3D Lidar for Hazard Detection & Autonomous Deep Space Operations

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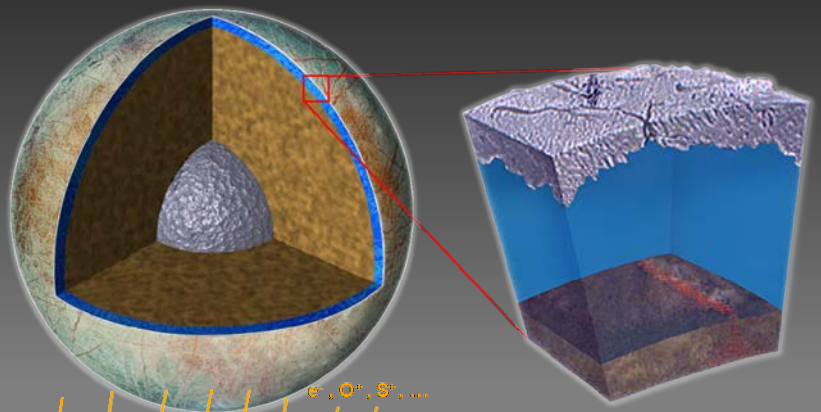
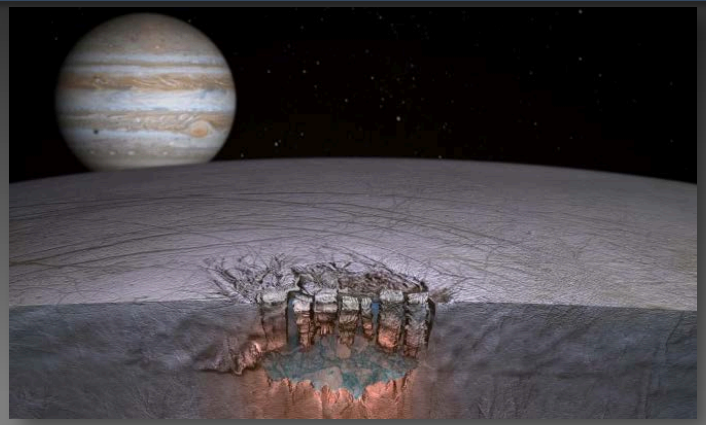
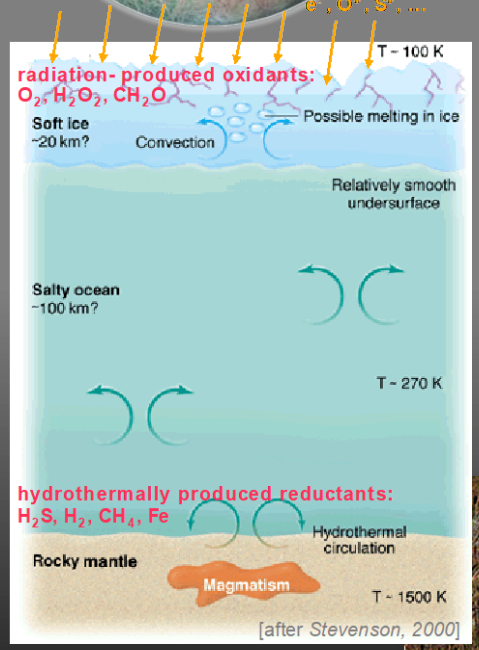
INGREDIENTS FOR LIFE (AS WE KNOW IT)



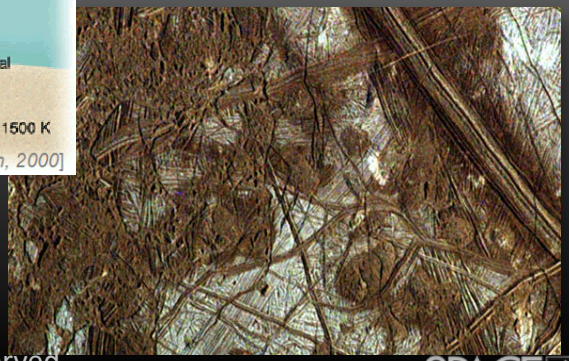




water

chem

energy



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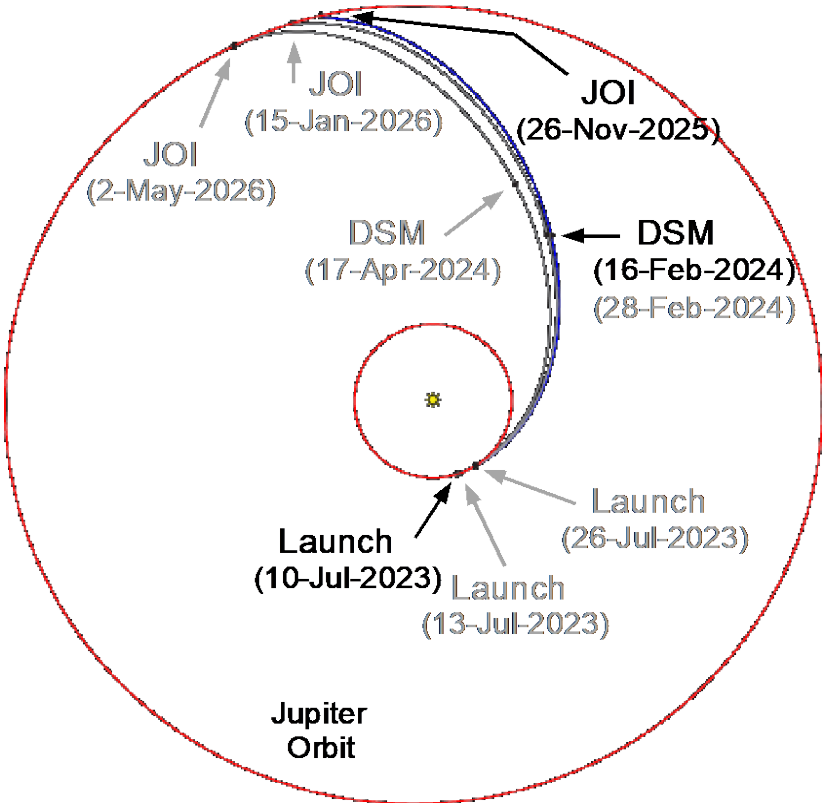
Getting to Jupiter – Launch & Trajectories

DeltaV-EGA



Direct

- Project PDR: Fall 2018
- Schedule requires the sensor prototype to be developed and tested in relevant environments (performance at altitude, velocity) in Summer 2018

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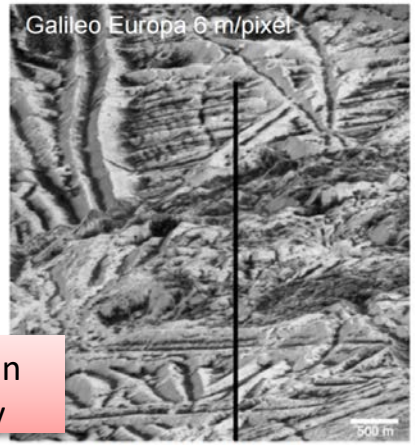
Challenges for Navigation Sensors for Europa Environment & CONOPS

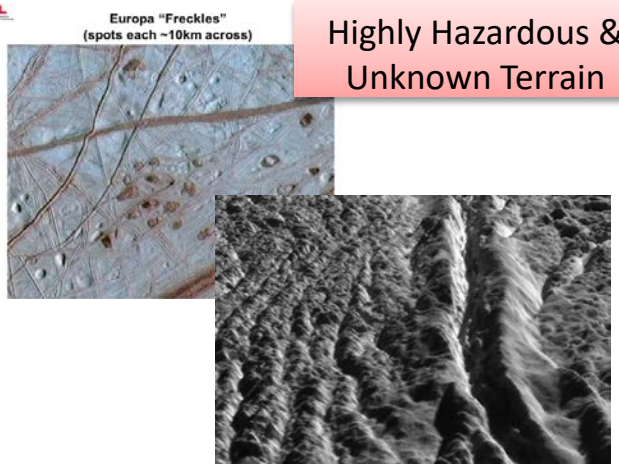
Current Lack of High-res Recon Maps



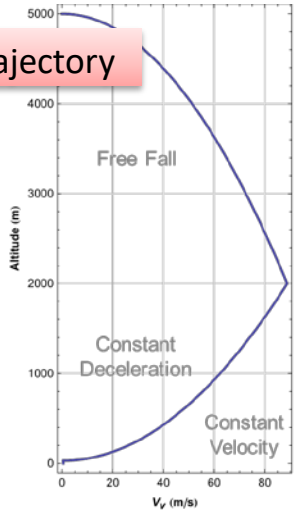
Highest Resolution Europa image currently available

Illumination Variability

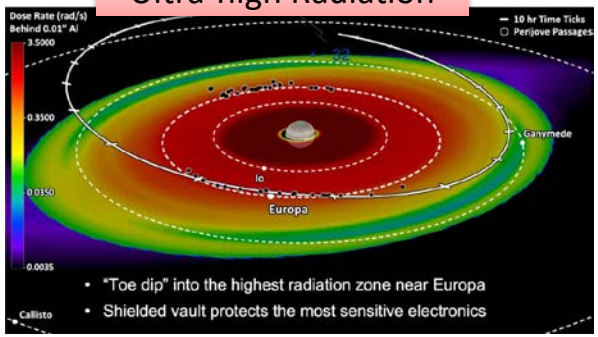
Highly Hazardous & Unknown Terrain

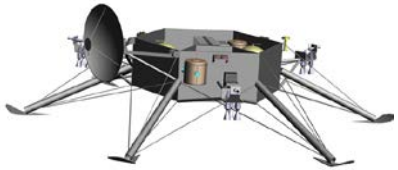


Unique Trajectory



Ultra-high Radiation





Limited Lander SWAP Resources

Existing navigation sensors cannot survive in the severe environments

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Need for Hazard Detection

Ubiquitous hazards at all scales

Lack of recon 3D data at required scales and at time of launch

Highest Resolution Europa image currently available

Terrain relative navigation can resolve large scale hazards but <u>not</u> lander scale hazards

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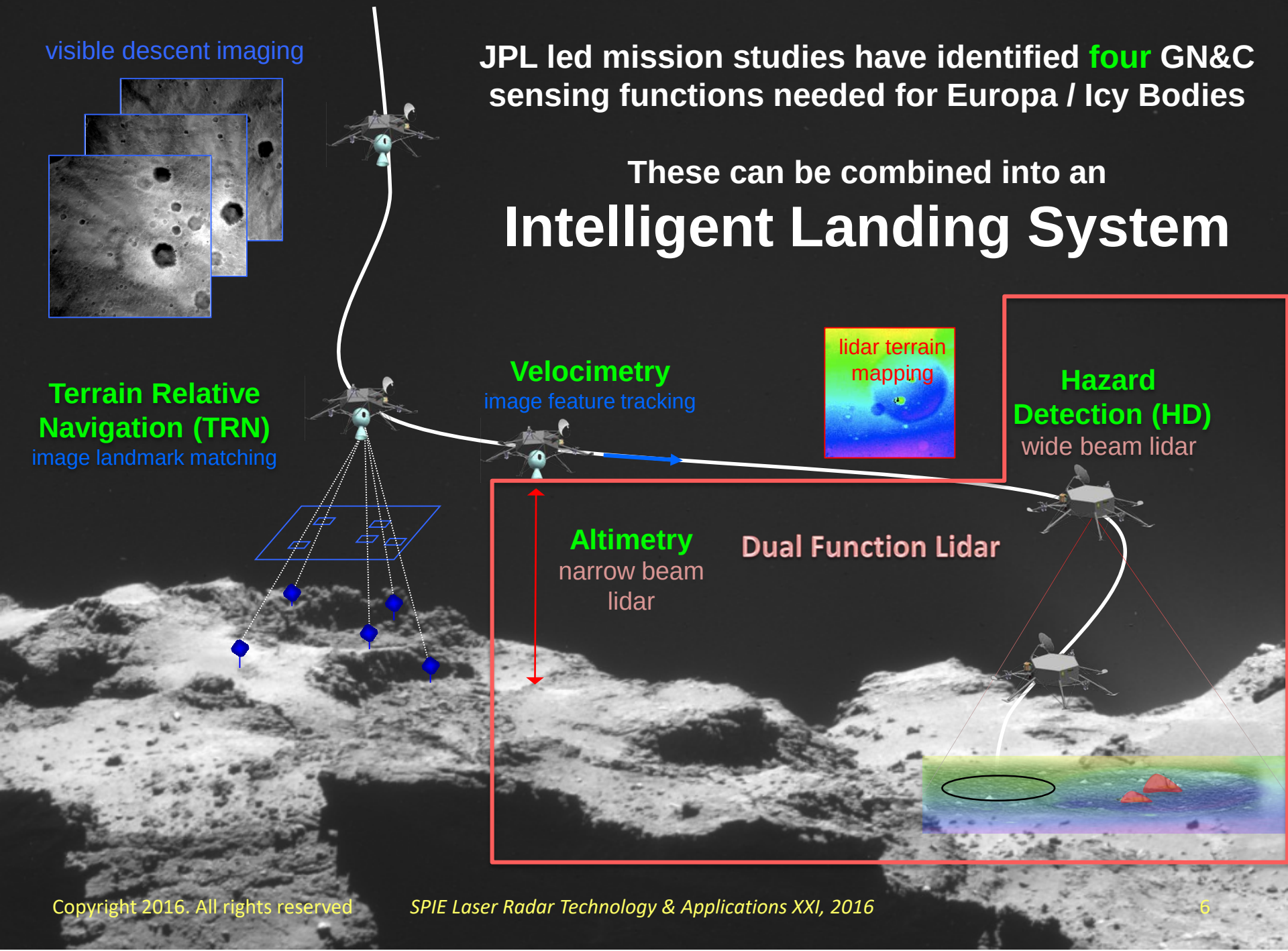
JPL led mission studies have identified four GN&C sensing functions needed for Europa / Icy Bodies

These can be combined into an

Intelligent Landing System



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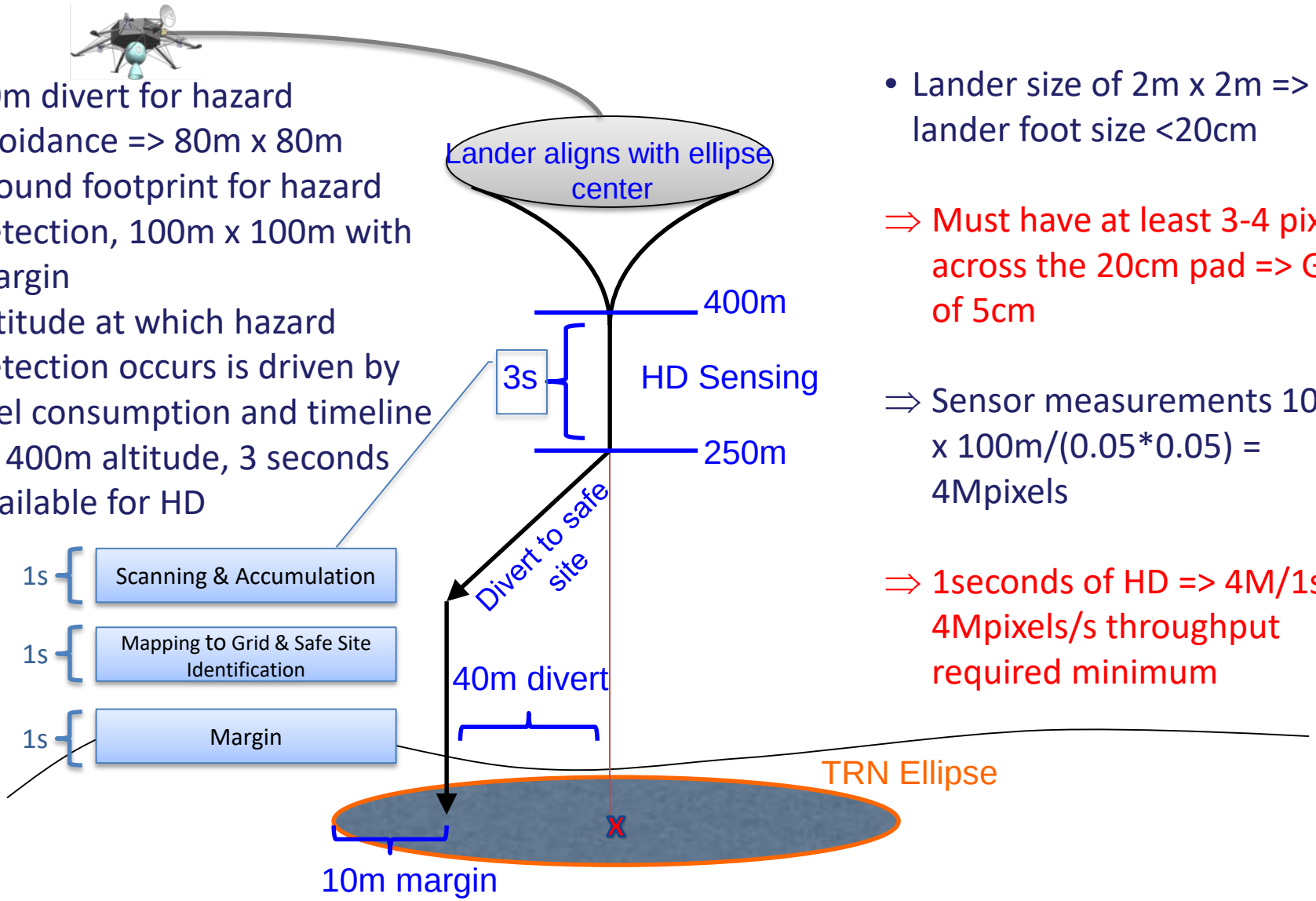
CONOPS – Hazard Detection (HD)

- 40m divert for hazard avoidance => 80m x 80m ground footprint for hazard detection, 100m x 100m with margin
- Altitude at which hazard detection occurs is driven by fuel consumption and timeline
- At 400m altitude, 3 seconds available for HD



- Lander size of 2m x 2m => lander foot size <20cm

⇒ Must have at least 3-4 pixels across the 20cm pad => GSD of 5cm

⇒ Sensor measurements 100m x 100m/(0.05*0.05) = 4Mpixels

⇒ 1seconds of HD => 4M/1s ~ 4Mpixels/s throughput required minimum

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4 Steps of Hazard Detection

1. Terrain Mapping
   - Ensure sufficient ground sample distance
   - Potentially oversample for noise reduction
   - Account for vehicle motion during scan

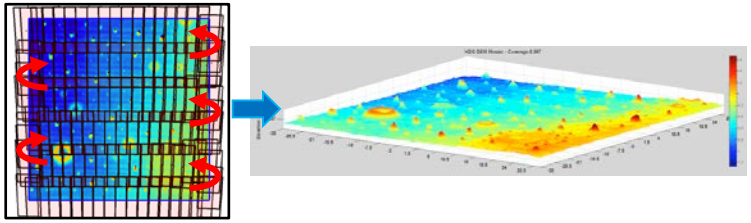
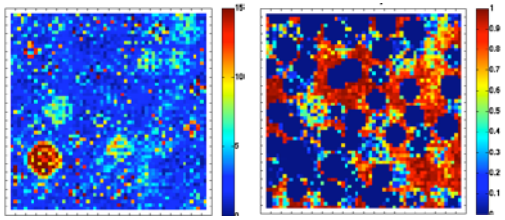


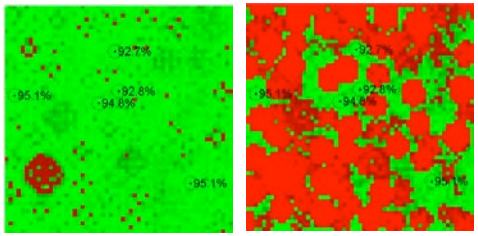
Image Mosaic 3D Digital Elevation Map

2. Terrain Characterization
   - Slope
   - Roughness (terrain height difference from local plane)



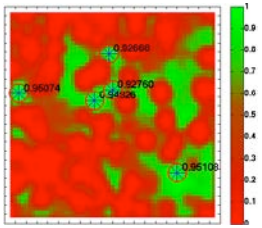
Slope and Roughness Map

3. Hazard Detection
   - Compare local slope and roughness against Lander Tolerances



Slope and Roughness Hazard Map

4. Safe Site Selection
   - Account for Navigation Uncertainty



Safety Map

Hazard Detection requires an accurate, high-resolution 3D terrain map to reliably measure slopes and roughness

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Representative System Features: *3D Hazard Detection*

Field of View	16.3° x 16.3°
Minimum Albedo	0.22 (i.e., 0.67 ÷ 3)
Target Area	100 m x 100 m
Ground Spatial Resolution	0.05 m
Imaging Range (Nominal, min, max)	(350, 250, 500) meters
Descent Velocity	50 m/sec
Nominal Horizontal Velocity	0 m/sec
3-axis velocity knowledge error	1 m/sec
Range Precision (1σ)	≤ 2 cm
Data Acquisition Time	≤ 1 sec
Image Size	2000 x 2000 (4 Mpixels)
Data Rate	≥ 4 Mpixels/sec
Solar Constant (Background compared to Earth)	$\geq 4.08 \times 10^{-2}$
Probability of Detection (Post Processed)	≥ 0.999
Probability of False Alarm (Post Processed)	$\leq 2.5 \times 10^{-8}$

Mass: <6kg (with shielding) **Power: <50W**

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Representative System Features: *Altimetry*

Field of Regard	Single Point
Minimum Albedo	0.22 (i.e., 0.67 ÷ 3)
Minimum Range	10 meters
Nominal Range	3 kilometers
Maximum Range	5 kilometers
Descent Velocity	50 m/sec
Range Precision (1σ)	0.1% of range, ~1-2m at high altitude
Data Acquisition Time	0.1 sec
Data Processing Time	0.1 sec
Image Size	N/A
Data Rate	10 Hz
Solar Constant (Background compared to Earth)	$\geq 4.08 \times 10^{-2}$
Probability of Detection (Post Processed)	0.9
Probability of False Alarm (Post Processed)	6×10^{-4}

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Lidar Modalities under Consideration

- Linear mode
  - Single detector with 2D scan
    - Limited rates on 2D scan mechanisms limit the data collection rate, and therefore coverage
  - 2D Flash arrays
    - 128x128 or 256x256 APDs, requires 2D scan for ground coverage
    - Scanning the entire box is inefficient, scanning just the array requires major redesign
    - Inefficient in terms of signal photons required for a valid measurement
- Photon Counting
  - Lack of atmosphere and reduced solar illumination makes photon counting options attractive from a view point of the system SWAP
  - Single photon avalanche detectors
    - 2D arrays of 32x32 (or custom sizes), or custom line arrays (2048x1, 256x4…)
    - Risley prism or fast steering mirrors for ground coverage
  - Photomultiplier based focal plane arrays
    - 10x10 PMT arrays
  - Susceptibility to radiation remains biggest concern
    - Increase in dark count rate (DCR) due to TID and DD
    - Effects of transient events or particle tracks on pixel dropouts or full frame dropouts
- Studies underway to address concerns and identify mitigations

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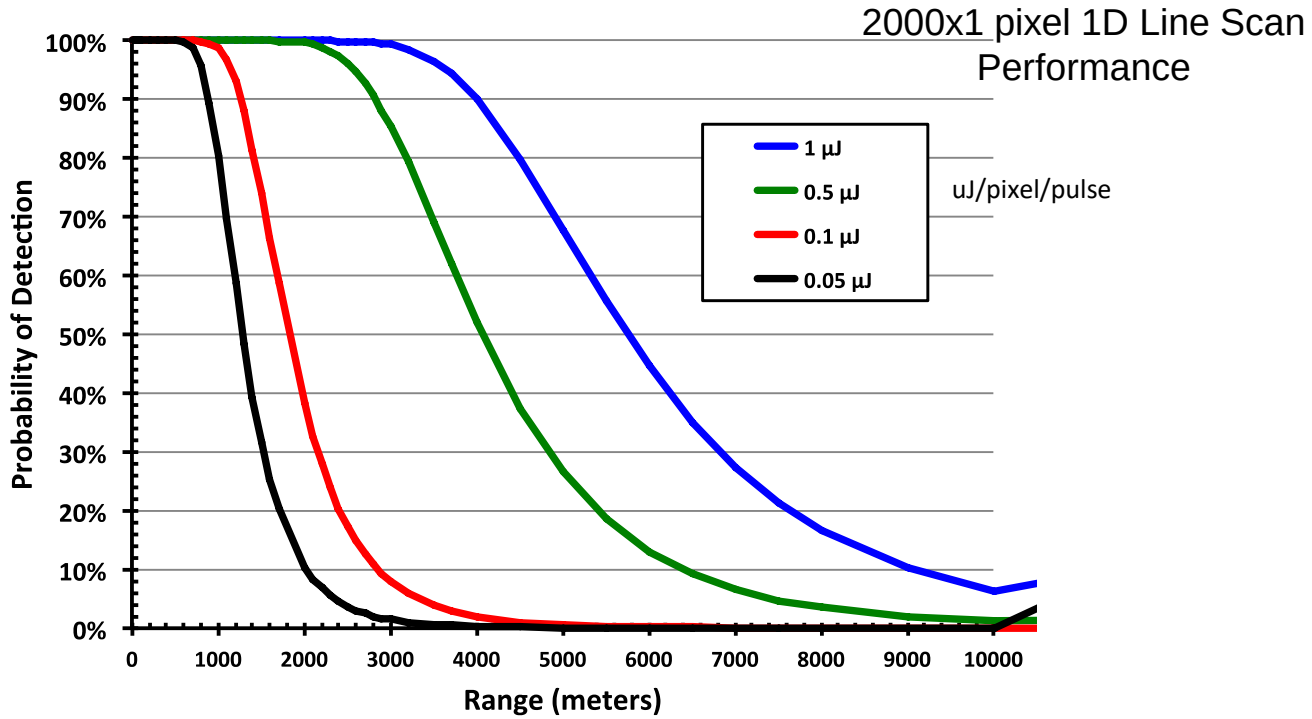
Conceptual Lidar Sensor Link Analysis

- Trade studies are being performed over several configurations – 2D arrays, line scan
- Radiometric analyses show that required performance wrt detection probabilities is feasible



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Summary

- Landing on Europa represents significant and unique challenges for navigation sensors
- The previously unmapped and highly hazardous terrain requires active 3D sensing and mapping of the surface during landing
- Existing lidars do not provide the performance nor have the capability to survive the environments in a form factor that is amenable to the limited SWAP resources of the lander
- Photon counting systems show promise in meeting the performance and SWAP requirements
- Lidar link analysis shows a photon counting approach is feasible
- However, susceptibility to radiation is still a big concern and efforts are underway to identify and investigate solutions

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BACKUP

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Conceptual 1D Line Scan Characteristics

- Multiple 2xNd:YAG Transmitters
  - 532 nm
  - 1 nsec pulse, 10 kHz (10 pulse per pixel)
  - 1, 0.5, 0.1 or 0.5 μJ/pixel/pulse
  - $M^2 = 2$
  - $\eta_T = 0.92$
- 1” Receiver
  - Fiber-optically coupled focal plane
  - $\eta_R = 0.81$
  - $\eta_Q = 0.45$
  - Fiber optic coupling efficiency = 0.25
  - DCR = 200 kHz

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Linear Array Line Scan

- Single Pulse/ 2000 Detector Elements
  - 1 x 2000 element array
  - No Averaging
  - High Precision
- 1-axis Scanner
- Single Electronic Signal Processing Chain
- 1000 pulses per second minimum
  - 100% scan efficiency
  - 1.0 millisecond interpulse period
  - 150 kilometer maximum unambiguous range

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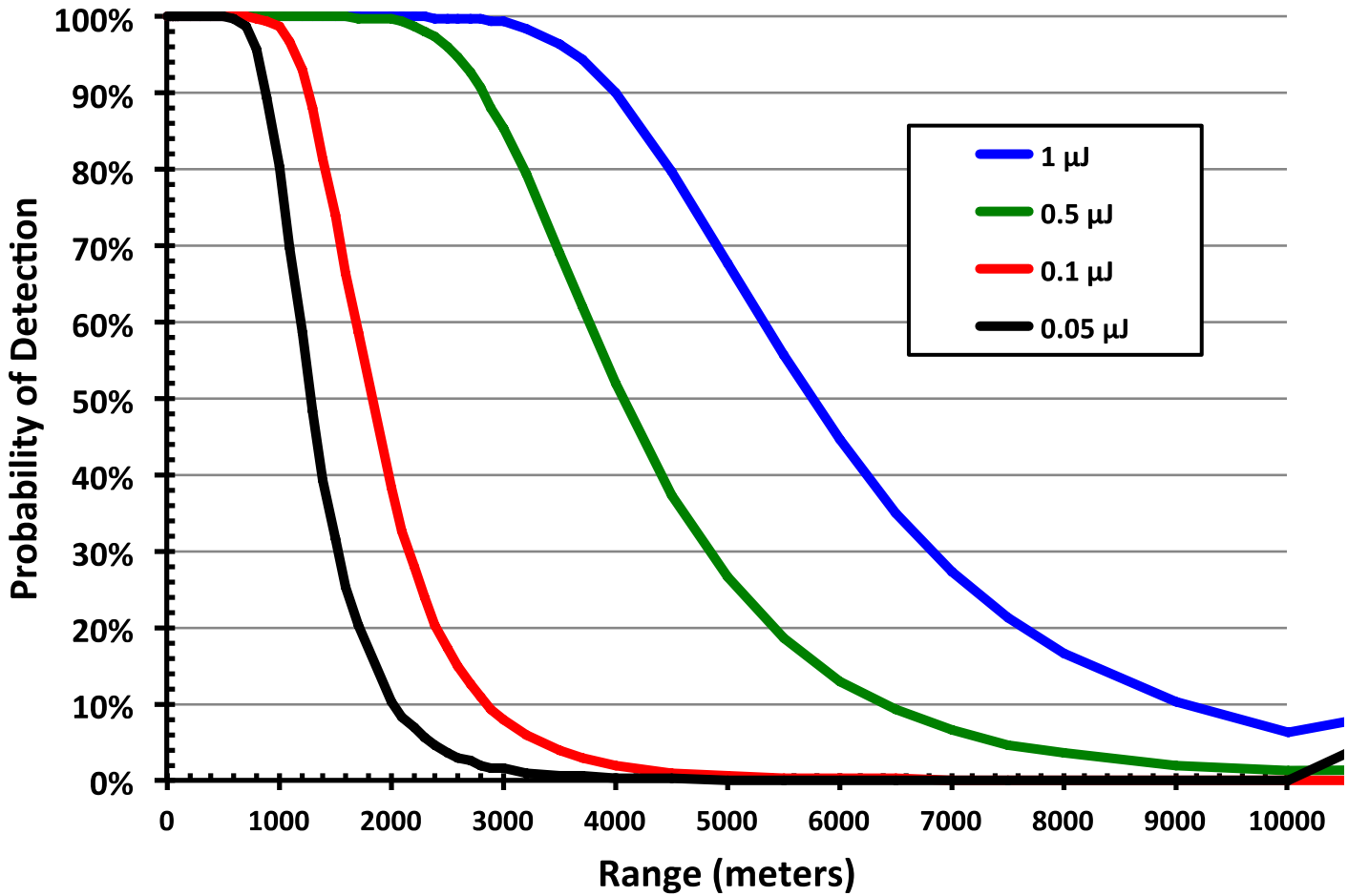
1D Line Scan Performance



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