Multiplying Mars Lander Opportunities with MARS\textsubscript{DROP} Microlander

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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 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.
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

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

- 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 1st mission
  - <$10 M next mission; <<$10 M for copies
  - Encourages high risk destinations, such as canyons
Landing Architecture

Entry Interface
100 km, V=7km/sec

T+1 min, Max Q
35 km, 15 g’s

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

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

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

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

3-DOF Simulation
(Range, Height, Orientation)

Foreground Image Courtesy of NASA

Pre-Decisional Information -- For Planning and Discussion Purposes Only
Parawing Deployment Test Sequence

100,501 feet, -40°C

Balloon Release & Freefall

Cover Jettison, 300 mph, 200Pa

Chute Extension

Inflation
<table>
<thead>
<tr>
<th>Instrument Type</th>
<th>Mass (g)</th>
<th>Power (mW)</th>
<th>Max Dimension (mm)</th>
<th>Example</th>
<th>Modification Required</th>
<th>Measurements &amp; Remarks</th>
<th>JPL POC</th>
</tr>
</thead>
<tbody>
<tr>
<td>Video Camera</td>
<td>74</td>
<td>600-1900</td>
<td>60</td>
<td>GoPro Hero3</td>
<td>Rad tolerance; modify for external control</td>
<td>720p, 960p, 1080p video with 3 FOVs up to ~150 deg. 5, 7, 10 MP pictures with 3-10 fps.</td>
<td>T. Imken/ T. Goodsmall</td>
</tr>
<tr>
<td>Legacy still camera</td>
<td>220</td>
<td>210</td>
<td>67</td>
<td>MER/MSL Hazcam &amp; Navcam</td>
<td>Lander to provide input voltages and camera control</td>
<td>High heritage; scientific quality CCD still images up to every 5 sec. &gt;20 units to Mars.</td>
<td>M. Walch</td>
</tr>
<tr>
<td>SmartCam</td>
<td>&lt;100</td>
<td>&lt;1600</td>
<td>58</td>
<td>PIXHAWK</td>
<td>Low op temp, Rad tolerance.</td>
<td>Machine vision camera and processing to support glide-to-target guidance.</td>
<td>J. Boland</td>
</tr>
<tr>
<td>uSeismometer</td>
<td>200</td>
<td>100</td>
<td>30</td>
<td>JPL Microdevices</td>
<td></td>
<td>Performance comparable to conventional terrestrial seismometer.</td>
<td>R. Williams/ PSI</td>
</tr>
<tr>
<td>Weather Monitor</td>
<td>≤1930</td>
<td>12,750</td>
<td>140</td>
<td>REMS/MSL, Twins/InSIGHT</td>
<td>Adapt to the desired envelope.</td>
<td>Configuration is flexible and sensors can be added or subtracted/replaced + aerosol monitoring sensor via a dedicated camera.</td>
<td>M. de la Torre Juarez</td>
</tr>
<tr>
<td>Aerosol Properties</td>
<td>630</td>
<td>4300</td>
<td>70</td>
<td>REMS/MSL, Twins/InSIGHT</td>
<td>Adapt to the desired envelope.</td>
<td>Camera from above + set of photodiodes; from Mars 2020</td>
<td>M. de la Torre Juarez</td>
</tr>
<tr>
<td>Sensor</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Multispectral</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Microscopic</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Imager VNIR</td>
<td>240</td>
<td>3000</td>
<td>67</td>
<td>Phoenix RAC</td>
<td>Wider FOV</td>
<td>Infer mineral grain composition at &lt;1 mm scale. Operates day (panchromatic) or night (multispectral 0.4 to 1.0 microns).</td>
<td>R. Glenn Sellar</td>
</tr>
<tr>
<td>Multispectral</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Microscopic</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Imager VSWIR</td>
<td>150</td>
<td>9000</td>
<td>110</td>
<td>MIMI Mars 2020 proposal</td>
<td>Wider FOV ~30 x 30 xm.</td>
<td>Infer mineral grain composition at &lt;1 mm scale. Passively-cooled HgCdte - operates at night (multispectral 0.45 to 2.45 microns).</td>
<td>R. Glenn Sellar</td>
</tr>
<tr>
<td>Deep UV Fluorescence</td>
<td>700</td>
<td>3000</td>
<td>150</td>
<td>Lab demo</td>
<td>Communication/power from vehicle.</td>
<td>Organic detection. Small UV light sources dependent on current DARPA efforts.</td>
<td>R. Bhartia</td>
</tr>
<tr>
<td>Imager</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Deep UV Fluorescence</td>
<td>3000</td>
<td>15000</td>
<td>250</td>
<td>SHERLOC/ Mars 2020</td>
<td>Reduce mass, comm/power from vehicle</td>
<td>Organic detection, astrobiological-relevant minerals, Ops short burst laser source high TRL.</td>
<td>R. Bhartia</td>
</tr>
<tr>
<td>Tunable Laser</td>
<td>400</td>
<td>400</td>
<td>100</td>
<td>CH₄ sniffer for PG&amp;E</td>
<td>Miniaturized cell, electronics, low power laser packages.</td>
<td>CH₄ to 1 ppb. Heritage from TLS-MSL and quadcopter versions.</td>
<td>L. Christensen/S. Forouhar</td>
</tr>
<tr>
<td>Spectrometer</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
# Driving Performance Desirements

<table>
<thead>
<tr>
<th>Performance Parameters</th>
<th>Tech Demo (Initial Flight)</th>
<th>First science demo</th>
<th>“Operational” Capability Target</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of Mars$_{DROP}$ Landers</td>
<td>One</td>
<td>One+</td>
<td>2 - 10</td>
</tr>
<tr>
<td>Allowable payload mass</td>
<td>100 g</td>
<td>&lt;1 kg</td>
<td>1 kg, growing to 2+ kg</td>
</tr>
<tr>
<td>Spacecraft landing orientation control</td>
<td>50% chance of achieving desired orientation</td>
<td>90% chance of achieving desired orientation</td>
<td>90% chance of achieving desired orientation</td>
</tr>
<tr>
<td>Average Collected Solar Power (sunlit)</td>
<td>0.5 W</td>
<td>~10 W</td>
<td>&gt;10 W</td>
</tr>
<tr>
<td>Battery Capacity</td>
<td>16 Whr</td>
<td>70 Whr</td>
<td>same or greater</td>
</tr>
<tr>
<td>Surface Survival Duration</td>
<td>1 sol</td>
<td>90 sols</td>
<td>1 Mars year</td>
</tr>
<tr>
<td>Data Volume Return</td>
<td>100 kbits</td>
<td>&gt;20 MBytes</td>
<td>&gt;100 MBytes</td>
</tr>
<tr>
<td>Host Support</td>
<td>position knowledge before deployment.</td>
<td>position knowledge at deployment.</td>
<td>add trickle charge, command &amp; sw upload, checkout data download</td>
</tr>
<tr>
<td>Glide distance</td>
<td>10 km</td>
<td>10+ km</td>
<td>10+ km</td>
</tr>
<tr>
<td>Landing accuracy to one of available sites across uncertainty ellipse</td>
<td>1 km</td>
<td>100s m</td>
<td>10s m</td>
</tr>
</tbody>
</table>

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

<table>
<thead>
<tr>
<th>Proposed Payload Suites (each with multiple small instruments)</th>
<th>Organic detection</th>
<th>Ambient conditions &amp; Dust Hazard</th>
<th>Mineralogy</th>
<th>Geology</th>
<th>Internal Structure</th>
<th>Total Mass</th>
</tr>
</thead>
<tbody>
<tr>
<td># Goals</td>
<td>1,3</td>
<td>1,2,4</td>
<td>1,3</td>
<td>3</td>
<td>3</td>
<td></td>
</tr>
<tr>
<td>Still camera, seismometer, multispectral imager, Aweather station</td>
<td></td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>1 kg</td>
</tr>
<tr>
<td>Still camera, seismometer, Baerosol sensor</td>
<td></td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>1.05 kg</td>
</tr>
<tr>
<td>Still camera, seismometer, Cdeep UV fluorescence</td>
<td>✓</td>
<td></td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>&gt;1.5 kg</td>
</tr>
<tr>
<td>Video camera, tunable laser spectrometer (CH4, DH2O, CO2), T, P, RH</td>
<td>✓</td>
<td>✓</td>
<td></td>
<td>✓</td>
<td></td>
<td>&lt;1 kg</td>
</tr>
</tbody>
</table>
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/cm² at ~40 km altitude from Mars surface.

Representative descent characteristics for Mars Microprobe (MarsDROP is very similar with $\beta = 36.4 \text{ kg/m}^2$ 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

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

- TLS Methane Detector
- Pressure Sensor
- Solar Panels (x3)
- Descent / Nav Camera
- UHF Antenna
- Humidity Sensor
- Air Temperature Sensor
- Pressure Sensor
- Science Camera
- Gumstix Processor
- 18650 Batteries (x6 underneath)
- UHF Modem
- Science Camera
- Optical head: 60 g, 450-cm optical path

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

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

- UHF Antenna
- Descent / Nav Camera
- Science Camera
- IMU - Gyro & Accelerometer
- GumStix Processor
- Humidity Sensor
- Air Temperature Sensor
- Pressure Sensor
- EPS Power Card
- TLS Methane Detector
- Structure
- Solar Panels
- Sprung (x6)
- Parawing control stepper motors (x2)
- 18650 Batteries (x6 underneath)
- Thermal IR Sensor
- UHF Modem
- UHF Proxy-1 Radio
- Science Camera
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°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.

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

*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):

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

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)

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

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.

Pre-Decisional Information -- For Planning and Discussion Purposes Only
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
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)*
- MarsDROP instrument and components are expected to survive ~500 g’s

\[ E = \frac{1}{2} m v^2 \]
\[ E = Fd \]
\[ F = ma \]
\[ a = \frac{v^2}{2d} \]

E= Impact Energy  
\[ m = \text{object mass} \]
\[ v = \text{impact velocity} \]

F= Deceleration Force  
\[ d = \text{displacement} \]
\[ a = \text{acceleration} \]

Note acceleration does not directly depend on mass

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

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

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Specification</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mass, Power, Volume</td>
<td>33 g, 475 mW, &lt; 6 cc</td>
</tr>
<tr>
<td>FOV, iFOV, pixels</td>
<td>48°, 1 milliradian, 1 MP</td>
</tr>
<tr>
<td>framerate</td>
<td>60 fps</td>
</tr>
<tr>
<td>lens</td>
<td>4-element glass, f/4, 6 mm</td>
</tr>
<tr>
<td>Radiation tested</td>
<td>3.2 krad (RDF = 8)</td>
</tr>
<tr>
<td>Computation</td>
<td>TI AM3703 DSP with 1GHz ARM CORTEX A8</td>
</tr>
</tbody>
</table>

Modifications likely required:
- Materials compatibility.
- Thermal tolerance or heater.
- Add pressure sensor and MEMS gyro.

image source: https://pixhawk.ethz.ch/electronics/camera
Synergy with Mars Lander Vision System (LVS)

State Estimation

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

Coarse Landmark Matching

Remove Position Error (3km 3-σ)

Fine Landmark Matching

Improve Accuracy (40m 3-σ)
• LVS prototype tested over Mars-analog terrains in Feb/March 2014

• Test collected data to validate technology over a wide operational envelop defined by expected M2020 conditions

• LVS meets position accuracy and robustness requirements

• Field test demonstrated maturity of the algorithms
LVS Helicopter Test
March 2014

- 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

Position error < 20m

Coarse matches

Fine matches
**Example Instrument:** Tunable Laser Spectrometer (300 g, 2W for continuous measurement) could measure gases such as Methane (CH₄), Water (H₂O) and isotope ratios within these gases: D/H, ¹³C/¹²C, ¹⁸O/¹⁷O/¹⁶O 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

Pre-Decisional Information -- For Planning and Discussion Purposes Only
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 (MRO) launched in 2005 observed methane in the Martian atmosphere. What is the source of methane generation on Mars? Does life exist on Mars?

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

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

Pre-Decisional Information -- For Planning and Discussion Purposes Only
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)*
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 1cm²
- 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)

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

• 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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818 354-1176