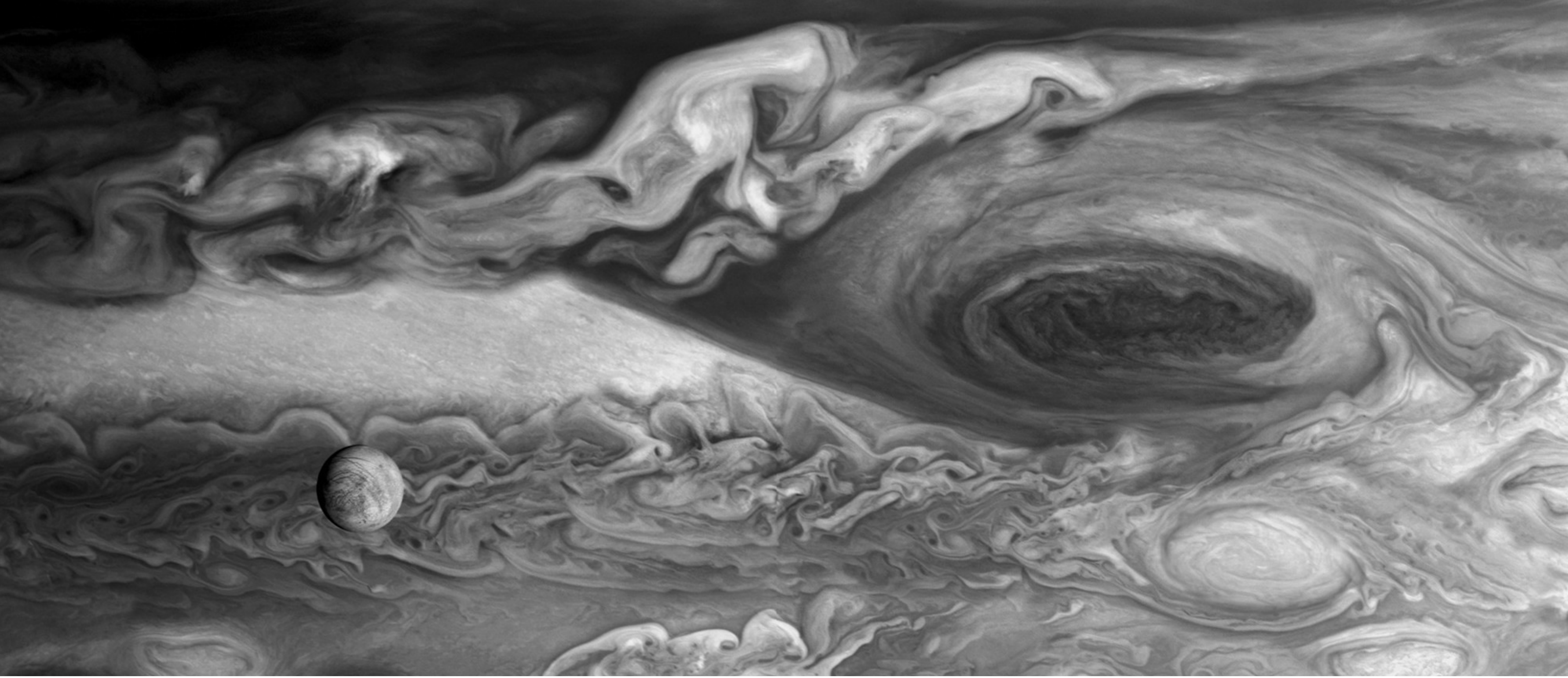
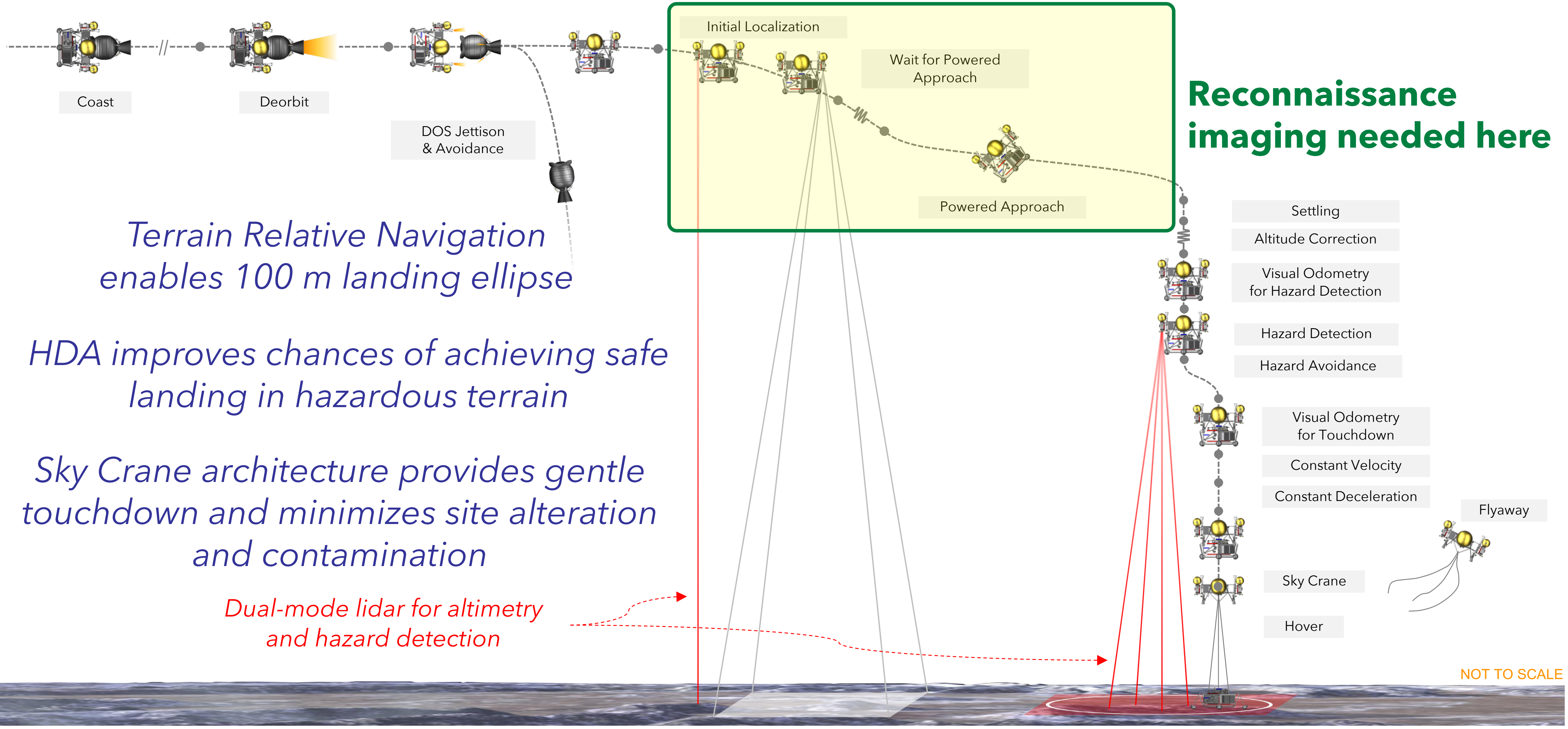


DDL Overview and Reconnaissance Needs

Greg Garner, David Skulsky, Nikolas Trawny
Jet Propulsion Laboratory, California Institute of Technology
September 10, 2018

Pre-Decisional Information – For Planning and Discussion Purposes Only

DDL Concept of Operations



Terrain Relative Navigation enables 100 m landing ellipse

HDA improves chances of achieving safe landing in hazardous terrain

Sky Crane architecture provides gentle touchdown and minimizes site alteration and contamination

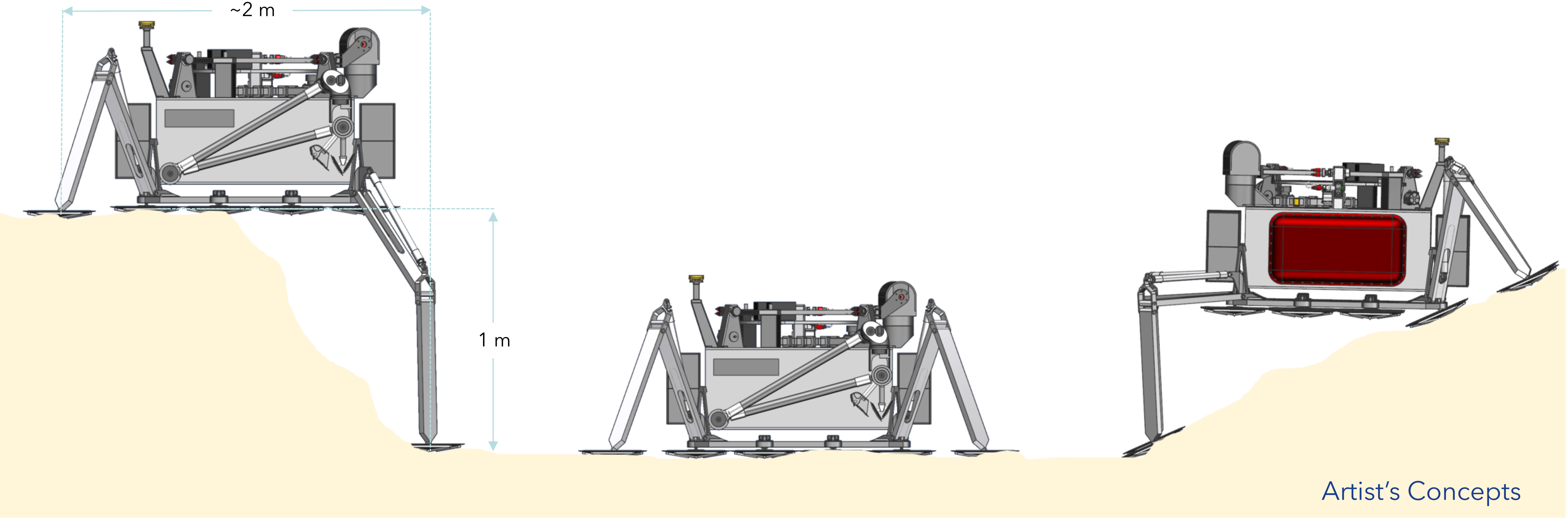
Hazard Detection and Avoidance

Hazard Detection and Avoidance ensures that the vehicle would find and land in the safest location within a 100 m diameter circle

- Hazard detection: In 3 sec map a 100 m × 100 m area from an altitude of 500 m with a ground sample distance of 5 cm and select the safest place to land
  - 100 m × 100 m provides many lander-sized regions to land, only one of which needs to be safe
- Hazard avoidance: Be capable of diverting up to 50 m in any direction
- In July we completed Phase 1 of a three phase study to investigate promising 3D-lidar architectures for hazard detection
  - Three vendors participated in Phase 1; will downselect to two vendors prior to start of Phase 2
  - At the end of Phase 3 (2020), vendors will provide brassboards for field testing as well as a path to flight
- Lidar would also function as an altimeter

Landing Stabilizers

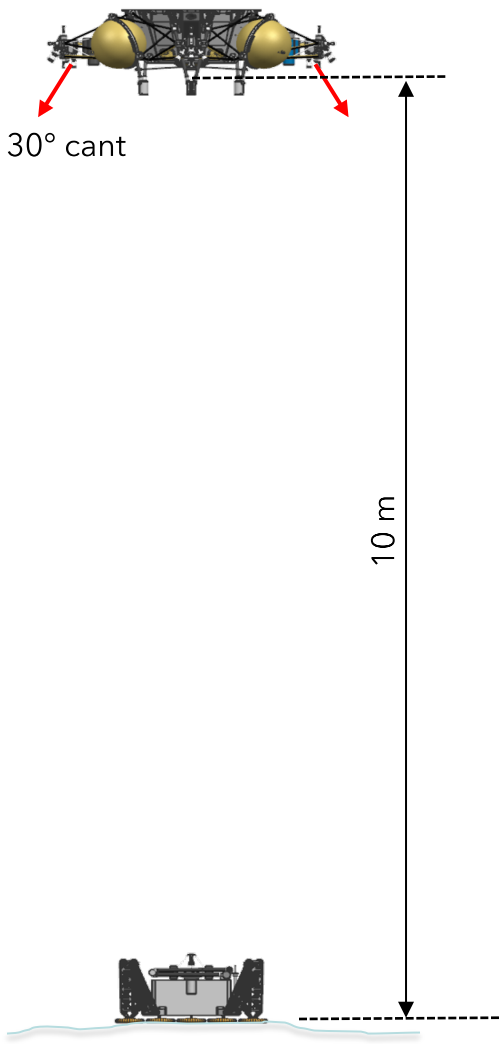
Landing Stabilizers ensure that the Lander is stable and level in the presence of up to 1 m of terrain relief



Sky Crane

Sky Crane ensures that the Lander would be delivered to the surface gently and with minimal disturbance and contamination of the landing location

- <u>Gentle touchdown</u>:
  - V_V @ Touchdown < 0.8 m/s
  - V_H @ Touchdown < 0.3 m/s
- <u>Don't disturb landing location</u>:
  - Bridle length ~10 m
    - MSL was 7.5 m
  - Canted Descent Engines
    - Canted at least 30°
    - Plume impingement modeling and analysis underway



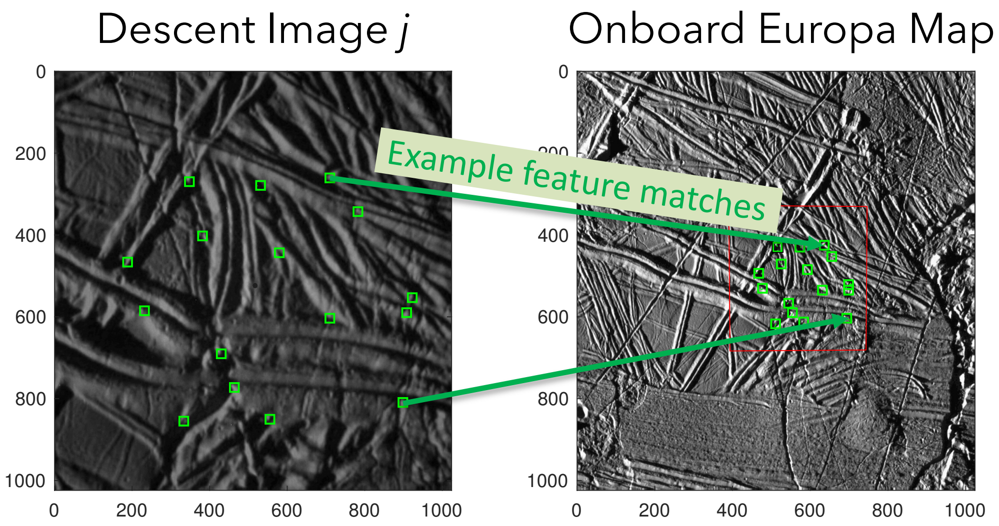
Terrain Relative Navigation (TRN)

Terrain Relative Navigation provides the surface-relative position and velocity so that the vehicle can be steered to the targeted landing location

- Position knowledge uncertainty:
  - 100 m (3σ)
- Velocity knowledge uncertainty:
  - 1 m/s (3σ) during Powered Approach
  - 0.1 m/s (3σ) during Sky Crane

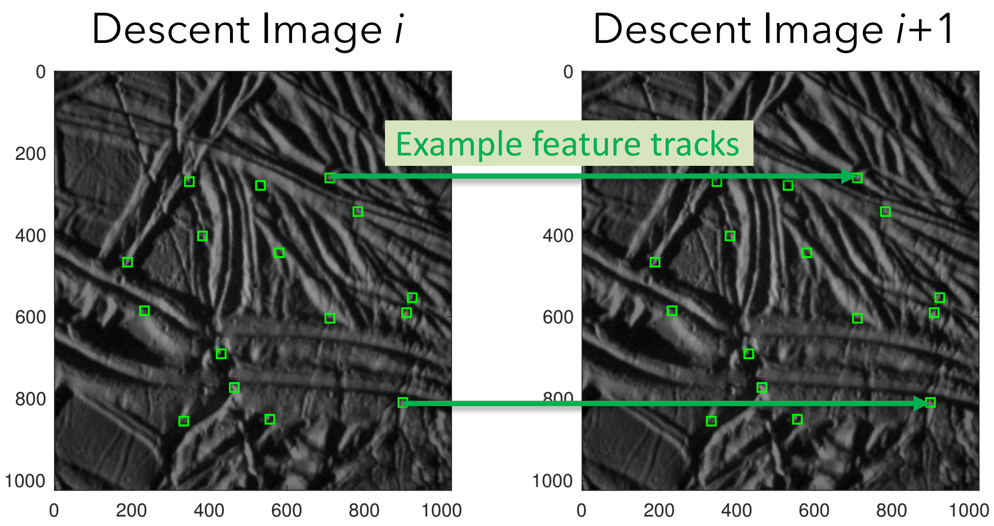
- TRN has two distinct functionalities, map-relative localization (MRL) and visual odometry
  - MRL enables landing at certified safe landing site
  - VO enables required small touchdown velocities

TRN Functions



Map-Relative Localization

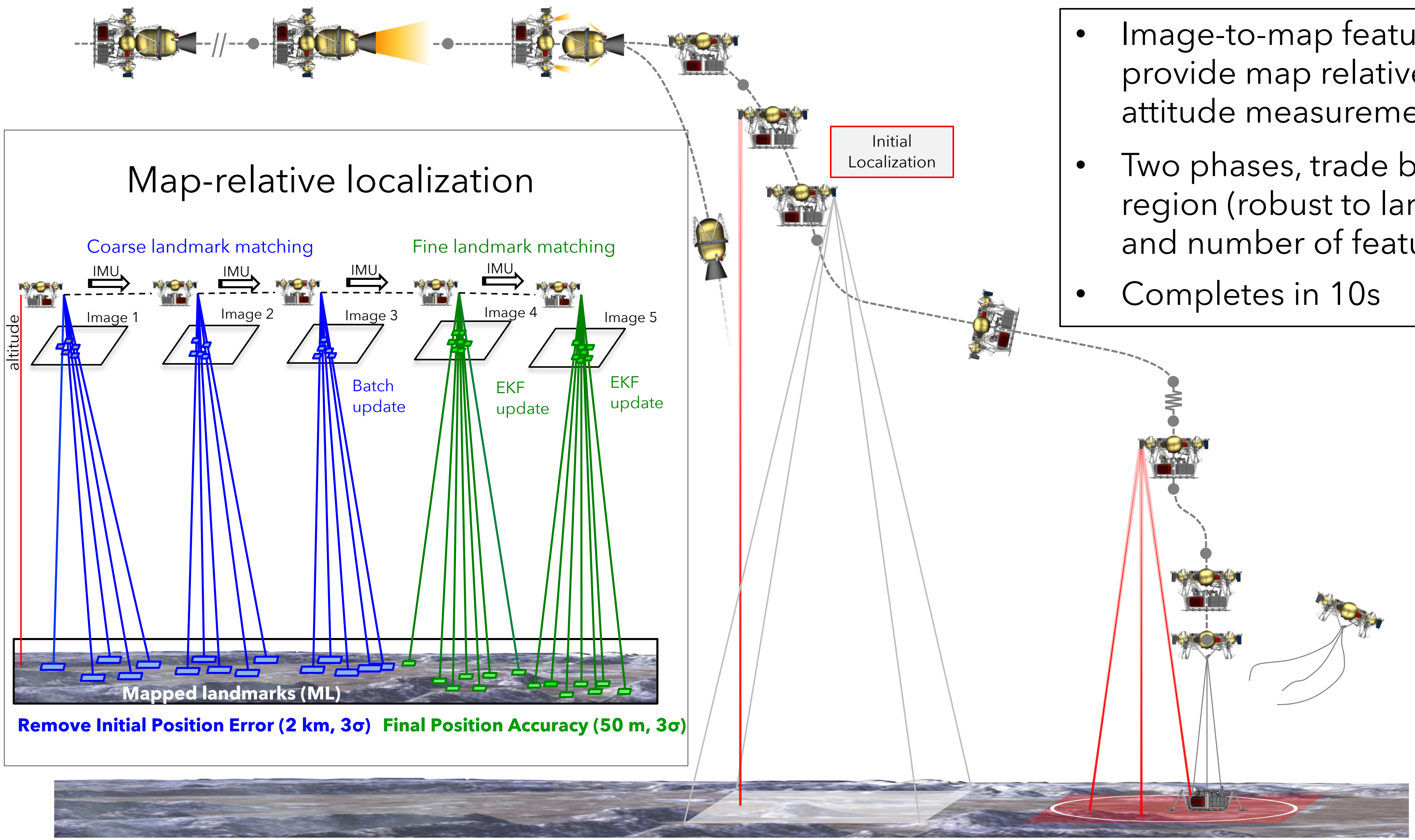
- Provides map-relative position and attitude estimates
- Performs image-to-map feature matching
  - Requires Clipper-provided co-registered albedo and elevation map
  - Requires similar lighting conditions between descent image and map
- Baselined on Mars 2020
  - Europa Lander leverages Mars 2020 software, firmware, hardware, and simulation development



Visual Odometry

- Provides surface-relative velocity estimate
- Performs image-to-image feature tracking
  - Requires light and contrast
  - Does not utilize an onboard map
- Currently being integrated with Mars 2020 TRN software and firmware

Map-Relative Localization: How it works

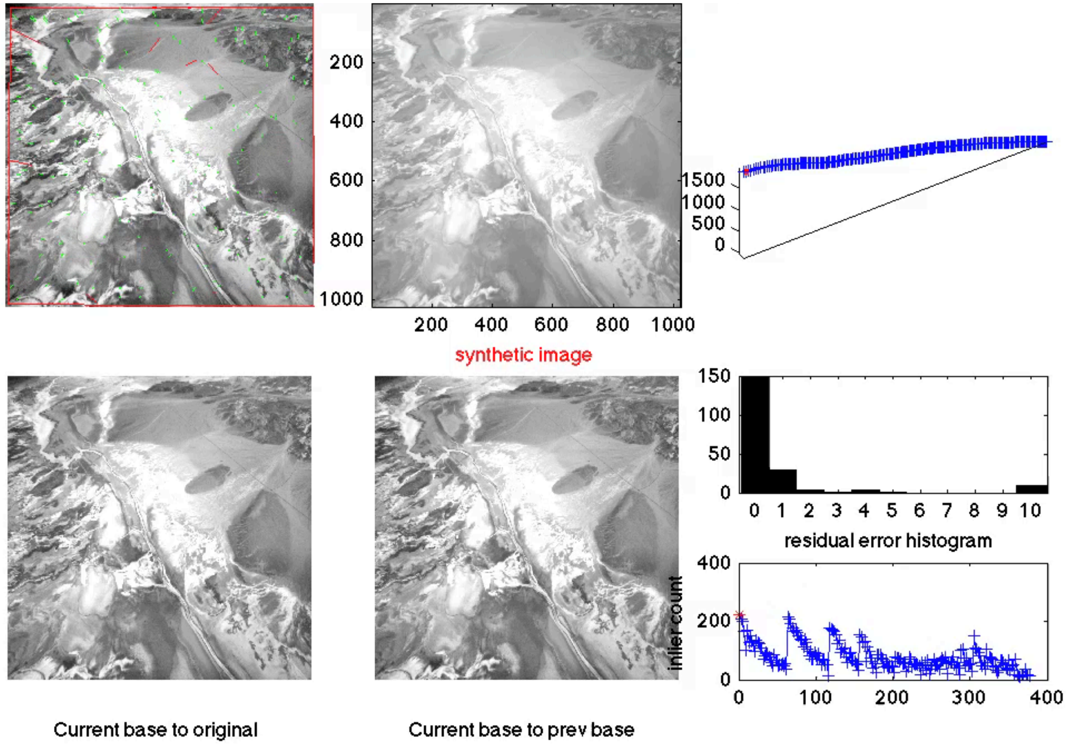


- Image-to-map feature matches provide map relative position and attitude measurement
- Two phases, trade between search region (robust to large initial error) and number of features (accuracy)
- Completes in 10s

TRN Field Testing

Europa Lander TRN field tests planned for 2019 through 2020

Map-Relative Localization

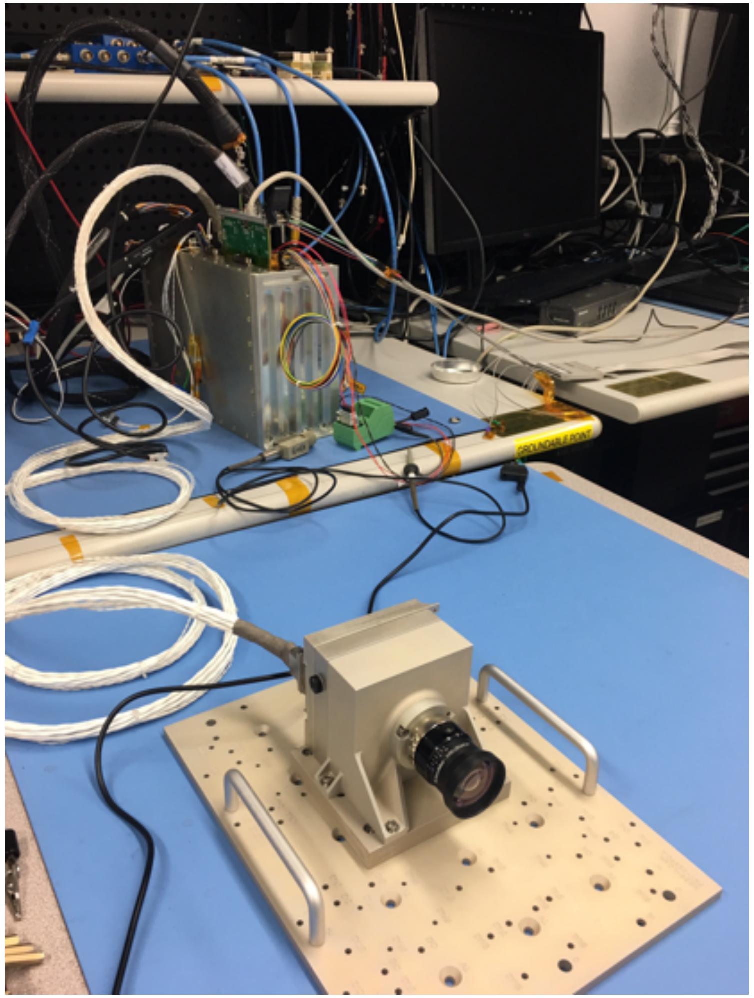


Visual Odometry

Pre-Decisional Information – For Planning and Discussion Purposes Only

TRN Hardware

- MRL and VO use the same hardware
- Mars 2020 Co-Funded Development
  - FSW/algorithms for Map Relative Localization (MRL)
  - Computer Vision Accelerator Card (CVAC)
  - Analysis and simulation environment
- Enhancements for Europa Lander:
  - Development of FSW/algorithms for velocimetry
  - Procurement of radiation-tolerant camera
  - Radiation hardening of CVAC
  - Validate MRL algorithms for Europa Lander
- Phase 1 of competitive technology development for TRN camera is underway



Mars 2020 Lander Vision System
Engineering Development Unit

Pre-Decisional Information – For Planning and Discussion Purposes Only

Landing Site Engineering Considerations

- Lander TRN requires an onboard map to be used to navigate back to the selected landing site after SRM burn-out error
  - Clipper NAC imagery should be centered within the Clipper WAC imagery
  - We estimate the Lander onboard WAC imagery should be at least 42 km x 42 km
- TRN compares image taken by Lander camera to onboard map produced from Clipper WAC imagery; similar resolutions required
  - We estimate Clipper WAC imagery should have 11-m Ground Sample Distance or better
- Shadows help identify navigation landmarks but should not be too long and obscure features
  - TRN algorithm requires Lander & Clipper imagery taken with solar incidence angle between 30 and 60 degrees
- Image-matching performance degrades with deviation in lighting conditions between Lander and Clipper imagery
  - Land within 1 hour of Local Solar Time of when WAC images were taken by Clipper
- Confidence in landing site safety increases with image resolution
  - Better resolution helps identify terrain hazards, meter-scale resolution desired to identify terrain hazards at Lander length-scale
  - Knowledge from other instrument data sets desired to infer terrain characteristics