NORTHROP GRUMMAN

Terrestrial Ladar

"Defining the Future"

KISS Workshop
Monitoring Earth Surface Changes
October 28-30, 2009

William Cottingame, PhD

History – Lidar Atmospheric Remote Sensing

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Miniature Aerosol Lidar

Eye-Safe Autonomous Aerosol Lidar

CALIOPE IR DIAL

Mobile Backscatter Lidar Facility

Raman Lidar

Fluorescence Lidar

UV Differential Absorption Lidar

Desert Storm Lidar

Philosophy – Laser-Based Remote Sensing

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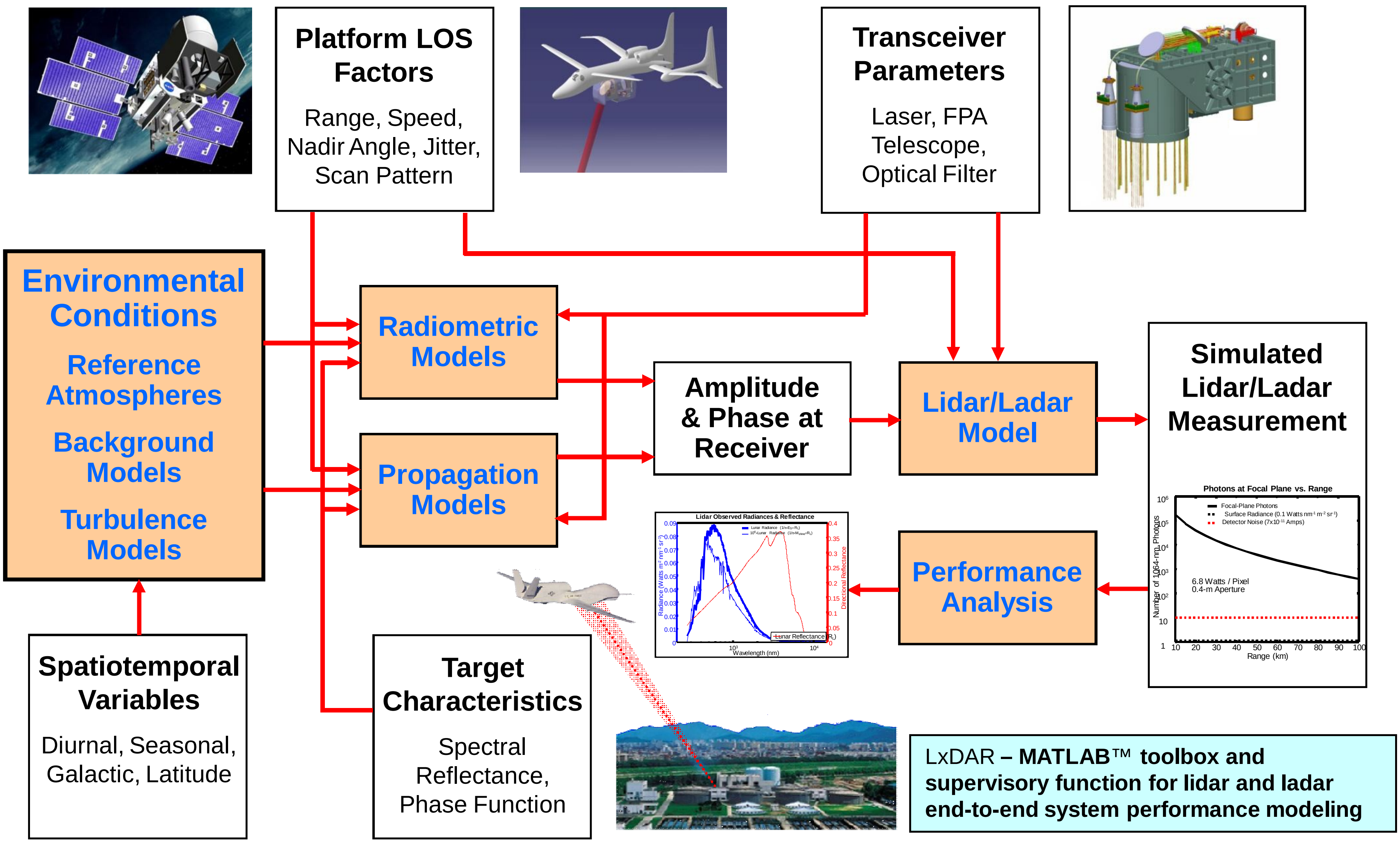
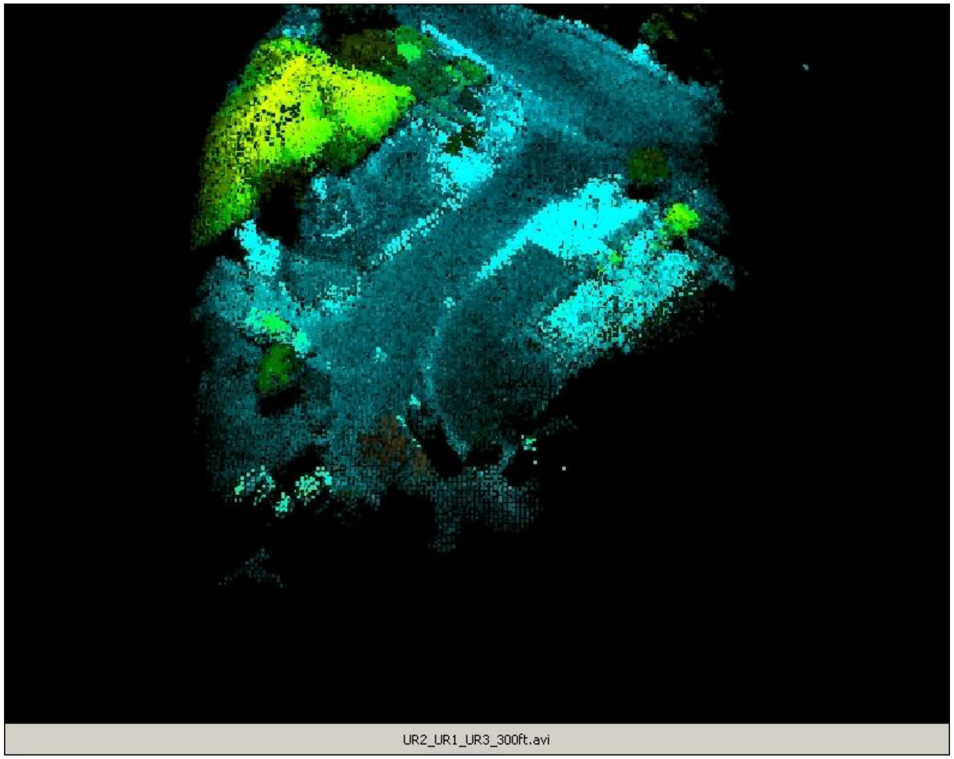
- If a measurement can be achieved without a laser then do so
- Rigorous phenomenology-based methodology must be applied to both instrument design and data reduction
  - Physics-based error analysis used to set system error budgets
  - System variables must be monitored, e.g., laser power, beam quality, pulse width, boresight, receiver transfer function, and dark noise
  - Correction for environmental variables must be based on validated models, e.g., atmospheric extinction, solar/thermal backgrounds, surface reflectance, and atmospheric turbulence
- Regression analysis applied to partially or poorly corrected data cannot substitute for sound phenomenology-based data reduction
- Separation of technology and science not viable for laser remote sensing
  - Note: no commercial system shown on the previous page

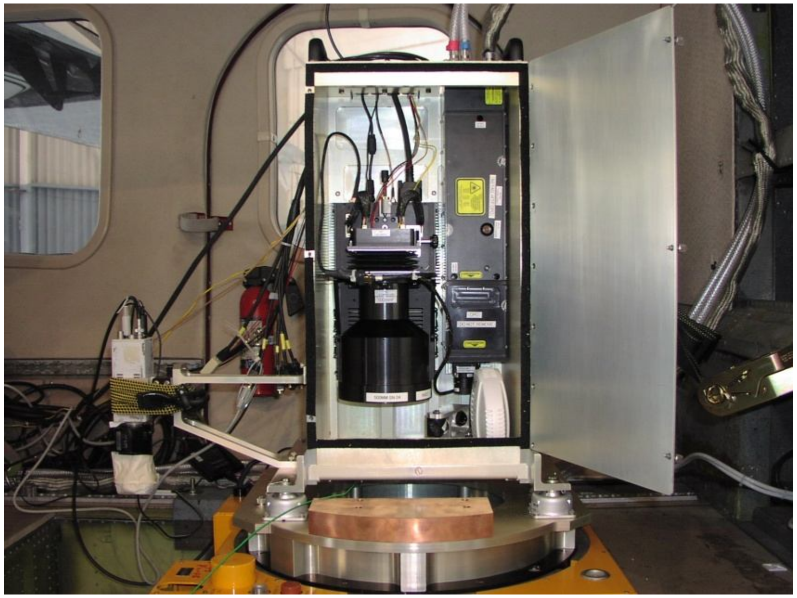
LxDAR Lidar/Ladar Performance Modeling



Future – 3D Imaging with “Flash Ladar”

- Replace singe-element detector with a focal plane array, FPA
- 3D image with a single laser pulse
- FPA formats – 8×8 to 256×256
- Validation flights in 2008 – urban scenes and forest canopy





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Eye-Safe NIR Ladar – High-Altitude & Space

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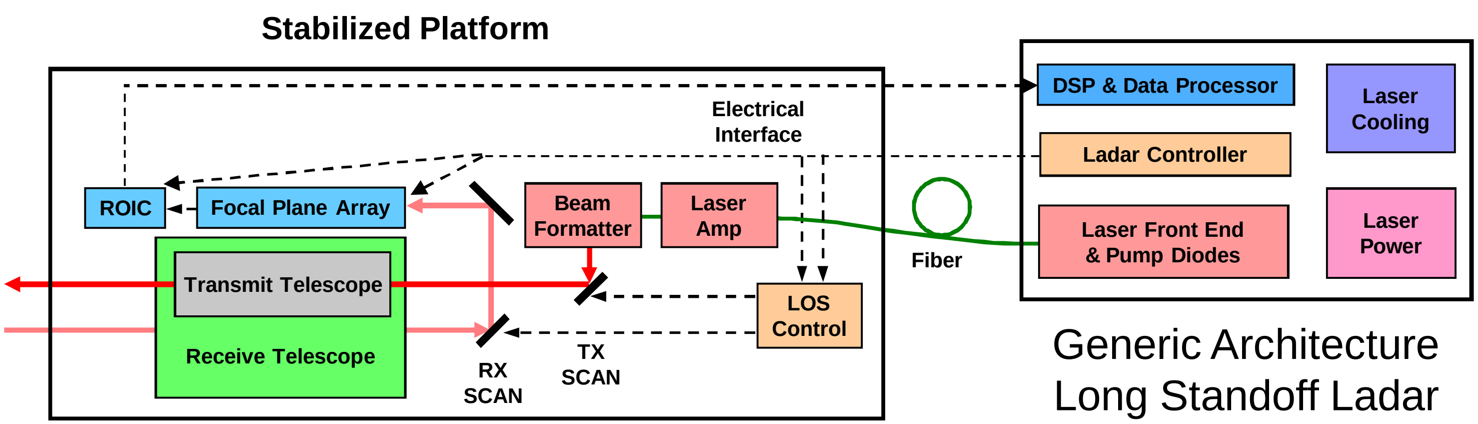
- High FPA frame rate, e.g., 20-kHz for ≥32×32 and 1-MHz for 8×8, gives high average laser powers at a modest pulse energy allowing use of very efficient fiber lasers
- 1.064-μm laser with beam reformatter uniformly flood illuminates the complete receiver's field of view, i.e., illuminate all pixels simultaneously
- 0.5- to 1-ns laser pulse width & ≤50 GHz bandwidth (8- to 15-cm)
- 0.5- to 1-ns FPA temporal sampling rate – 1 ns temporal resolution (15-cm)
- Fast scan mirrors behind separate receiver and transmitter telescopes allows cross-track scanning of a wide swath (3° to 5.5°)



Generic Architecture
Long Standoff Ladar

High-Efficiency Laser Development at NGAS

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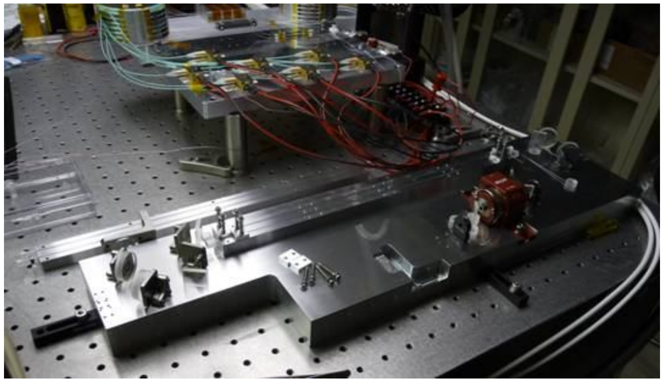
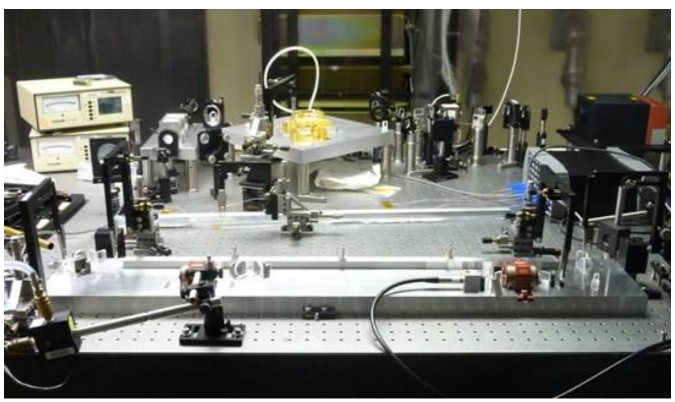
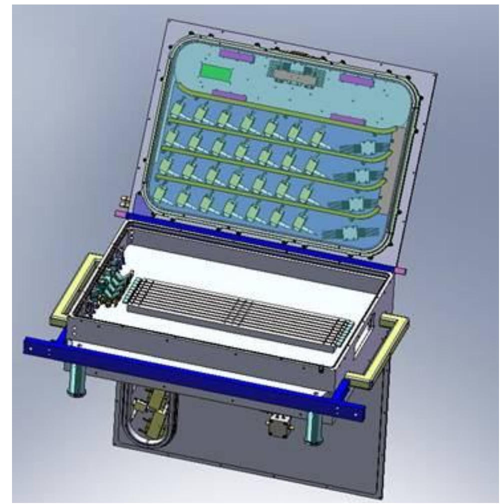


Compact Fiber Laser Demonstrator
Facilitates compact, ruggedized high energy, pulsed fiber opto-mechanical assemblies
Demonstrated operation at power with only a 2.5% loss (32.5% bus-plug)



High Efficiency Fiber Amplifier Testbed
Validated fiber laser efficiency advantage over conventional solid state laser systems
Demonstrated 33.5% bus-plug efficiency to date

High-Efficiency Fiber Laser

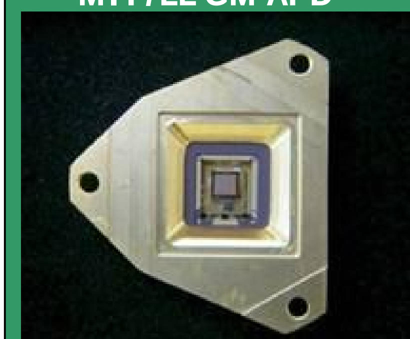


1-μm, 1-ns, high PRF pulsed laser
4 fiber amplifier, ~8 mJ/pulse
40-GHz wavelength separation
Spectrally combined beam
>160 W (20 KHz) average power
>300 W (50 KHz) average power
16”×19”×5.75” laser envelope
~50 lb. total weight
Scalable to higher energies
Design progressing, expected completion by Q1/2010

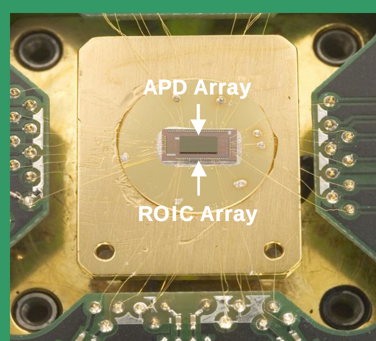
Single-Photon NIR Sensor Array Development

- Government sponsoring 1-μm Geiger-mode FPA/ROIC development at MIT LL
- Aggressive development of 1- to 2-μm low-noise, linear-mode FPA/ROIC at NGAS
  - Low ionization ratio homojunctions, e.g., k~0 for $Hg_{0.7}Cd_{0.3}Te$
  - Impact ionization engineered, I^2E, III-V materials
- Moderate Q.E. IR intensified photodiode, IPD, complete and over 1-yr. life testing
- Space qualification of single-photon sensitive lidar/ladar FPA's is ongoing

MIT/LL GM APD

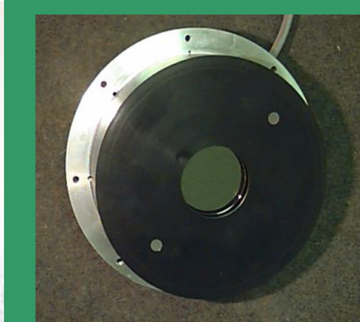


RVS LM APD



INTEVAC IPD

LANL RULLI

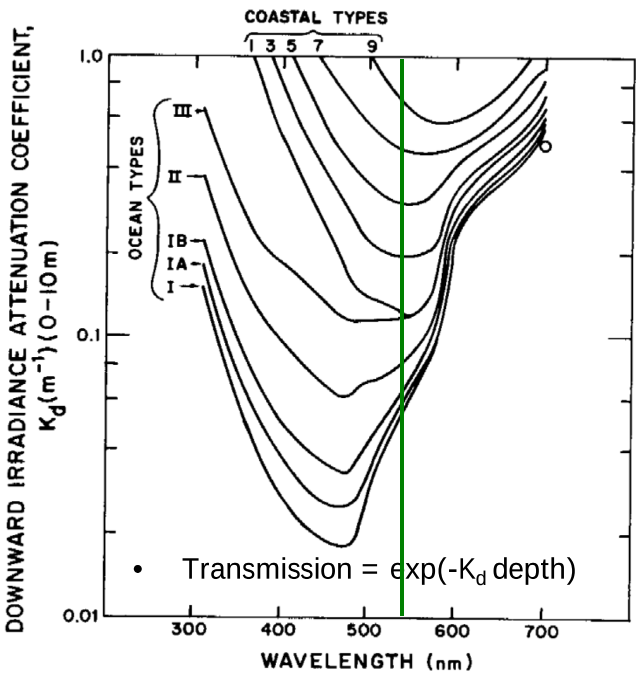


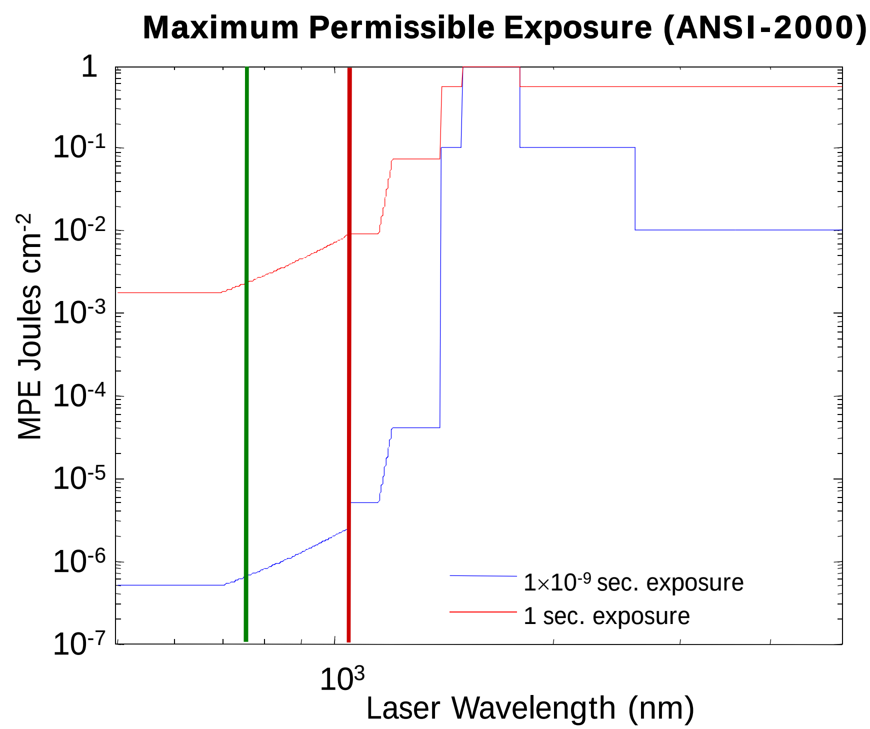
Performance Estimates – Two Examples

- Earth surface under vegetation canopy at 50,000- to 60,000-ft altitude
  - 0.5-m ground sampling distance, GSD, with 0.5-m spatial resolution
  - Single-frame range resolution <15 cm
  - Absolute vertical accuracy – IMU/GPS dependant
  - Swath width of ~1.8 km and area coverage rate of ~18 km^2/min
  - ≥98% probability of detection for each GSD under a canopy with 80% closure and 10% reflectance surface
- Open terrain mapping from 450-km altitude
  - <1-m ground sampling distance, GSD, with <1-m spatial resolution
  - Multiple integrated frames (i.e., ≥6) range resolution ≤10 cm
  - Absolute vertical accuracy – IMU/GPS dependant
  - Area coverage rate of ~30 km^2/min
  - ≥99% probability of detection for each GSD for 10% reflectance surface
- These performance estimates are for instruments that accommodate size, weight, and power limitations for realistic host platforms

Bathometry – Questions

- Bathometry can be done by frequency doubled-YAG (1.064 μm) laser
  - Bathometry has been done since the early 1970
- Requires ~4× more payload power to achieve same statistics as at 1 μm
- Issues of visibility the public and potential increase in eye hazard

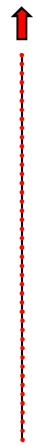




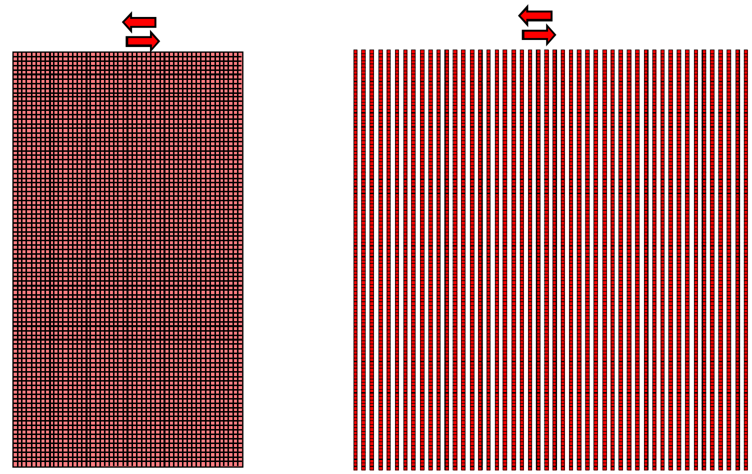
Cross-Track Scanning Enhances ICESat Data

- ICESat I approach – single-track evenly spaced ground samples
- NGAS has proposed high-density sparse mapping– whiskbroom scanned focal plane array (FPA)
  - 2-m IFOV under sampled on a pixel-by-pixel basis but statistically meaningful at the scale of the full array (70 m)

ICESat I has single track of 70-m spots separated by 172 m

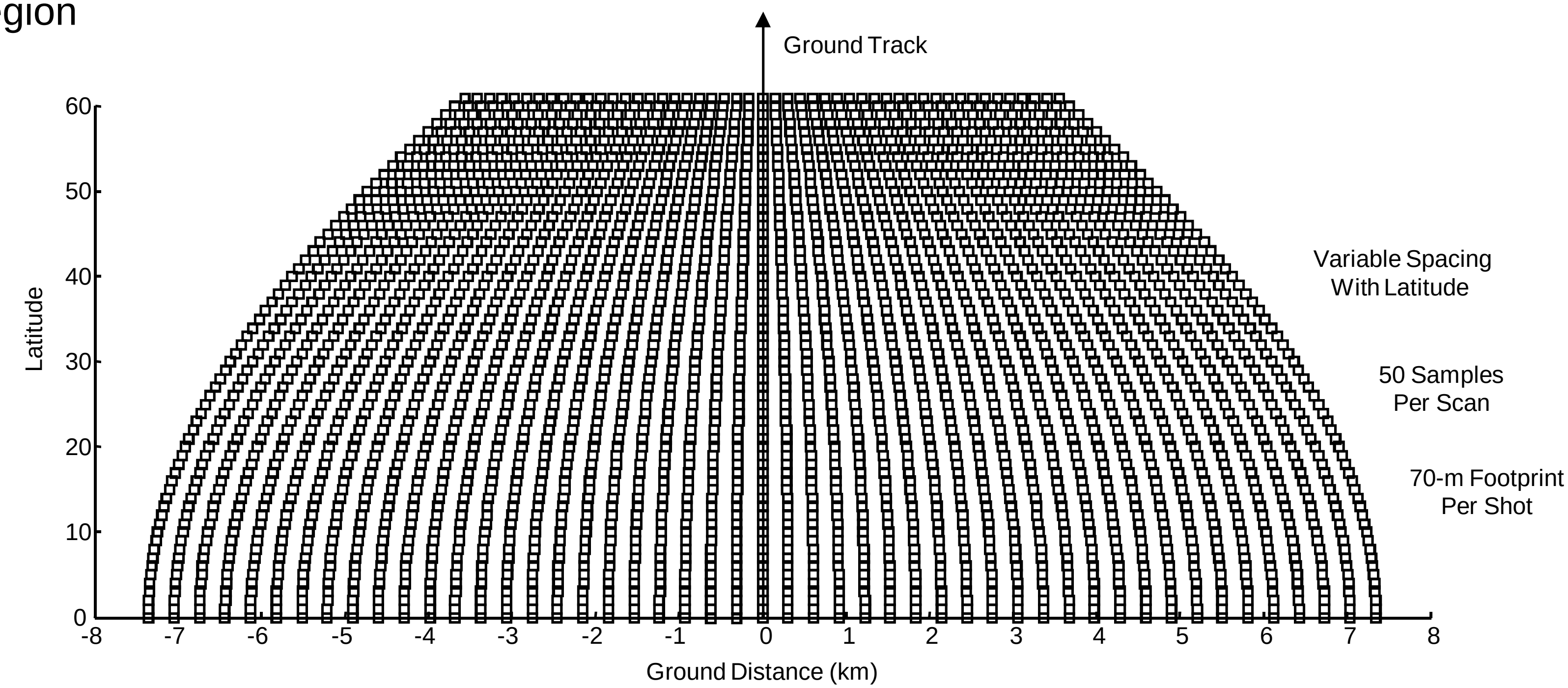


Proposed ICESat has continuous swath of 70-m spots 3.5 km wide or continuous tracks over a wider area



Cross-Track Scanning Increases Coverage

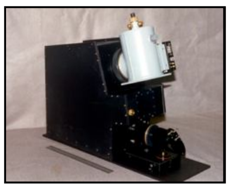
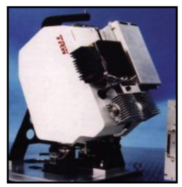
- Variable spacing per shot allows uniform global coverage
  - Contiguous sampling in latitude evenly spaced in longitude
  - Alternatively evenly spaced in both latitude and longitude
- Above ~76º latitude 70-m GSD gives contiguous sampling in both latitude and longitude
  - Reduce laser repetition rate to save power and still provide complete coverage in polar region



Ladar/Hyperspectral Data Fusion

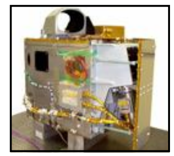
- An objective of the validation ladar was to provide ladar data to demonstrate fusion with that from NGAS hyperspectral instruments

1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008

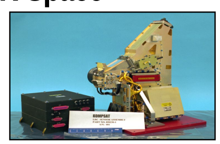



TRWIS-Series VNIR/SWIR Airborne

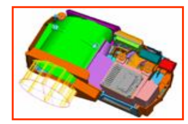
Lewis HSI VNIR/SWIR Space



Hyperion/EO-1 VNIR/SWIR Space



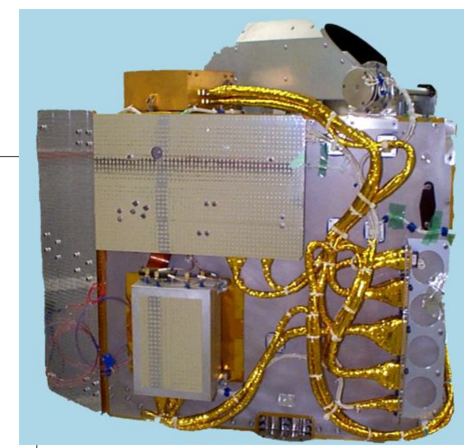
KOMPSAT OSMI

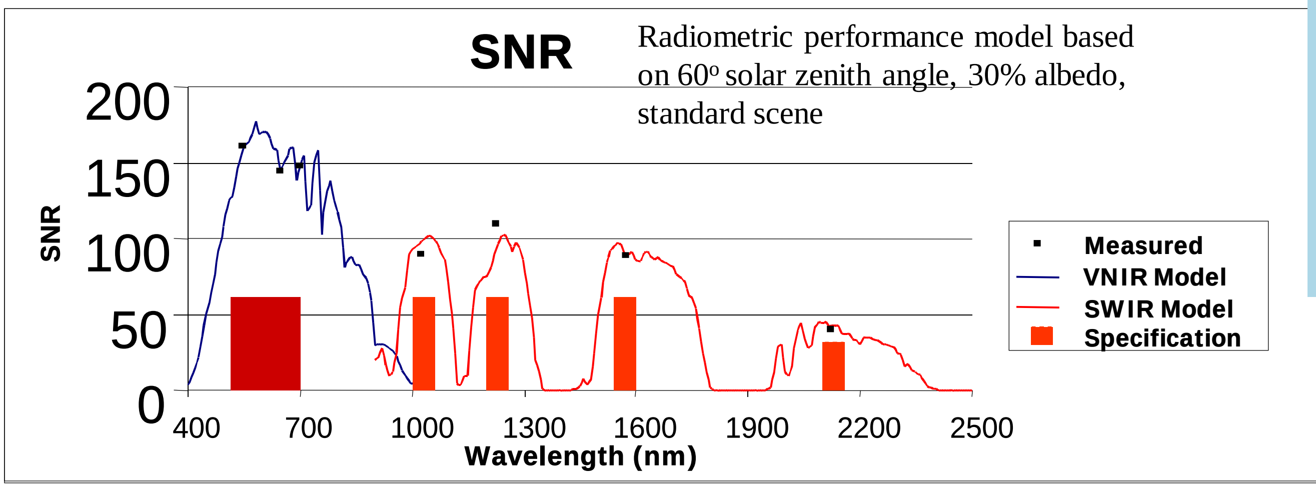


VSHCA High Alt UAV

NGST LWHIS LWIR Airborne

High Alt UAV Recon HSI





Level 1 Hyperspectral/Ladar Data Product

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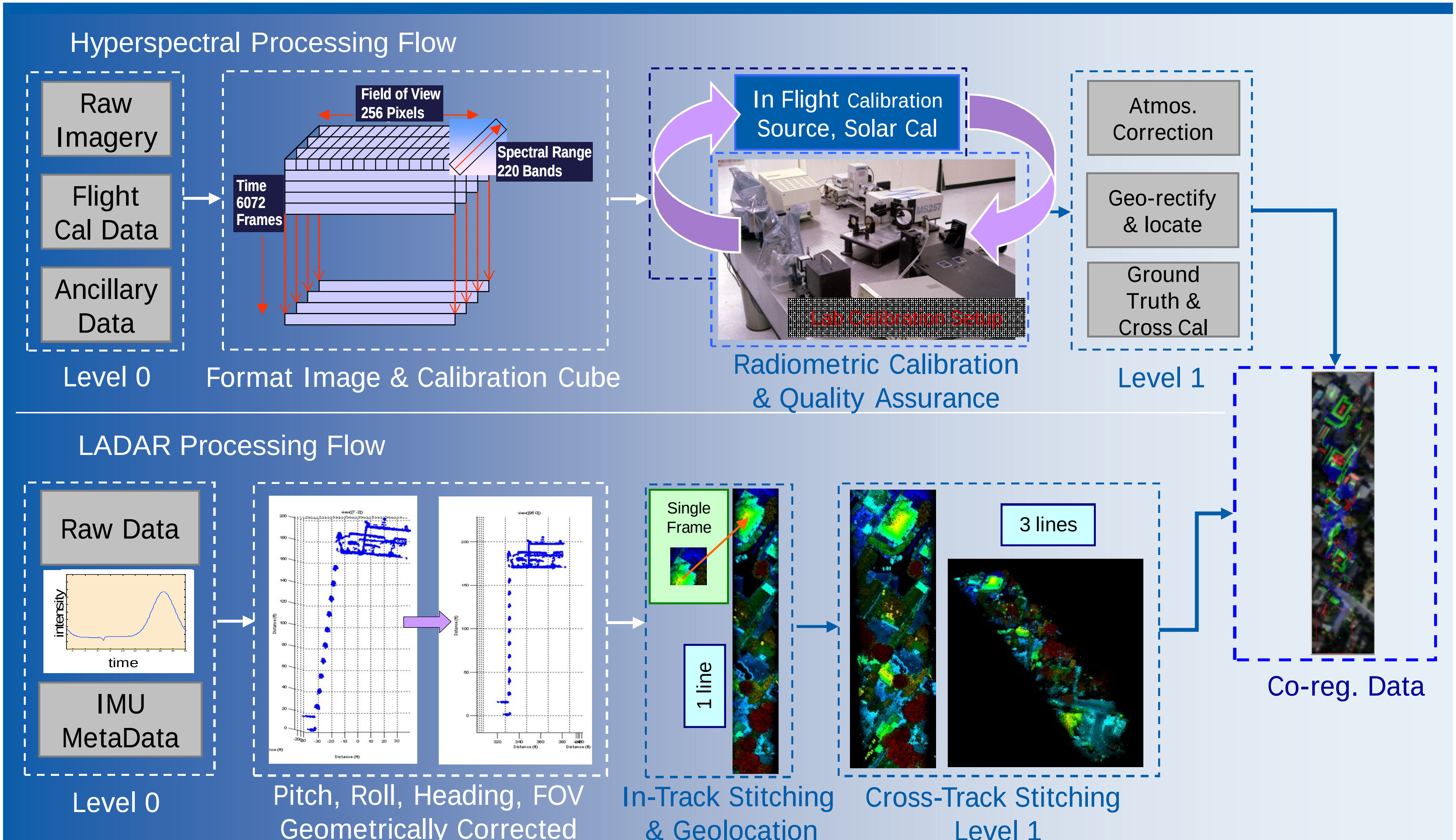

HSI and LADAR are measurement devices and must be well calibrated