On the Challenges of Designing a Soft Lander for Europa

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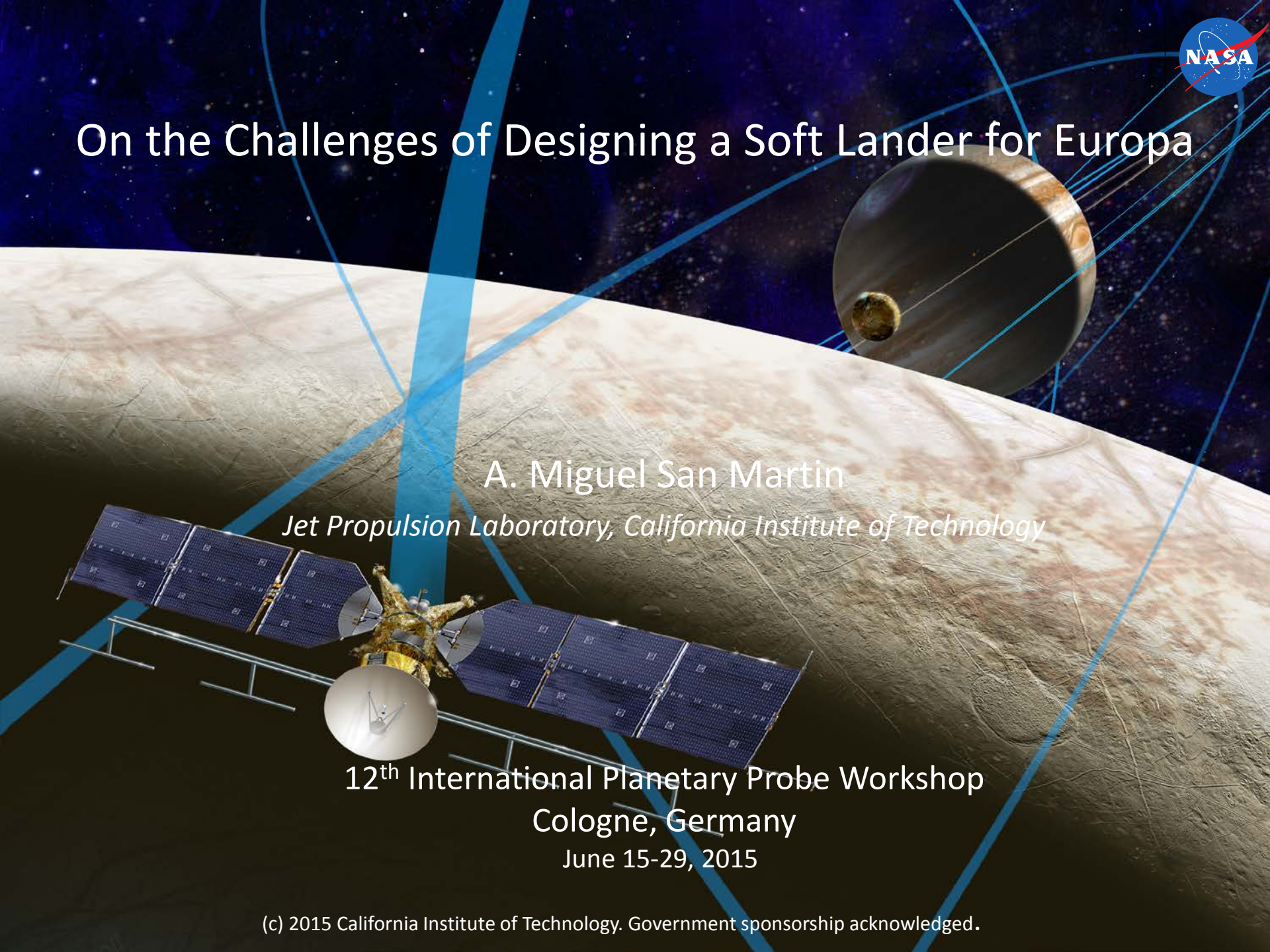


12th International Planetary Probe Workshop
Cologne, Germany
June 15-29, 2015

(c) 2015 California Institute of Technology. Government sponsorship acknowledged.

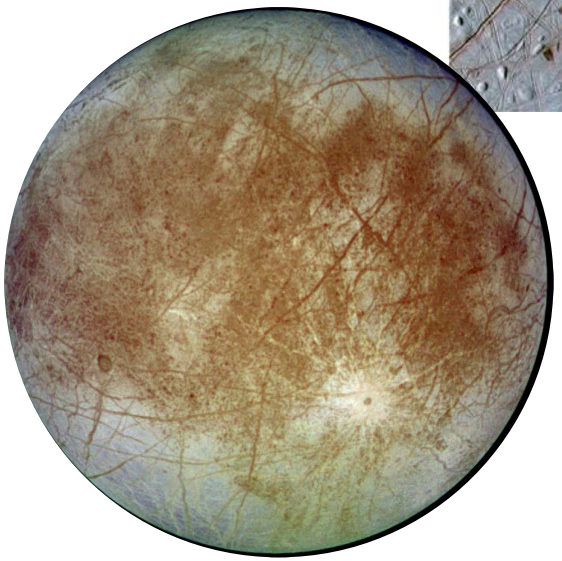
Acknowledgements

- Sam Thurman
- Dara Sabahi
- Kevin Hand
- Aline Zimmer
- Michael Fong
- Bryan Kobie
- Ed Jorgensen
- Andrew Johnson
- Anup Katake
- Nikolas Trawny

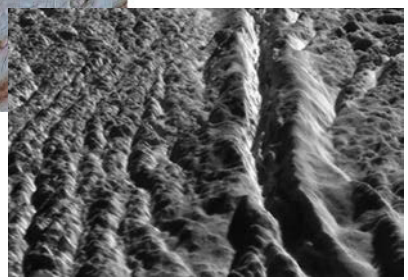
Challenges of Landing in Europa

Current Lack of High-res Recon Maps

Highest Resolution Europa image currently available

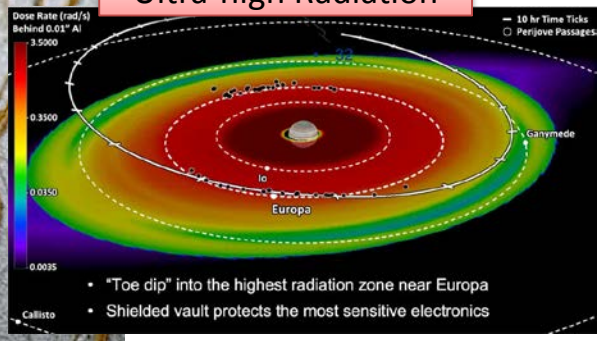


Highly Hazardous & Unknown Terrain

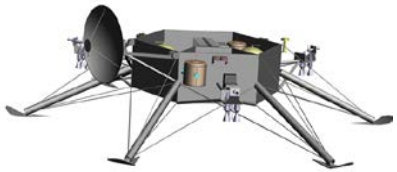


Illumination Variability

Ultra-high Radiation

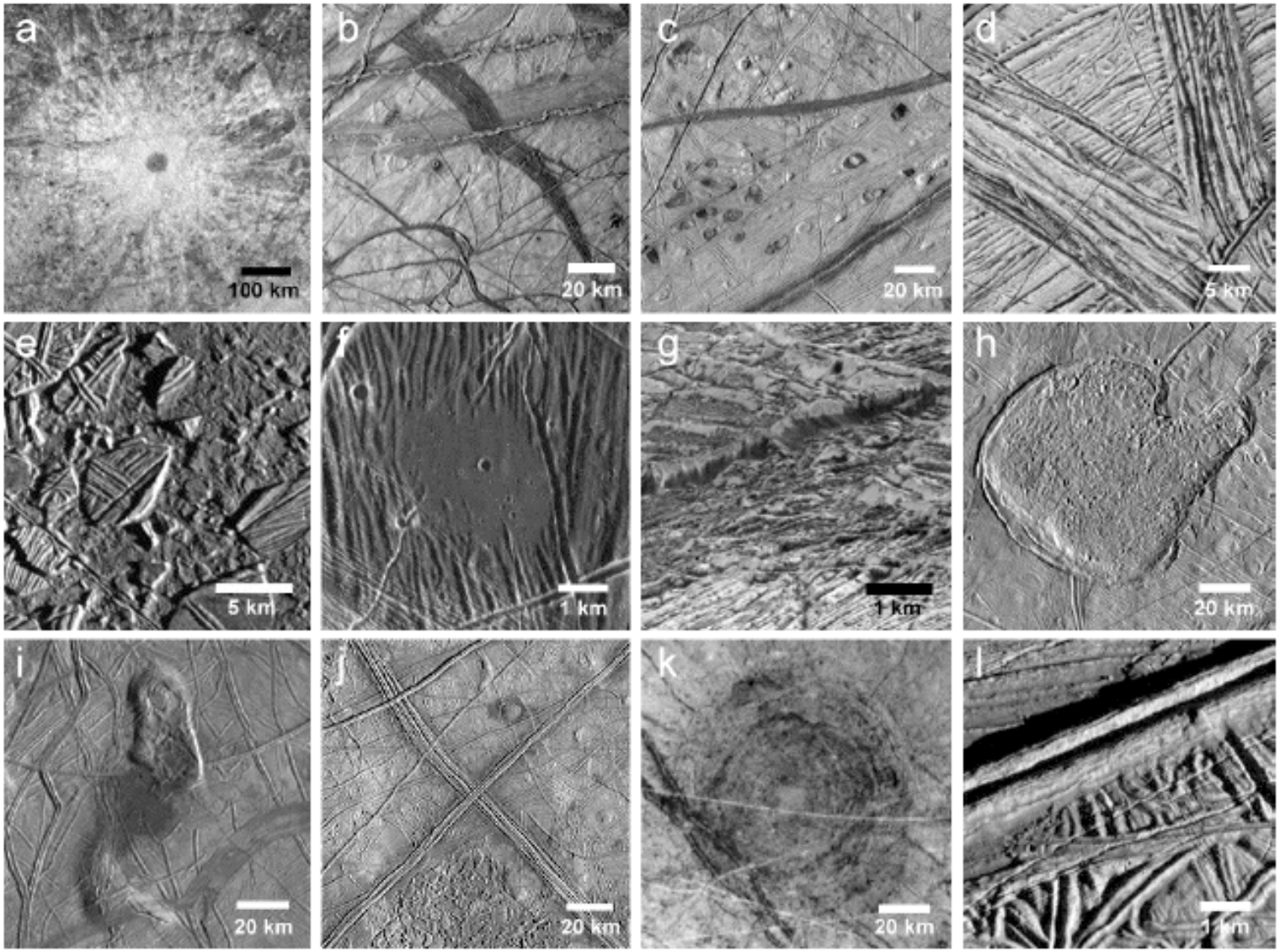


Large Propulsive Delta-V

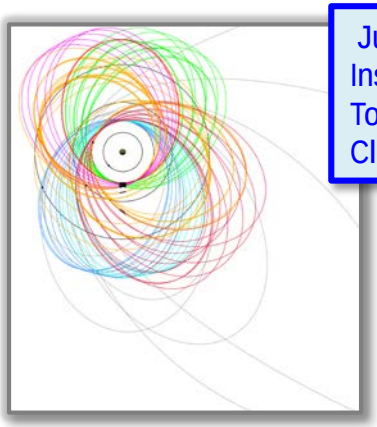


Limited Lander SWAP Resources

Examples of Europa's Surface

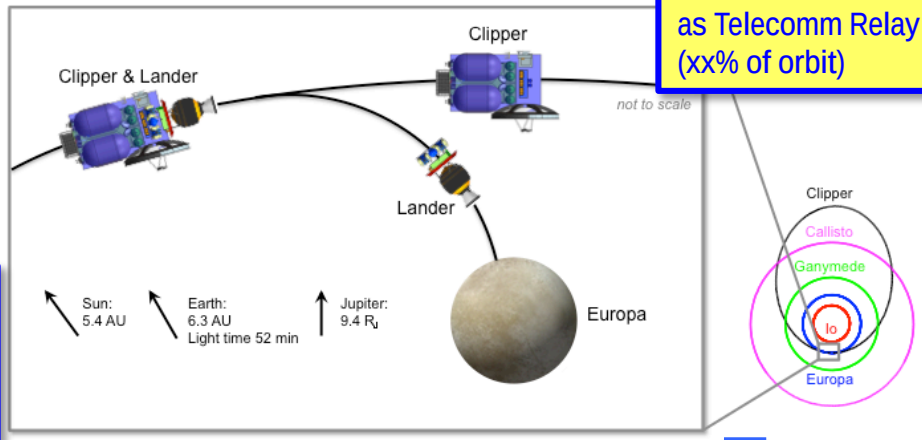


Landed Package Mission Summary and Key Assumptions

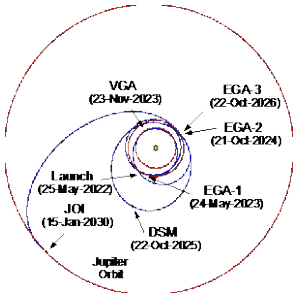


Jupiter Orbit Insertion and Satellite Tour (to nominal Clipper EOM)

Clipper Orbit Period Reduction (6 months, to reduce Europa flyby velocity)



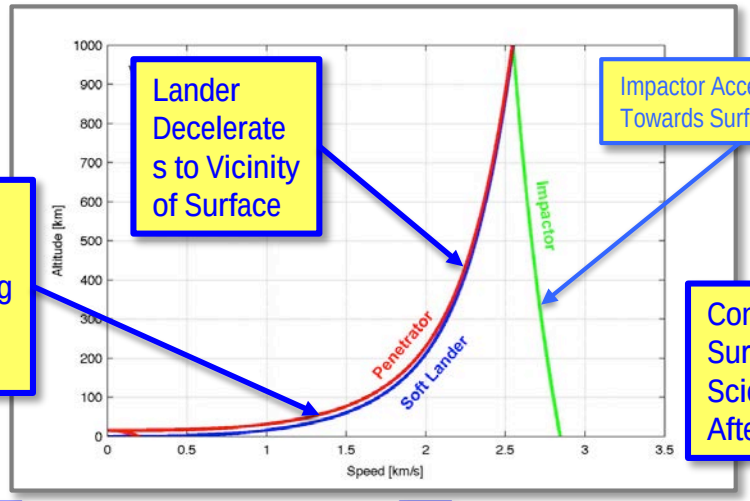
Clipper Deploys Lander and Serves as Telecomm Relay (xx% of orbit)



ΔVEGA Interplanetary Transfer (4.7 yr.)

SLS Launch of Integrated Clipper + Lander Stack

Altitude vs. Speed Regimes for Europa Probes



Lander Decelerates to Vicinity of Surface

Impactor Accelerates Towards Surface Impact

Terminal Guidance to Landing (Impact) Site

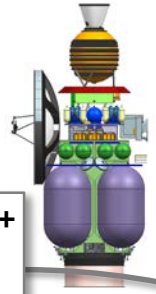
Conduct Surface Science Ops After Landing

Clipper Nominal Mission

Mods for Lander Mission

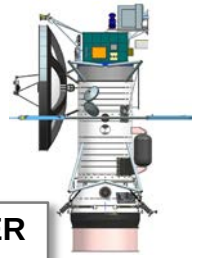
Pre-Decisional Information -- For Planning and Discussion Purposes Only

Very Large Propulsive Capability (and Mass) Needed to Reach Surface from Clipper Flyby



CLIPPER + LANDER

9,200 kg



CLIPPER ONLY

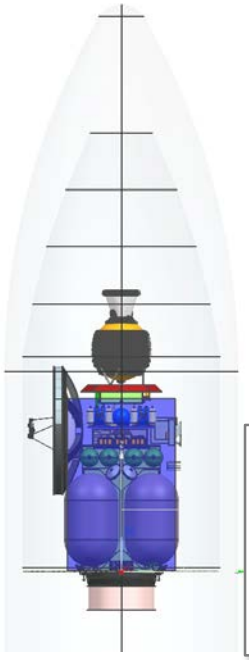
4,400 kg

LANDER
ACCOMMODATION

3,500 kg

- **PROPELLENT**
- **PROPULSION**
- **SOLAR ARRAY**
- **STRUCTURE**
- **THERMAL & HARNESS**

Clipper Only (4,400 kg) + **Lander Accommodation** (3,500 kg) + **Breaking Stage** (1,000 kg) + **Descent Stage** (200 kg) + **Surface Package** (100 kg) = **Integrated Clipper/Lander Stack** (9,200 kg)



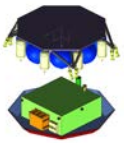
SLS LAUNCH CAPABILITY

5,200 kg Direct

13,300 kg **ΔVEGA**

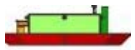
BREAKING STAGE

1,000 kg



DESCENT STAGE

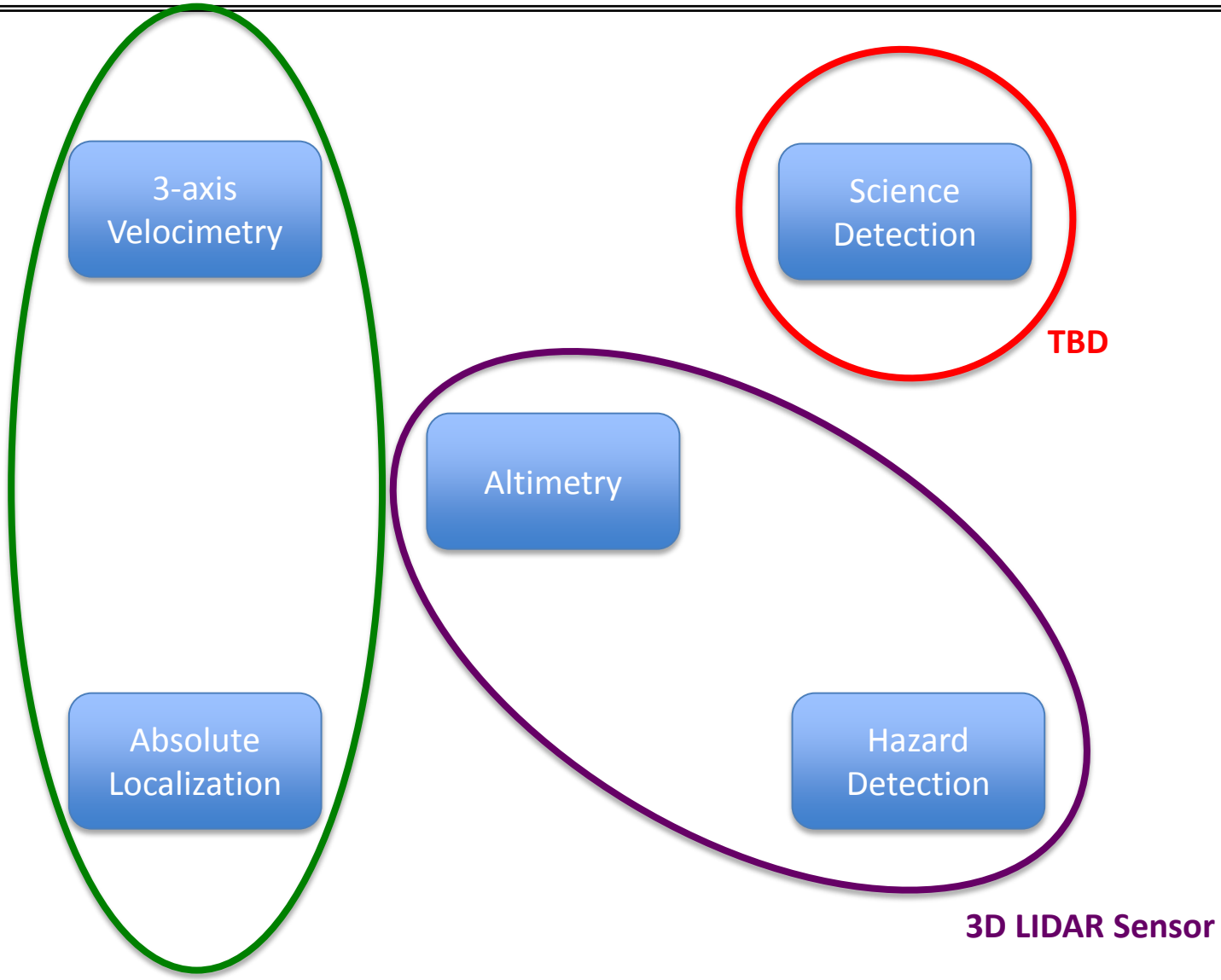
200 kg



SURFACE

100 kg

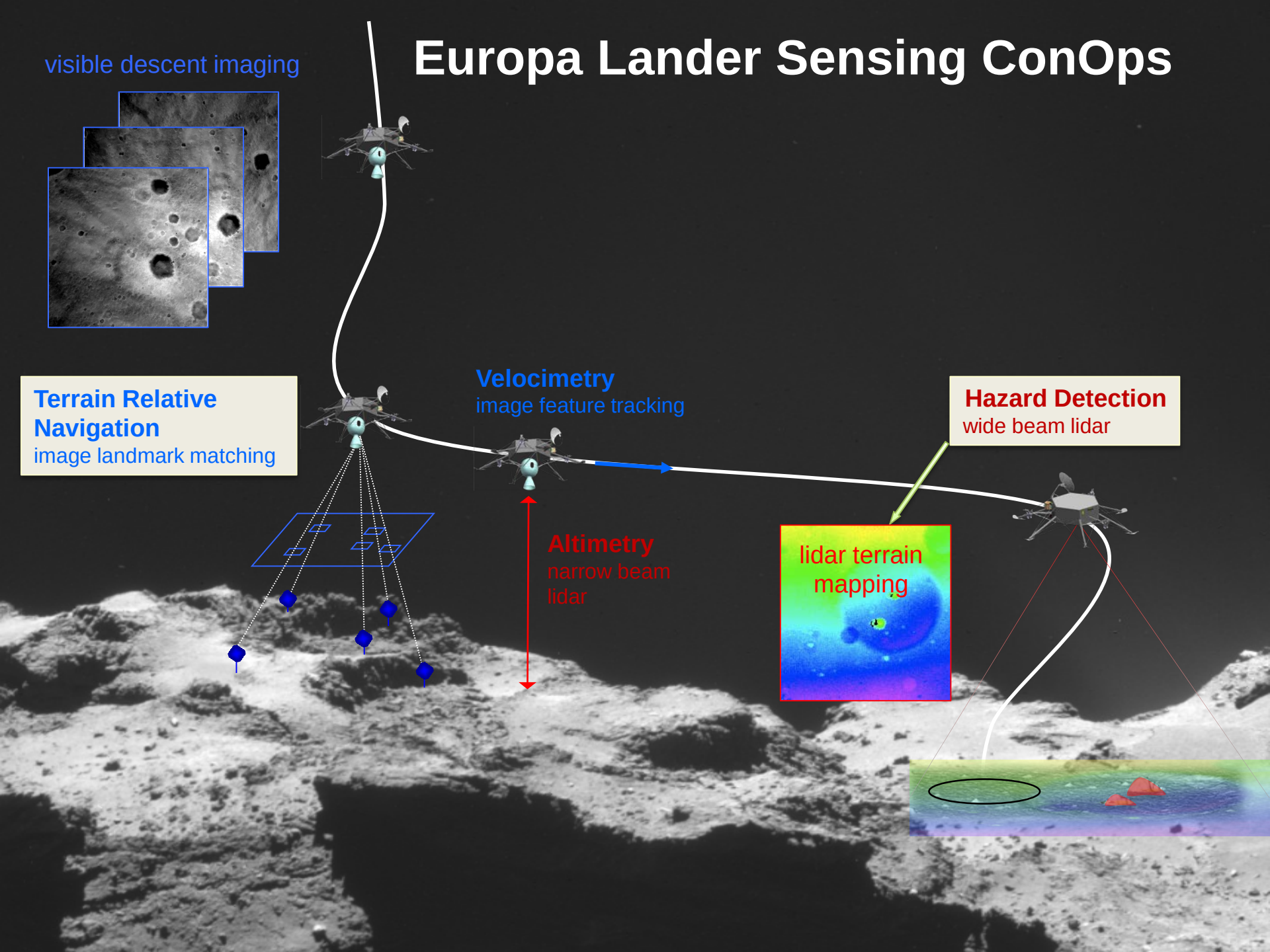
Proposed Europa Lander Sensors



Terrain Relative Navigation (TRN) Sensor

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

Europa Lander Sensing ConOps



TRN: JPL Lander Vision System (LVS)

Flight Processor
Navigation Filter
Data Flow

Virtex 5 FPGA
Image Processing
Sensor Interfaces

Memory
for map

LVS Compute Element

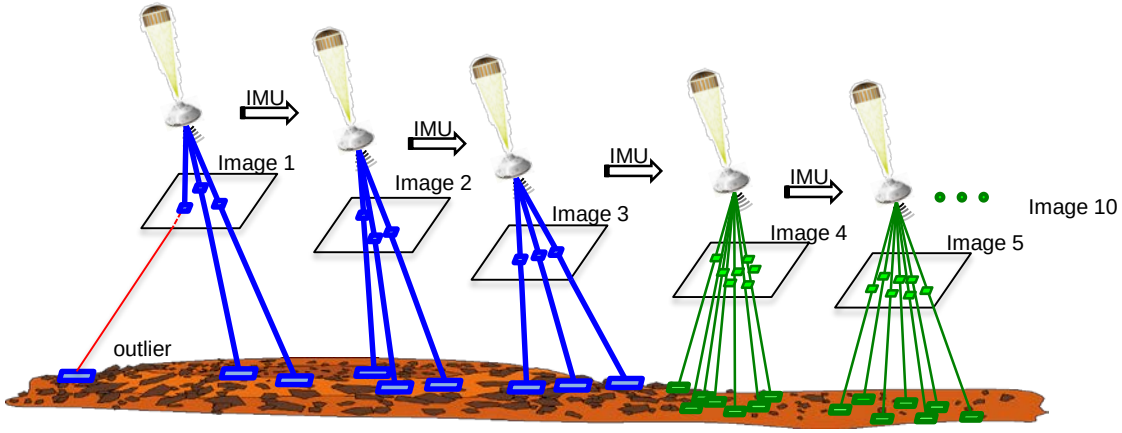
LVS Inertial Measurement Unit

LVS Camera

LVS Requirements for Mars 2020
- Remove 3km initial position error
- <40m accuracy
- <10s processing time

State Estimation

Fuse inertial measurements from Inertial Measurement Unit (IMU) with landmarks from 1024x1024 images and complete in 10 seconds



Coarse Landmark Matching

Remove Position Error (3km 3-σ)

Fine Landmark Matching

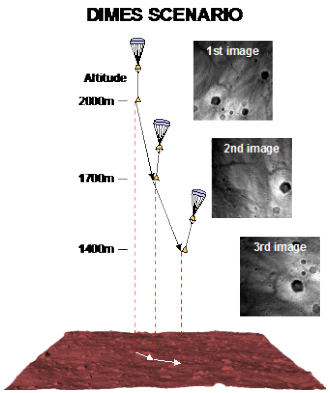
Improve Accuracy (40m 3-σ)

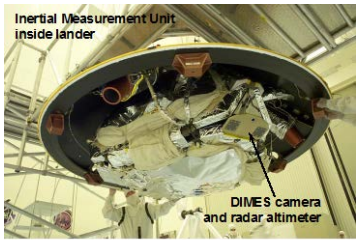
LVS is a prototype, flight-like implementation of TRN for Mars 2020, leveraging 15 years of JPL TRN investments

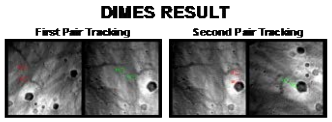
LVS Development History: MER through MSL

Mars Exploration Rover Project

MER-DIMES: 2001 - 2004





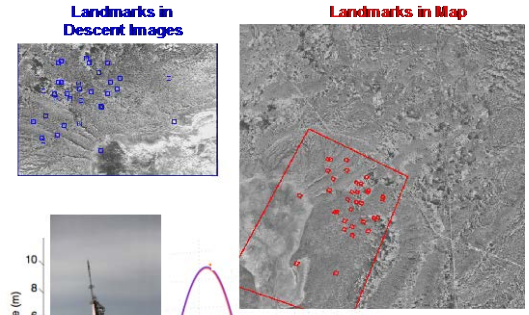


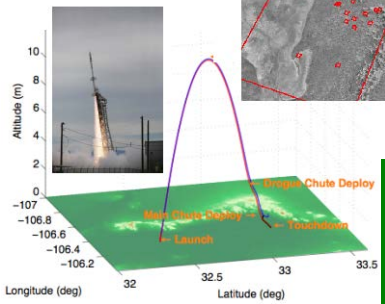
MER-A/Spirit, Gusev Crater, January 4th, 2004

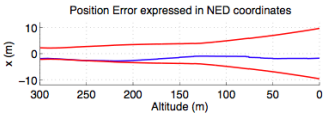
First use of descent images for navigation during EDL. Like TRN, used interest operator, spatial correlation and homography warping.

New Millennium Program

Sounding Rocket Flights: 2005 - 2010



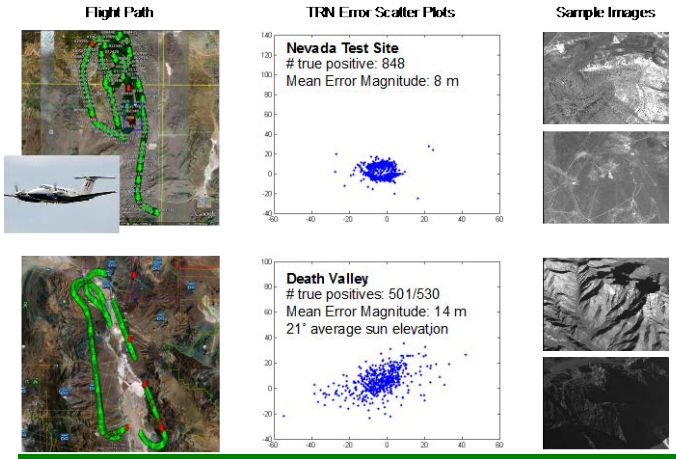




Extended MER-DIMES to estimate position for TRN. Showed that fusing image and IMU leads to more accurate and higher rate TRN.

Autonomous Landing and Hazard Avoidance Technology

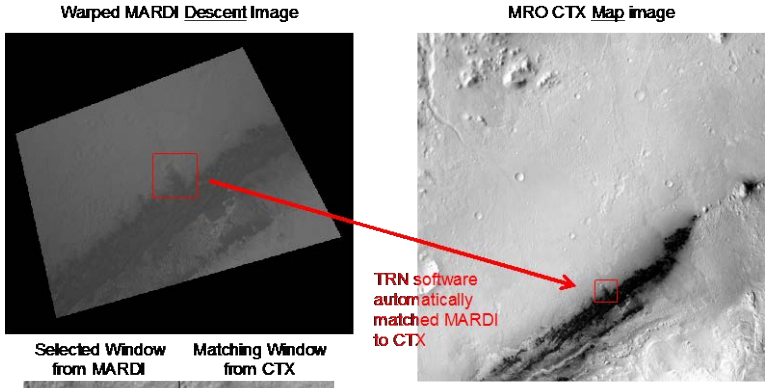
Airplane Field Tests: 2009 - 2011

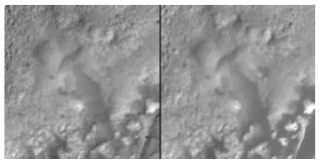


Showed that TRN works with terrain relief, oblique illumination and variety of terrains

Mars Technology Development

MSL MARDI/CTX Post-Processing: 2012





TRN matching works very well
- Correlation peak is tall and narrow
- correlation peak is unambiguous
- position accuracy ~30m

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

Hazards of Landing on Europa and Icy Bodies

Earth glacier surfaces

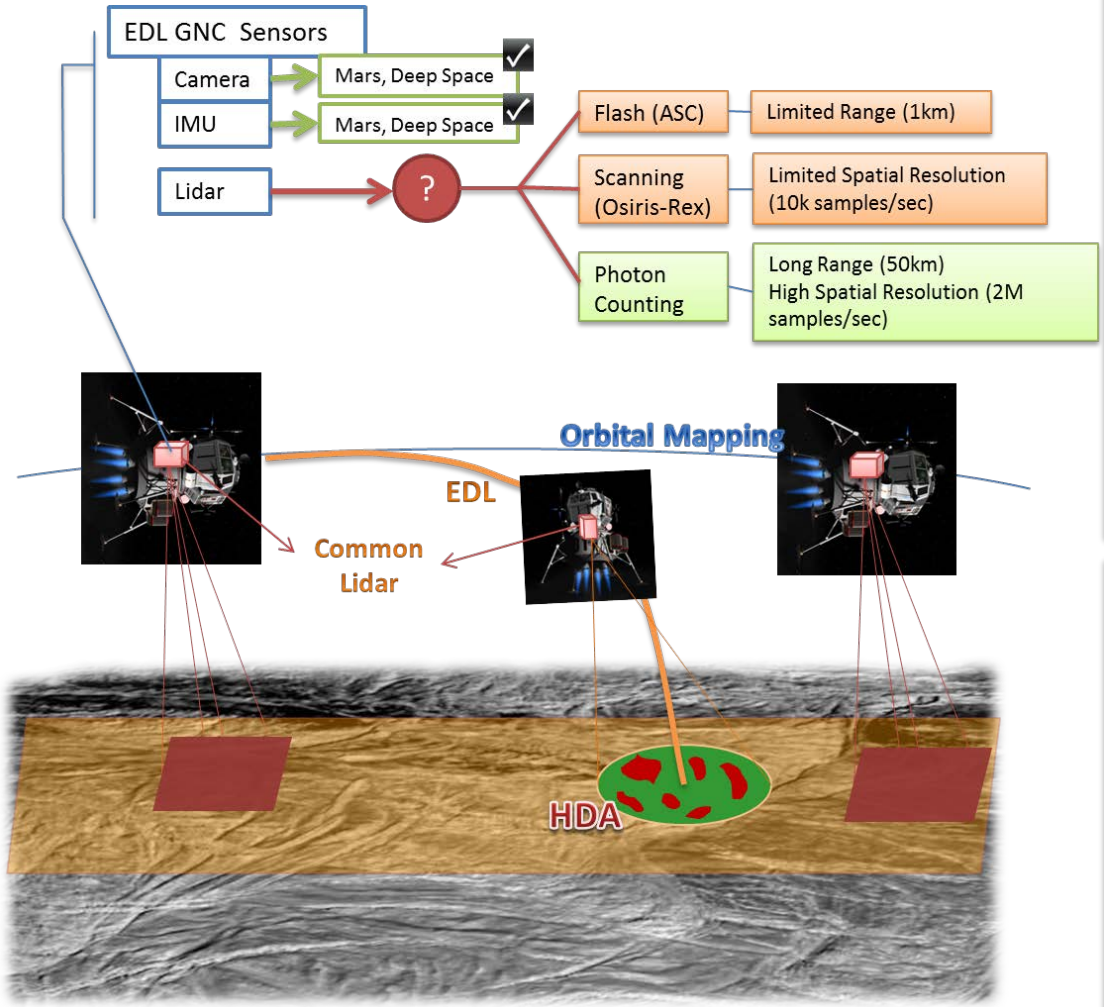
Europa at 12 m/pixel and 10 m/pixel

1 m/pixel

Devil's Golf Course – Death Valley

Current knowledge cannot exclude the possibility of ubiquitous landing hazards

Need for HD Sensor (LIDAR) for Europa



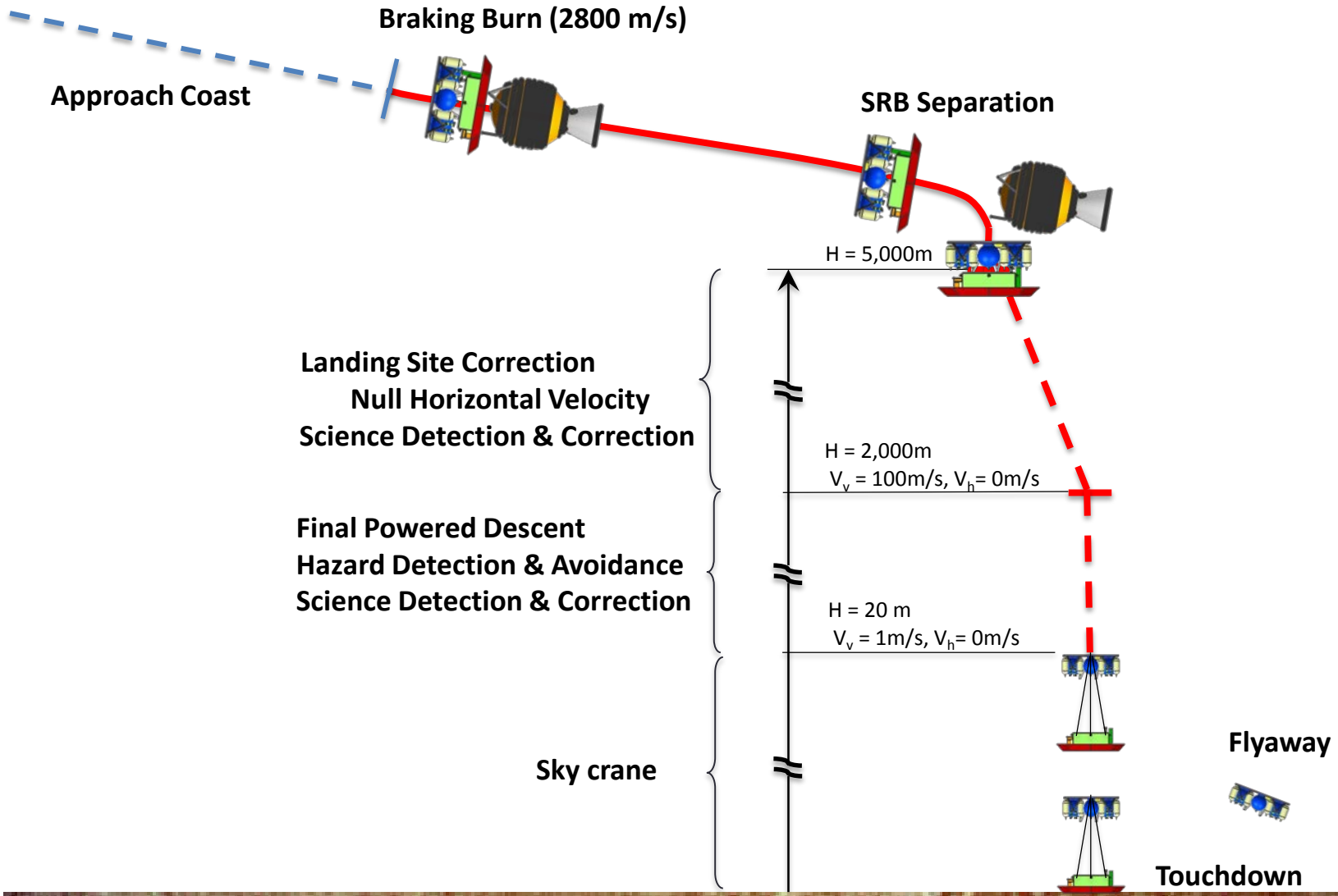
Problem

- Evidence of hazardous terrain at all scales
- Current EDL technology relies on use of orbiting assets (eg. MRO) to generate precision terrain maps used during EDL
- Current HD LIDAR technology has limitations in Range, Resolution, and SWAP
- Extreme radiation environment

Proposed Solution Space Objectives

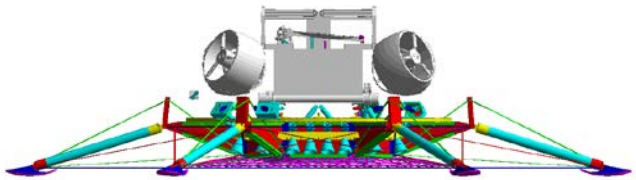
- Overcome range and sampling limitations of SOA LIDARs
- Capable of mapping from 50km orbital range to 1m during EDL
- High/adaptable density mega-pixel per second sampling allows for same sensor to be used for hazard detection and landing site selection
- Must handle extreme radiation environment

Europa Landing Sequence Outline



Europa Surface

Touchdown System

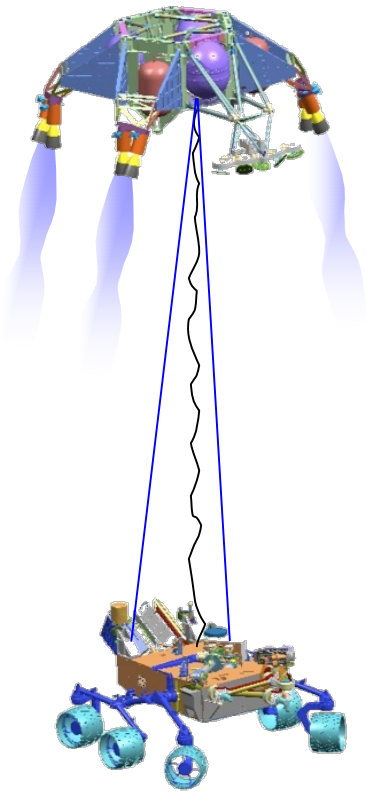


Pallet

Other

?

Legged Lander



SkyCrane

Conclusions

- Landing on Europa requires solving unprecedented challenges
  - Large propulsive needs for JOI and Braking burns have a large impact on lander and carrier spacecraft mass and configuration
  - Hazardous terrain at all scales
  - Lack of high resolution maps and images of Europa's surface
  - Very high radiation environment

- NASA is currently studying mission concepts and technology developments to support a Europa Lander as part of Europa Clipper with a launch date in the 2022 timeframe