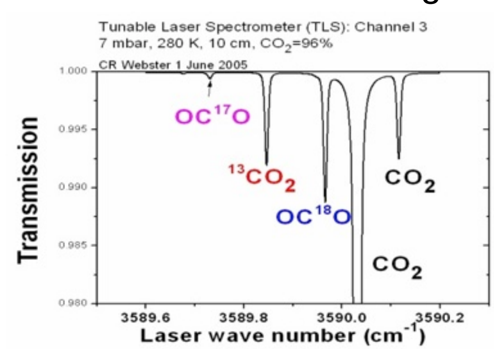
JPL + industry has invested in miniature methane sniffers for public safety and reducing fugitive emissions

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

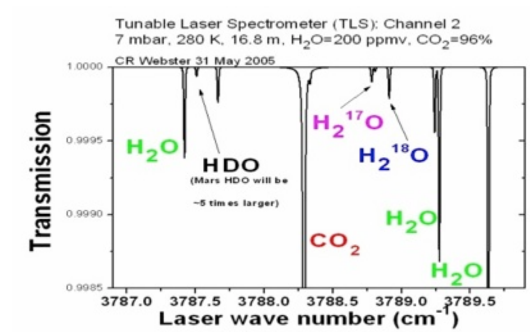
Capability:



Methane Isotope Ratios at 3.27 μm



Carbon Dioxide Isotope Ratios at 2.78 μm



Water isotope ratios at 2.64 μm

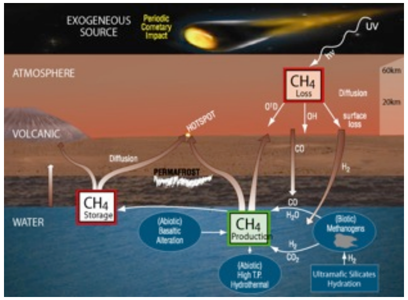
Methane and Planetary Atmospheric Studies

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

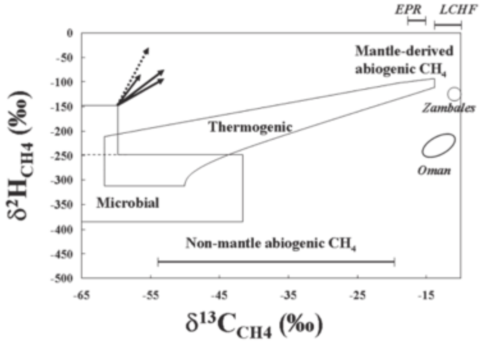
MRO spacecraft

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

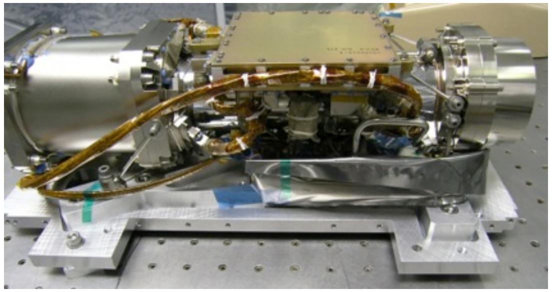


Mars Methane Cycle

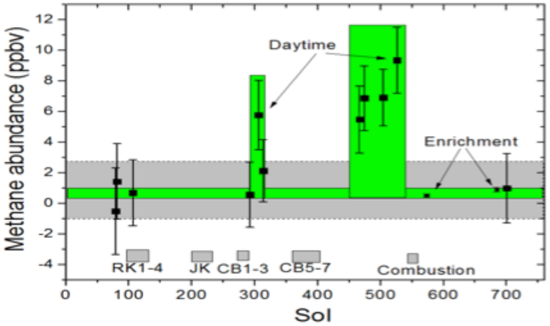
Measurement of isotopic ratio of $^{13}C/^{12}C$ could answer the origin of methane on Mars



Curiosity Rover landed on Mars Aug.5th,2012



TLS instrument PI: (C. Webster)



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

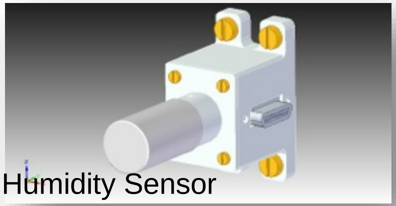
POC: Lance Christensen/JPL

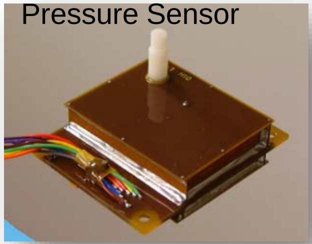
Example Instrument: suite of meteorological sensors

Weather monitoring at the surface: crucial for weather exploration, verifying models used for Entry Descent & Landing, understanding the near surface environment for human exploration of a planet.

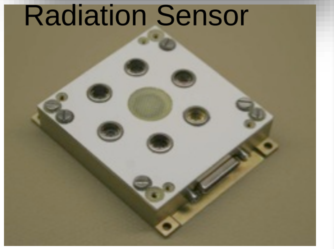
Most lander missions included environmental monitoring. Those that did not, used other instruments to characterize it.

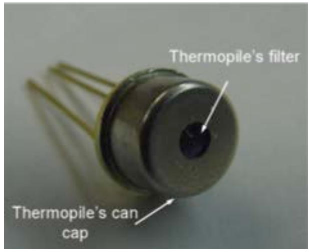
Temperature, Humidity, pressure cycle near the surface





UV-Visible-Near IR radiation downwelling at the surface *(for solar power generation)*



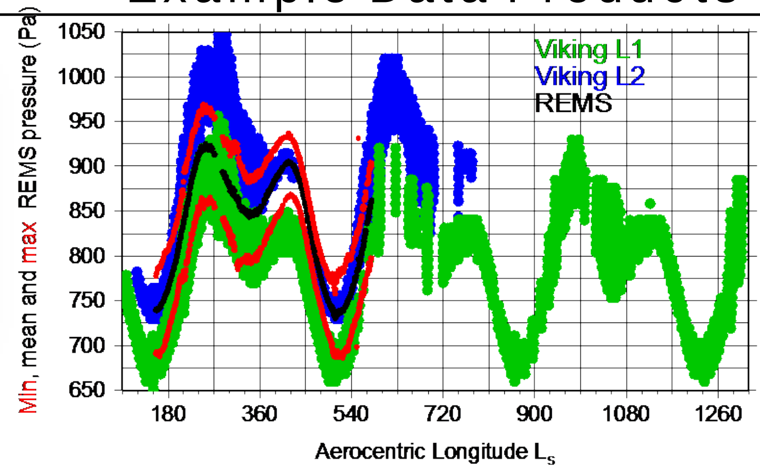


Ground temperature cycle, for interactions atmosphere-surface

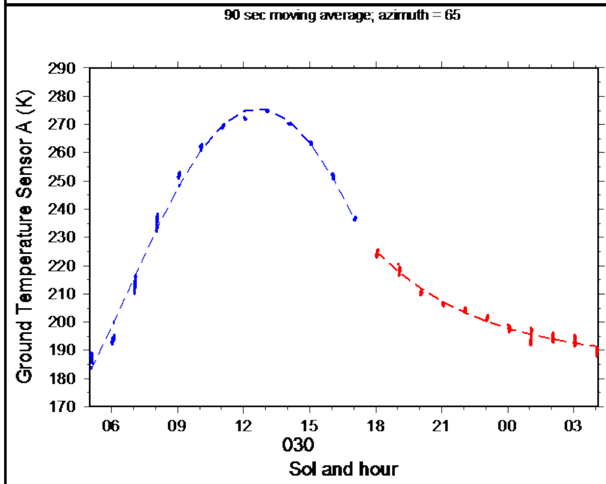
Current Status

- Tested on Mars (MSL) and adaptable to MarsDrop microlander capabilities.
- MSL – REMS and InSight Twins spares available.
- Mars 2020 – MEDA instrument under development;

Example Data Products



Pressure cycles from REMS (MSL) and Viking
(de la Torre et al; AGU 2014)



Diurnal cycle of Mars surface temperatures: surface thermal properties (on Gale)

(de la Torre et al; LPSC 2012)

(POC: M de la Torre *mtj@jpl.nasa.gov*
Javier Gómez Elvira, *gomezej@cab.inta-csic.es*

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

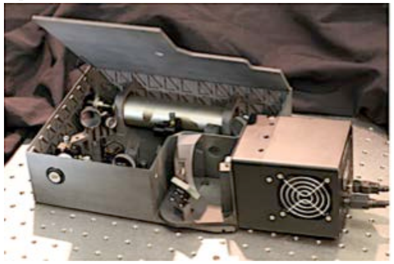
- Enables detection and characterization of a wider range of organics relevant to biosignatures and alteration processes.
- Presently too large for MarsDrop microlander capability.

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.

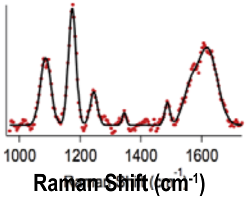


SHERLOC-Mars 2020 Prototype

Example Data Product

Macroscopic Image

DUV Fluor: Organic Detection, Classification, & Distribution

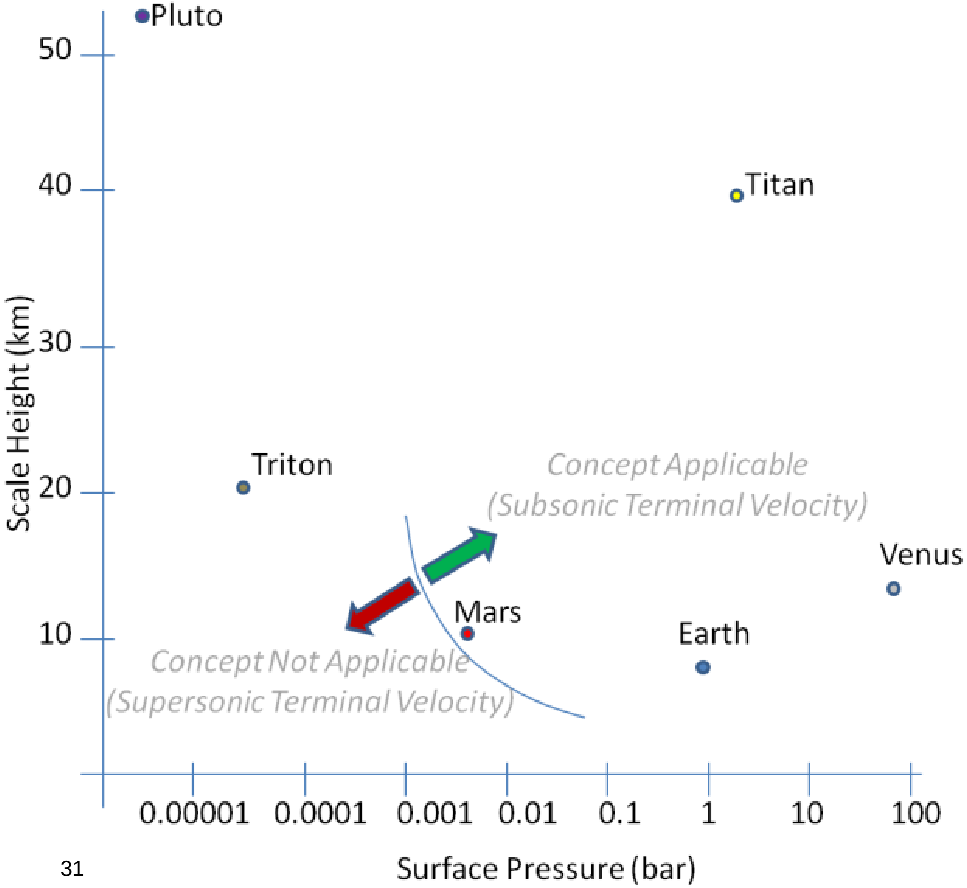


Raman Shift (cm^{-1})

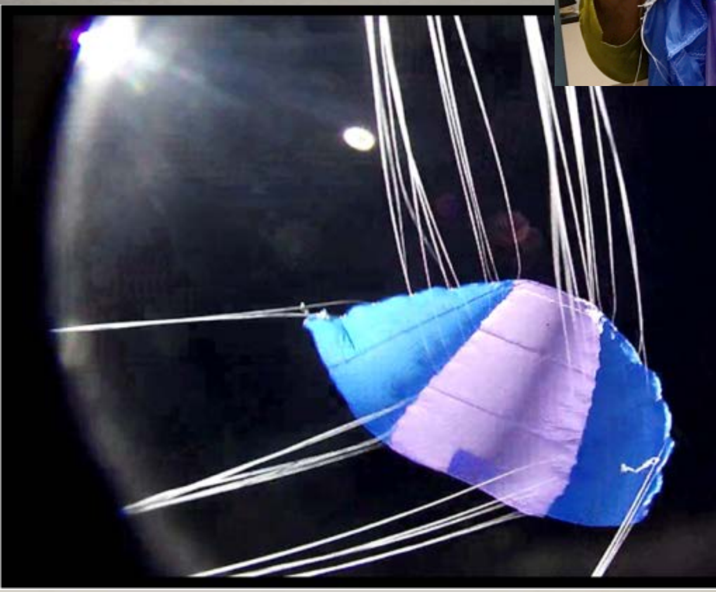
DUV Raman: Organic analysis & mineralogy

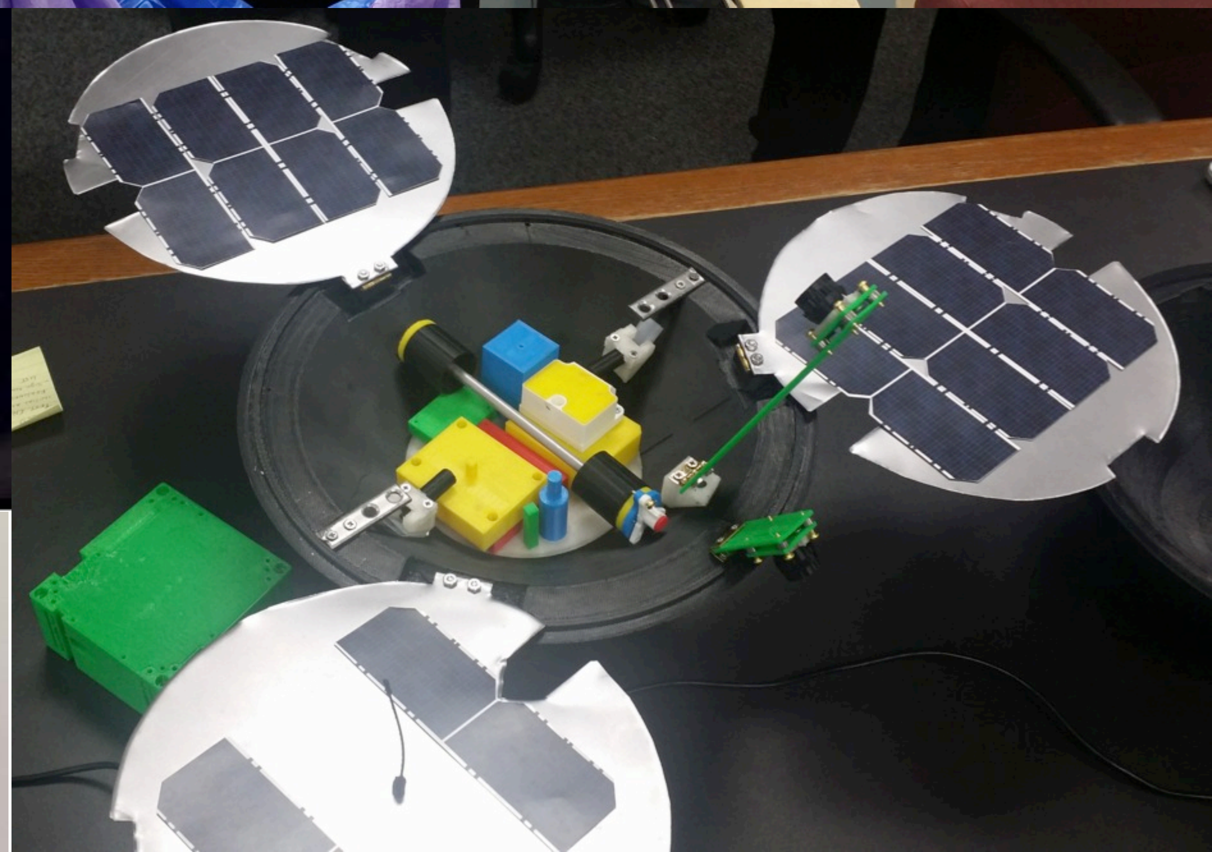
Beyond Mars

- 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

Mars$_{DROP}$ for Getting Small Payloads to Mars' Surface:

How many would you like, and where would you like them?

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

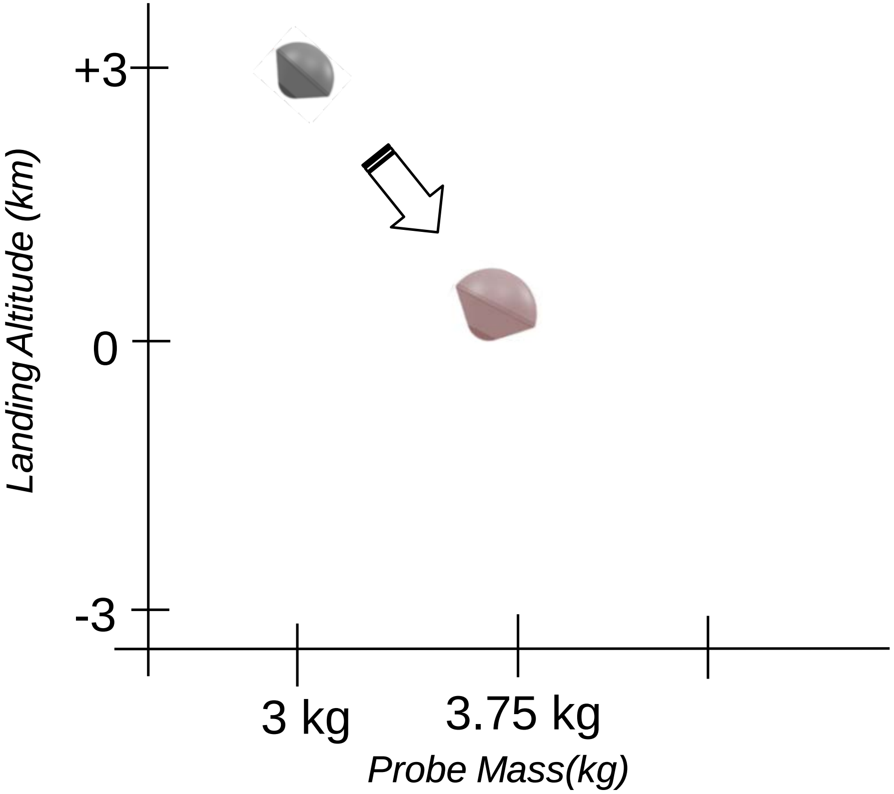
- Double or triple the number of Mars landers at small additional cost for each mission opportunity.
- Target high-risk locations, including canyons and crater walls.
- Distributed science from multiple sites simultaneously.
- Allow heavy university and small business involvement, at a level just now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

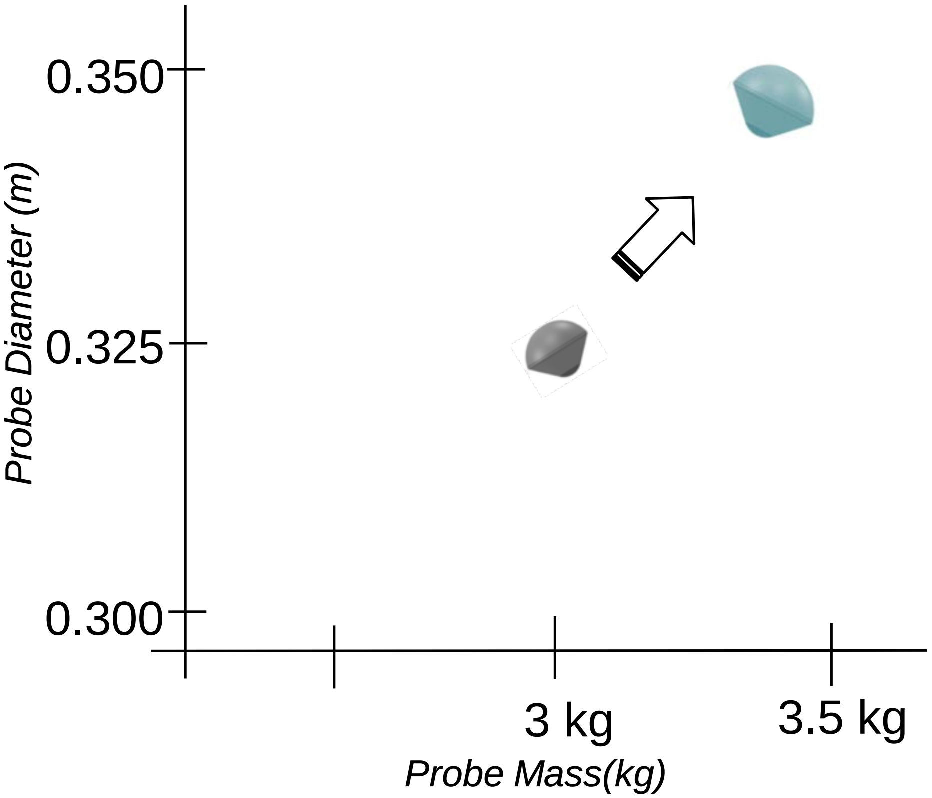
…and maybe one day canyons, craters, and lakes of worlds beyond Mars.

More Details…

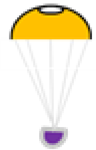
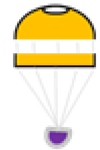
Mission Trades

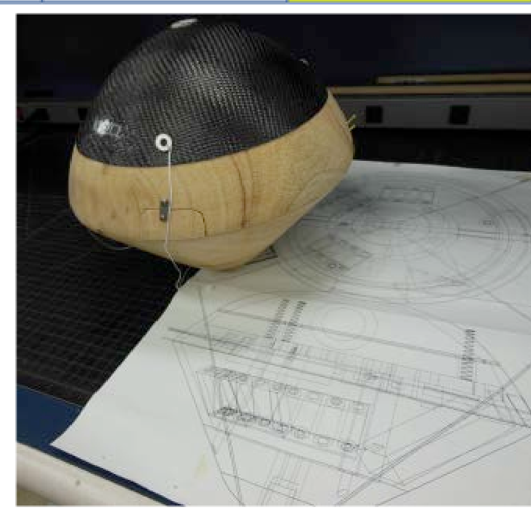
- Small trades, off reference case, can provide meaningful increases in payload mass, with similar EDL performance



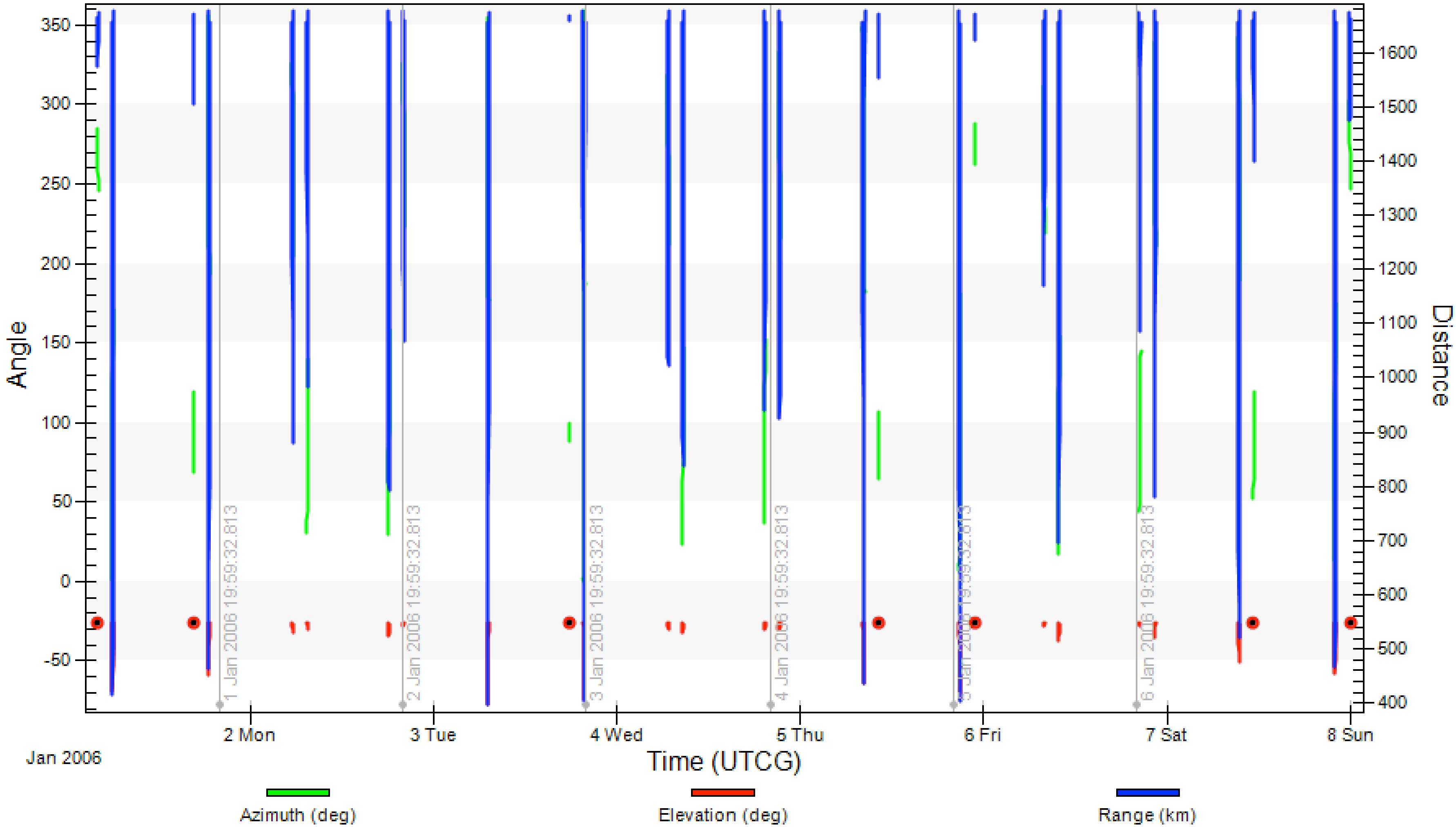


Aerodynamic Decelerator Optimized for Volume, Scaled Down from a Gemini Parawing Design

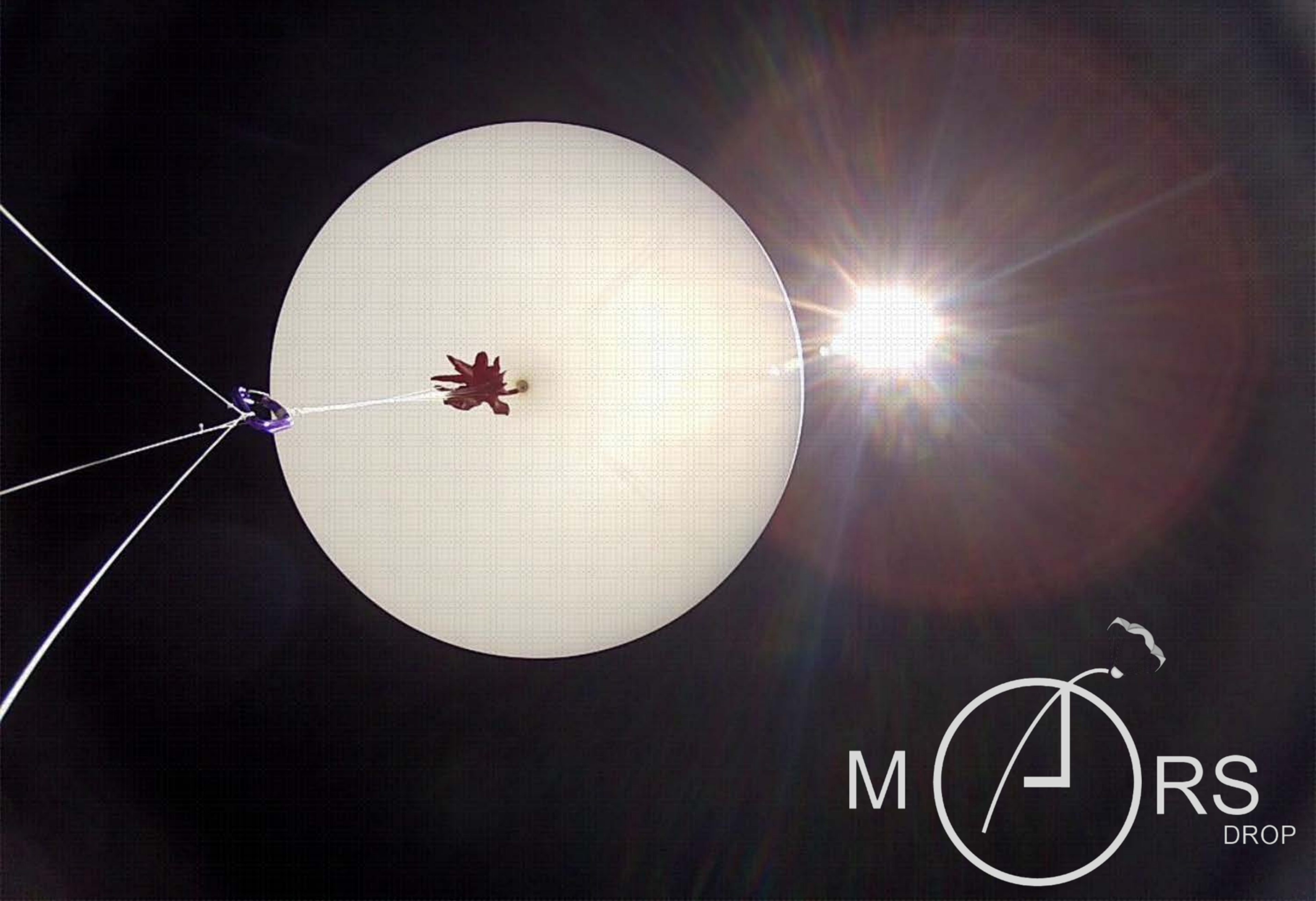
Concepts:	Solid Circular Parachute 	Disk-Gap-Band Parachute 	Inflatable Decelerator 	Vortex Ring Parachute 	Parawing 
Claim to Fame	"Standard" Round Solid Parachute	Used on all NASA Mars Landers	Targeted for future NASA Mars Landers	Highest Drag	Gliding Chute
Supersonic	No	Yes	Yes	Unreliable	No
Complexity	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



Example MarsDrop to MRO Telecom Link



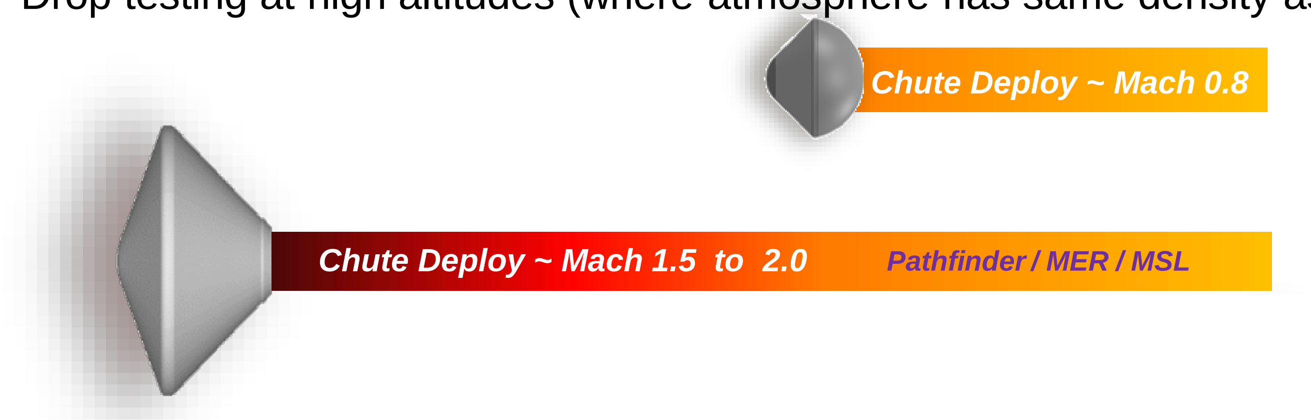
Overview: Concept, EDL, Balloon Testing



Entry, Descent, & Landing

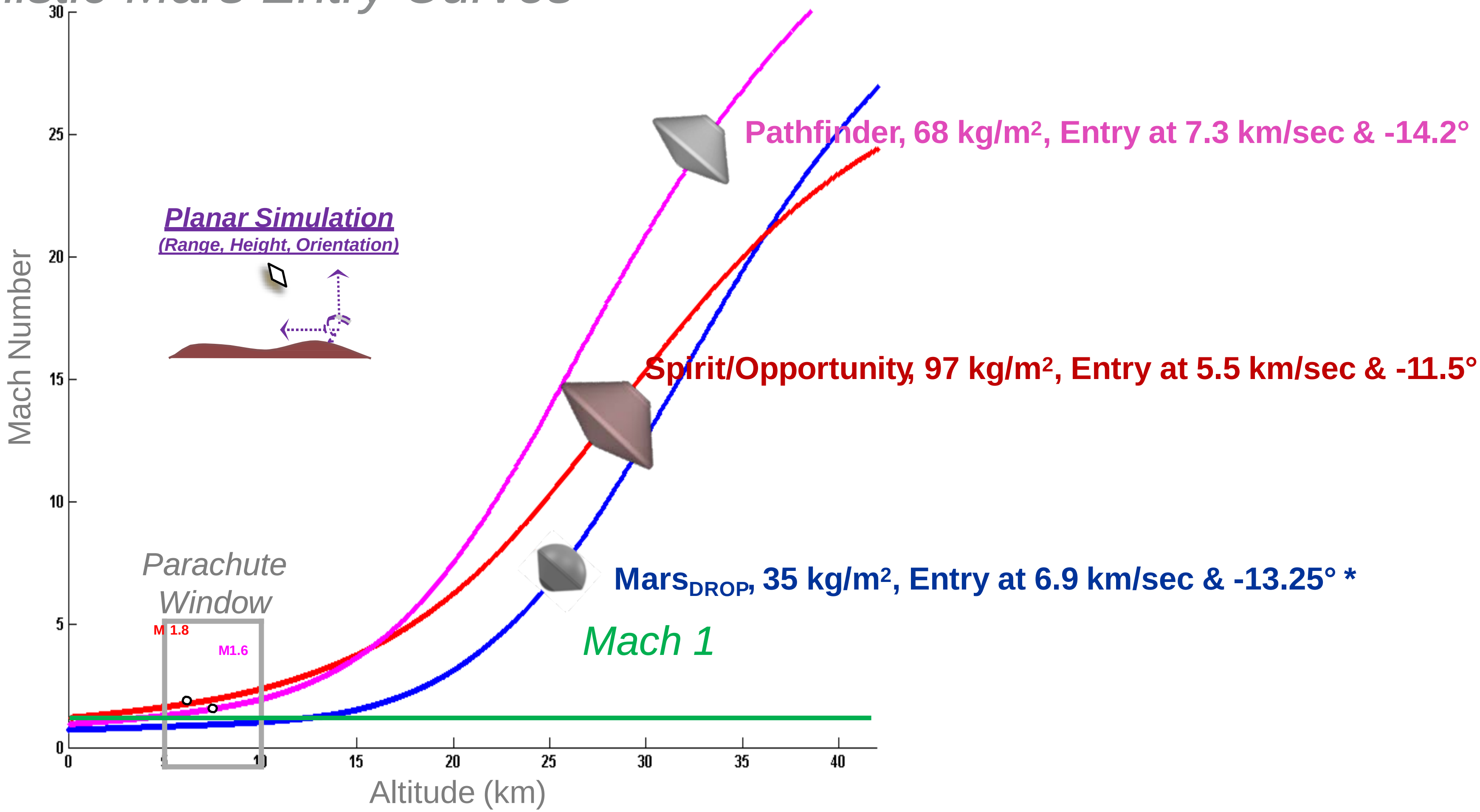
"7 Minutes of Terror"

- Progressively larger NASA Mars Landers have produced progressively more "exciting" landings (e.g. MSL's "7 Minutes of Terror")
  - *Larger mass densities equate to higher ballistic coefficients and faster terminal velocities, requiring complex multi-stage, supersonic deceleration*
  - *Multi-stage, supersonic deceleration largely untestable as a system on Earth (cost prohibitive)*
- A micro-probe has the advantage of going smaller, with a low ballistic coefficient that greatly simplifies the landing architecture.
  - *A sufficiently low ballistic coefficient will produce a subsonic terminal velocity, requiring a simple, single-stage, subsonic deceleration to reach landing velocity*
  - *Single stage, subsonic deceleration is easily tested on Earth*
    - Drop testing at high altitudes (where atmosphere has same density as Mars surface)



Entry, Descent, & Landing

Ballistic Mars Entry Curves



- Microprobe goes subsonic around 10 km → subsonic landing system
  - Pathfinder, Spirit, Opportunity, MSL all supersonic during parachute deploy

**Microprobe goes subsonic at similar height across wide range of entry parameters (flat profile under 10 km)*

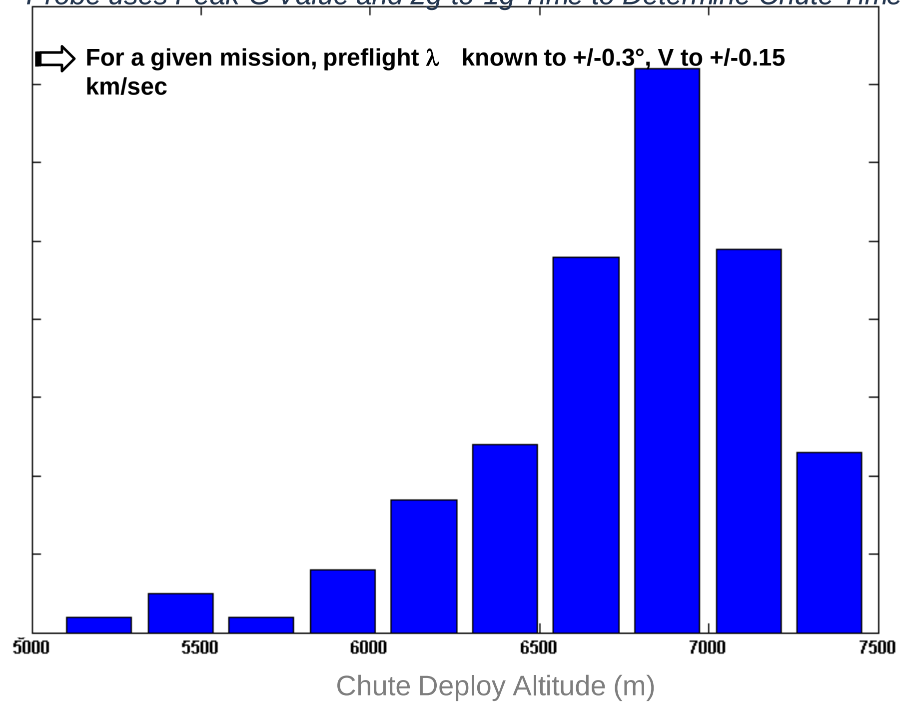
Parachute Window

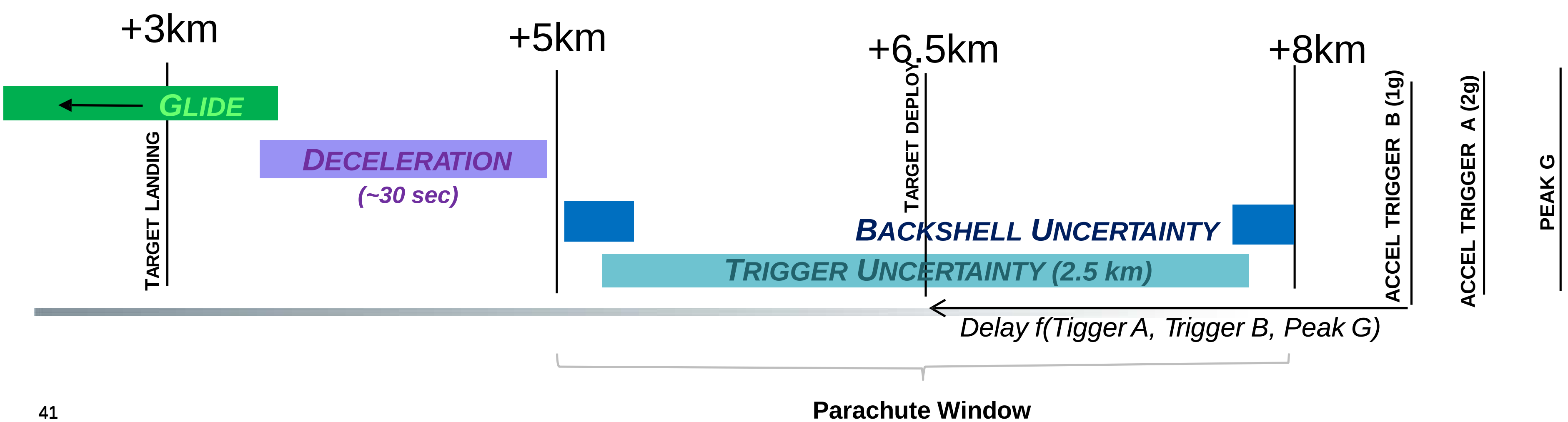
Trigger Uncertainty

- Acceleration based trigger, upstream of terminal velocity phase (at 1g)
- After trigger, delay counted off until deploying the parachute
  - Delay between 1g and target altitude is a function of entry angle (*Peak-g*) and atmospheric density variability (*2g to 1g time*)
  - *Simulation estimates a 2.5 km trigger uncertainty*

Trigger Uncertainty Study

Probe uses Peak-G Value and 2g-to-1g Time to Determine Chute Time






3.0 kg, 0.325m Probe

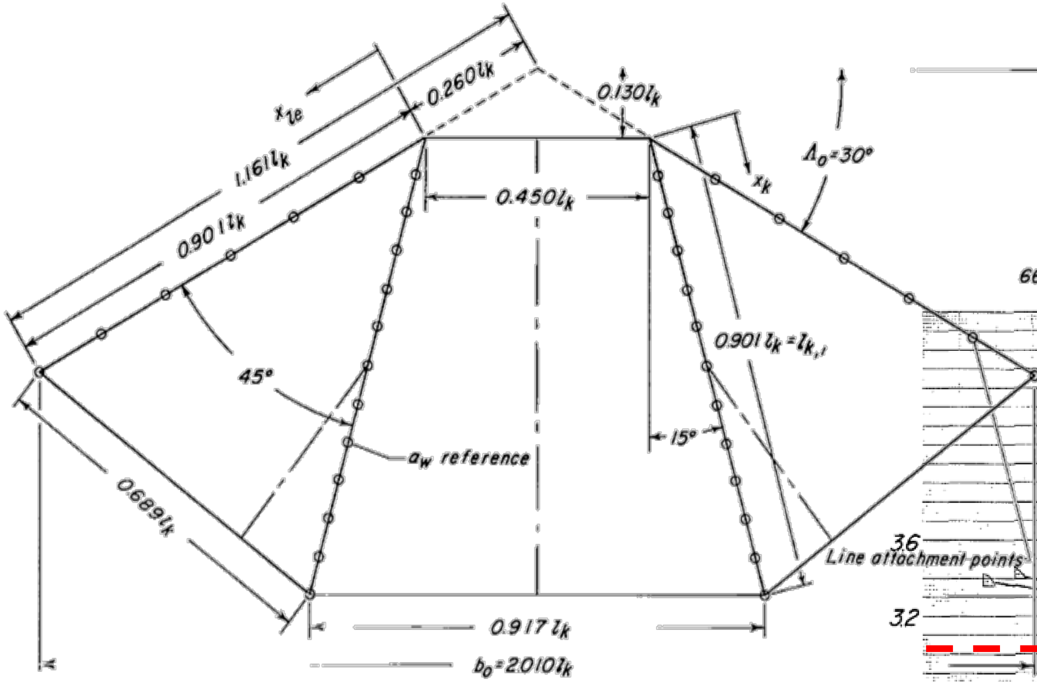
The Reference Case

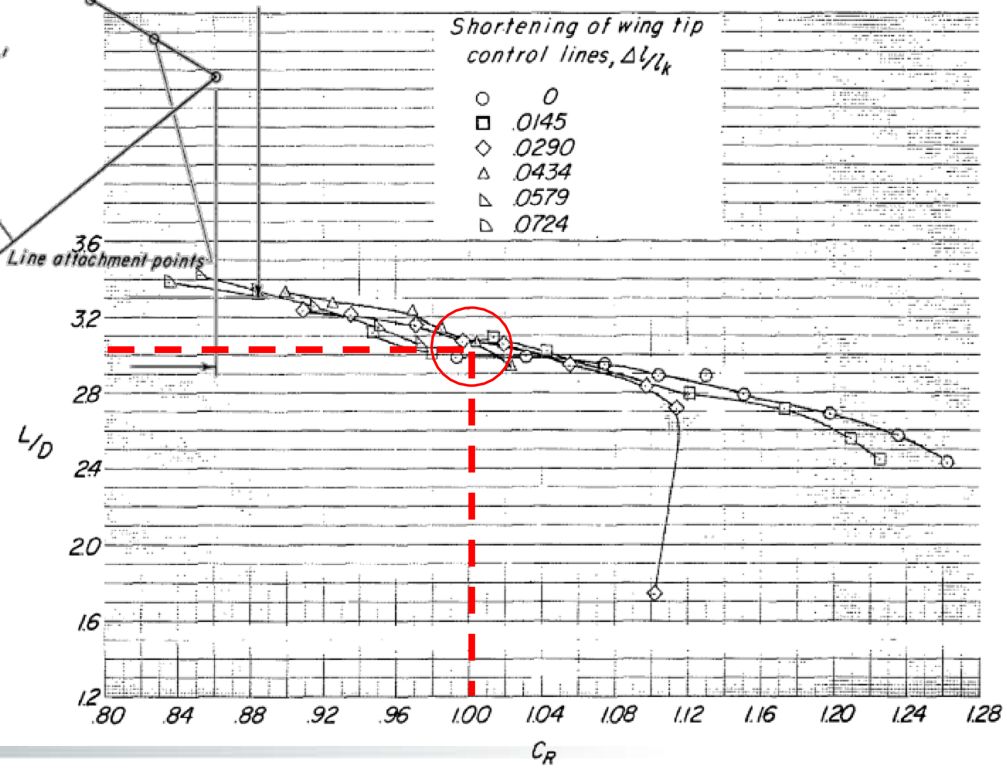
3kg to 3km

- Reference case selected to study the architecture viability and to size the parawing
  - *Chose an appropriately stressing case, landing at high altitude with a meaningful payload mass*
  - *Once reference case is established, one is free to trade altitude for mass, or altitude for glide time, or probe size for mass, or size for altitude, and so forth*
- A summary of what variability is considered in showing that parachute deployment is subsonic
  - *Entry conditions*
  - *Drag coefficient*
  - *Atmospheric conditions (density throughout entry, speed of sound at chute deploy, wind at chute deploy)*
  - *Parachute triggering uncertainty, resulting in a 3km deployment altitude range*
- Based on the variability considered, the parawing can be deployed high enough to permit landing locations covering a significant portion of the planet

Parawing Sizing

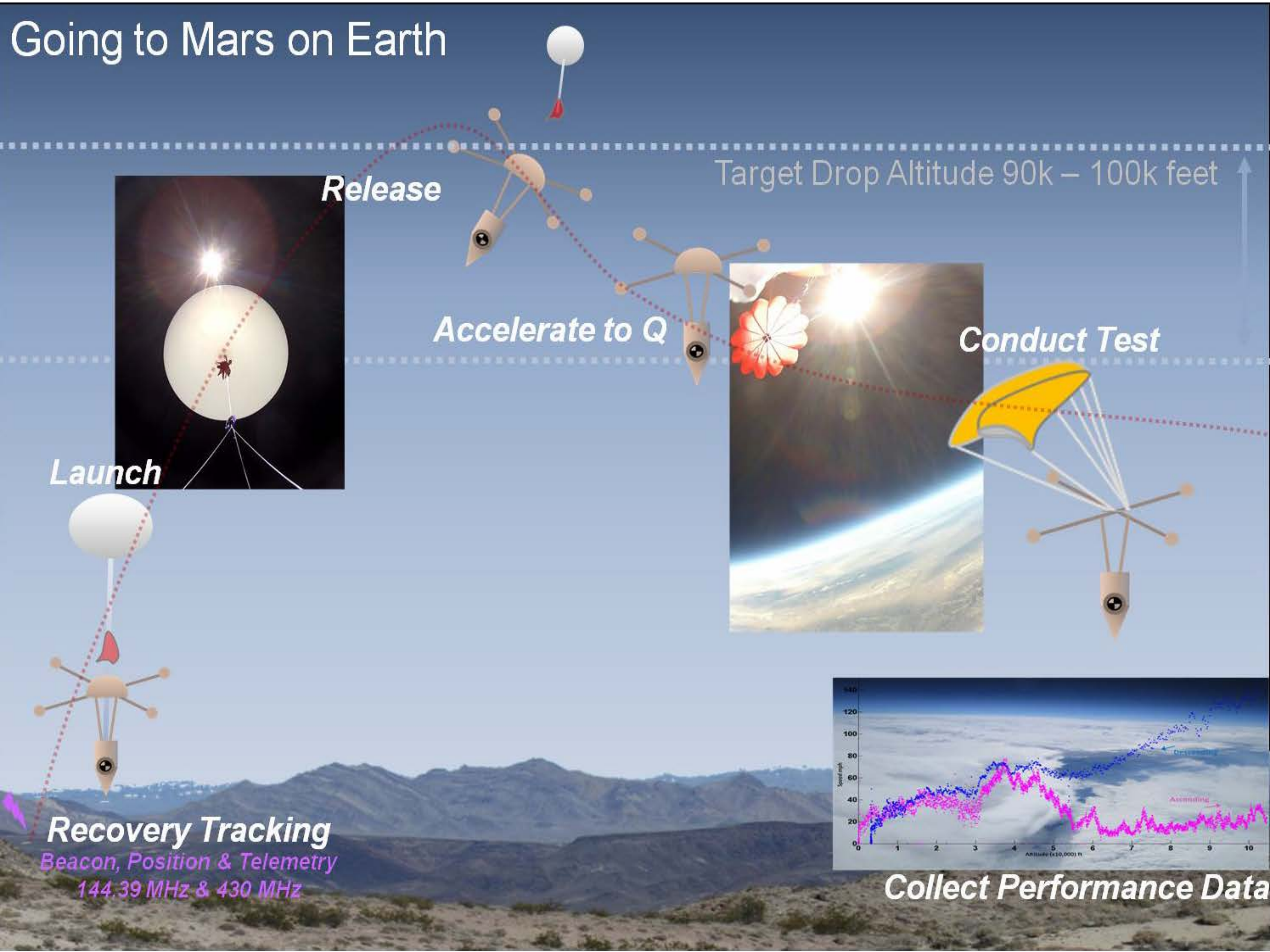
Scaled Version of NASA's Twin-keel Parawing Model 21





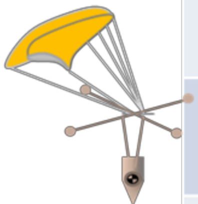
NASA Graph: Technical Note D-5965

- Design Sizing Point
  - L/D = 3, C_R=1.00
  - Produces a 70° Glide Angle


Going to Mars on Earth
Release
Target Drop Altitude 90k – 100k feet
Accelerate to Q
Conduct Test
Launch
Recovery Tracking
Beacon, Position & Telemetry
144.39 MHz & 430 MHz
Collect Performance Data

$MARS_{DROP}$ 2

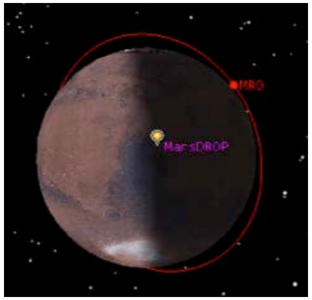
Flight	Test Objective	Setup	Drop Altitude	Chute Deploy V	Chute Deploy Q	Canopy Condition	Test Result
$MARS_{DROP}$ 0 *(May 2013)*	Launch, Tracking, Recovery	Only Flight Computer	104,000	N/A	N/A	N/A	Experimental Setup Checked
$MARS_{DROP}$ 1 *(May 2013)*	Parawing Deployment	Chute Bomb	80,000	-	-	-	Electrical 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



Data Management and Telecom

Data Storage and Margin

- Maximum stored data will be soon after landing (descent camera & geology images)
  - *Full resolution descent video: <2 GB (dominates all data)*
  - *Onboard data storage: 8 GB, storage margin = 300 %*



Command and control:

- Commanding direct-from-Earth is not feasible/required
- Real-time link during entry, descent, and landing is not planned/required
- Data will be continuously collected, stored, and transmitted to Mars orbiter *autonomously*
- Orbiter will also command $\text{Mars}_{\text{DROP}}$ from Earth to request desired data or change ops

Access Times and Data Return:

- Accesses to Mars orbiter (~370-400 km Sun Sync orbit): 3-4 times per sol for ≥10 minutes
- Assume we'll have ~ 8.5 min pass, once per sol: ~1 MB/sol at 16 kbps (TBC)
- Data collected during descent will be stored and transmitted in parts
  - *First, low-resolution (temporal and spatial) video and geological images*
  - *Thereafter high-resolution video and desired regions of geological images can be requested and returned over time (related to availability)*

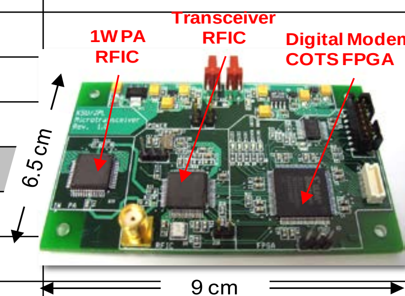
Power Sizing

- PV Ultra-high Junction (UTJ) solar cells all 3 “platters” expected to generate ~10.8 W (average)
- 18650 Li-Ion batteries selected due to high space heritage and energy capacity
- Analysis for maximum eclipse duration (12.5 hrs of 1.02 day sol)
- Batteries will provide required power to heater to keep electronics warmer than -40^{o}C

	PV UTJ Cells	
Mass per Area	84	mg/cm^2
Power per Area	135.3	mW/cm^2
Cell Area	26.63	cm^2
Power per Cell (at 1.54 AU on Mars)	1.5	W
Number of Cells	20	-
Solar Collection Max	30.4	W
Collection Efficiency (Sun Angle, Shadowing)	70.0	%
Average Maximum Power Collected in Sun	21.3	W
Average Power Collected in Sun	10.8	W
Average Required Continuous Power (day)	3.0	W
Average Required Power in Sol	6.0	W
Power Collection Margin (day)	45.1	%
Number 18650 batteries	6	-
Storage Capacity of one 18650 battery	12.0	Whr
Total Energy Capacity	72.0	Whr
Maximum Allowable Depth of Discharge	50.0	%
Average Required Power in Eclipse (2 W heater)	2.0	W
Energy Storage Margin (Night)	188	%

Telecommunication

- Proxy-1 UHF JPL radio to Mars orbiter for two-way communication, 1 W RF, whip antenna with 0 dBi
- Can achieve 16 kbps for uplink for worst-case range (971 km at 20º elevation)



KSU/JPL Proximity Microtransceiver

		MarsDROP to Orbiter (Uplink)	Orbiter to MarsDROP
Mars Small Lander			
1a) Transmitter Power	Watts	1.0	8.0
1b) Transmitter Power	dBm	30.0	39.0
2) Transmitter Circuit Losses	dB	-1.0	-1.0
3) Low Gain Antenna Gain	dBi	0.0	3.0
Link Parameters			
7) Elevation Angle	deg	20.0	20.0
8) Off-Nadir Angle, S/C to Lander	deg	0.0	0.0
9) Slant Range	km	971.0	971.0
10) 1-Way Light Time	msec	3.2	3.2
11) Link Frequency	MHz	401.5	437.1
12) Atmospheric Attenuation	dB	0.0	0.0
13) Space Losses	dB	-144.3	-145.0
Orbiter Receive Parameters			
14) Sky temperature	K	100.0	100.0
15) Polarization Loss	dB	-3.0	-3.0
16) Orbiter Antenna Gain	dBi	3.0	0.0
17) Orbiter Antenna Pointing Loss	dB	-1.0	0.0
Data Channel Performance			
32) Data Bit Rate	bps	16,000	8,000
38) Bit Error Rate		1.0E-06	1.0E-06
39) Prox1 Frame Error Rate		1.0E-03	1.0E-03
43) Performance Margin	dB	4.1	13.8

Reference: W. Kuhn et al., "A Microtransceiver for UHF Proximity Links Including Mars Surface-to-Orbit Applications", Proceedings of he IEEE, Vol. 95, No. 10, Oct. 2007.