SSC15-XI-3

MARS DROP

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

**2015 August 13**

**Utah State/AIAA Small Satellite Conference**

**Logan, Utah**

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 A. Paige/University of California-Los Angeles

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NASA

AEROSPACE

Planetary Science Institute

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

*What if we could…?*

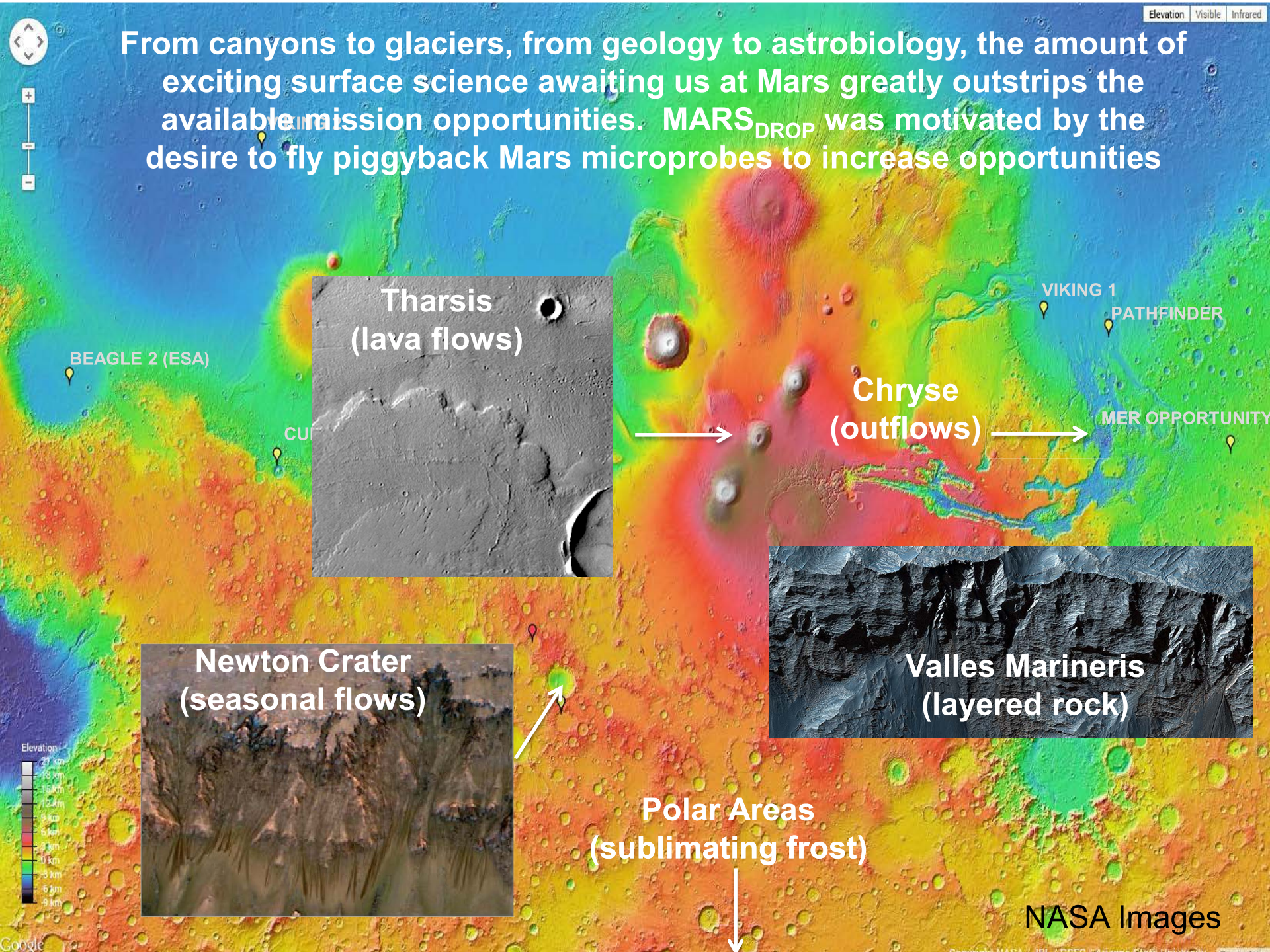
- Utilize excess cruise stage or orbiter mass capability to carry secondary payloads to Mars?
- Make a lander small enough that a few could be carried with most Mars missions?
- Have the ability to target the entry of the lander?
- After entry, have the ability to select among pre-determined high-priority landing points within uncertainty ellipse?
- Steer to landing within 10s of 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.*

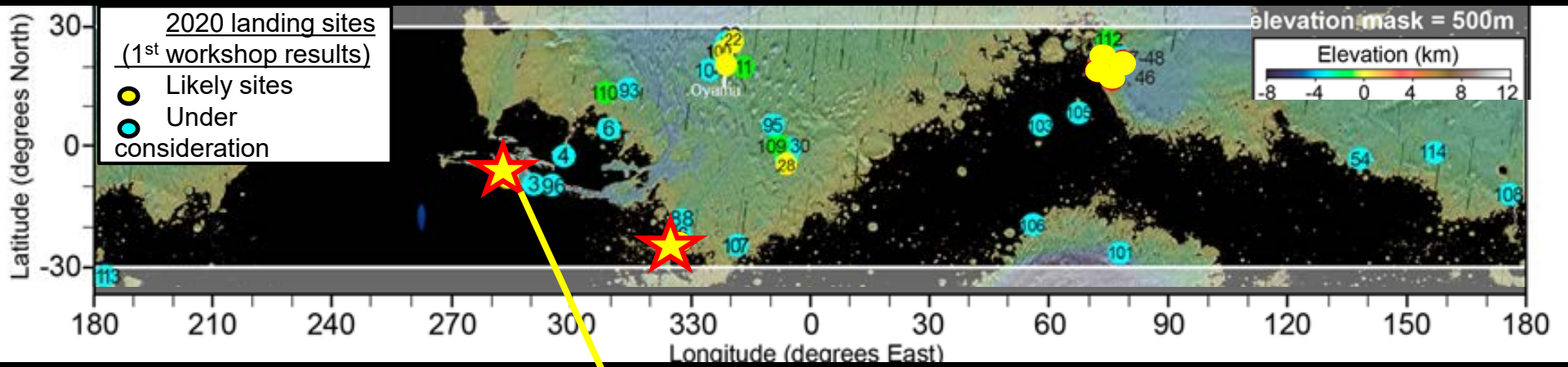
composite simulation, & L. Paul

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

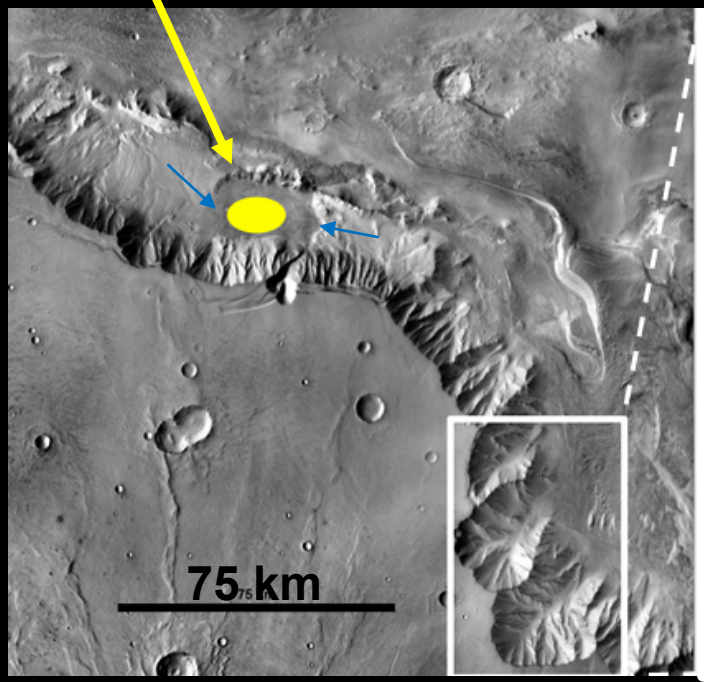
# Equatorial Landing Zone

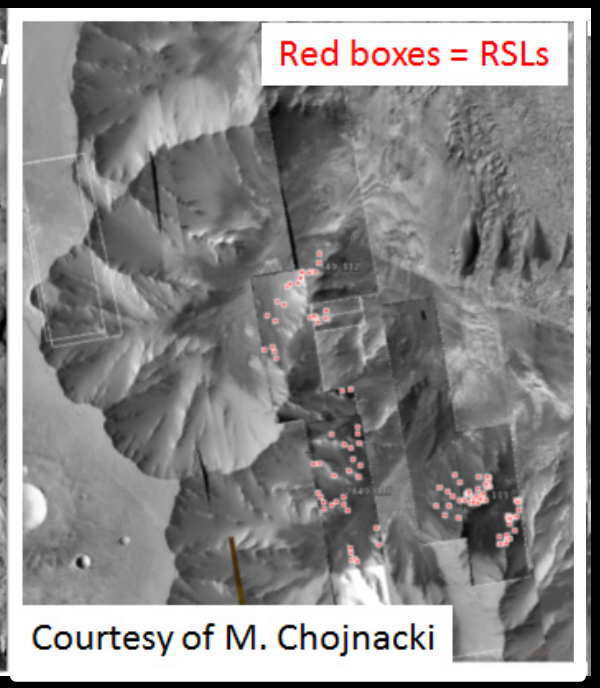



two likely Mars 2020 landing sites near RSL sites

## Example 2: SW Melas

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

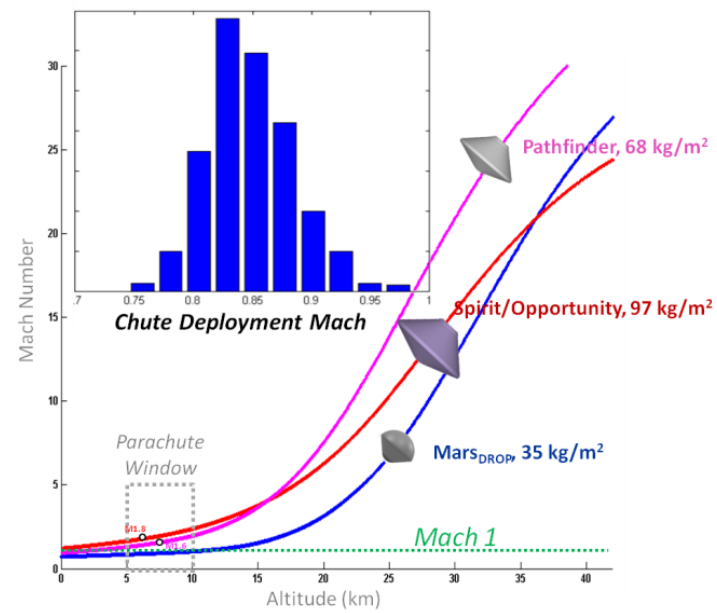


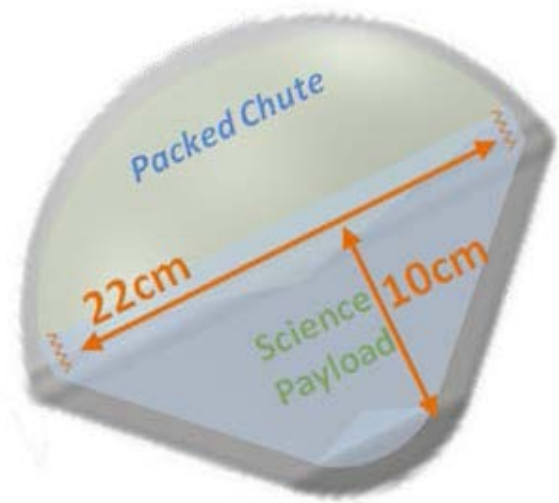




(Williams et al., 2014)

# Capability Summary (conceptual)

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



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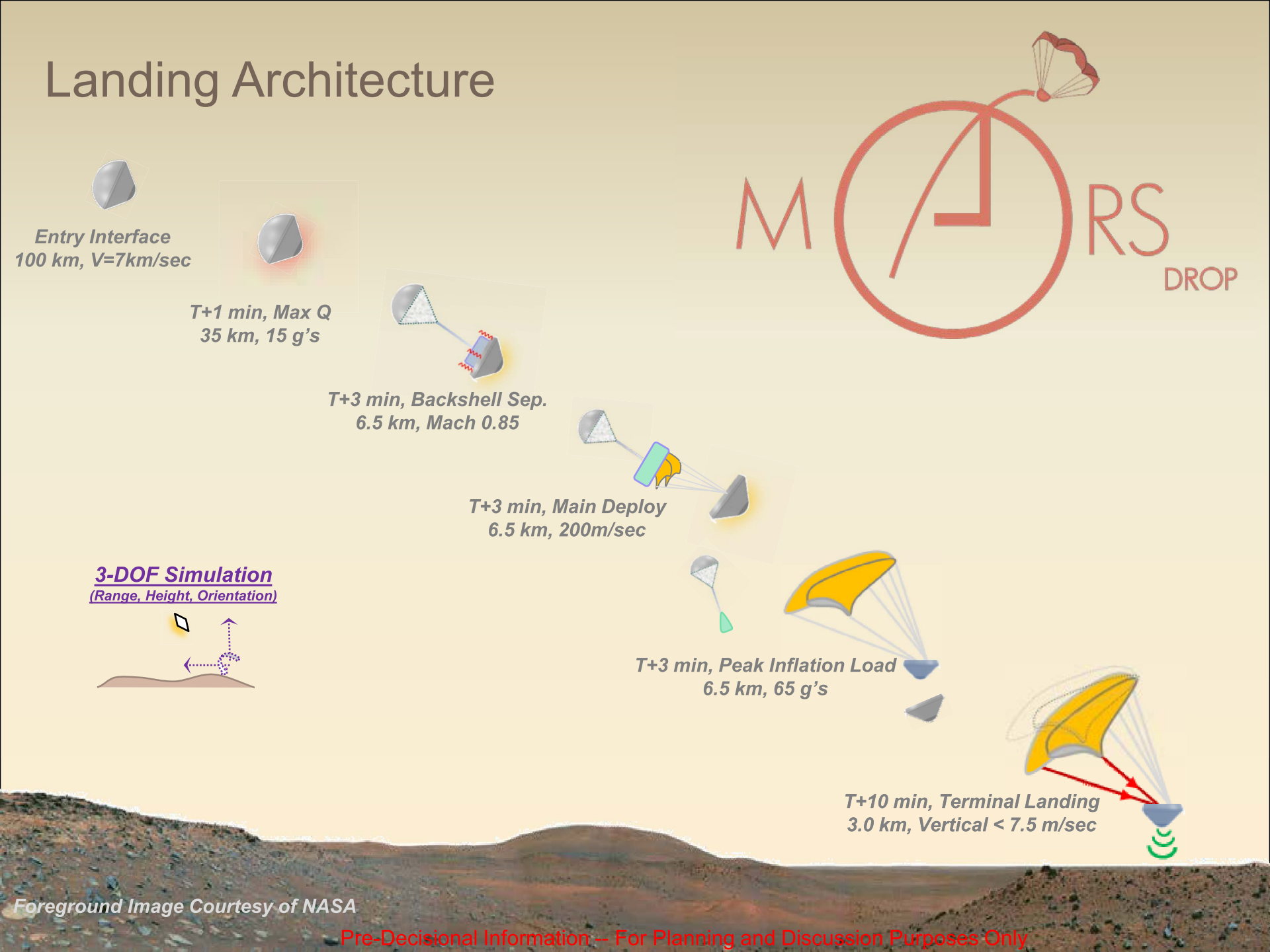
# Landing Architecture

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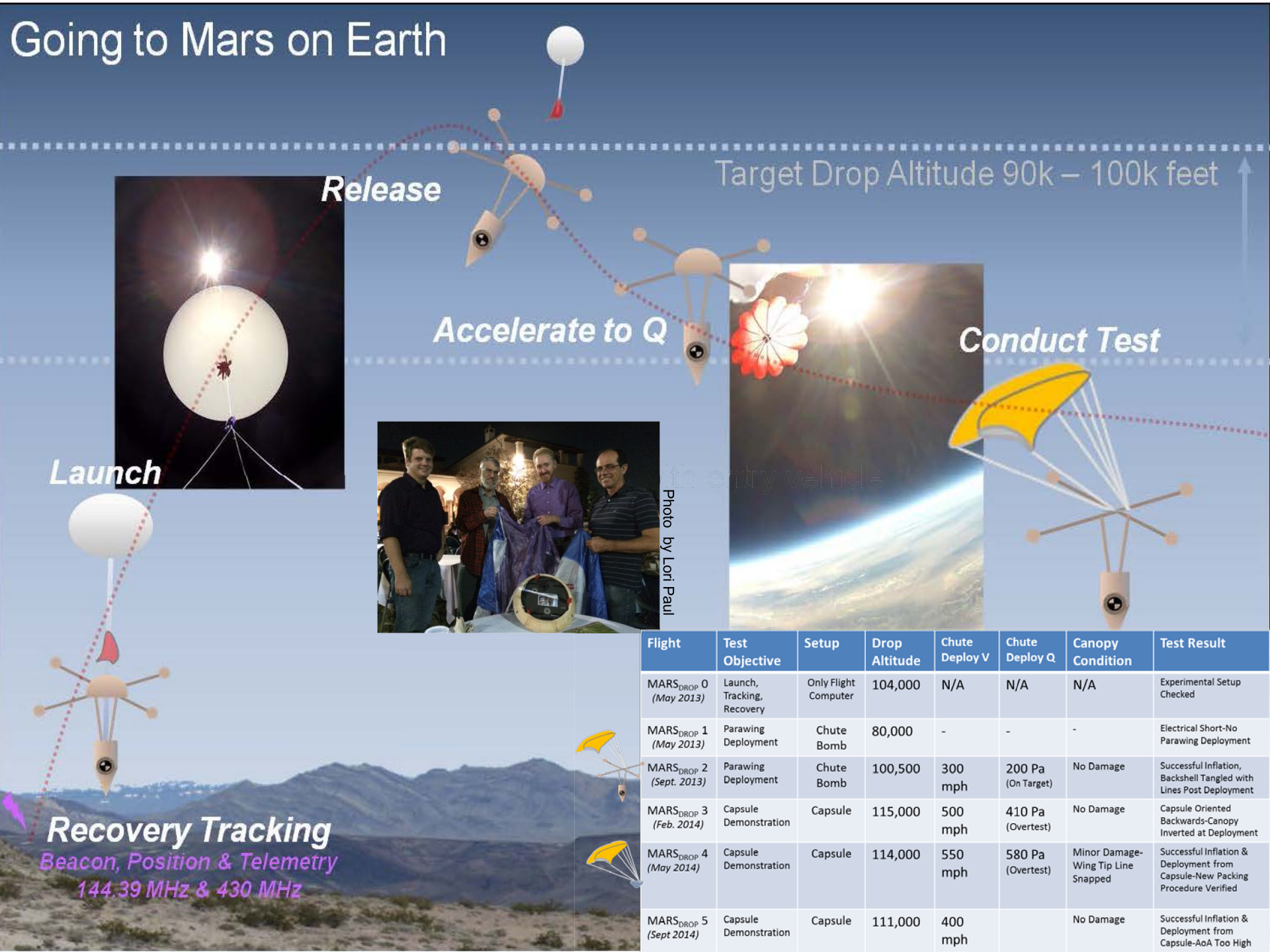
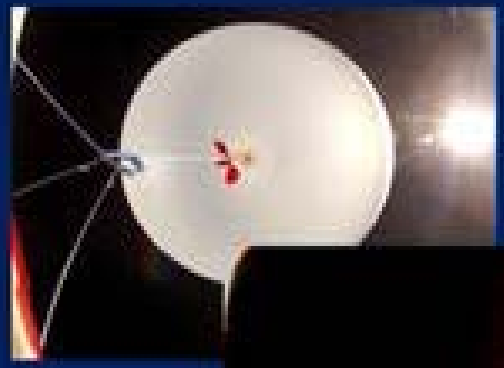
# Going to Mars on Earth

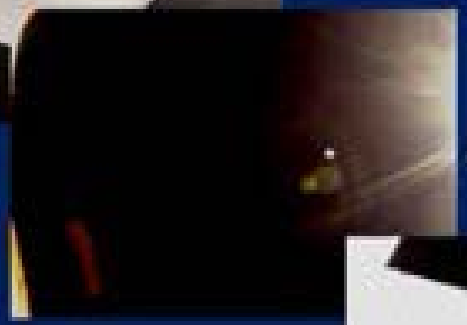



| Flight | Test Objective | Setup | Drop Altitude | Chute Deploy V | Chute Deploy Q | Canopy Condition | Test Result |
|---|---|---|---|---|---|---|---|
| $MARS_{DROP}$ 0 *(May 2013)* | Launch, Tracking, Recovery | Only Flight Computer | 104,000 | N/A | N/A | N/A | Experimental Setup Checked |
| $MARS_{DROP}$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

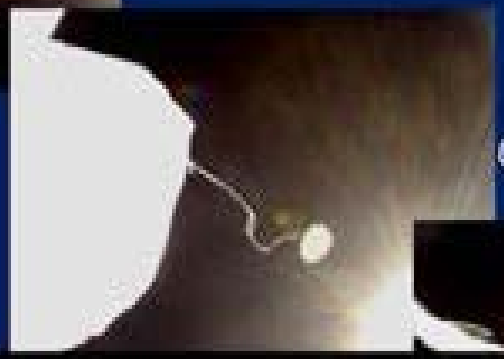
# Parawing Deployment Test Sequence



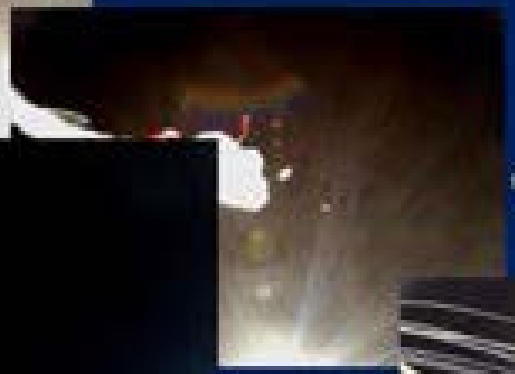
100,501 feet, -40°C



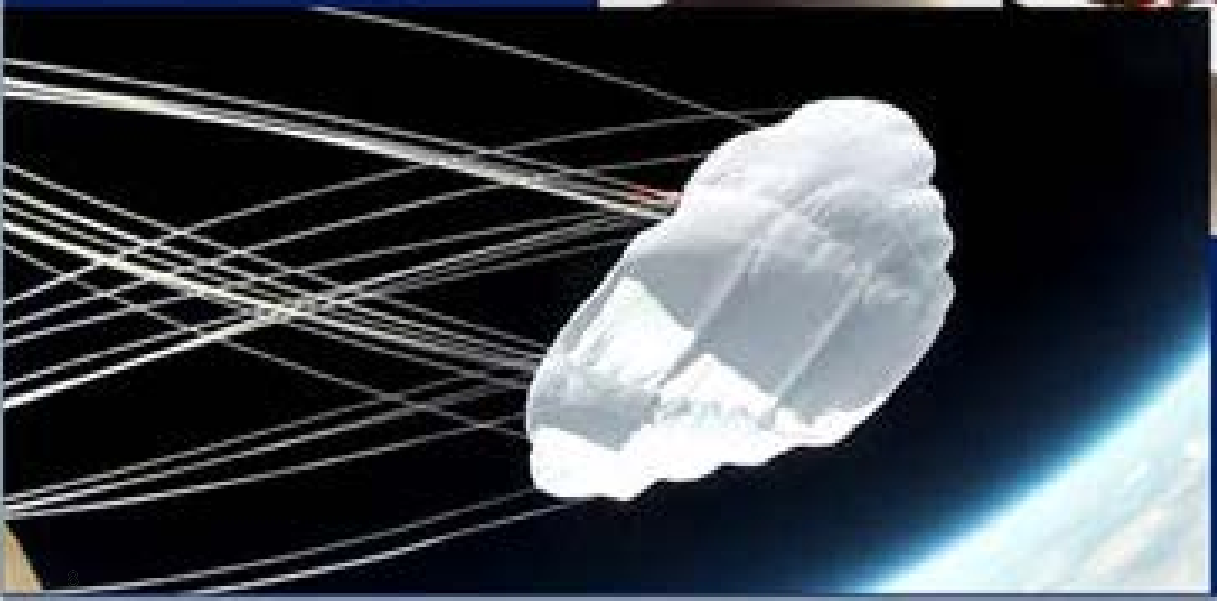
Balloon Release & Freefall

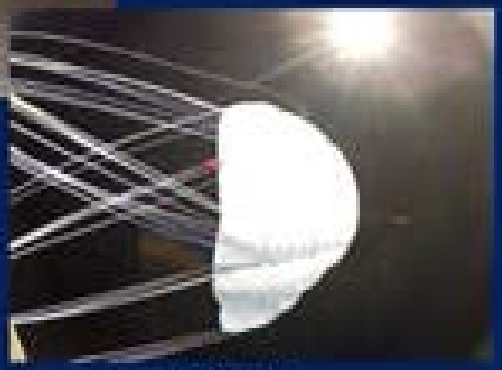


Cover Jettison, 300 mph, 200Pa

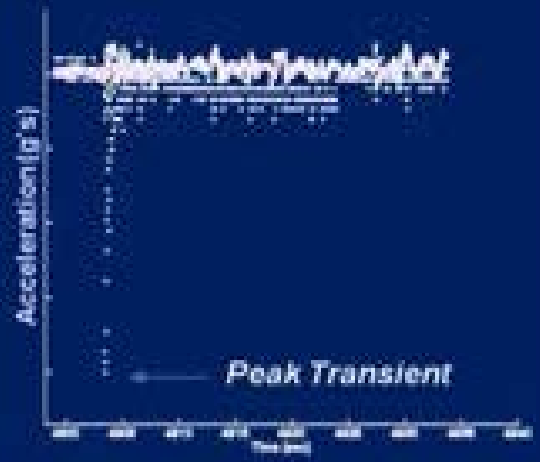


Chute Extension





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.<br>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 |



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# 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 |



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# 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 |



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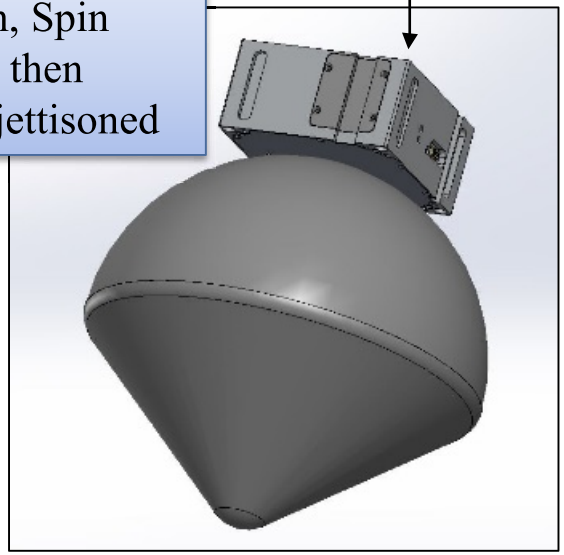
# Phases & Configuration (conceptual)

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

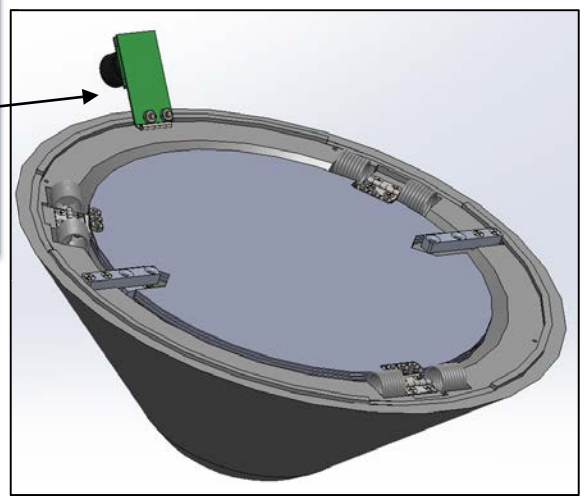


1) **Deployment:** *Backpack Unit* is 0.5 U XACT BCT (includes batteries) module to sense & control attitude, then impart spin (~2 rpm) required for stability through entry; jettisoned at entry interface

**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)

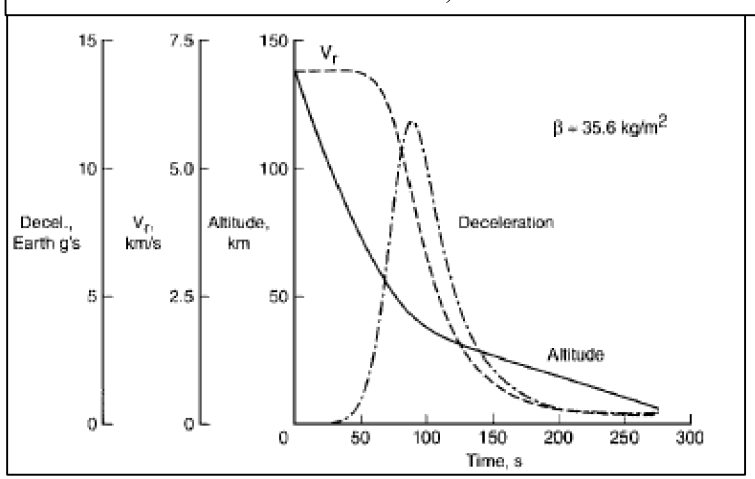



Figure reference: R. Braun et al., "Mars Microprobe Entry-to-Impact Analysis", JSR, 1999.

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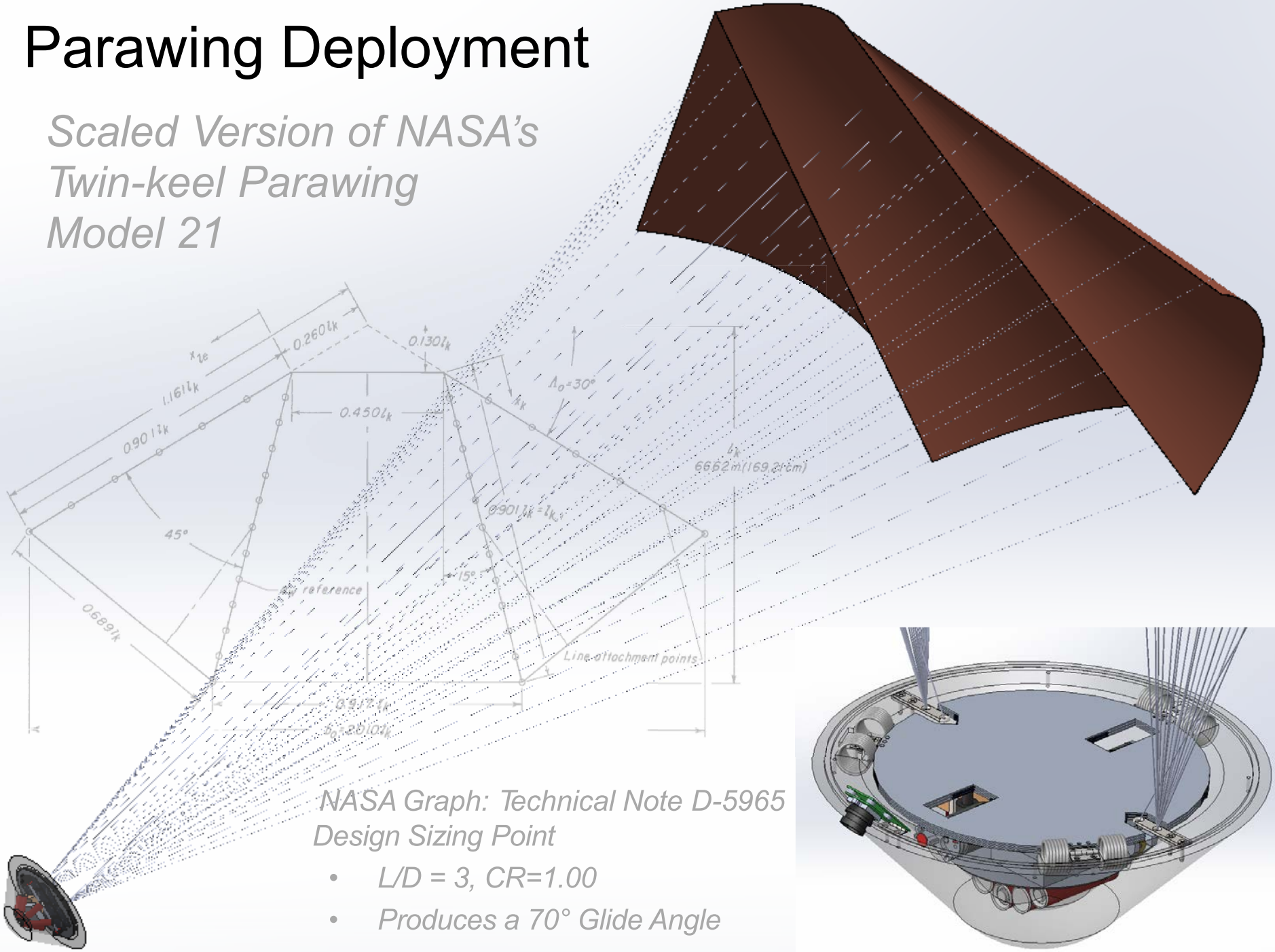
# Parawing Deployment

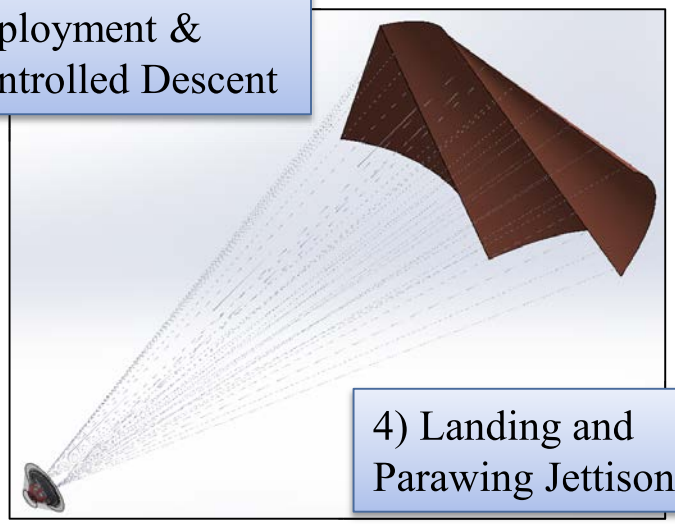
*Scaled Version of NASA's Twin-keel Parawing Model 21*

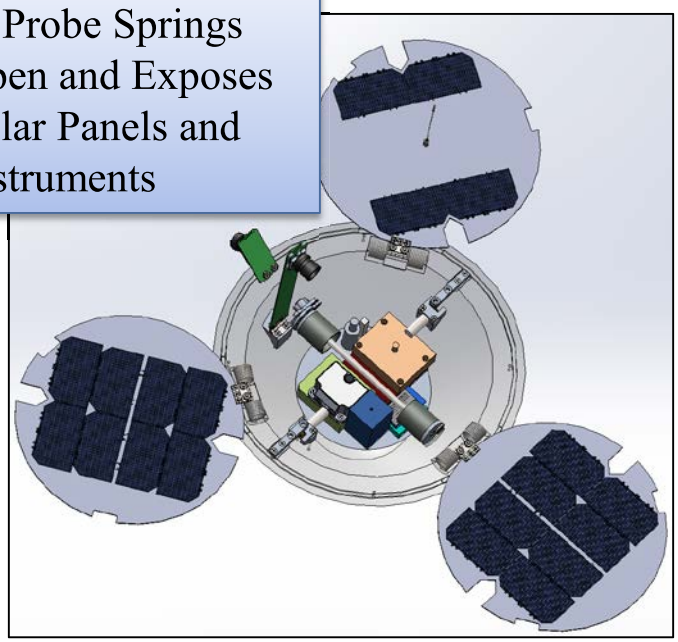



*NASA Graph: Technical Note D-5965*
*Design Sizing Point*

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

# Phases & Configuration (conceptual)




**3) Parawing 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.

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# Configuration Overview

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

UHF Antenna

Descent / Nav Camera

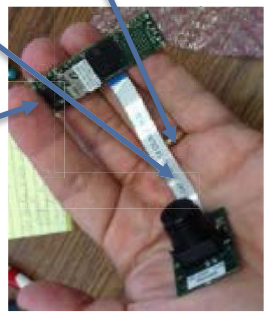
Science Camera

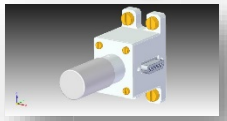
Humidity Sensor

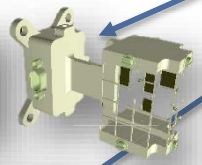
Air Temperature Sensor

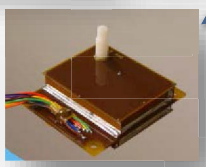
Pressure Sensor

Gumstix Processor



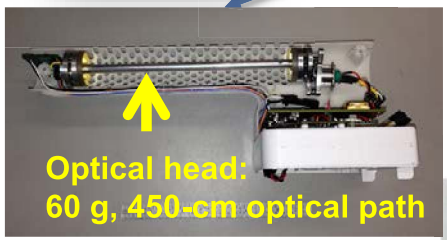






TLS Methane Detector

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



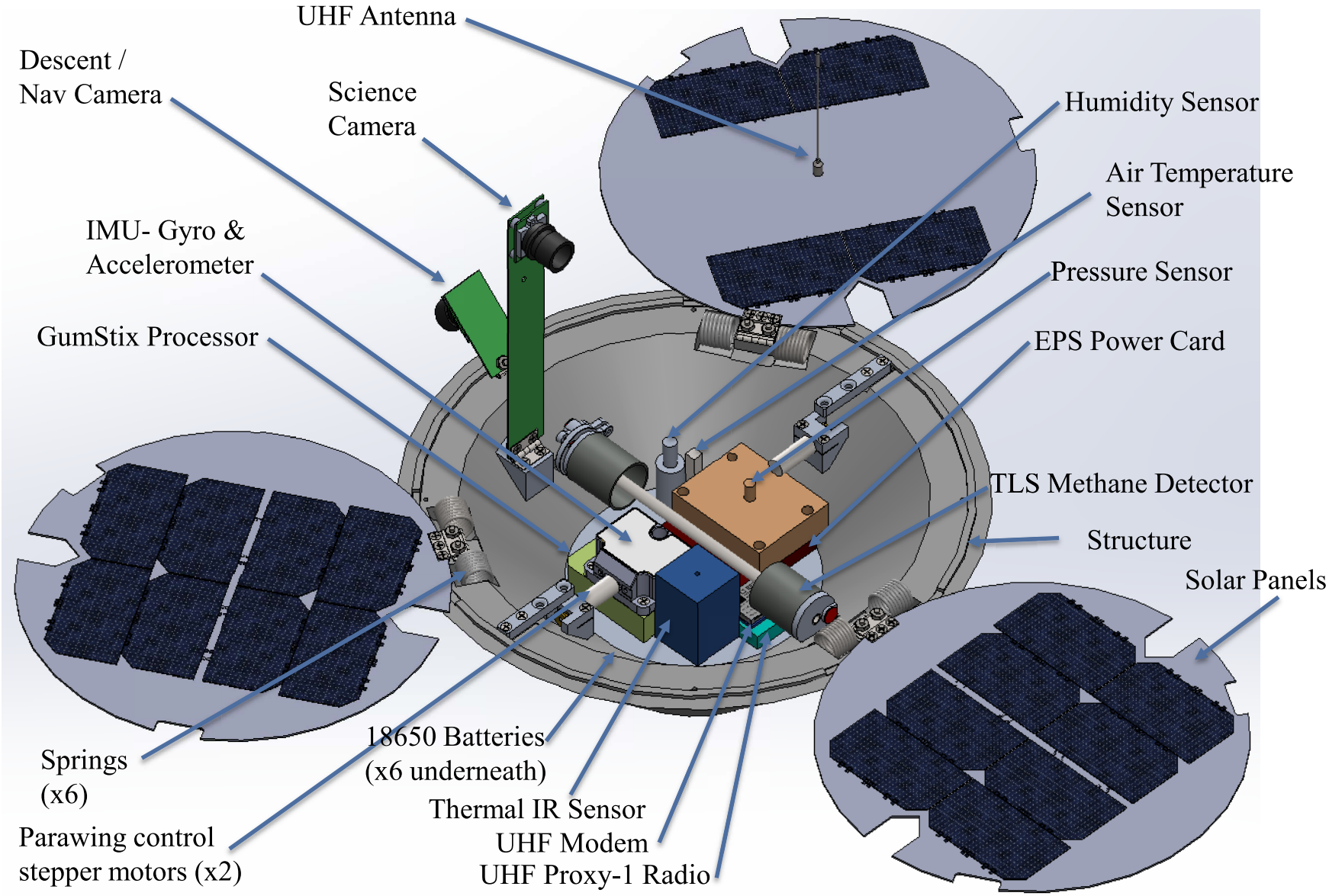

Solar Panels (x3)

18650 Batteries (x6 underneath)

UHF Modem
UHF Proxy-1 Radio

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

# Configuration Overview

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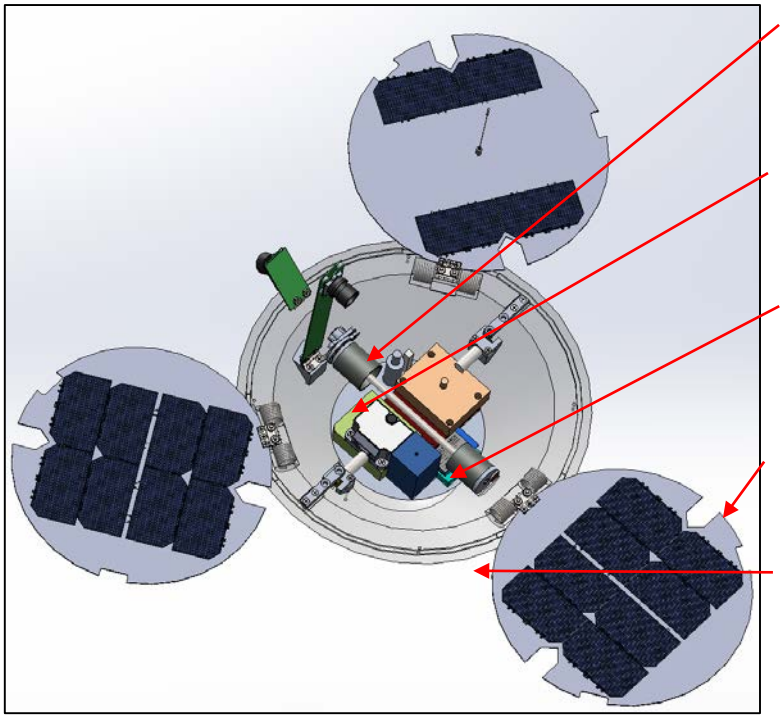
# System Overview

- 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.

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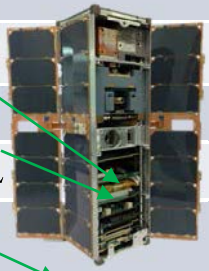
# Master Equipment List

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).

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# 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 (1/4$^{th}$ 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]


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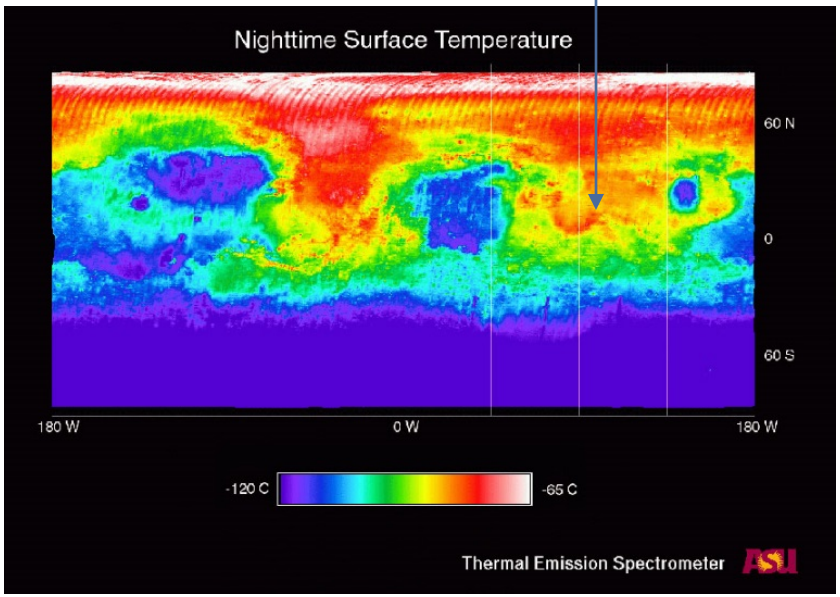
# Thermal

- Driving thermal requirement is during night to maintain:
  - *TLS (methane detector) > -60° C (survival)*
  - *18650 Batteries > -40° C (operational as require energy during night)*
- Mars surface temperatures drop to -120 C in expected landing zone (-/-30° 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 (-100°C)
  - Surface conduction loss to surface (-120°C)
  - Design includes 2 W heater (require ~1.2 W)
  - Thermal equilibrium at +17° C
    - *20% margin on -40° C requirement, margin computed based on °K*

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# 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 |

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# *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).

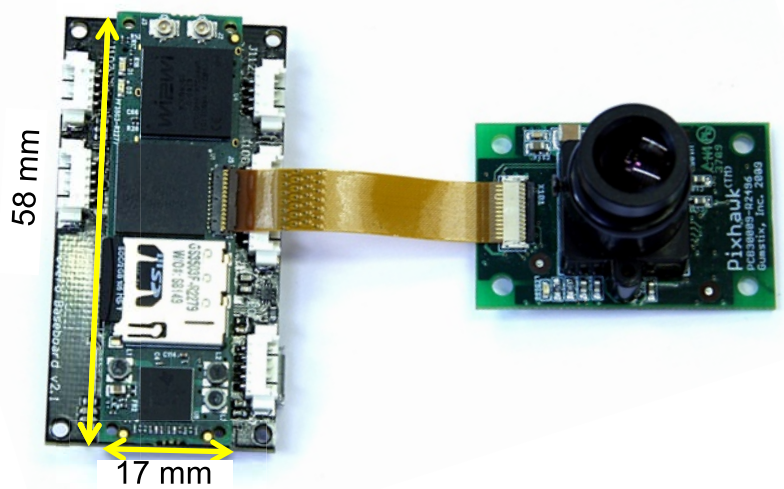



image source: https://pixhawk.ethz.ch/electronics/camera

| 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.

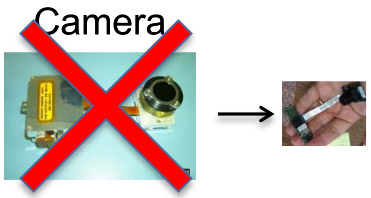
# Synergy with Mars Lander Vision System (LVS)

## State Estimation

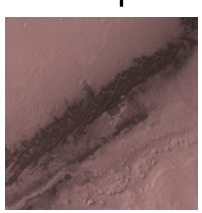
**Fuse inertial measurements from IMU with landmarks from 1024x1024 images and complete in 10 seconds**

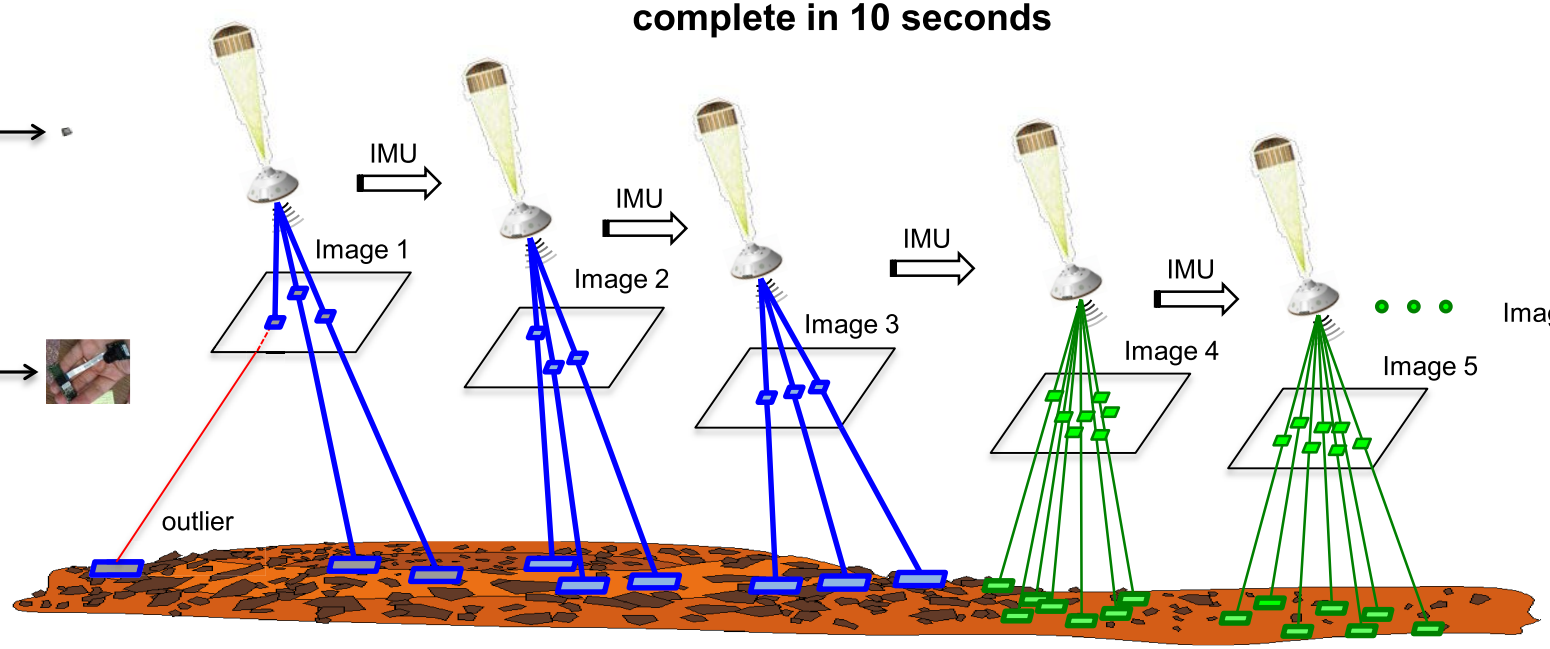
Inertial Measurement Unit (IMU)

Camera



Map






**Coarse Landmark Matching**

**Remove Position Error (3km 3-σ)**

**Fine Landmark Matching**

**Improve Accuracy (40m 3-σ)**



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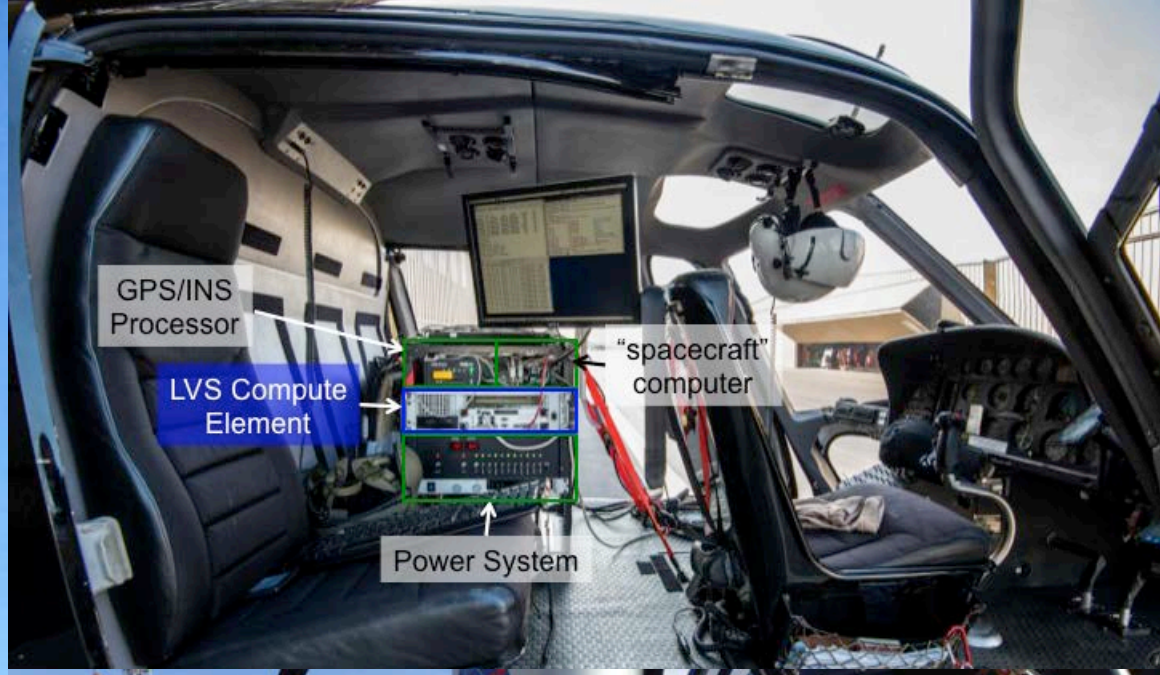
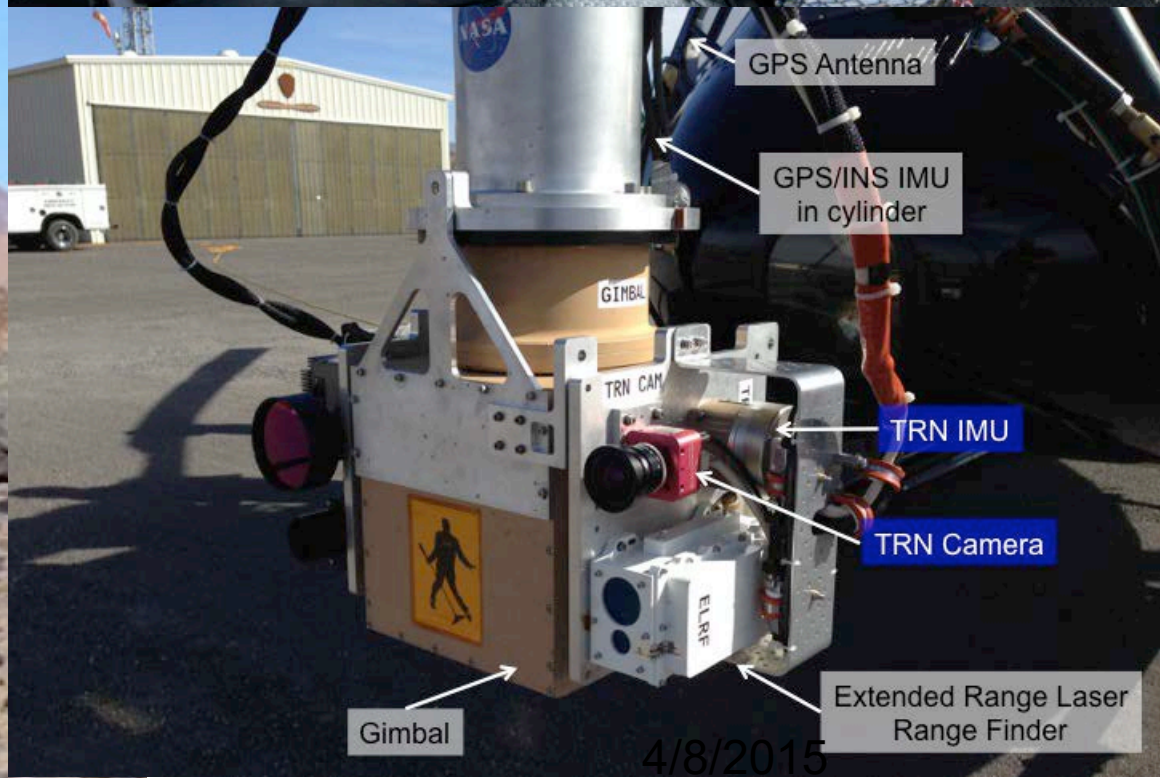
- LVS prototype tested over Mars-analog terrains in Feb/March 2014

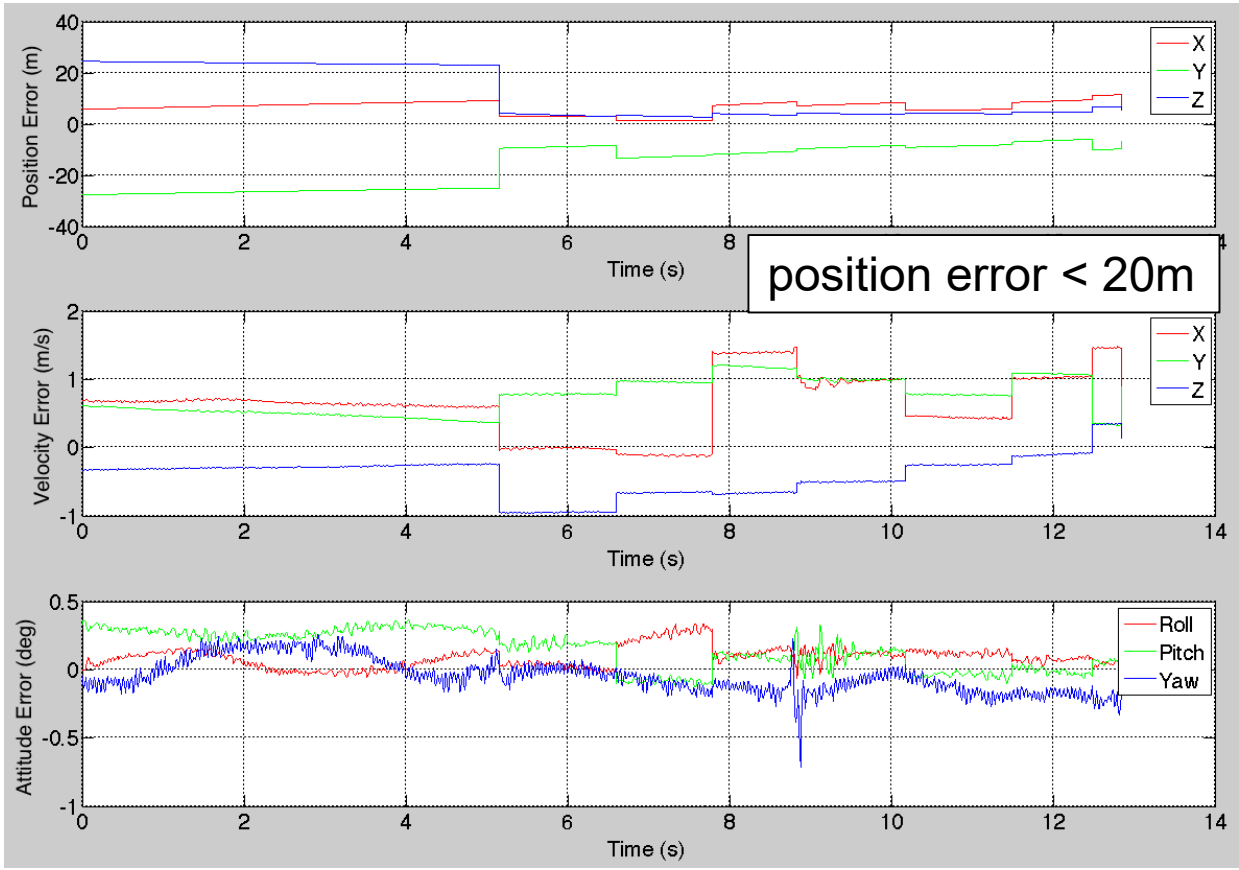
- Test collected data to validate technology over a wide operational envelop defined by expected M2020 conditions
- LVS meets position accuracy and robustness requirements
- Field test demonstrated maturity of the algorithms

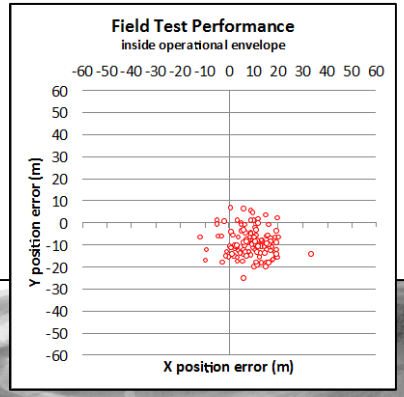


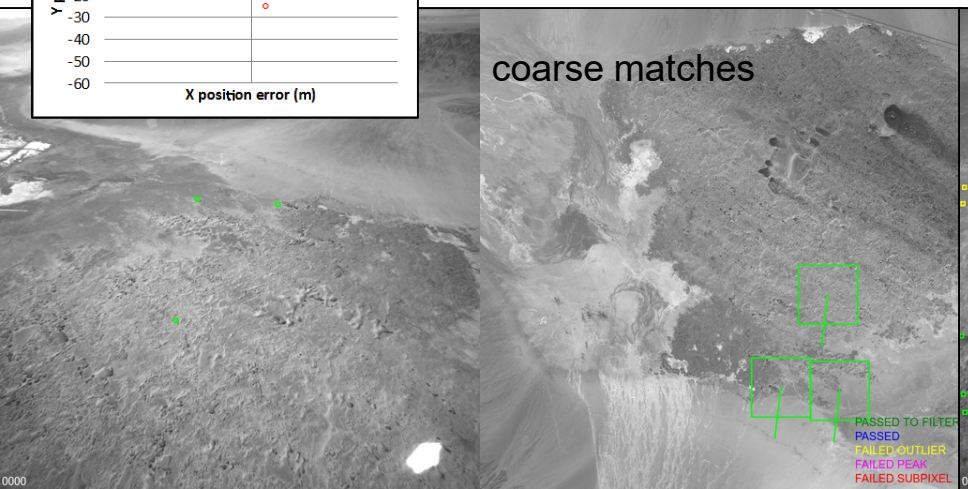



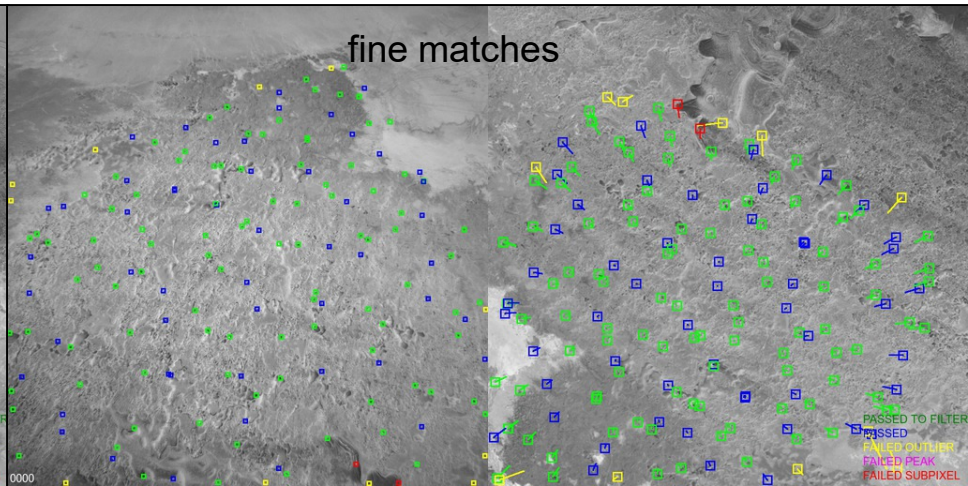
# LVS Helicopter Test March 2014

- 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

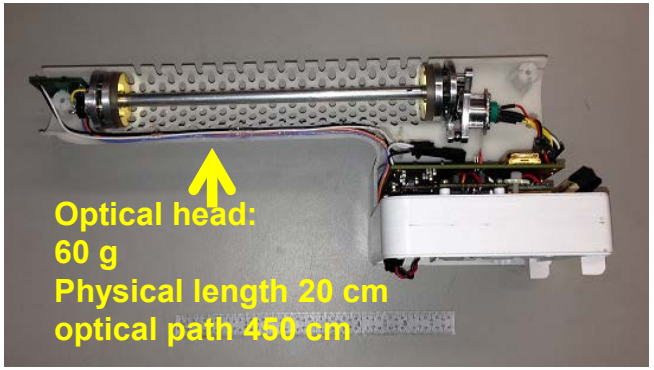


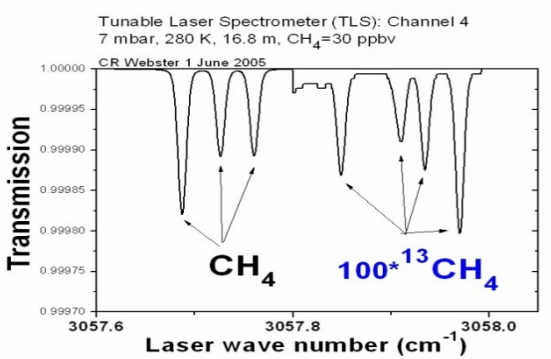
*Example Instrument:* Tunable Laser Spectrometer (300 g, 2W for continuous measurement) could measure gases such as Methane ($CH_4$), Water ($H_2O$) and isotope ratios within these gases: D/H, $^{13}C/^{12}C$, $^{18}O/^{17}O/^{16}O$ in a descent (DROP) profile or on-surface sampling.



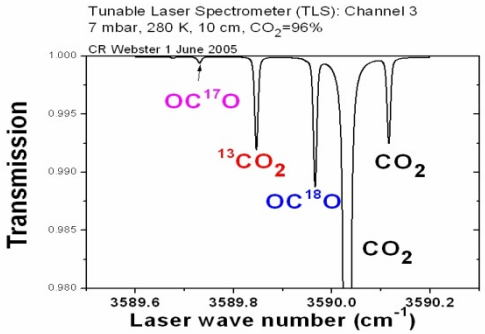

JPL + industry has invested in miniature methane sniffers for public safety and reducing fugitive emissions

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

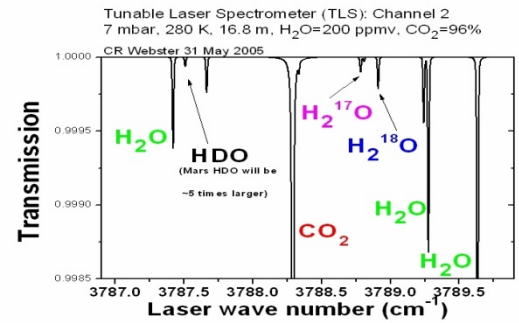
**Capability:**




**Methane Isotope Ratios at 3.27 µm**




**Carbon Dioxide Isotope Ratios at 2.78 µm**




**Water isotope ratios at 2.64 µm**



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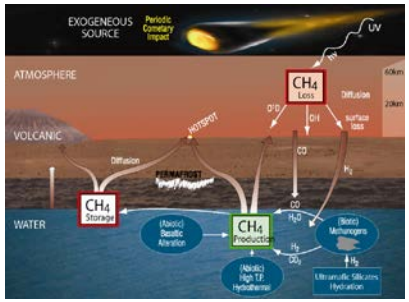
# Methane and Planetary Atmospheric Studies

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

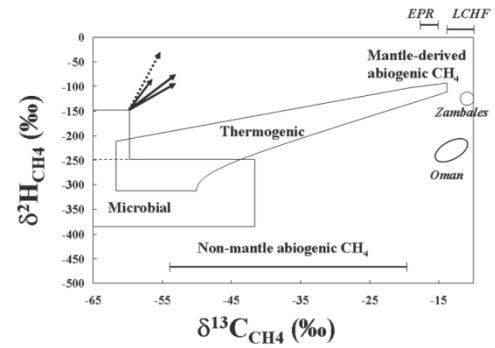
MRO spacecraft

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

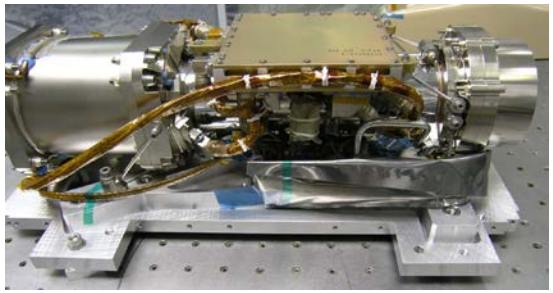



Mars Methane Cycle

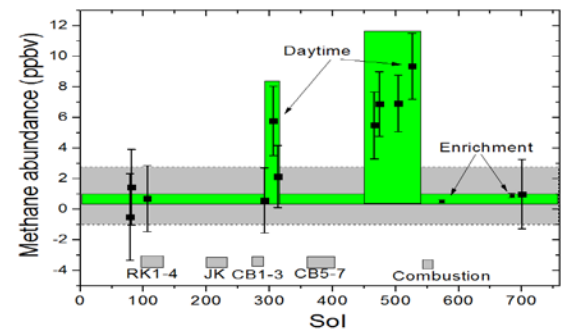
Measurement of isotopic ratio of $^{13}C/^{12}C$ could answer the origin of methane on Mars



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

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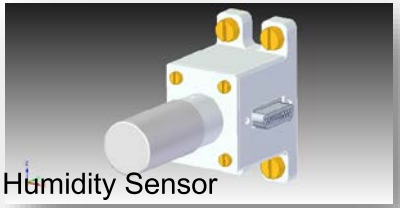
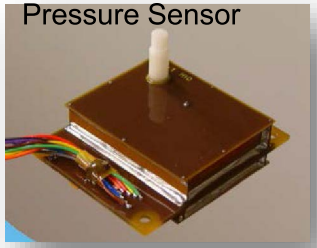
# Example Instrument: suite of meteorological sensors

*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.*

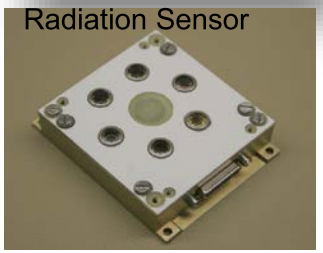
*Most lander missions included environmental monitoring. Those that did not, used other instruments to characterize it.*

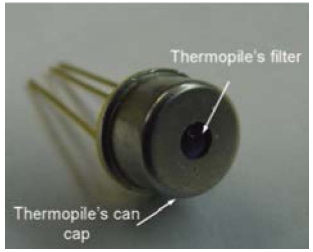
**Temperature, Humidity, pressure cycle near the surface**




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



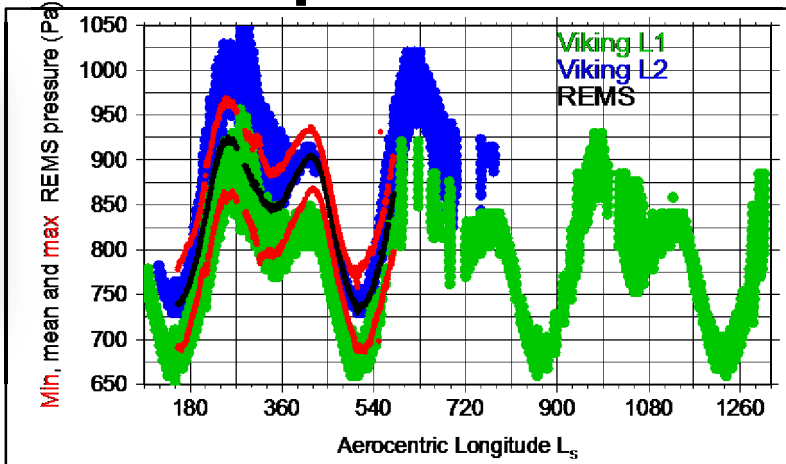




**Ground temperature cycle, for interactions atmosphere-surface**

## Current Status

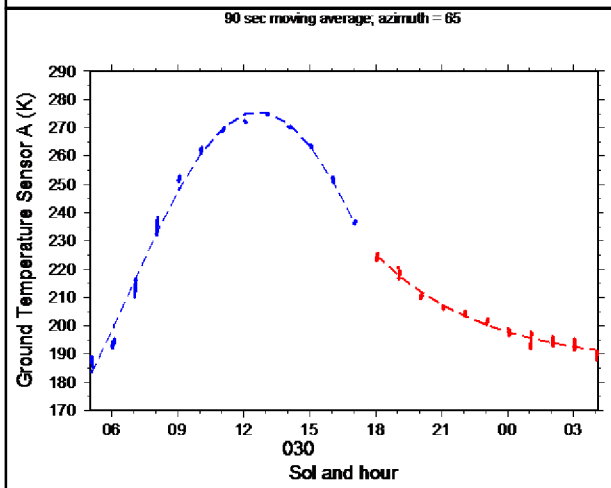
- Tested on Mars (MSL) and adaptable to MarsDrop microlander capabilities.
- MSL – REMS and InSight Twins spares available.
- Mars 2020 – MEDA instrument under development;

## 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



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# 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**

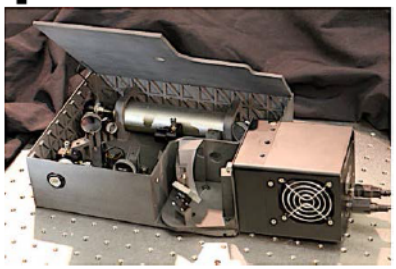
- Enables detection and characterization of a wider range of organics relevant to biosignatures and alteration processes.
- Presently too large for MarsDrop microlander capability.

## 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.

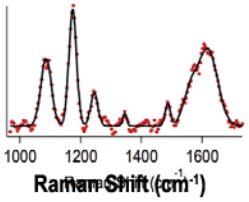


SHERLOC-Mars 2020 Prototype

## Example Data Product

**Macroscopic Image**

**DUV Fluor:** Organic Detection, Classification, & Distribution




Raman Shift (cm$^{-1}$)

**DUV Raman:** Organic analysis & mineralogy



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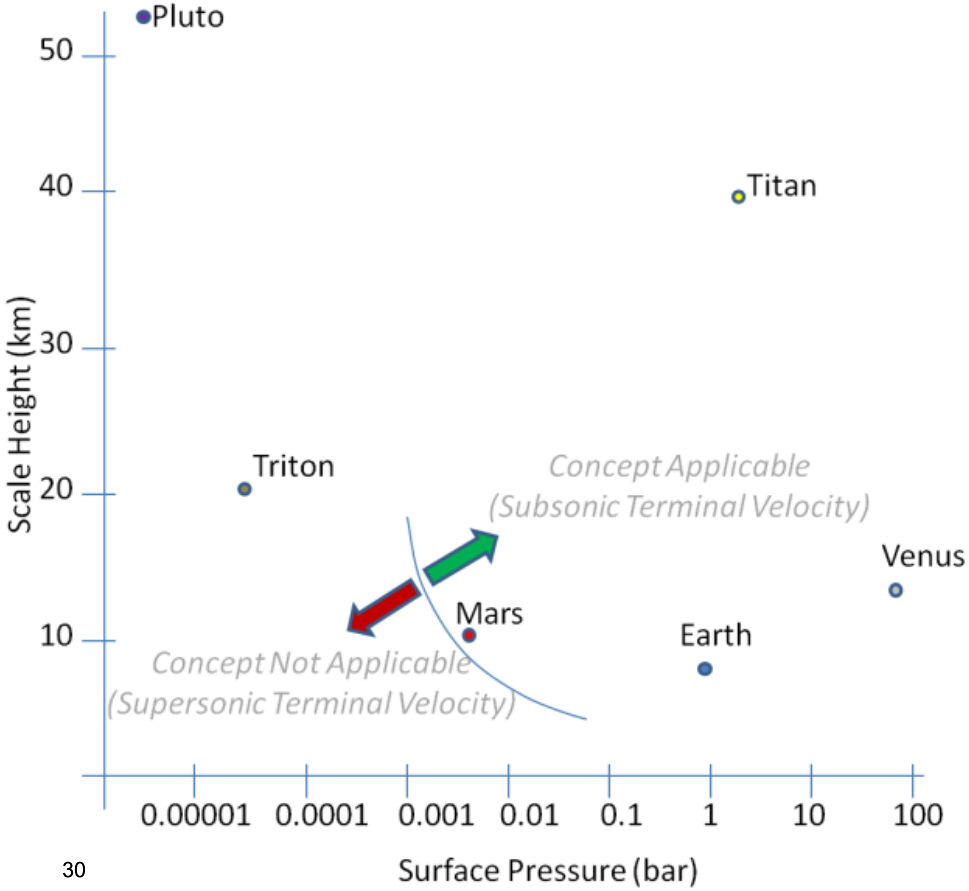
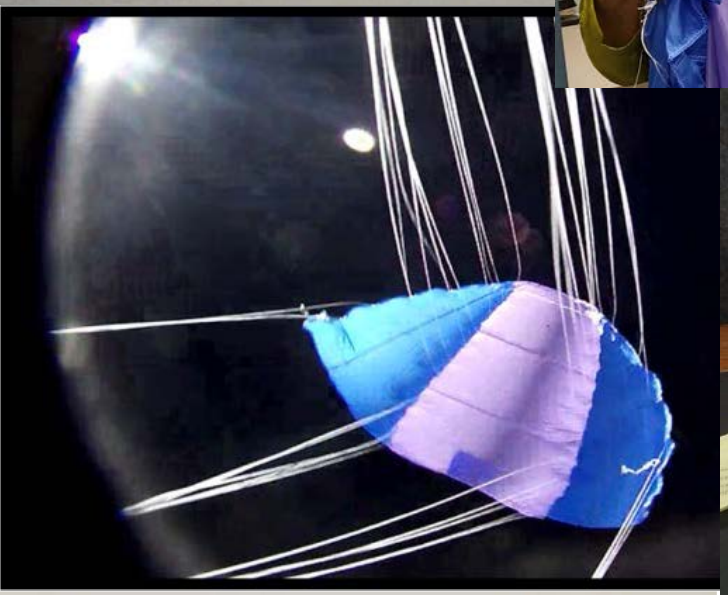
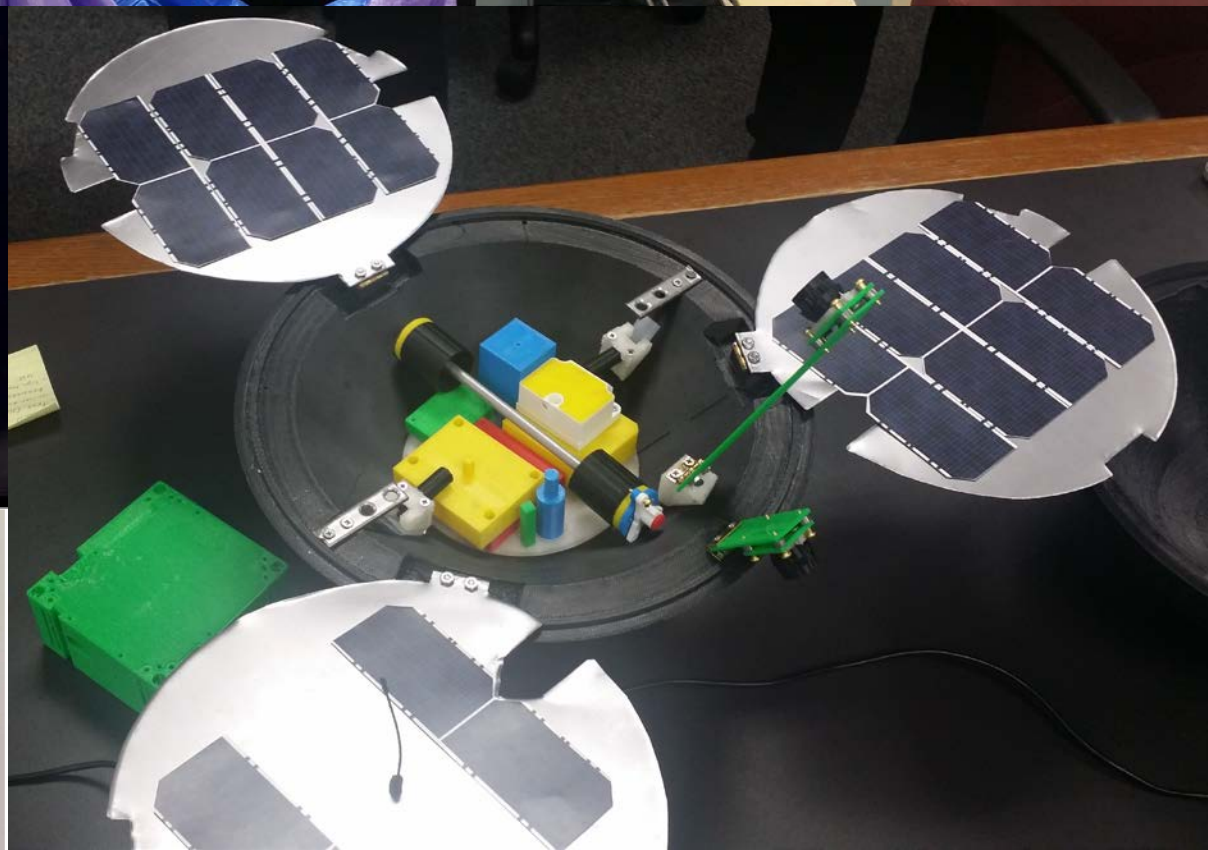
# Beyond Mars

- 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

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 spacecraft.

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

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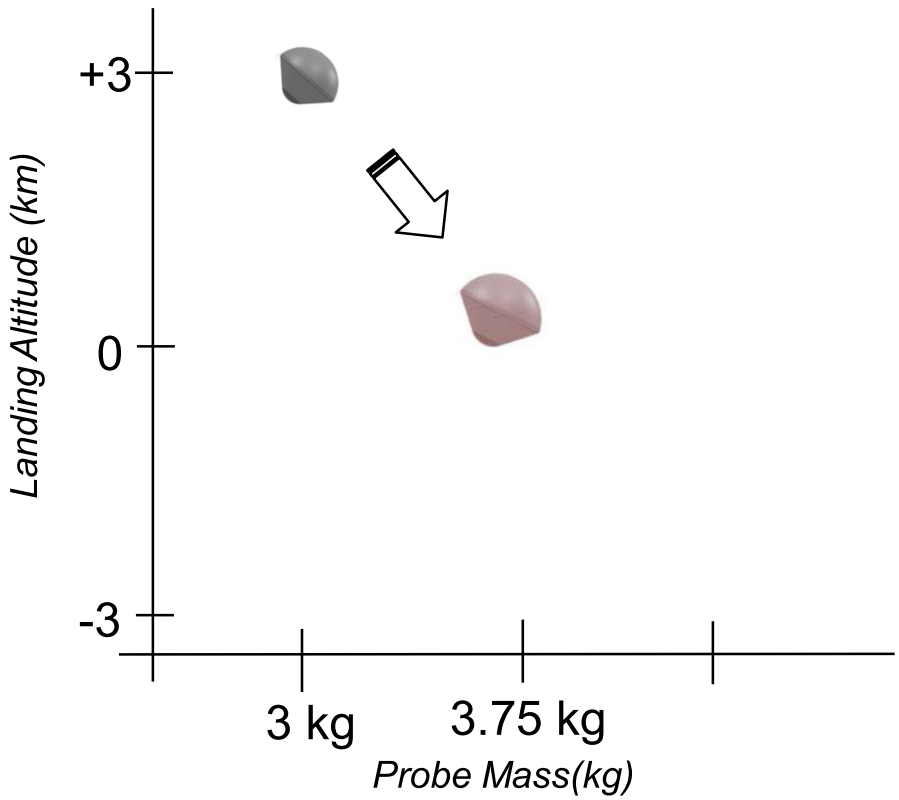
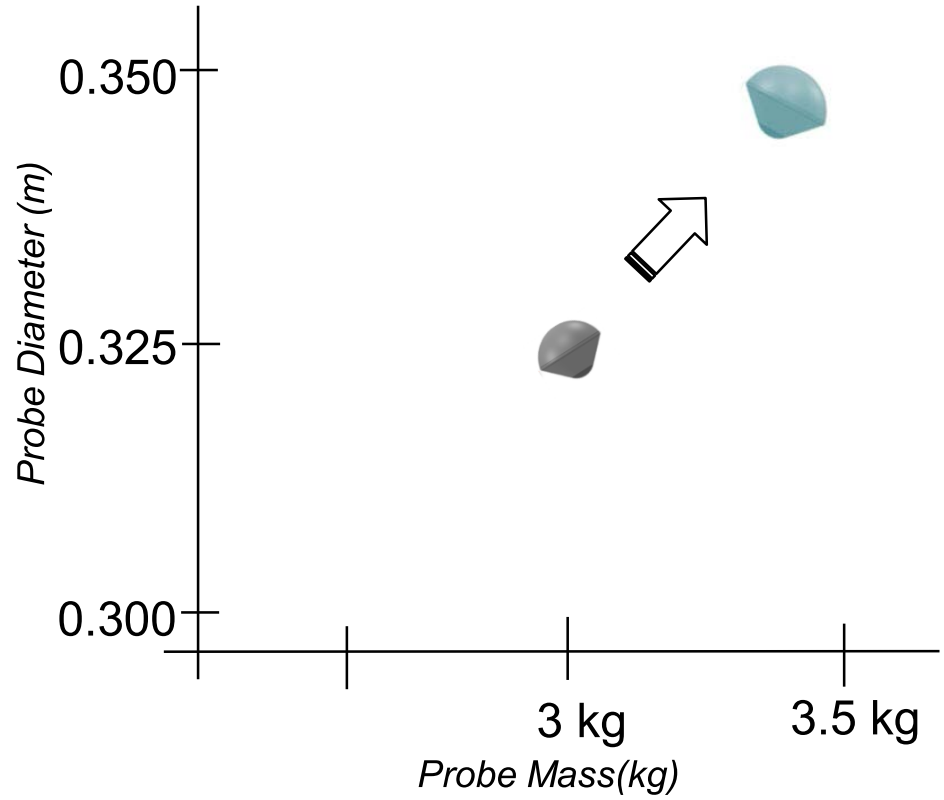
# More Details…

# Mission Trades

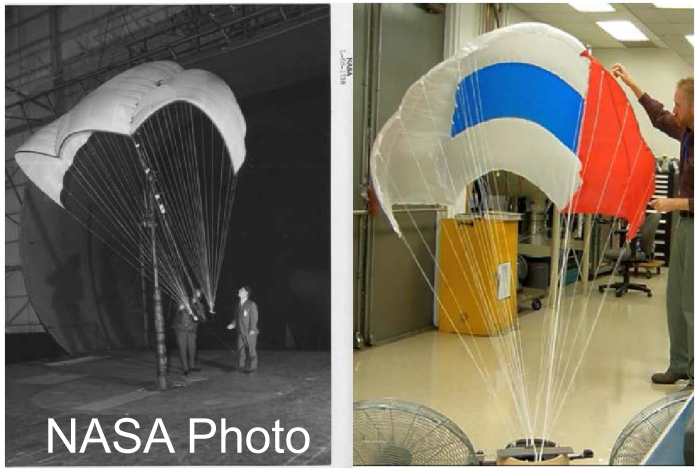
- Small trades, off reference case, can provide meaningful increases in payload mass, with similar EDL performance

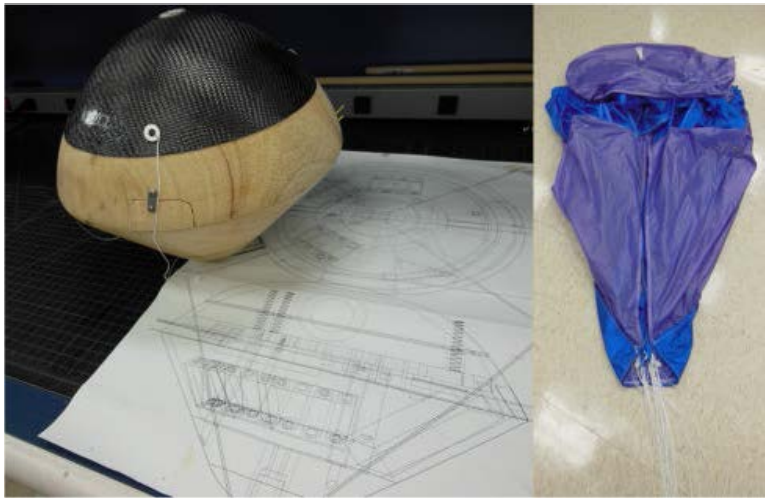


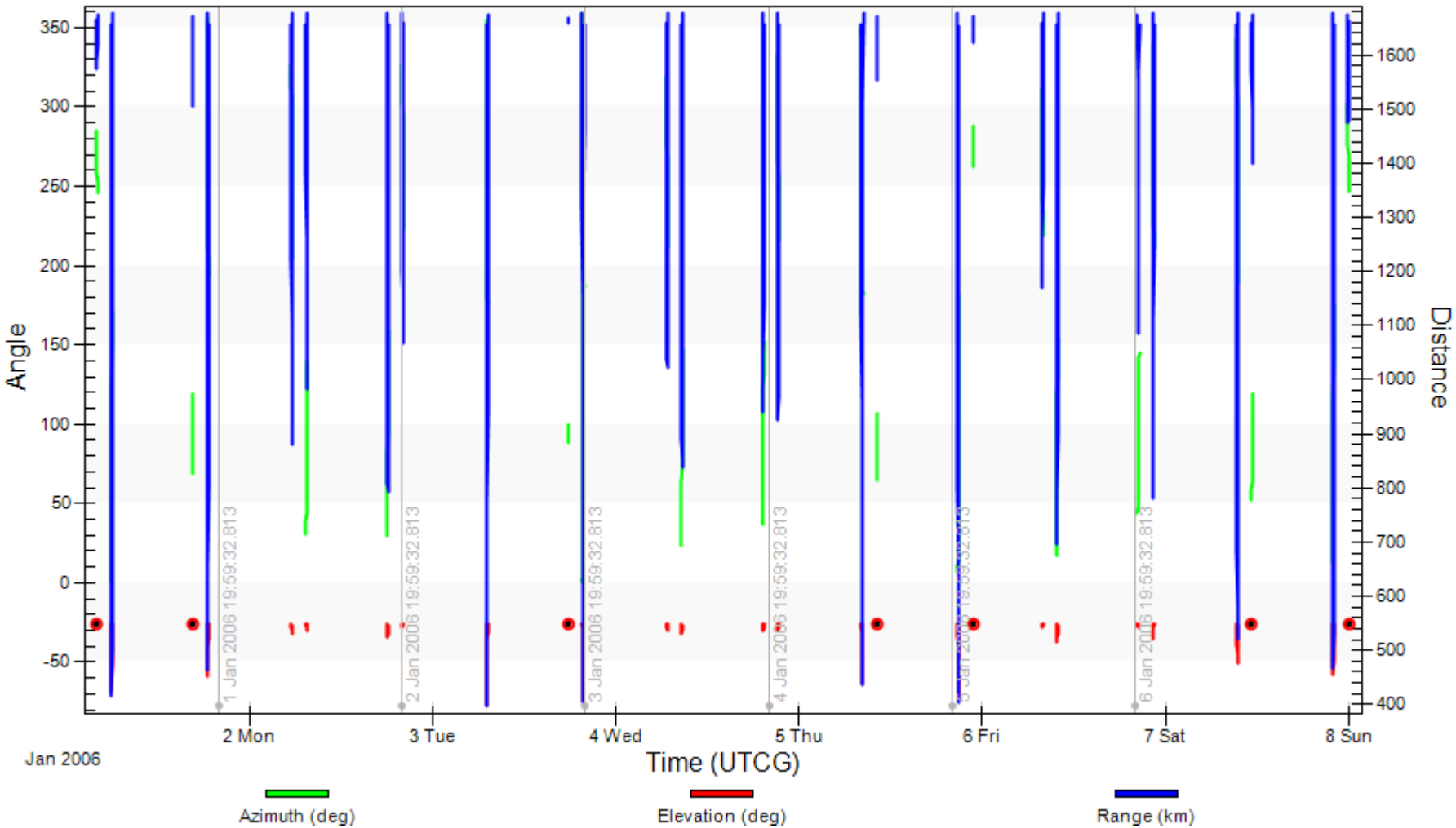
# Aerodynamic Decelerator Optimized for Volume, Scaled Down from a Gemini Parawing Design

| *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 |

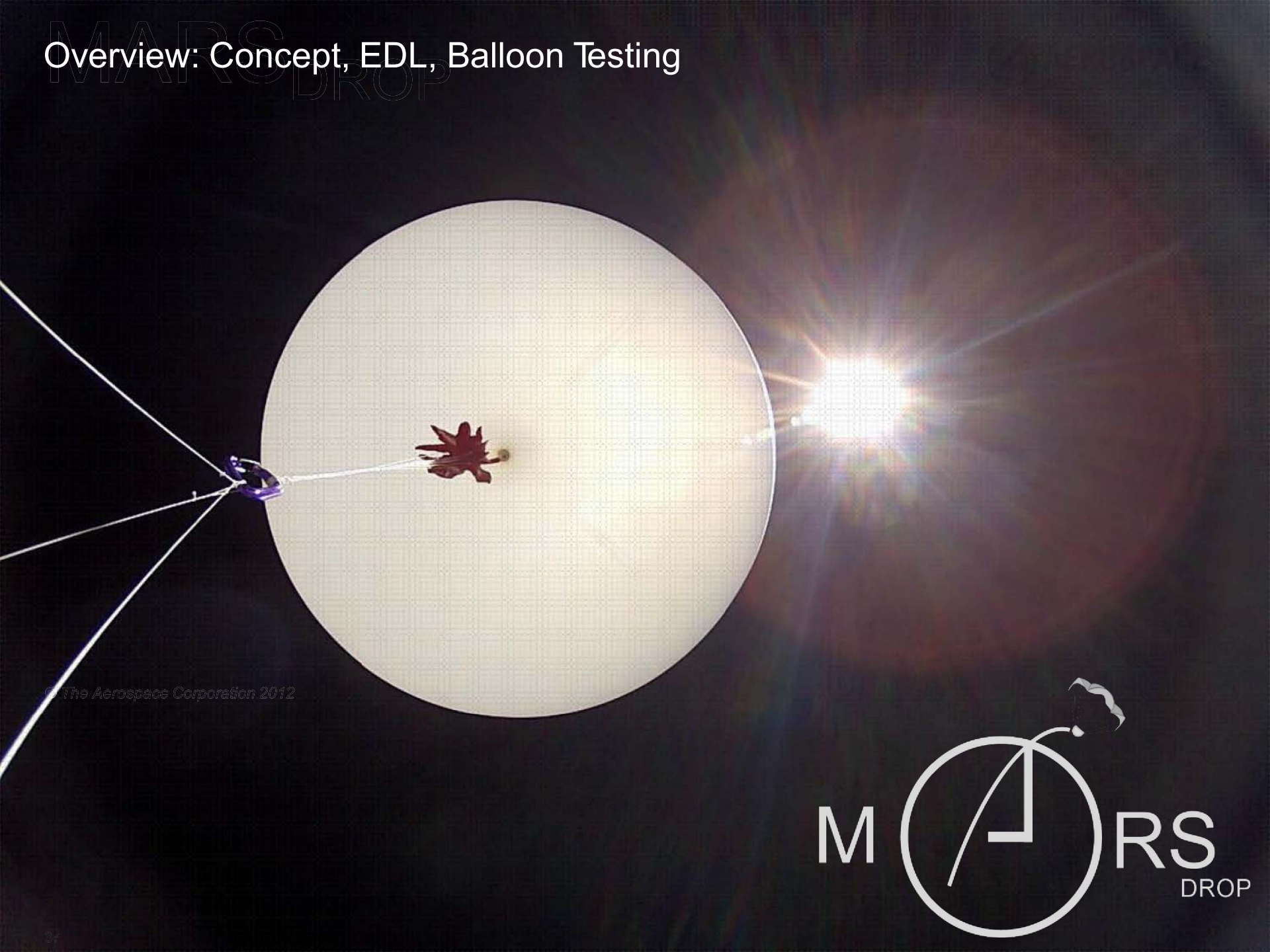


# Example MarsDrop to MRO Telecom Link



# Overview: Concept, EDL, Balloon Testing

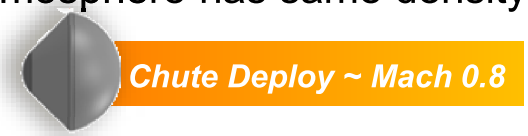


© The Aerospace Corporation 2012

# 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)



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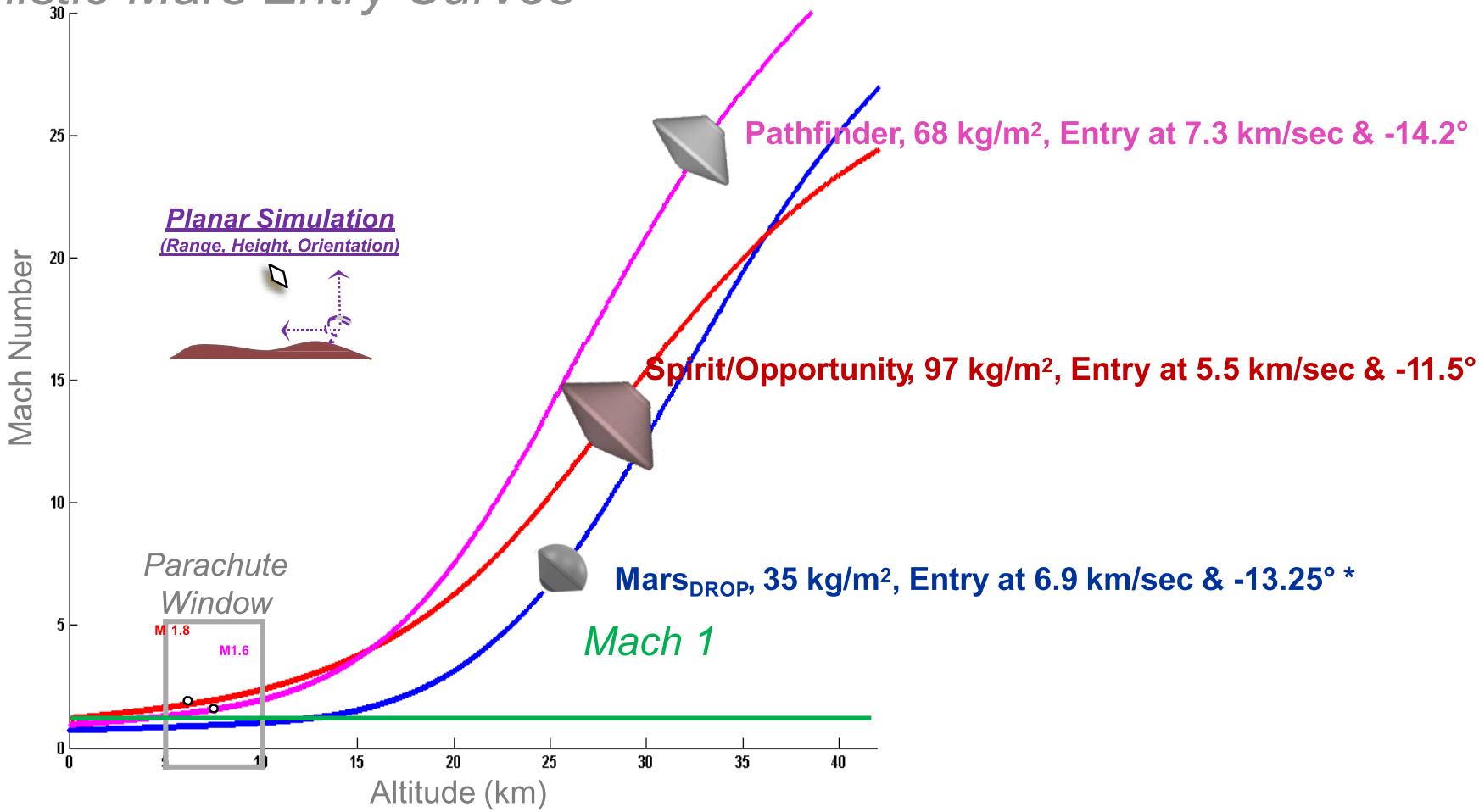
## *Ballistic Mars Entry Curves*



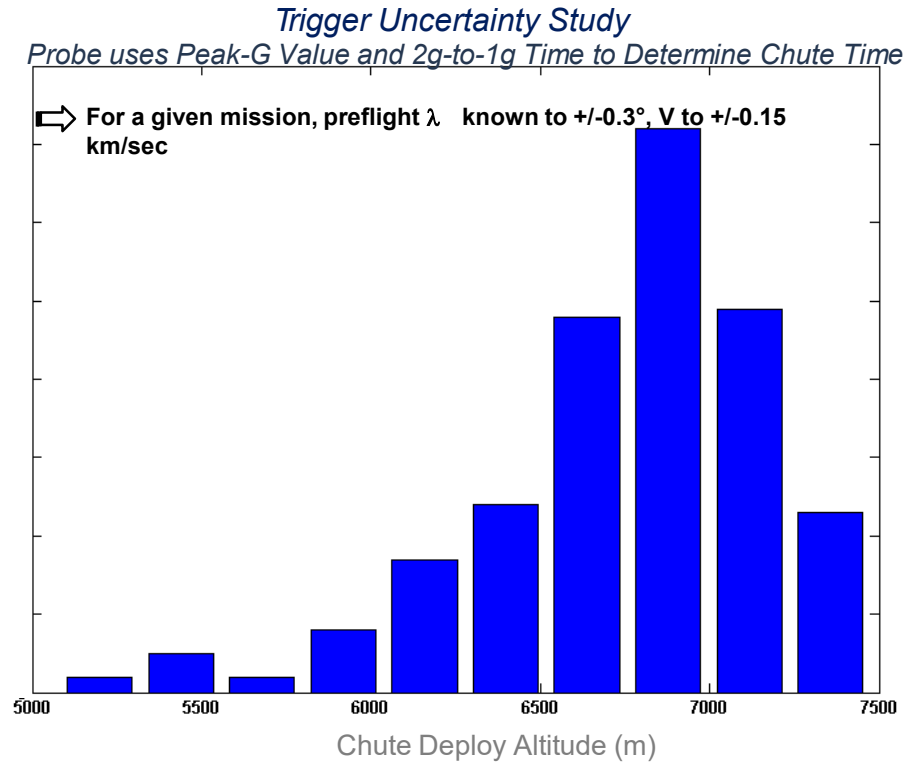

- Microprobe goes subsonic around 10 km → subsonic landing system
  - Pathfinder, Spirit, Opportunity, MSL all supersonic during parachute deploy

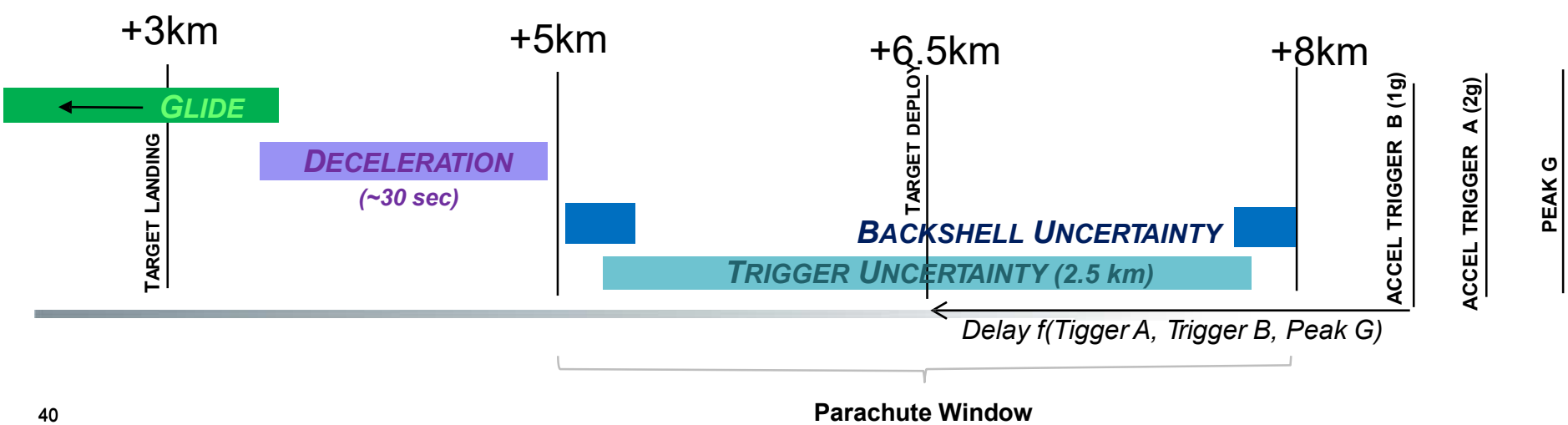
***Microprobe goes subsonic at similar height across wide range of entry parameters (flat profile under 10 km)***

# 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*



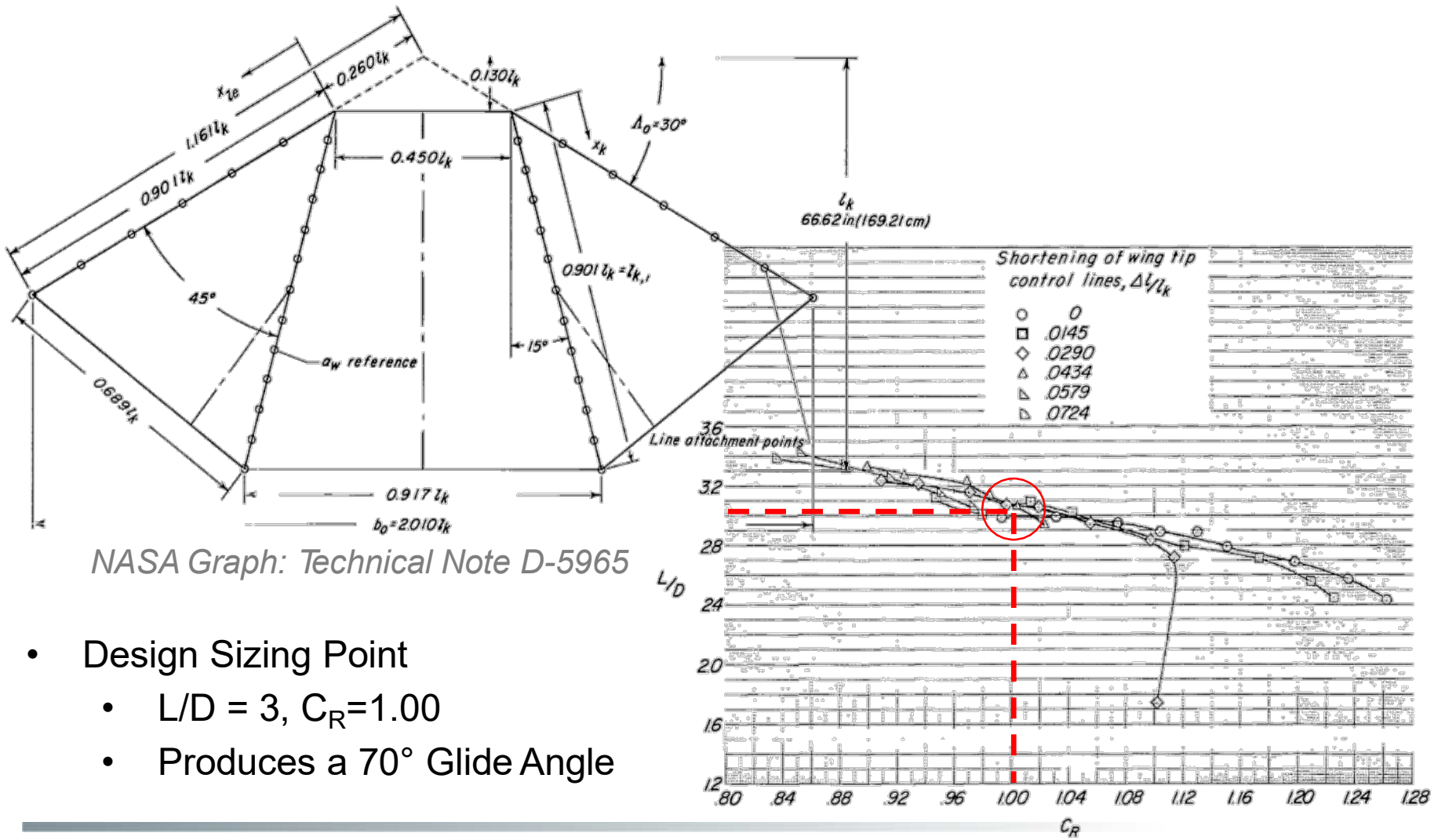
# The Reference Case

## *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

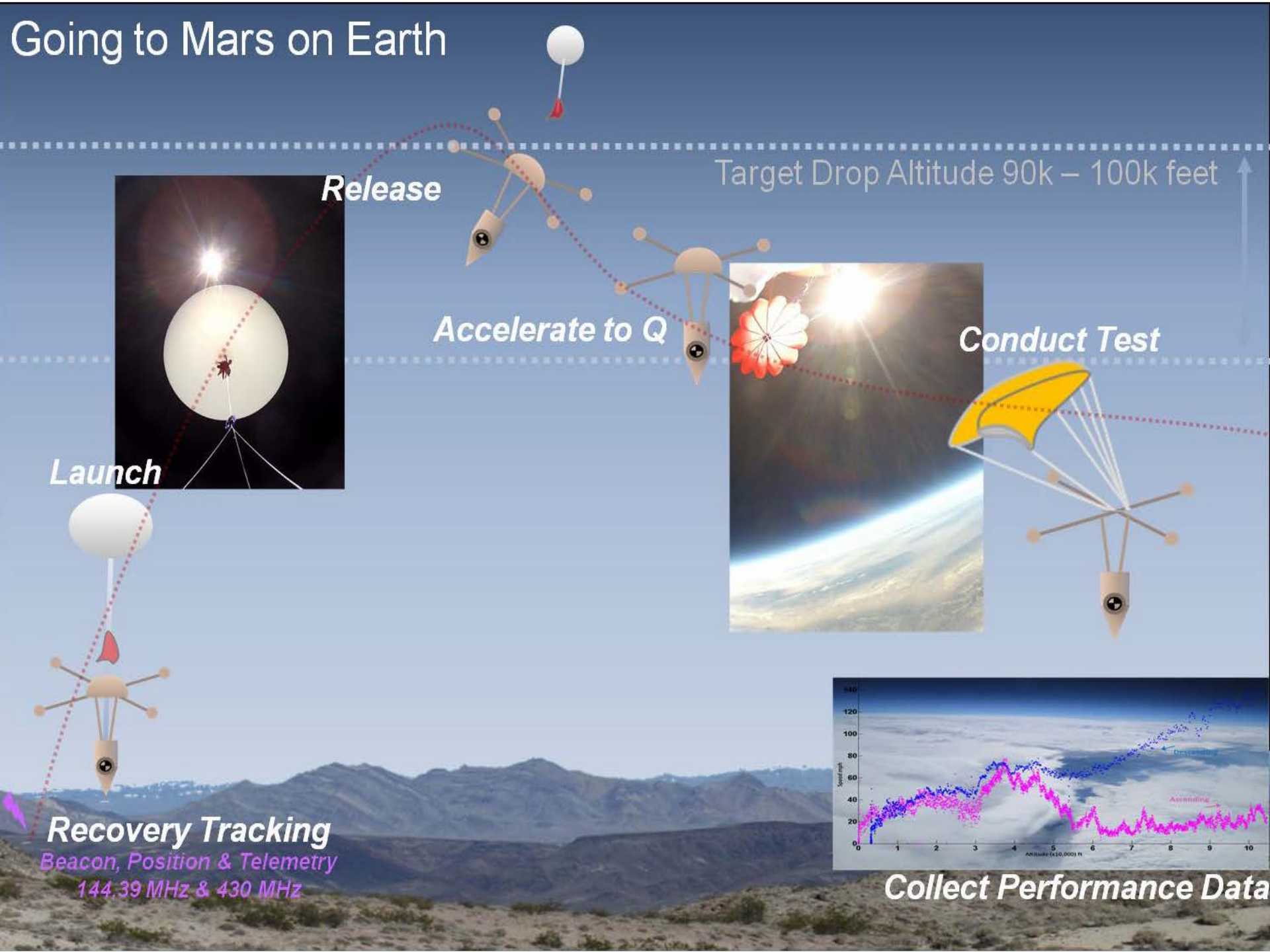
## *Scaled Version of NASA's Twin-keel Parawing Model 21*




*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



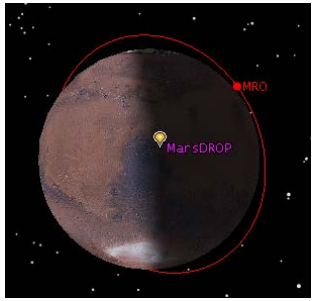
# $MARS_{DROP}$ 2

| 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)*

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

# 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°C

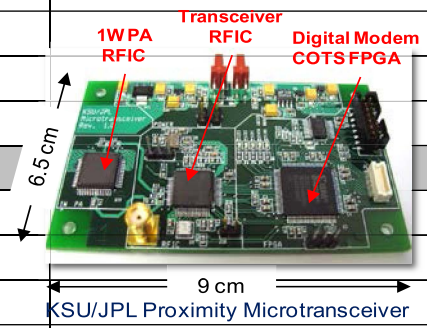
| | PV UTJ Cells | |
|---|---|---|
| Mass per Area | 84 | mg/cm^2 |
| Power per Area | 135.3 | mW/cm^2 |
| Cell Area | 26.63 | cm^2 |
| | | |
| Power per Cell (at 1.54 AU on Mars) | 1.5 | W |
| Number of Cells | 20 | - |
| Solar Collection Max | 30.4 | W |
| Collection Efficiency (Sun Angle, Shadowing) | 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 | % |

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

# 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 20° elevation)

| | | 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 |

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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.