Infusion of Vision Systems into Planetary Landers

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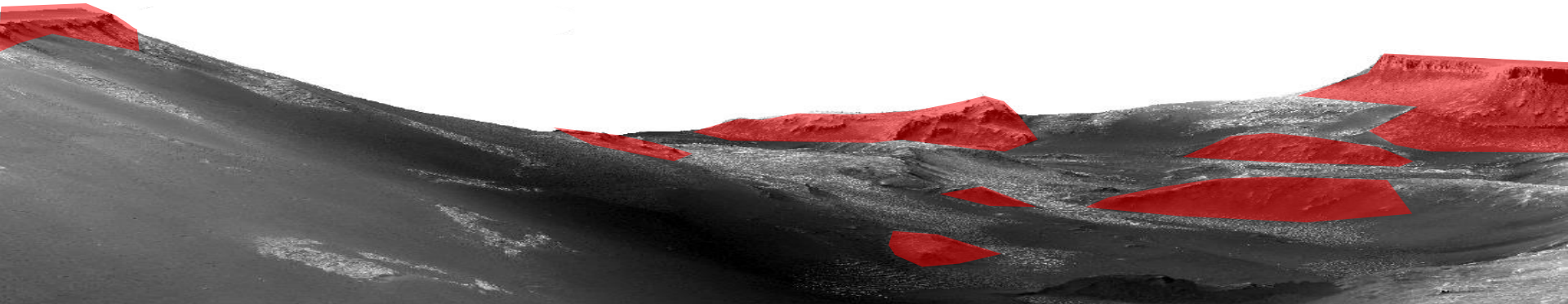
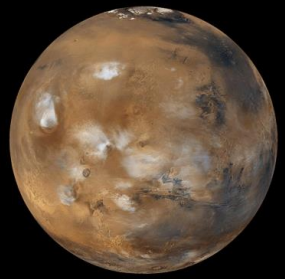
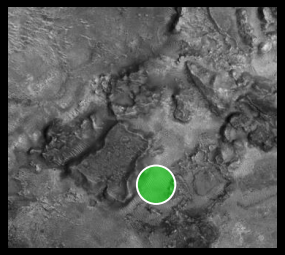


Overview

- The importance of vision systems for future planetary exploration
- The Lander Vision System for precision landing on Mars
- The Hazard Detection System for safe landing on the Moon

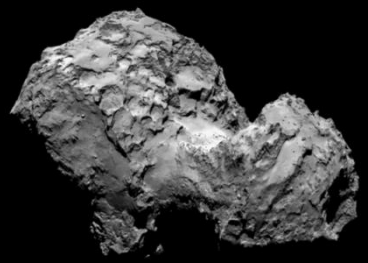
Mars

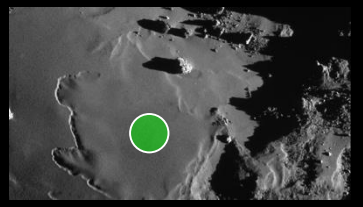




Vision required to access best science sites and land near pre-deployed assets

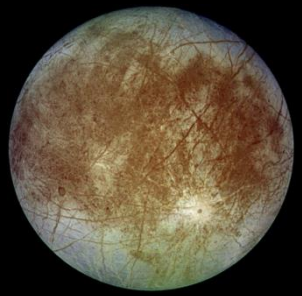
Comets

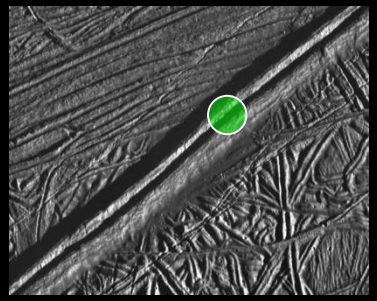




Vision required to safely acquire a sample

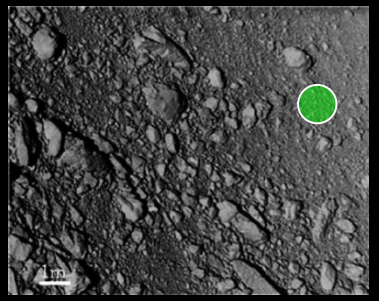
Europa





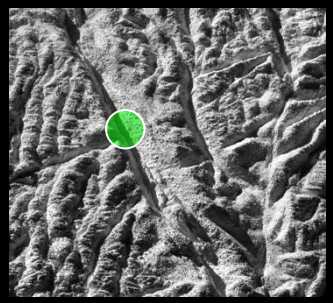
Vision required to land safely on science site

Asteroids



Vision required to pick up boulder

Enceladus



Vision required to land near water plumes

The Moon

Vision required to access permanently lit terrain

Mars 2020 Overview

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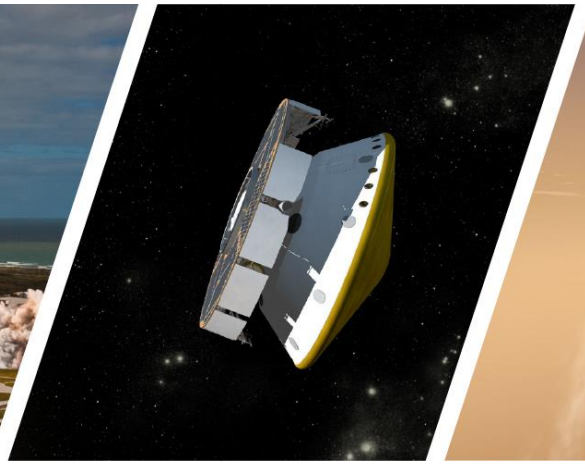

LAUNCH

- Atlas V 541 Rocket
- Period: Jul-Aug 2020

CRUISE/APPROACH

- 7.5 month cruise
- Arrive Feb 2021

ENTRY, DESCENT & LANDING

- MSL EDL System: guided entry, powered descent, and sky crane
- Augmented by ***range trigger***: 16 x 14 km landing ellipse
- Augmented by ***TRN***: enables safe landing at a greater number of scientifically valuable sites
- Access to landing sites ±30° latitude, ≤ - 0.5 km elevation
- Deliver a 1050 kg rover

SURFACE MISSION

- Prime mission of at least 1.5 Mars years
- 20 km traverse distance capability
- Enhanced surface productivity
- Seeking signs of past life
- Returnable cache of samples
- Prepare for human exploration of Mars

Candidate Mars 2020 Landing Sites

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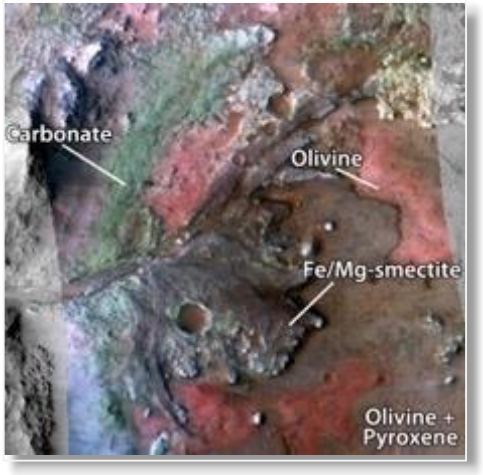
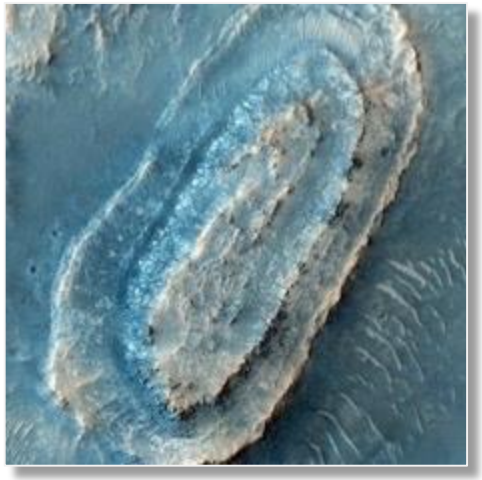


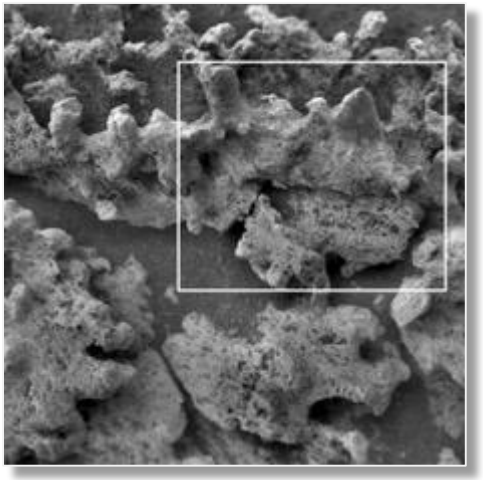
JEZERO

- Deltaic/lacustrine deposition with possible igneous unit and hydrous alteration
- Mineralogic diversity including clays and carbonates
- Shallow water carbonates?



NE SYRTIS

- Extremely ancient igneous, hydrothermal, and sedimentary environments
- High mineralogic diversity with phyllosilicates, sulfates, carbonates, olivine
- Possible serpentinization and subsurface habitability



COLUMBIA HILLS

- Carbonate, sulfate, and silica-rich outcrops of possible hydrothermal origin. Hesperian volcanics.
- Potential biosignatures identified
- Previously explored by MER

Entry Descent and Landing

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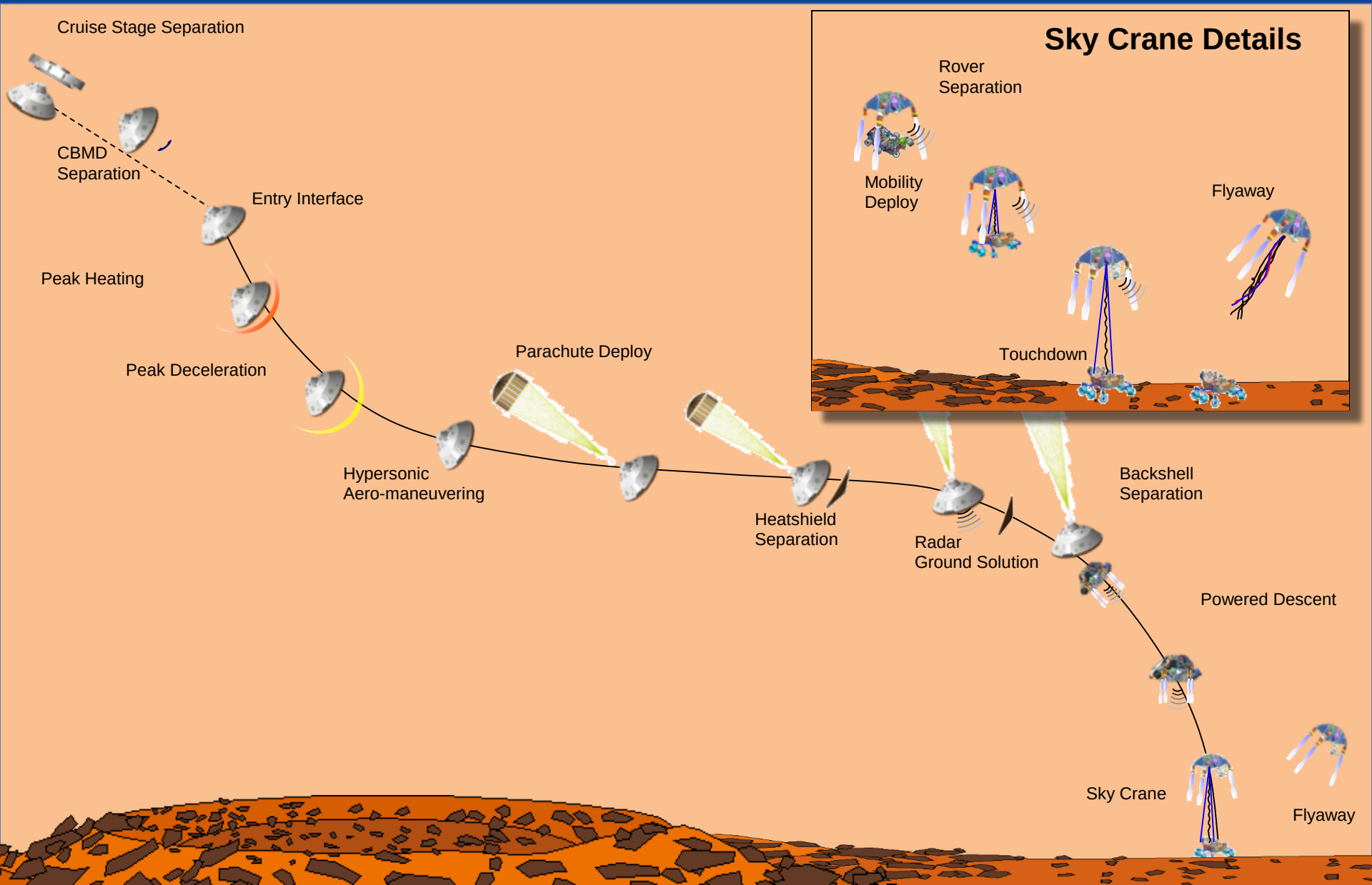

Terrain Relative Navigation: A New Capability for EDL

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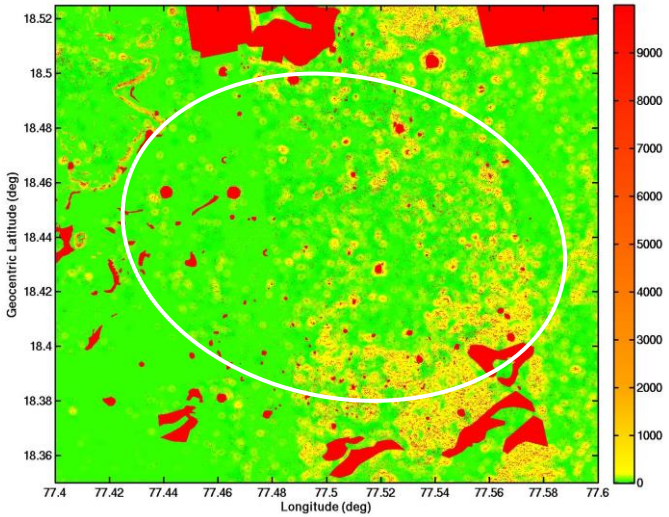
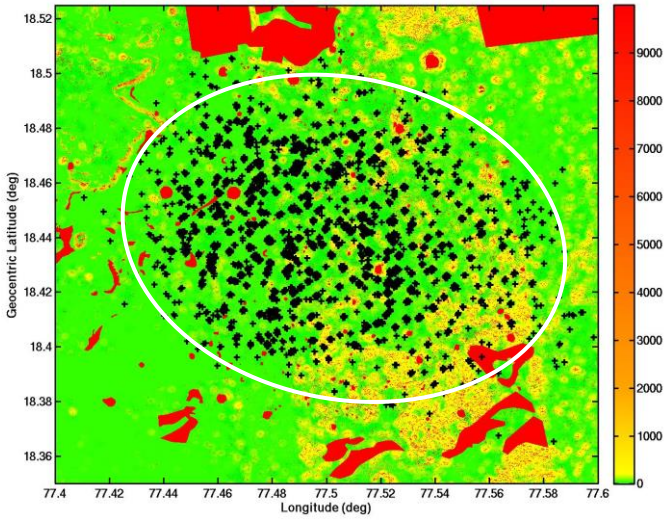
TRN enables access to hazardous landing sites

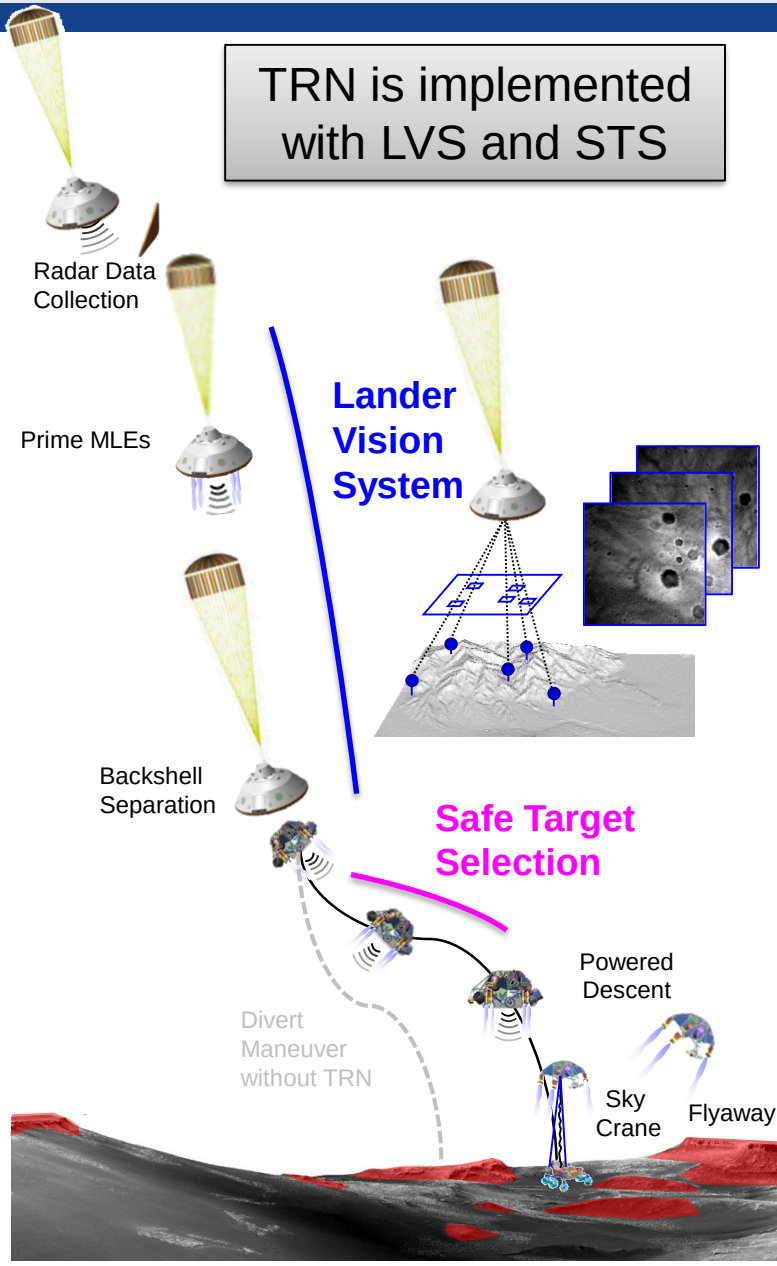


Mars 2020 landing ellipse can contain numerous hazards



TRN augments MSL EDL to avoid hazards and land safely

TRN is implemented with LVS and STS



LVS Problem Statement

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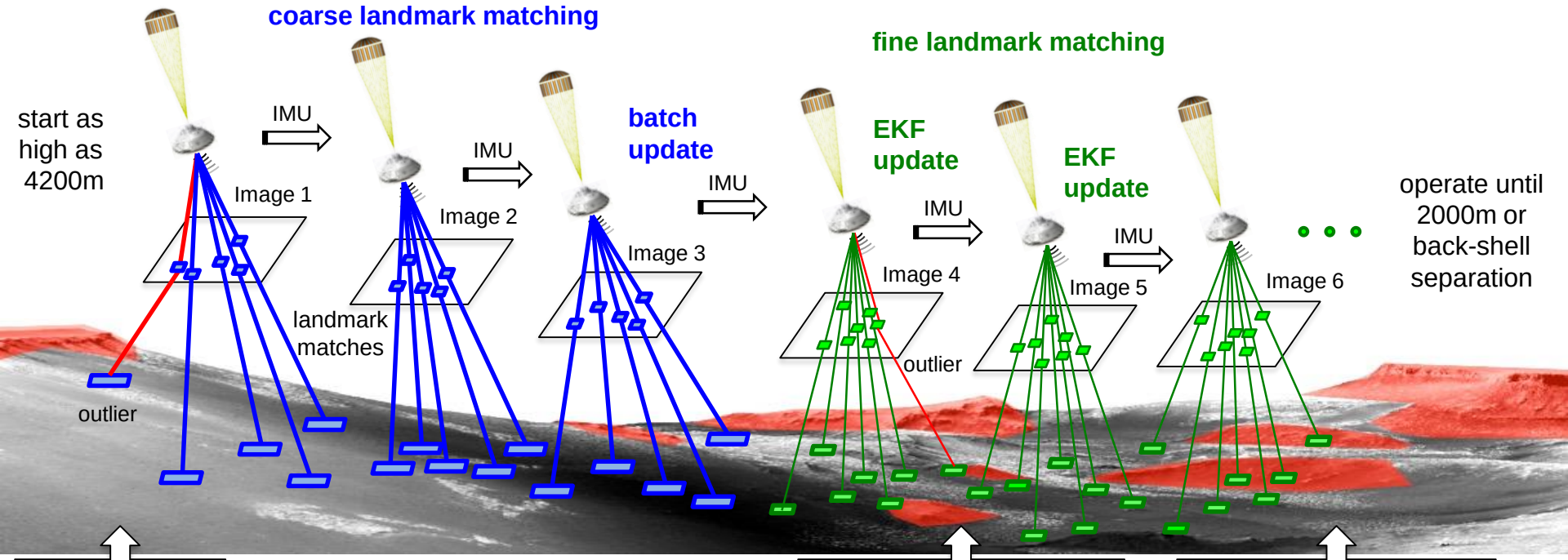
California Institute of Technology

LVS estimates position during parachute descent.

sun elevation between 38˚ & 49˚
sun azimuth between 256˚ & 292˚
+/-15˚ elevation and +/-35˚ azimuth
difference between map and landing

off nadir angle < 45˚ & angular rates < 50˚/s
horizontal velocity < 70 m/s & vertical velocity between 60 and 115 m/s



Remove Initial Position Error of 3.2km

slope < 15˚
terrain relief < 150m
appearance entropy > 4

Reduced Position Error
40m 99%tile
95% of the time
at 6 seconds

Nominal Position Error
40m 99%tile
99% of the time
at 10 seconds

STS Problem Statement

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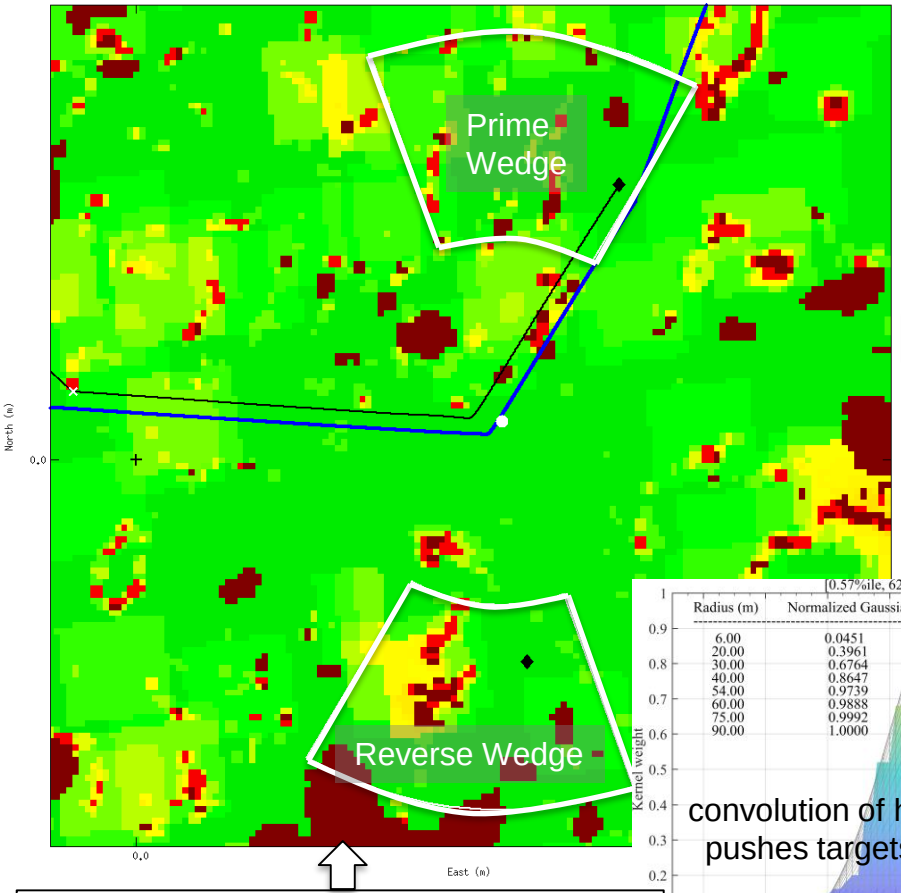
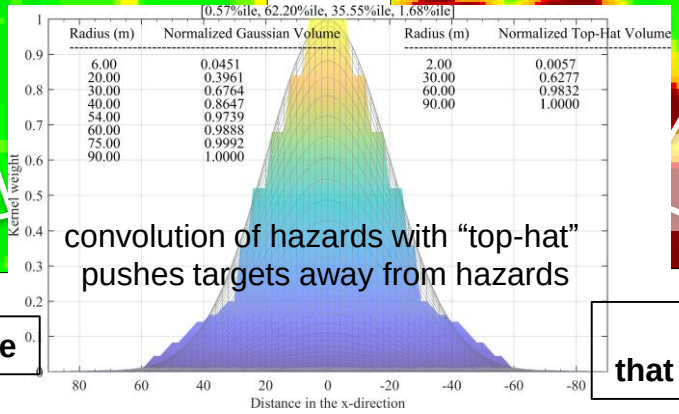
California Institute of Technology

STS selects a safe landing site that avoids landing hazards and the back shell.

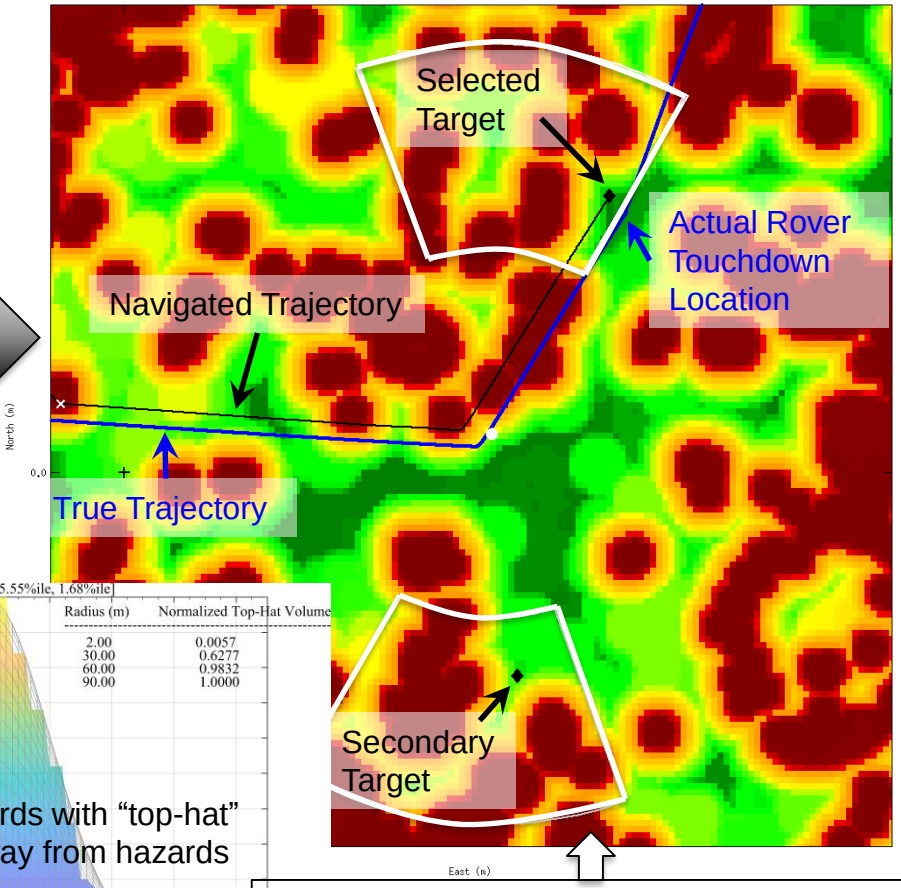
Hazard Map



Avoid hazards that are up to 200m wide



Safe Target Map



find a safe site in < 2.6 seconds that is reachable and avoids the backshell

TRN Flight Interfaces

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Descent Stage

Rover

Descent IMU

Descent IMU

422

422

Descent Motor

Control Assembly

422

422

5/8” Cutter

Heritage flight HW
Heritage flight SW
New flight HW
New flight SW
New firmware
New Data

422

422

Y

Y

422

422

IMU data

Rover Compute Element

EDL/GNC FSW

STS FSW

Safe Target Map

s/c state, cmds

positions, tlm

Rover 1553

LVDS (ITC/ICC)

Vision Compute Element

VCE FSW

IP firmware

LVS map

cmds

images

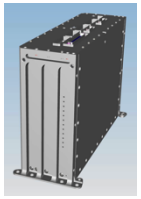
LVDS

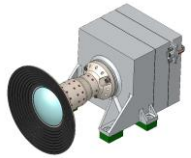
+5V

LVS Camera

Rover Power

28V

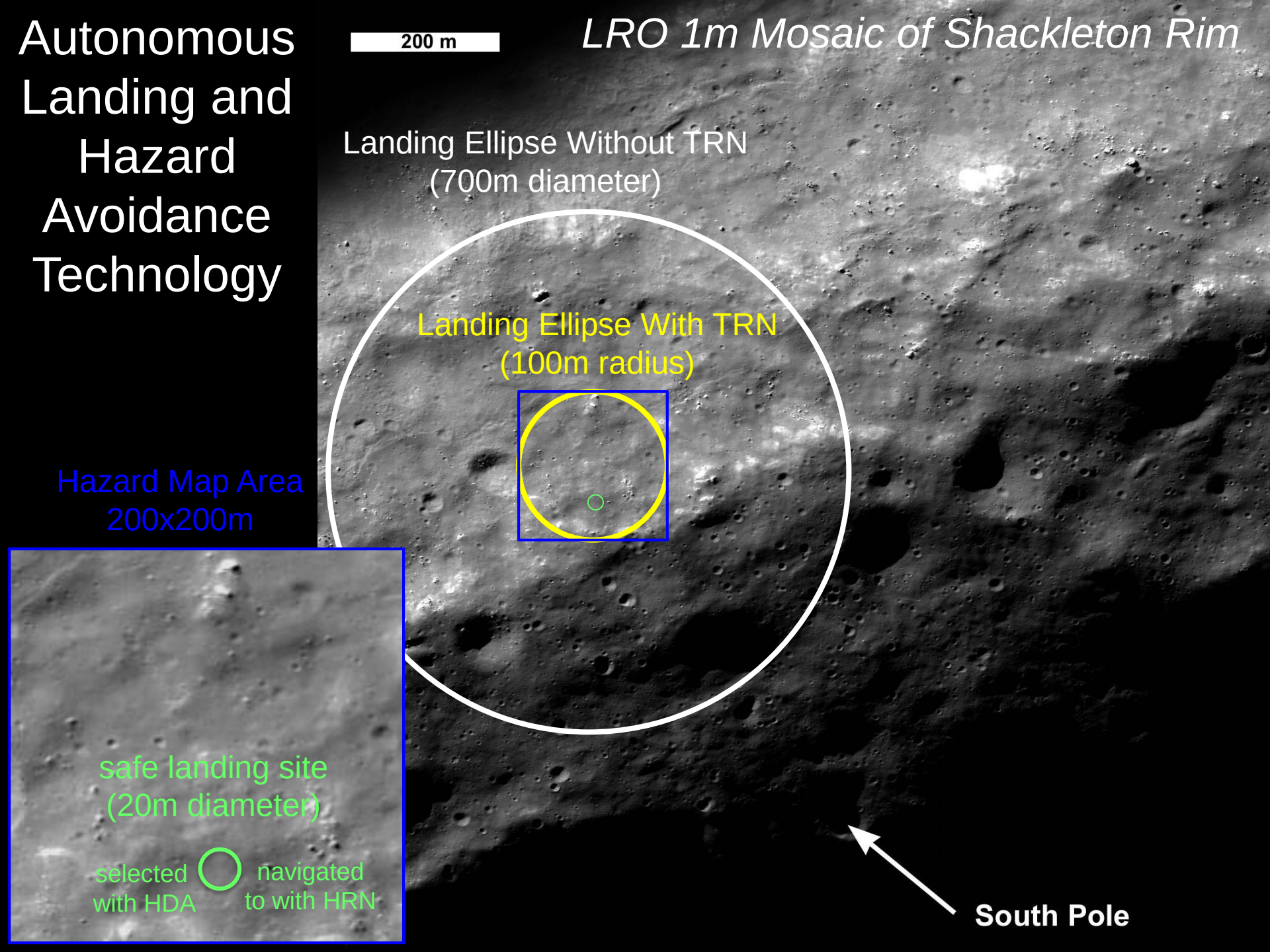




LVS Field Tests Movie

ADAPT Movie

Autonomous Landing and Hazard Avoidance Technology

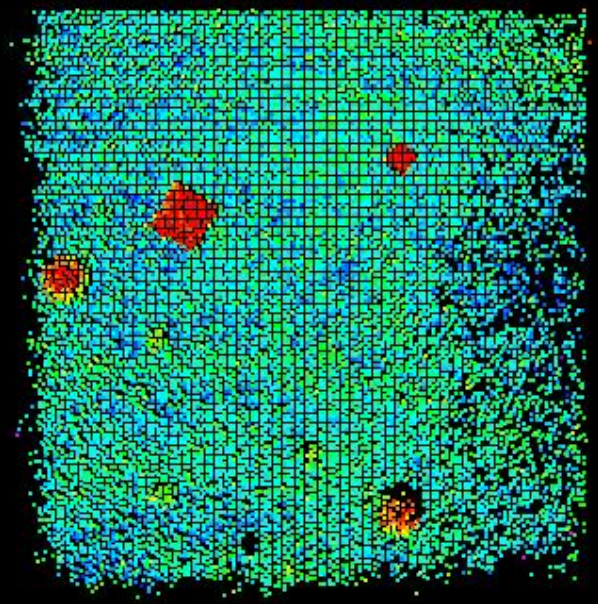


Example Flash Lidar Image

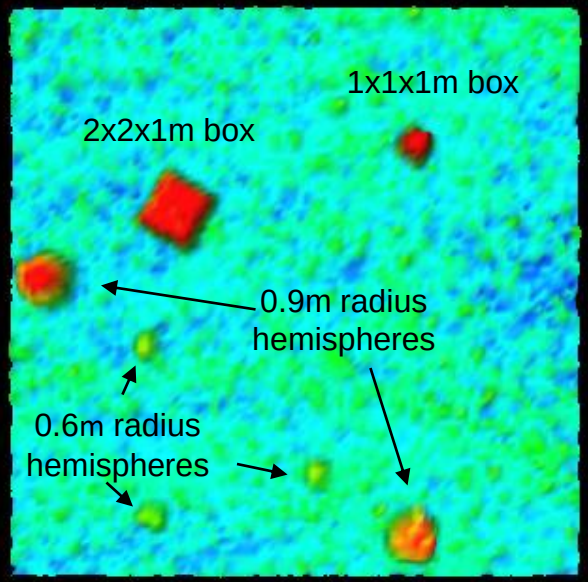
128x128 pixels
430m Range
7˚ Off Nadir

3D Points

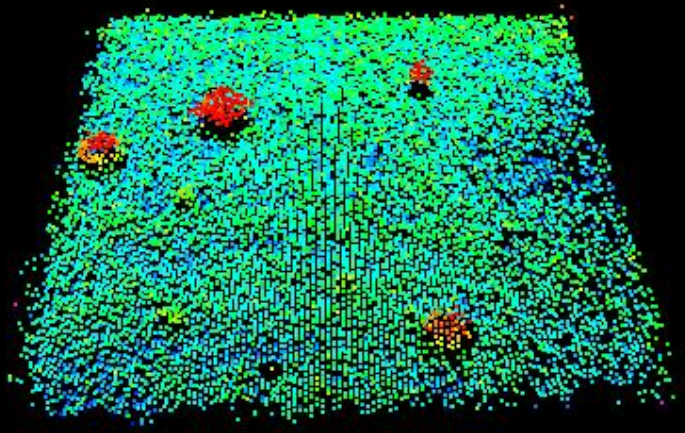
Elevation Map

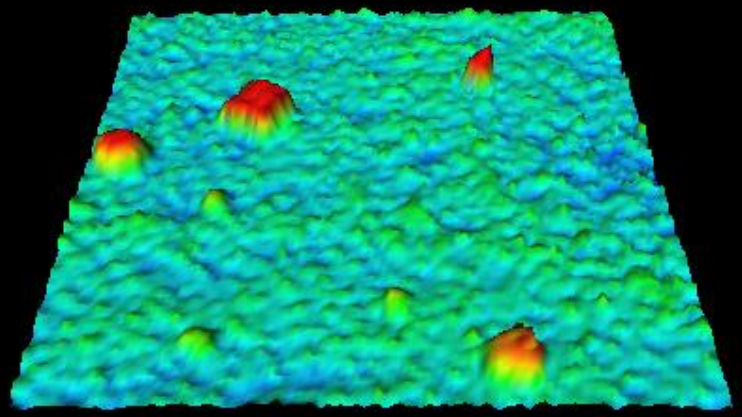


Top View

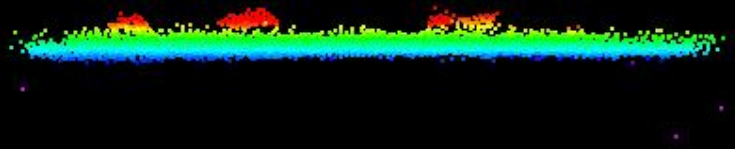


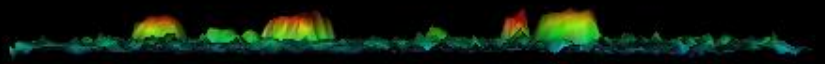
Oblique View





Side View





HDS Hardware/Sensors

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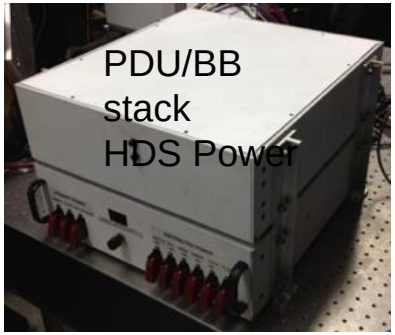
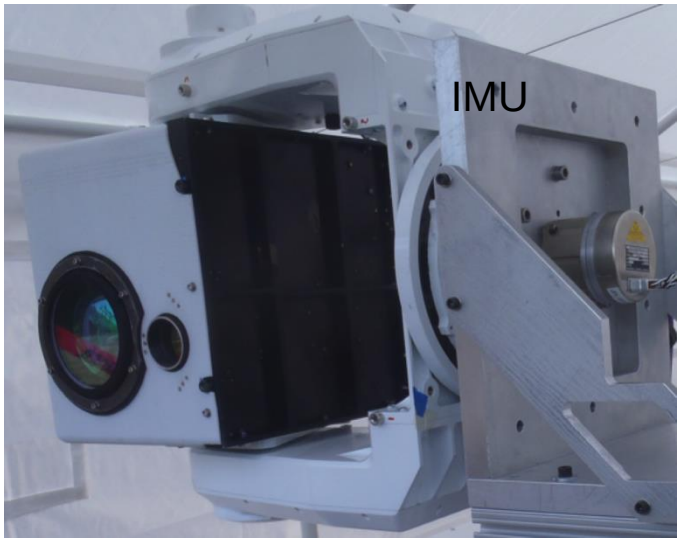


- Gimbaled Flash Lidar: 2D InGaAs APD (128X128 pixels), 8-cm (1σ) range precision, 1° FOV, 50 mJ, 1.06μm class IV laser
- Lidar Electronics: sensor controller, data handling, laser driver, sensor power distribution
- Dedicated LN200 IMU for high-rate state propagation
- Compute Element: Tilera Tile-64 multicore processor, Xilinx FPGA, 10 Gb/s XAUI interconnect, data logger



DEM Generation

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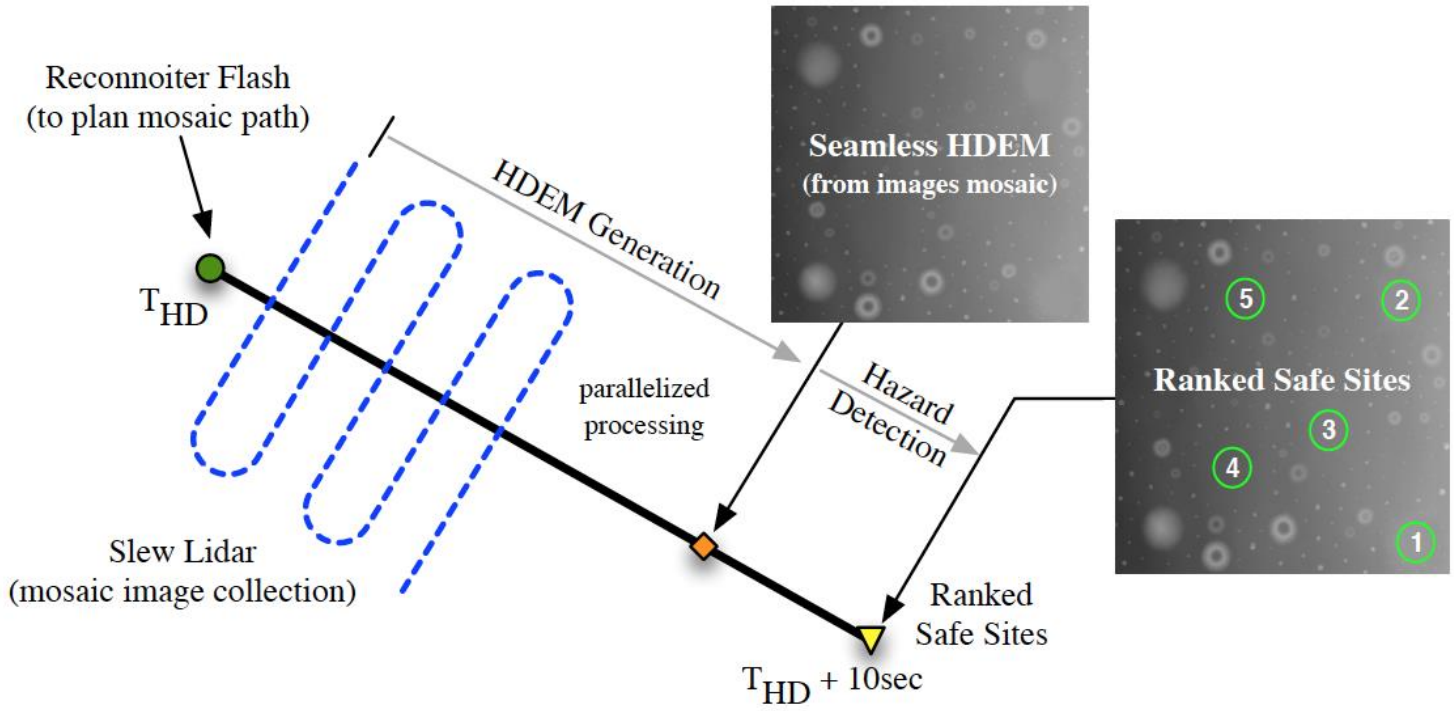

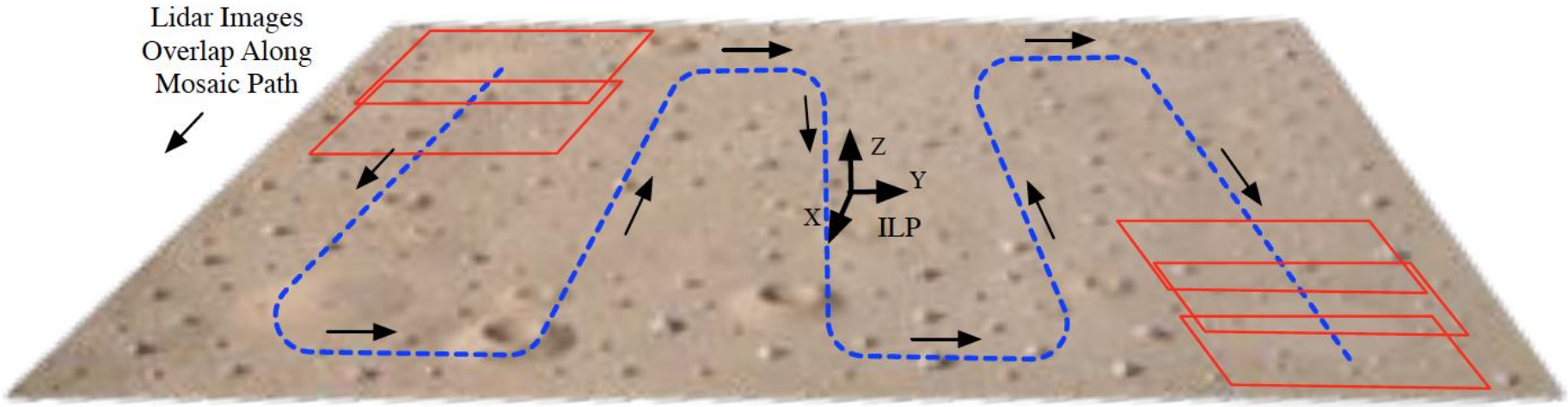

Morpheus and HDS Movie

DEM Evaluation

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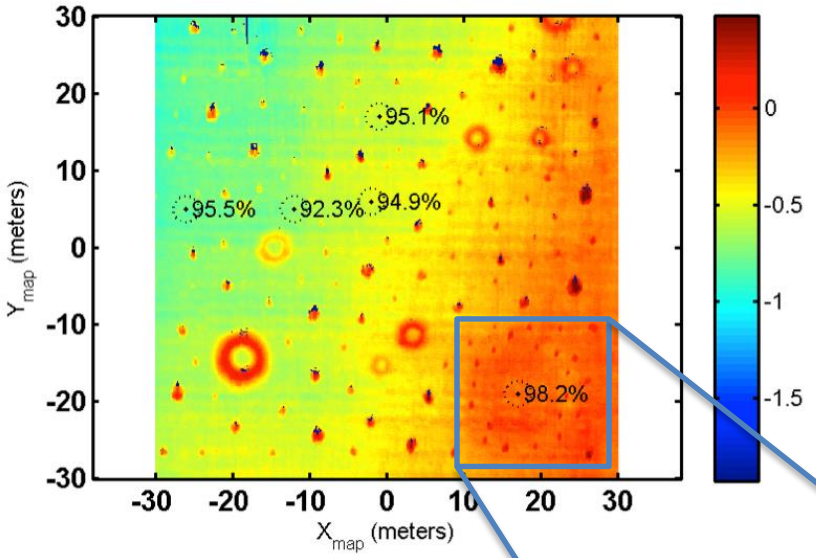
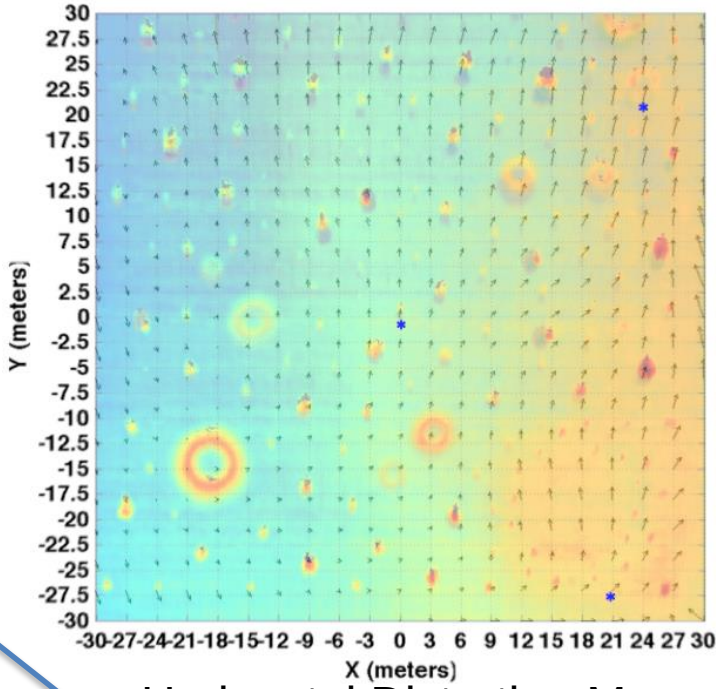
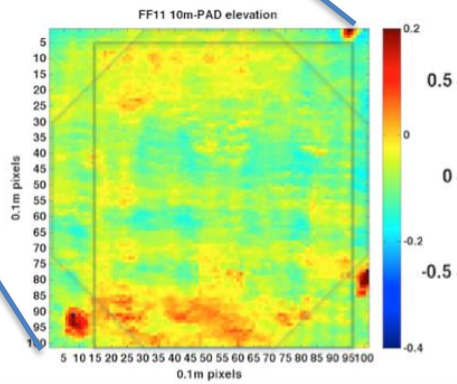
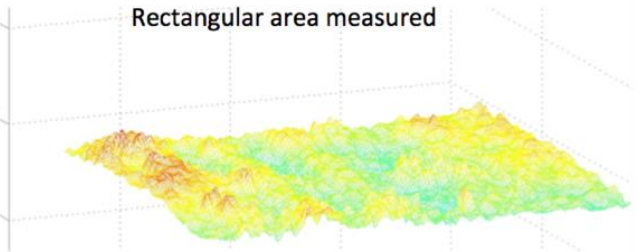




Horizontal Distortion Map

- DEMs are evaluated for completeness, distortion, map tie error, and noise.
- Overall map quality adequate for HD





Landing Pad Close-up
N. Trawny 18

January 5, 2015

Safe Site Selection

Jet Propulsion Laboratory
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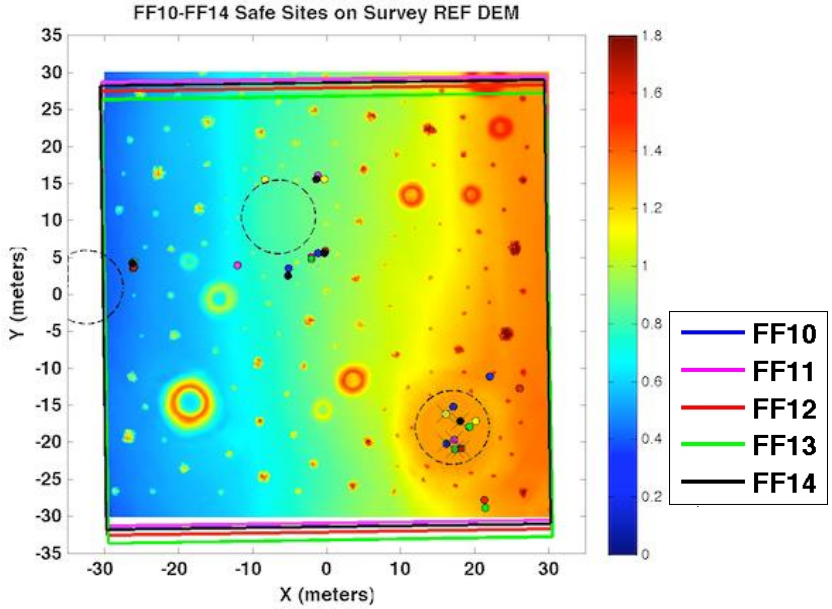
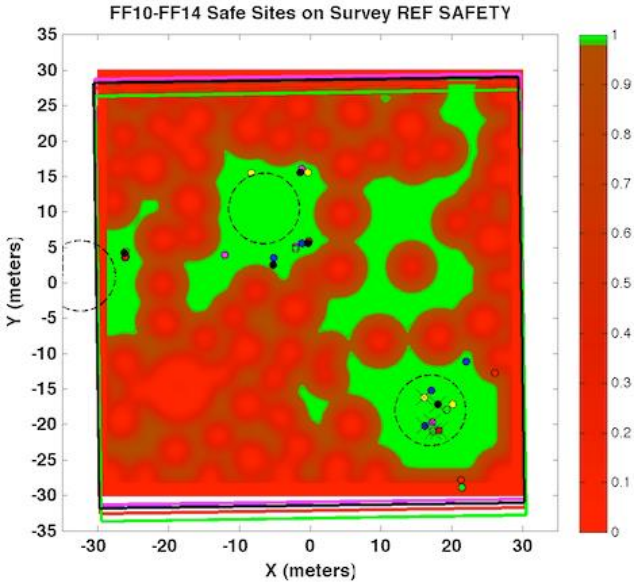
All Safe Sites overlaid on ORIGINAL ground truth DEM



All Safe Sites overlaid on ORIGINAL ground truth safety map



- Top safe sites clustered on pad1
- Safe sites within 2m Morpheus safety acceptance radius for all flights except FF10 and 14.
- Hazard Field modifications not reflected in ground truth

Flight #	10	11	12	13	14
Safest Site XY delta to center of pad (m) (For FF10 without spikes)	3.4 (1.1)	0.8	1.4	0.3	2.6
Safest Site within 2.0m allowance (For FF10 without spikes)	N (Y)	Y	Y	Y	N
Safe Site Landing Source	VTB-selected	VTB-selected	HDS-selected	HDS-selected	HDS-selected

Conclusion

- Future Challenges
  - Position Estimation
    - match without knowledge of altitude or attitude
    - match at night or through dust
    - match under large changes in illumination
  - Hazard Detection
    - 5kg hazard detection system
    - survive the radiation of Europa
    - image a 100x100m area at 5cm/pixel
- Open Questions
  - What is the right balance between pushing the envelope on technology versus decreasing infusion risk?
  - Should flight missions be required to infuse technology?