An Adaptive Lidar for Planetary Exploration

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Agility to Innovate, Strength to Deliver

Ball Aerospace
& Technologies Corp.

Motivation for Space-Based Lidars

- **Some advantages of lidar for Remote Sensing from space**
  - Vertically profile surfaces and atmospheres to give volumetric (3-D) information
  - Lighting independent
  - High: Sensitivity, spectral resolution, spatial sampling (3-D)
  - Use of collimated beams allows fine spatial sampling

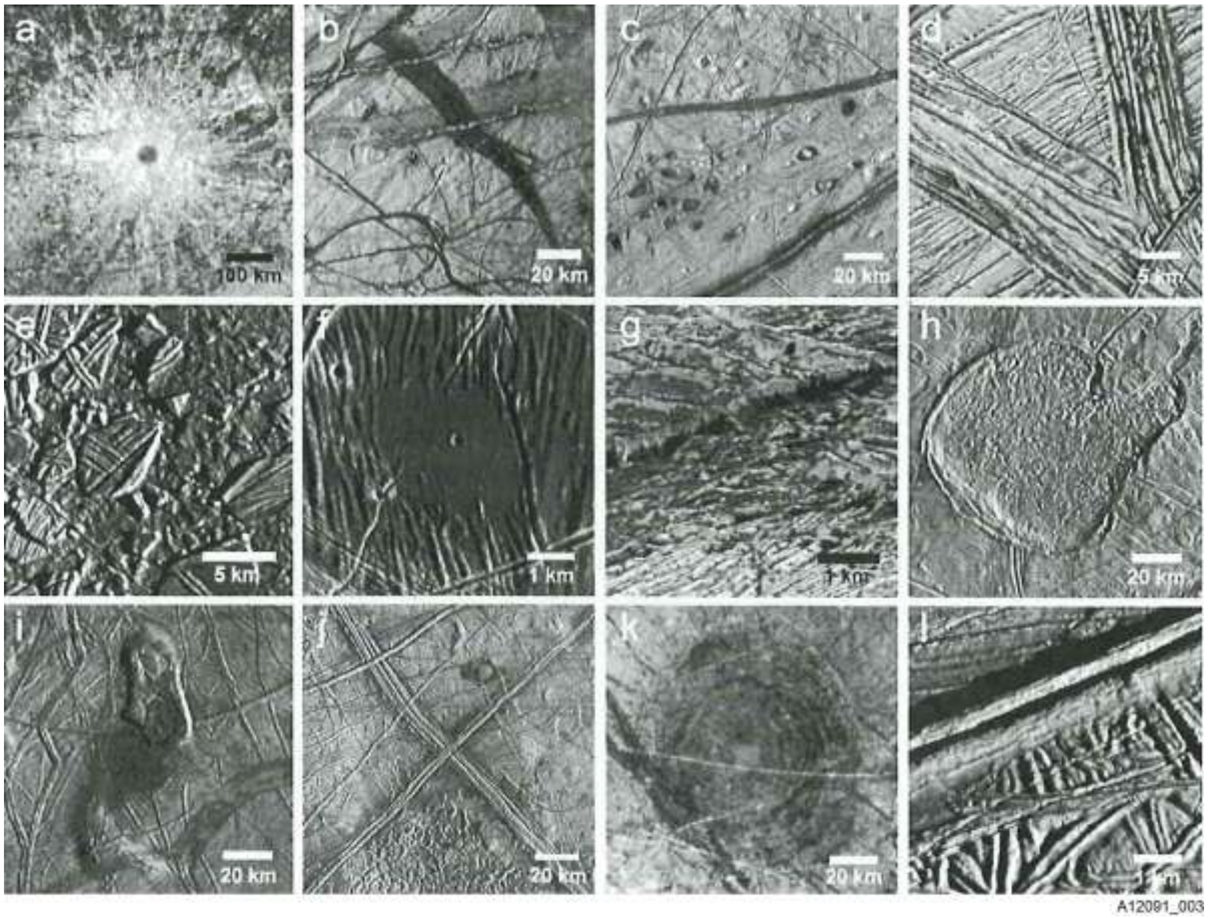
- **Some limitations as currently embodied and their implications**
  - Fixed beam (or beams) pointing

    ➡ Sampling of surfaces is limited by spacecraft orbit parameters, only fixed spatial scales measured
  - Fixed configuration – can't respond to changes in range, albedo, or measurement objectives

    ➡ System's are typically configured for worst case, becoming sub-optimal as scene parameters change, limiting information content

Laser remote sensing form space has a lot more to offer ……..

Europa – An example of diversity



- A wide variety of 3-D spatial scales
- Broad range of albedo
- Possibility of surface liquid?
- Possibility of geysers?

Current space-based lidars are transect sampling – they make dense measurements along the track and no (or a few) measurements across track. There are other options….

Adaptive Lidars (My Definition)

Design the lidar system so that it can autonomously:

1. Maintain the instrument performance by maintaining the Signal-to-Noise in an acceptable range
2. Maximize the science return by increasing the number of measurements being made
3. Make the measurements at the spatial scales that maximize the science content.

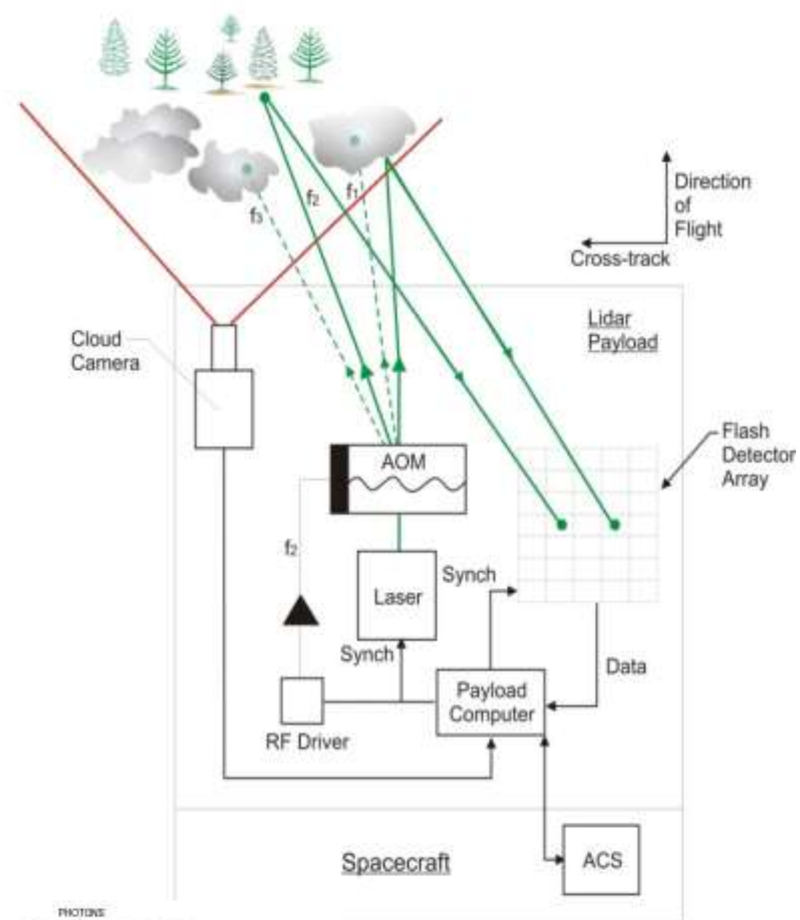
To achieve these goals use information from:

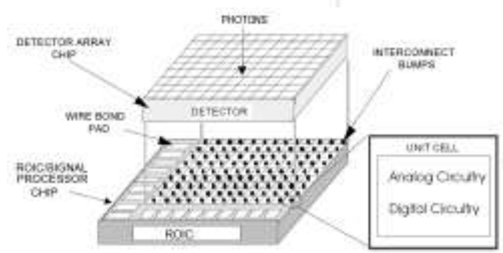
- Feedback from the lidar
- Secondary instruments integrated with the lidar
- Previous passes over the region
- Other satellites that have passed over (Sensor Web)
- Previously collected data stored in databases

Feedforward to anticipate scene

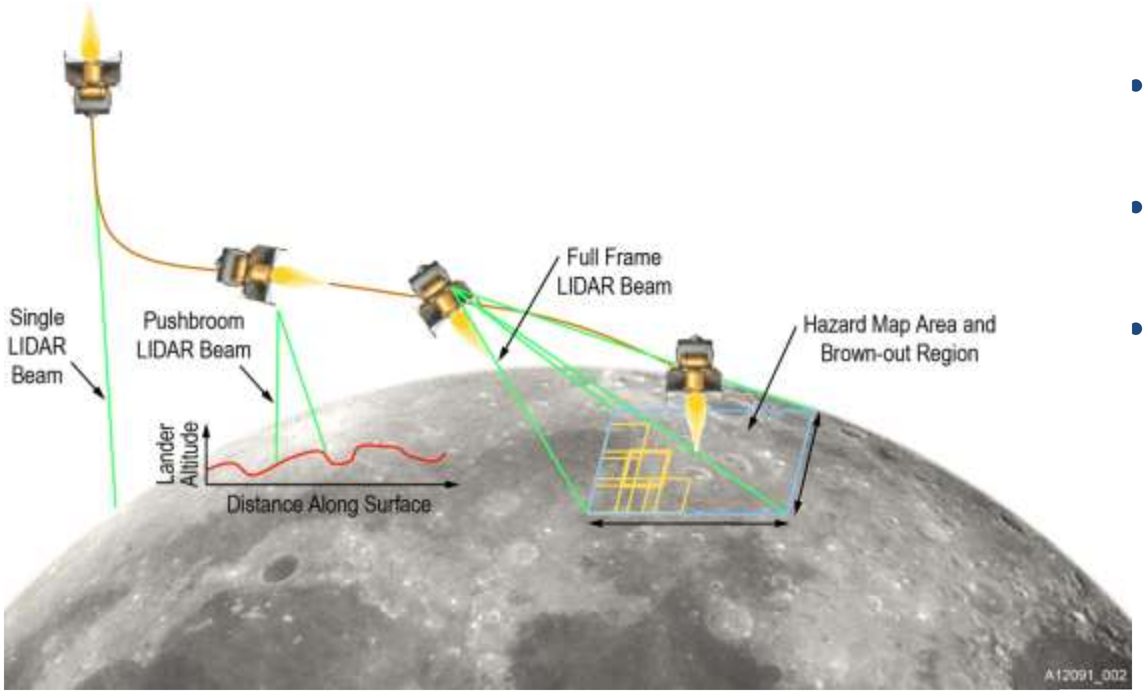
One Adaptive Lidar - Electronically Steerable Flash Lidar – NASA ESTO IIP

- Utilize Acousto-Optic Crystal to split single laser into multiple beams
- Each beam individually steerable with precise control
- Spots on ground imaged by telescope onto a Flash Focal Plane Array (now qualified for space – see Rich Dissly's talk this morning)
- Beam locations and number can be changed for every laser pulse - can adapt to the scene!
- Beam Configuration can be changed based on
  - Lidar Response (to optimize performance)
  - Secondary Camera (to track patterns)
  - Attitude Control System (to track specific features/transects)



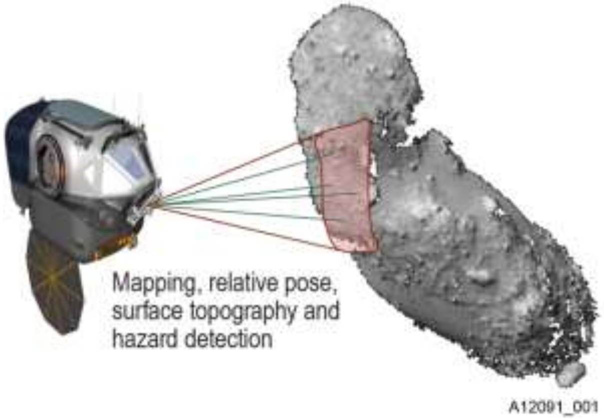


Examples of How it Could be Used



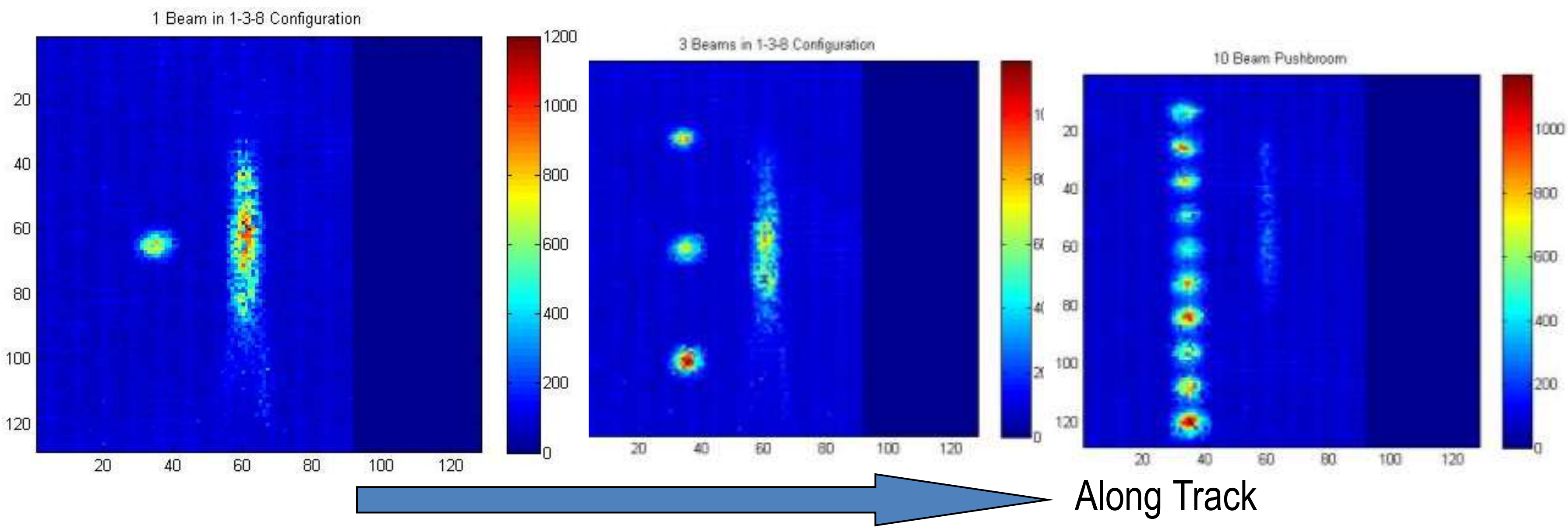
- For orbiters single beam or variable spacing pushbroom
- For landers, point to pushbroom to full frame as range decreases
- Surface and above surface can be ranged/imaged

- For asteroid/comets – relative navigation and full frame surface mapping
- Number of beams used set by albedo and range



Varying the Beam Configuration - Aircraft Demonstration

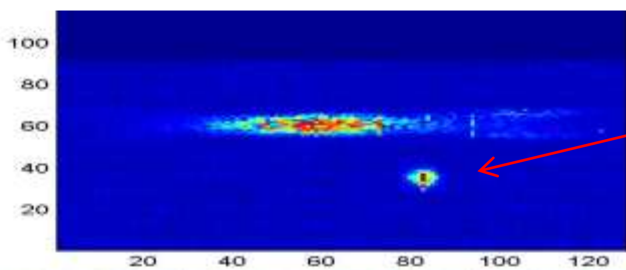
Laser light scattered from the ground from three consecutive laser shots. Demonstrates Beam Number and Spacing can be re-configured in a fraction of the pulse rate of the laser

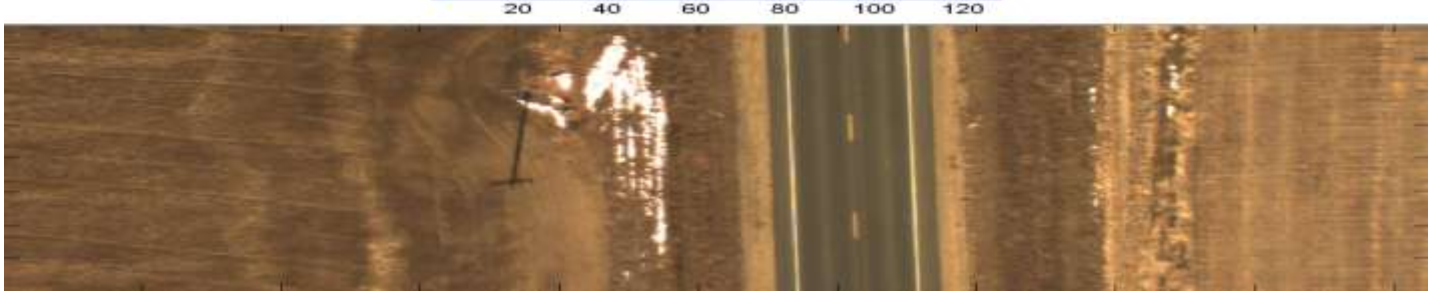


Geo-Tracking – Aircraft Demonstration

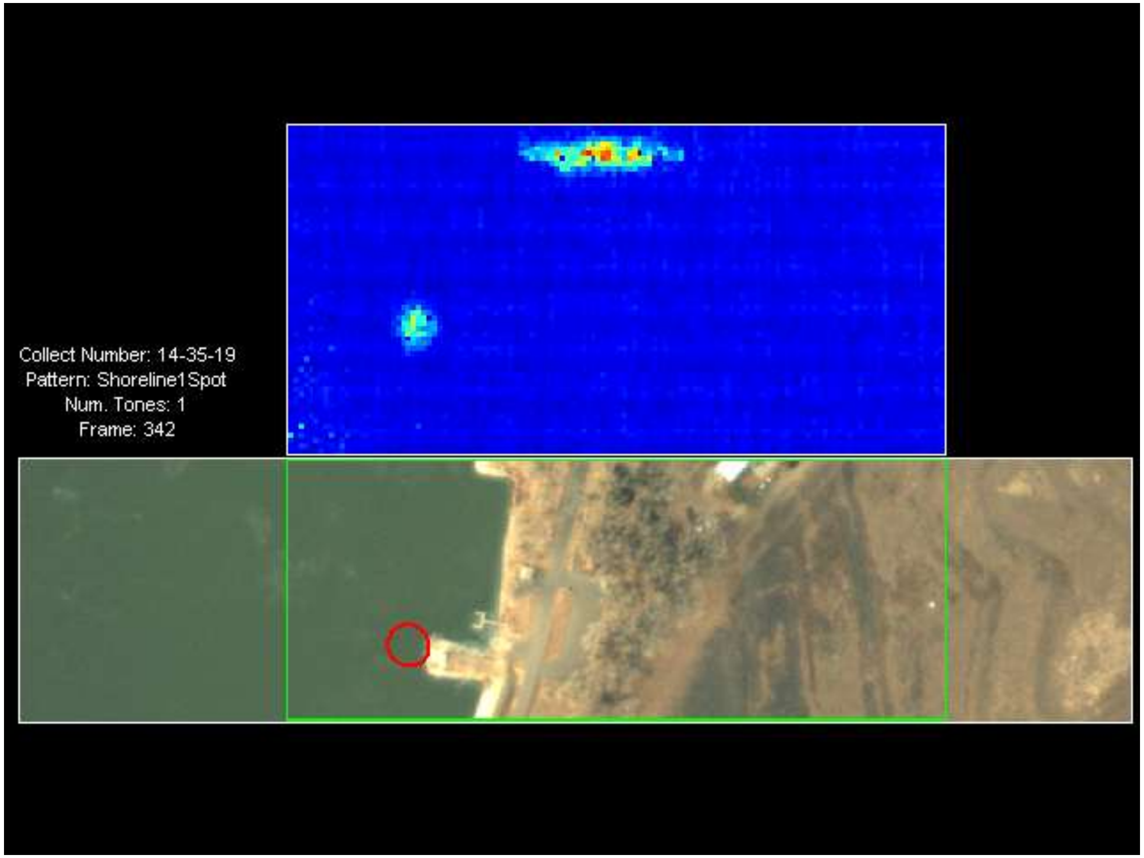
- **Knowing where the beams are pointed can be important to extracting the science**
- **Knowing where the beam is this time compared to last time over is critical if the goal is change detection are calibration (e.g. crossovers)**
- **Beam control takes out aircraft (spacecraft) attitude variations**

Beam tracking road centerline from knowledge of gps coordinates (aircraft)





Shoreline Tracking from Aircraft



- Shoreline is identified in the visible image from color and texture change
- Location of shoreline is fedforward to controller
- Controller calculates where the beam needs to be pointed when the aircraft passes over
- Exploits machine vision concepts while adding in active illumination

Summary

- **Use dynamic beamforming and steering to maximize science return for space based lidar system via adaptation:**
  - **Optimize signal for every scene – optimizes use of photons.**
  - **Make measurements at the natural spatial scales of scientific interest**
  - **Avoid Clouds – reduce cloud loss and systematic biases due to clouds (if present)**
  - **Follow pre-defined transects, or track features based on secondary instruments on-board or**
- **Ongoing work to advance the algorithmic aspect of adaptation and advanced control - now at TRL 5**
- **Actively pursuing scientific collaborations to utilize this technology**

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STK [Movie]

Demo Unit Optical Head