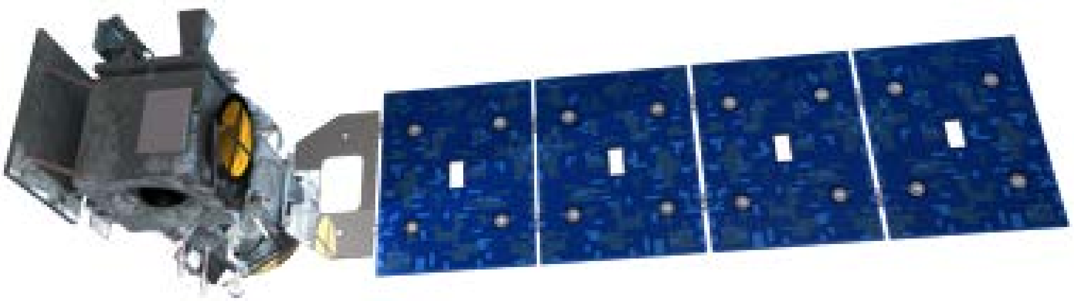
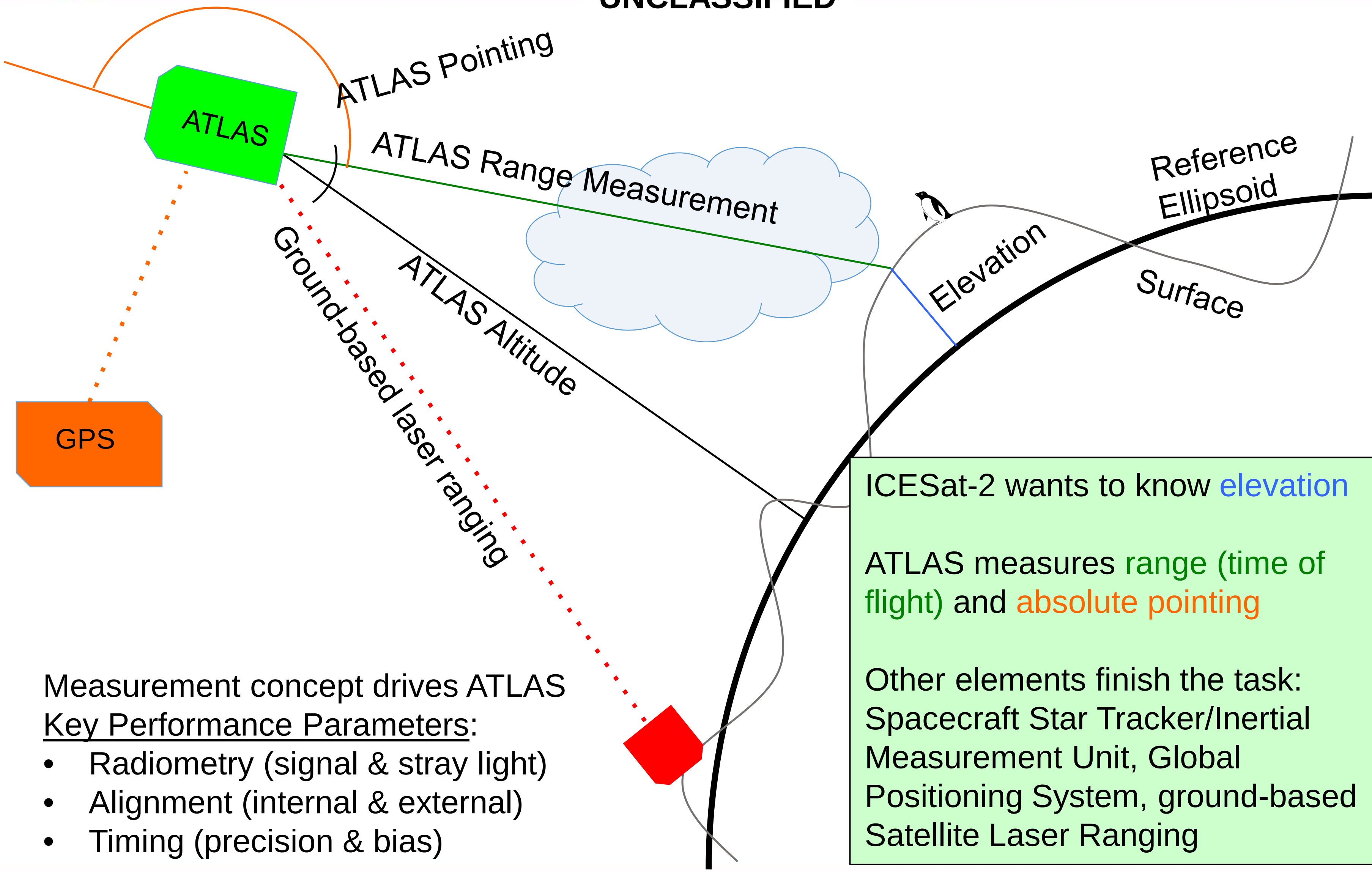


The Advanced Topographic Laser Altimeter System (ATLAS) for NASA's Ice Cloud and Land Elevation Satellite-2 (ICESat-2)

Design, Development, and On-Orbit Performance

John Cavanaugh
NASA Goddard Space Flight Center
Instrument/Payload Systems Engineering Branch
Code 592

ATLAS Measurement Concept



ICESat-2 wants to know elevation

ATLAS measures range (time of flight) and absolute pointing

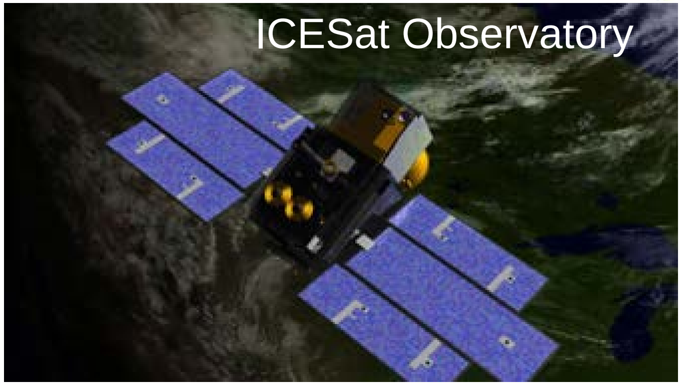
Other elements finish the task: Spacecraft Star Tracker/Inertial Measurement Unit, Global Positioning System, ground-based Satellite Laser Ranging

Measurement concept drives ATLAS Key Performance Parameters:

- Radiometry (signal & stray light)
- Alignment (internal & external)
- Timing (precision & bias)

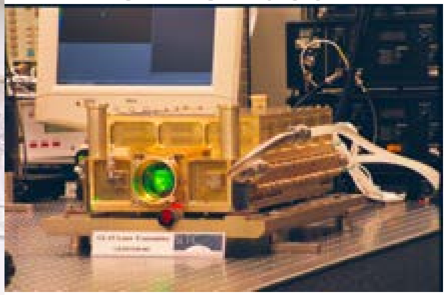
ICESat Background

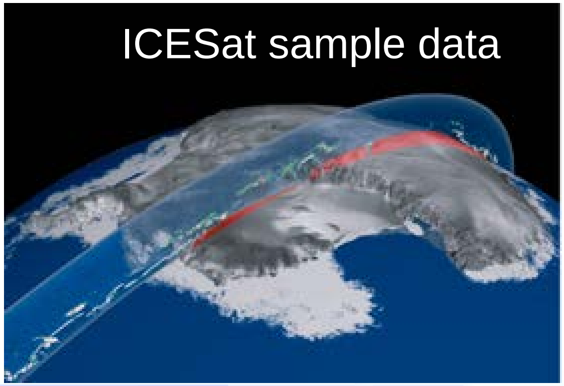
- **ICESat**
  - Launch : January 13, 2003
    - Decommissioned August 17, 2010
  - **Instrument : Geoscience Laser Altimeter System (GLAS)**
    - Diode Pumped-Nd:YAG Solid-state laser transmitter
      - 4-ns pulse
      - 40-Hz Pulse Repetition Frequency
      - 1064-nm altimeter
        - 70-m footprint
      - 532-nm atmospheric sounder
    - 1-m telescope receiver
    - Silicon –Avalanche Photodiode (Si-APD) altimeter detector
      - Analog waveform capture
    - Single Photon Counting Modules (Geiger-mode Si-APDs) for atmospheric detectors
      - Photon-counting atmospheric profiles
- Despite laser issues, ICESat collected a valuable dataset used to evaluate global ice sheets
  - This set the stage for ICESat-2



GLAS Instrument

GLAS Laser





ATLAS Design
Instrument Overview

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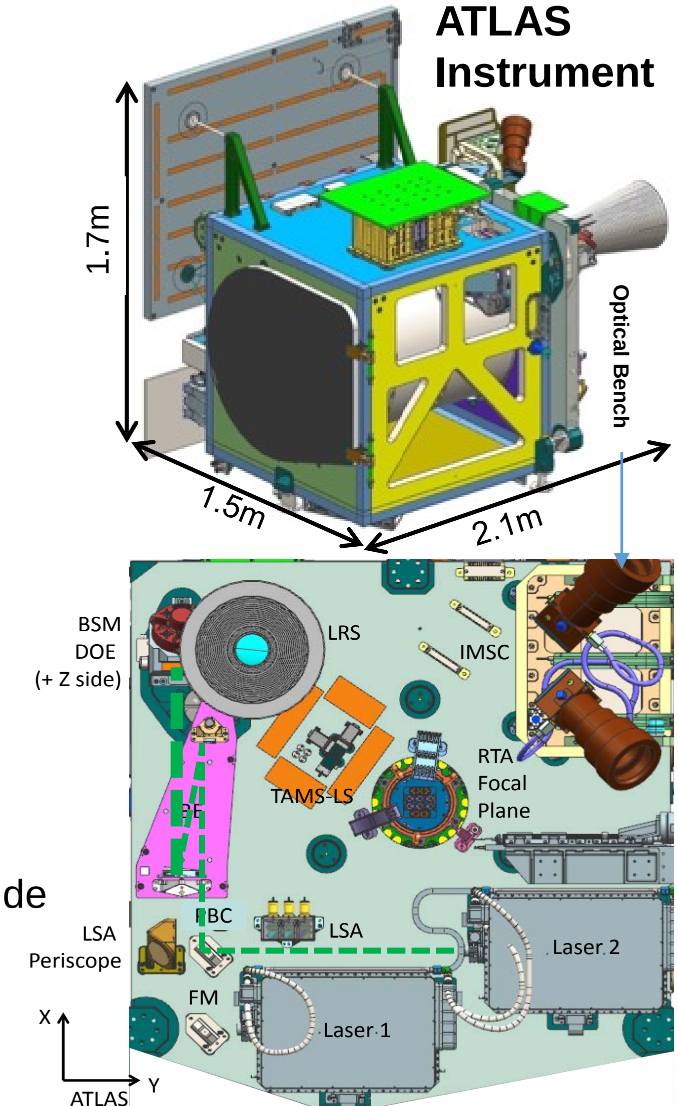
- **Transmitter**
  - Solid-state Nd:YVO_4 Master Oscillator Power Amplifier (MOPA) Architecture
  - 10-kHz pulse rate
  - 1.2-ns output pulses
  - 532.292-nm wavelength, tunable ±15 picometers
  - Diffractive beam splitter
    - 6 signal beams : 3 strong, 3 weak
- **Receiver**
  - 80-cm reflector telescope
  - 30-pm bandpass filter
    - Temperature-tuned to match transmitter
  - Single photon detection w/ 16-pixel photomultipliers
- **Timing**
  - 100-MHz Ultra Stable Oscillator w/ gate-delay Field Programmable Gate Array (FPGA)
  - Range tracking algorithm utilizing on-board Digital Elevation Model/Digital Relief Model and position/attitude updates from spacecraft
- **Alignment**
  - Active Transmit/Receive co-boresight alignment
    - Alignment Monitoring and Control System (AMCS)



ATLAS Instrument

ATLAS Optical Bench

ATLAS Optical Block Diagram

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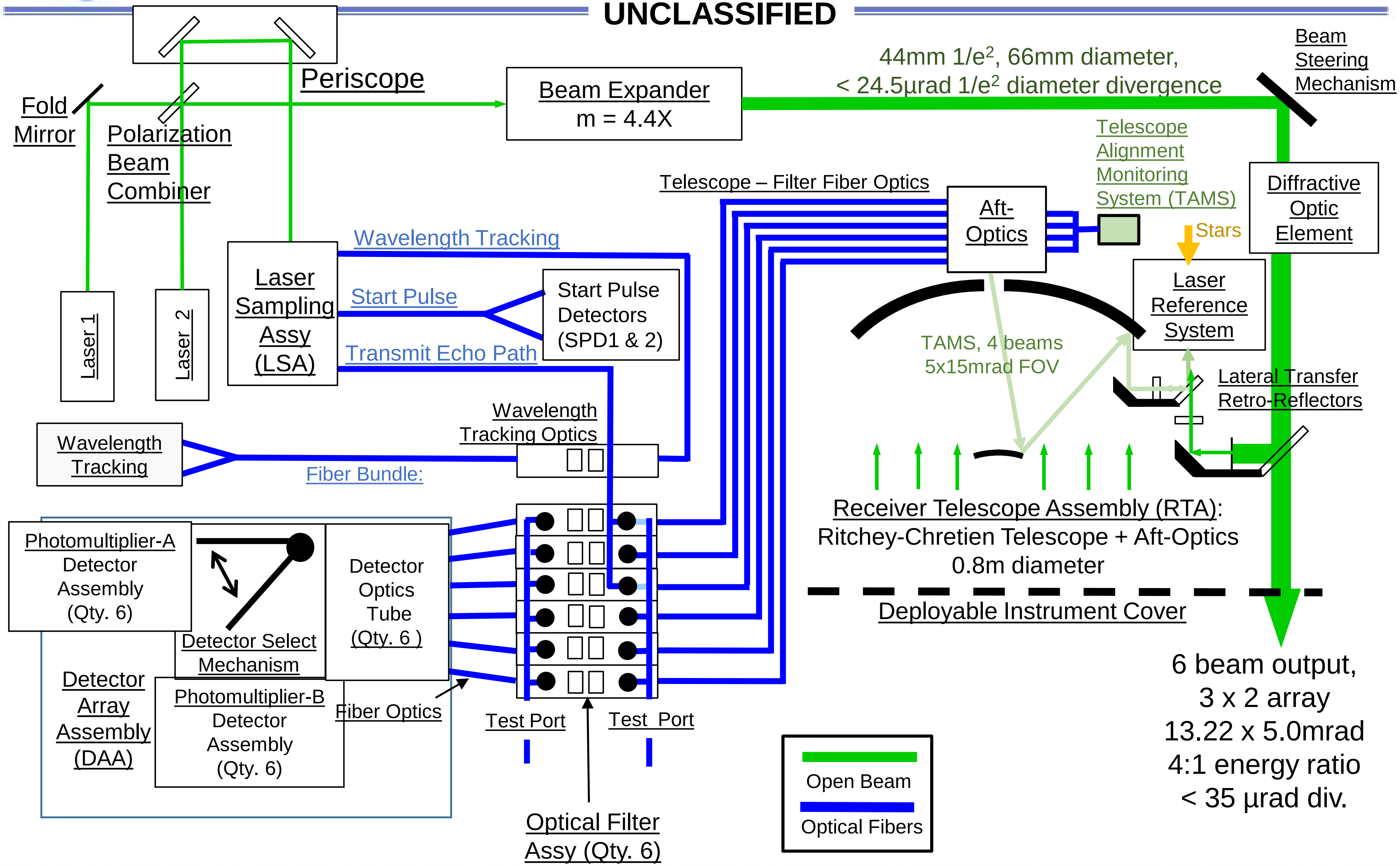

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ATLAS Transmit Path

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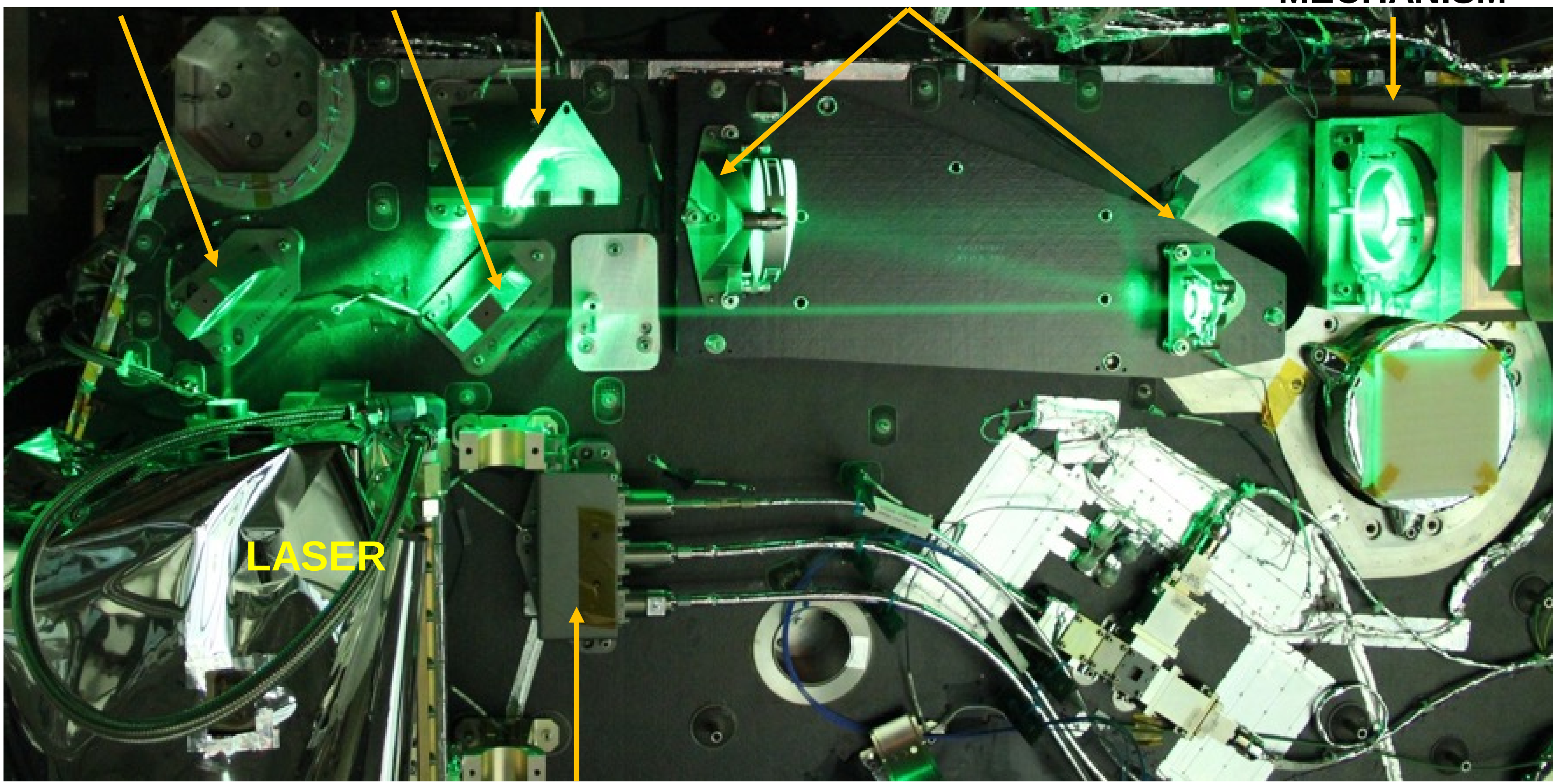
FOLD MIRROR

POL. BEAM COMBINER

LSA PERISCOPE

BEAM EXPANDER

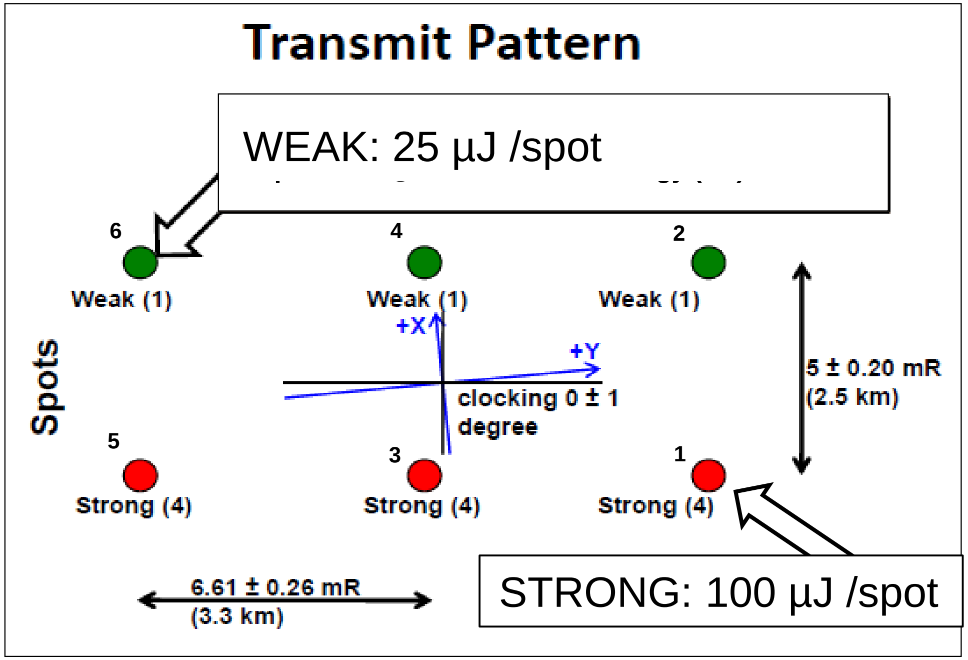
BEAM STEERING MECHANISM

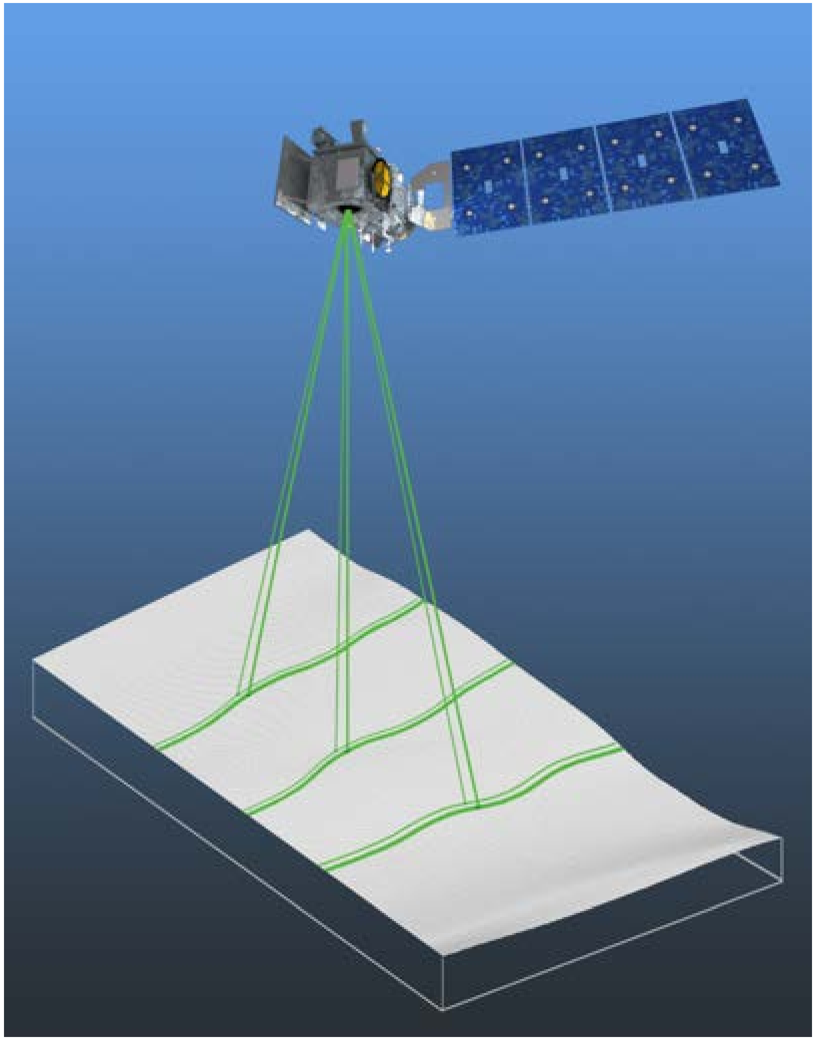


LASER SAMPLING ASSEMBLY

ATLAS Ground Track Illumination Pattern

- Diffractive Optical Element (DOE) splits single input laser beam into 6 beams
- 3 x 2 array – 3 ”Strong”, 3 “Weak”
  - 4:1 energy ratio (Strong:Weak)
- 13.22 x 5.0 mrad angular separation
- Each spot <25μrad divergence (same as input beam)
  - Each spot is ~12 m diameter on ground

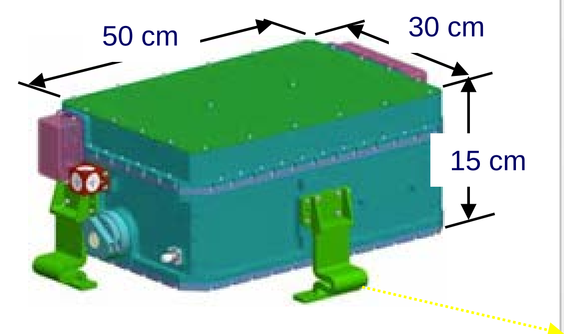


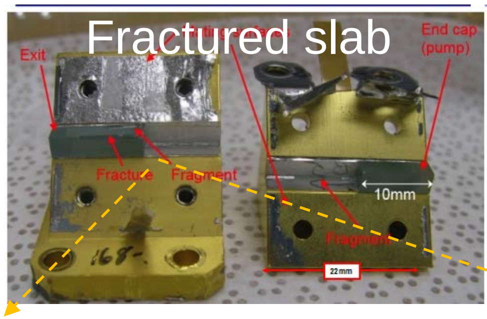


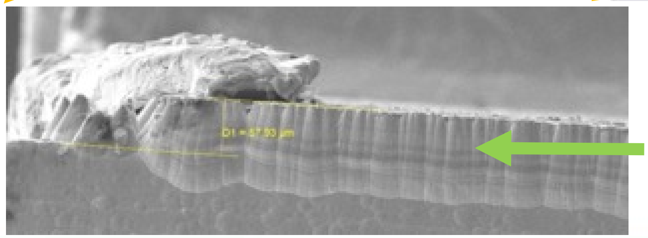
ATLAS Laser Overview

- Pulse energy: ~250 µJ – 900 µJ/pulse, programmable
- Master Oscillator – Power Amplifier
    - Diode laser end-pumped Nd:YVO_4
- Oscillator :
    - Volume Bragg Grating output coupler for wavelength control
    - Active Q-switch
- Nd:YVO_4 slab fractured during test in 2016, prompting re-design
    - Design for flight:
        - Eliminated gold plating
        - Minimized mount induced stresses on slab
        - Selected crystals with the fewest flaws

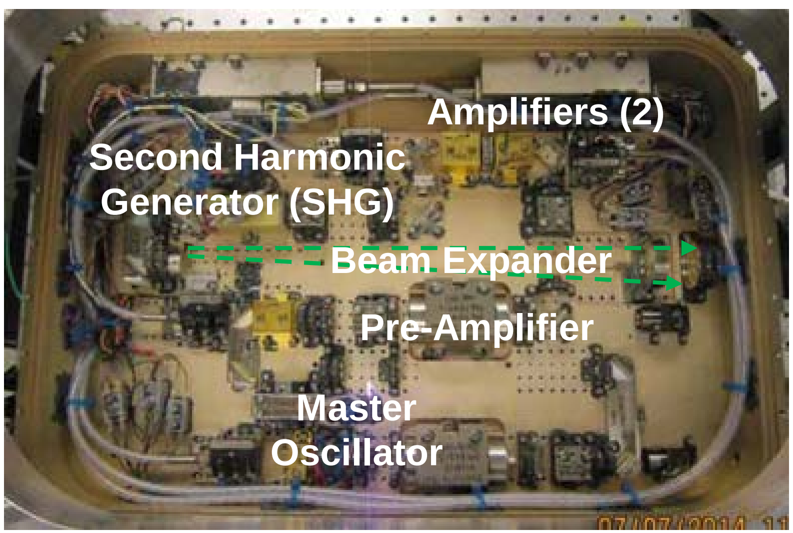
ATLAS Laser





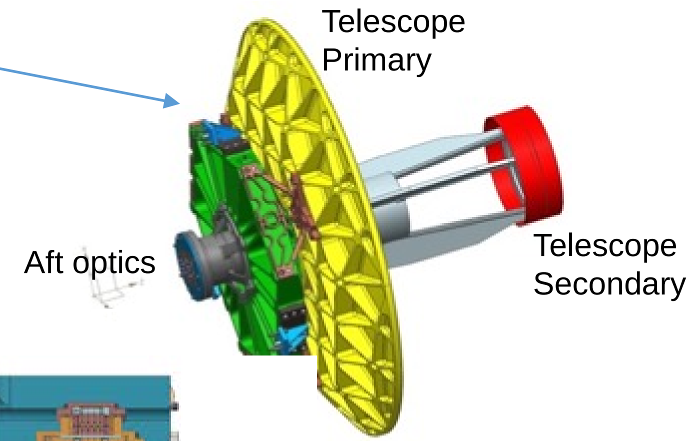


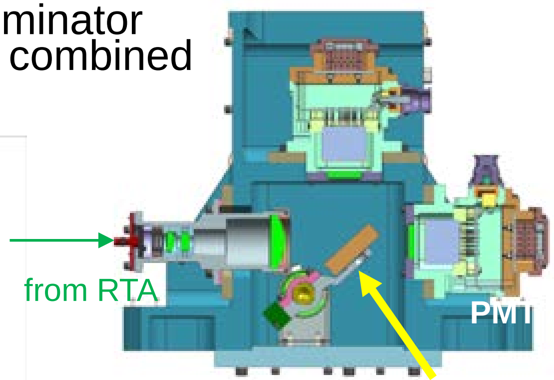
Gold-Indide growth at slab-mount interface



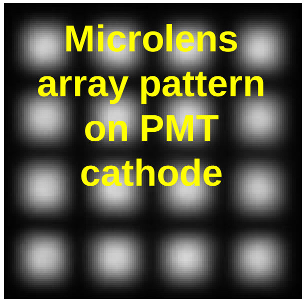
ATLAS Receiver

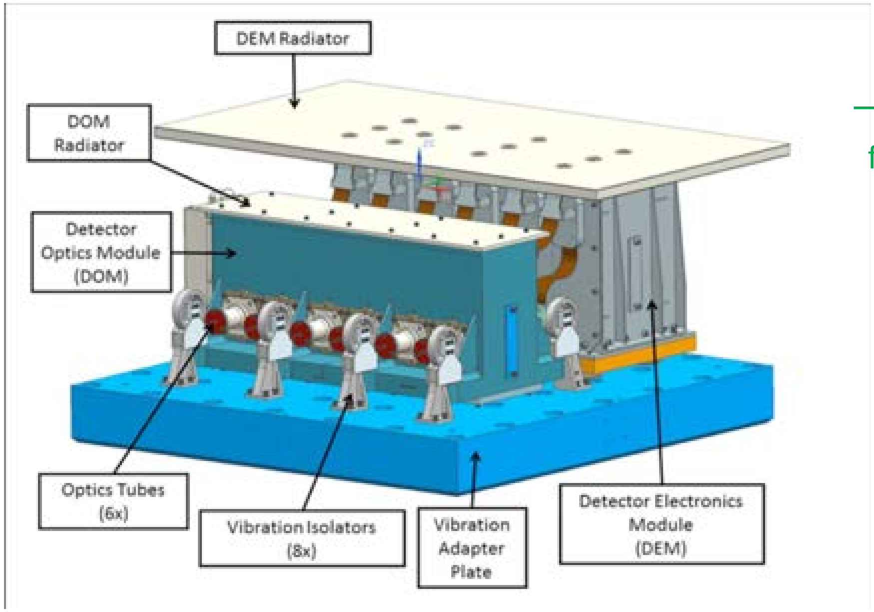
- Telescope : 80-cm Ritchey-Chretien Cassegrain
  - Fiber optics at focal plane couple received signals through temperature-controlled optical filters (30-pm bandwidth) to detector array
- Detectors : Hamamatsu R7600-300-M16 Green Extended Cathode Photomultipliers (PMT, qty. 6):
  - 16 channels Constant Fraction Discriminator (CFD) design for strong spots
  - 4 channels Constant Fraction Discriminator design for weak spots - 4 pixels are combined as one CFD channel.



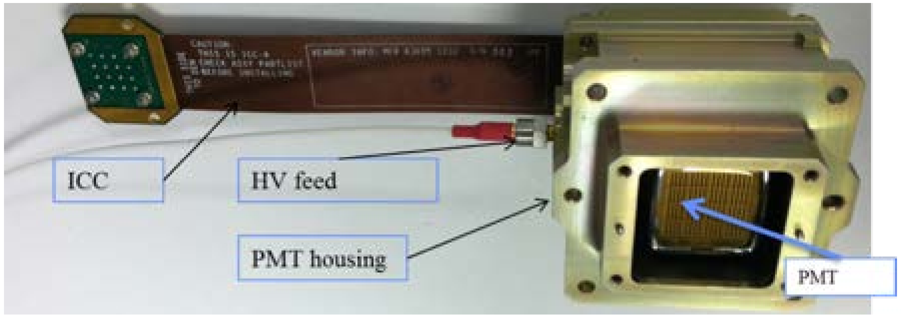


Detector Select Mechanism



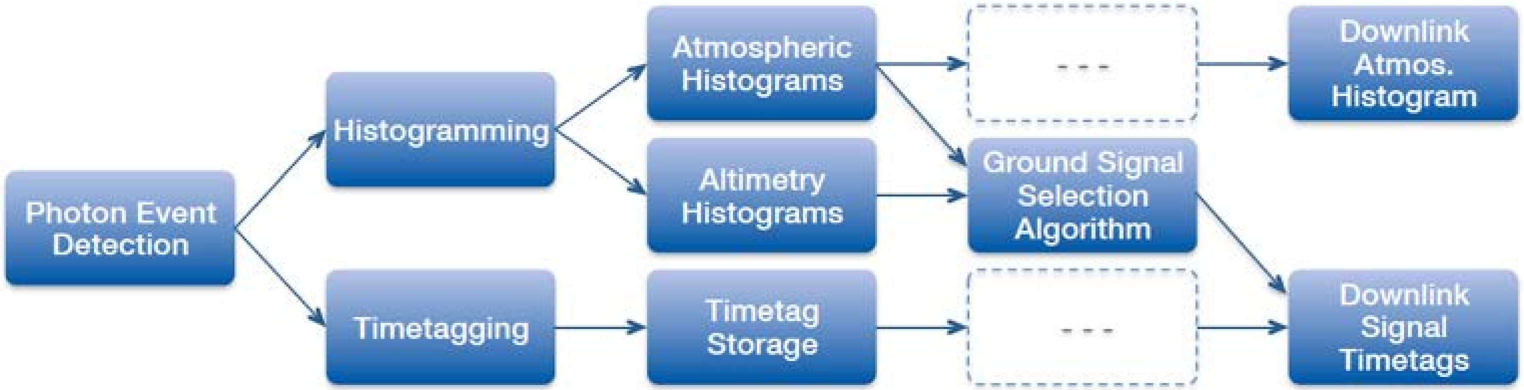


ATLAS Detector Array Assembly



ATLAS Timing and Algorithms

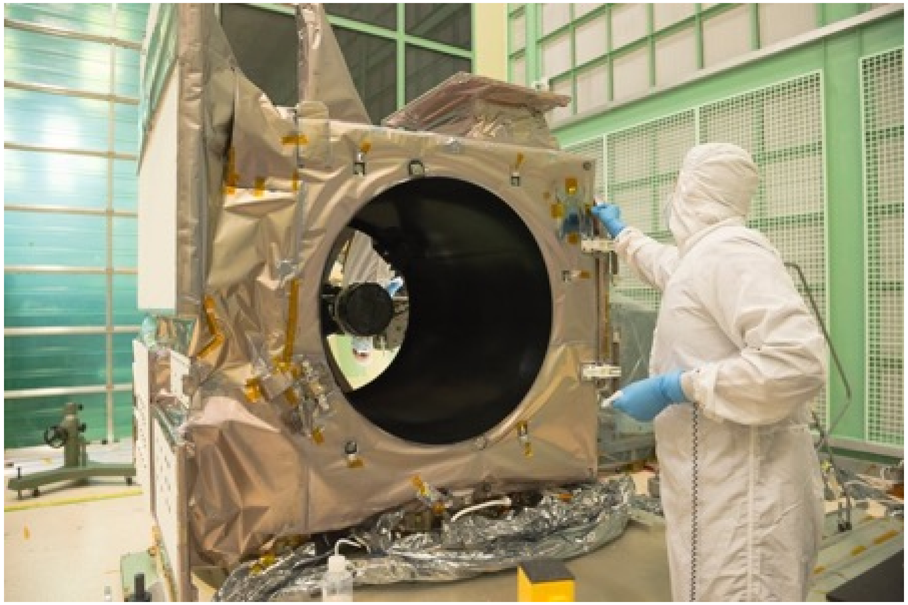
- Photon Counting Electronics
  - Time-tag each detected photon event from the Detector Electronics Module
    - Range gate determined by an on-board algorithm using
      - Digital Elevation/Relief maps (World Geodetic System 1984 ellipsoid)
      - Real-time spacecraft position and attitude (1-Hz, interpolated)
    - 100-MHz oscillator referenced to GPS 1-pps provides coarse time count
    - Gate delay FPGA provides fine time count with ~150-ps resolution
    - Time tags are histogrammed and likely ground signal selected for downlink by evaluating background, signal strength over time, and cloud cover



Data Processing Pipeline

ATLAS Instrument Overview

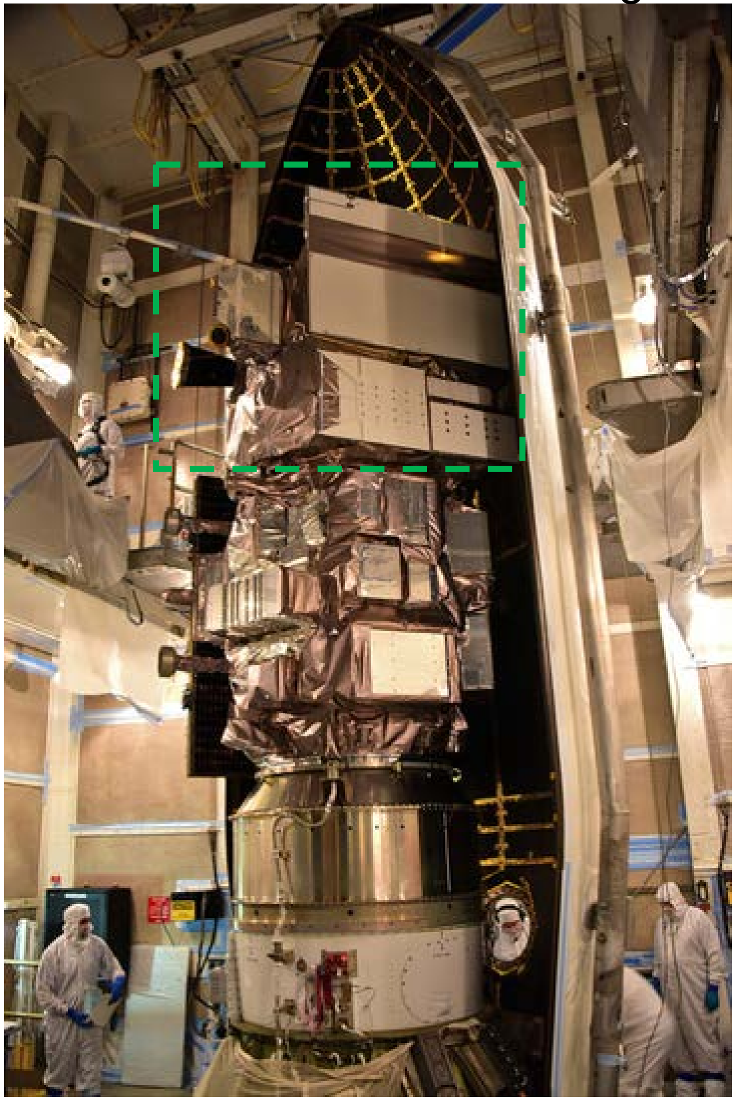
ATLAS in GSFC clean room



MASS	**470 kg**
POWER	**420 W**
DAILY DATA VOLUME	**~500 Gbits**

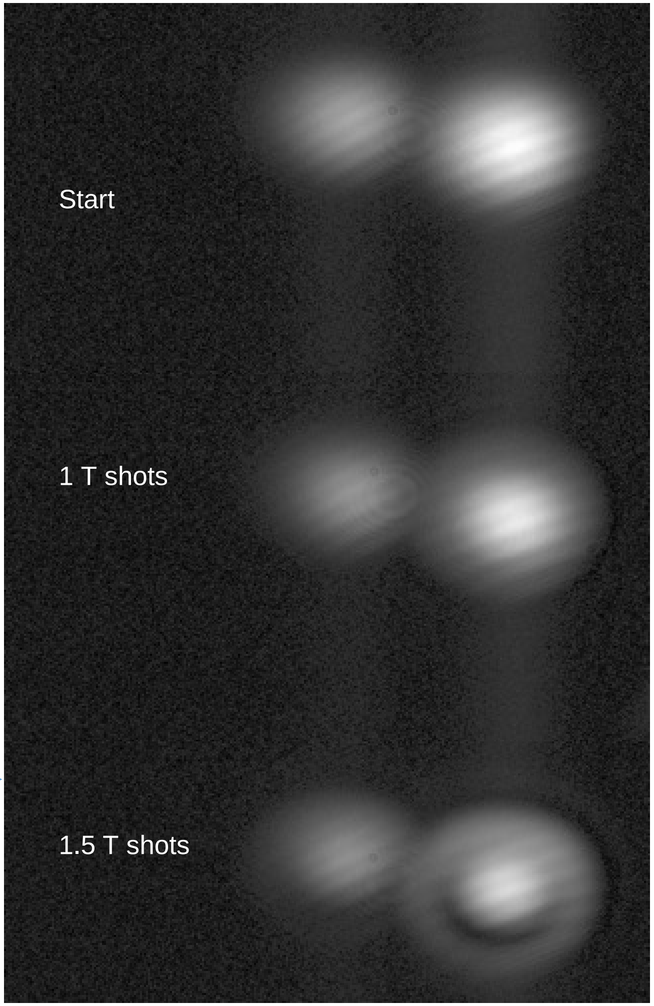
On orbit laser pulse energy: 450 μJ

ATLAS in DELTA-II Fairing



- **Transmit Optics Lifetime**
  - Optical coatings exposed to laser beams in vacuum tend to damage/degrade
  - ATLAS lifetime requirement = 1T shots
  - Mitigations:
    - Maintain 1 atm pressure inside laser
    - Expand laser beam inside pressurized laser before impinging on transmit optics in vacuum
    - Perform Laser Induced Damage Threshold testing to screen all optics
    - House transmit optics in heated enclosure to maintain temperature at 20°C
    - Optical Coatings Life Test (OCLT)
      - Exposed coated optics to laser energy with varying levels of expected contaminants in vacuum.

Typical Beam Quality Degradation

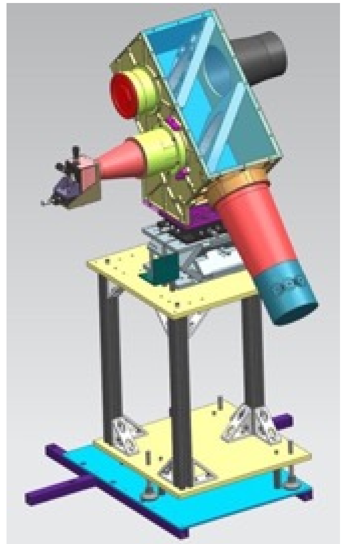


ATLAS GSE
Bench Checkout Equipment

LOAS

Laser Optical Attenuator and Sampler

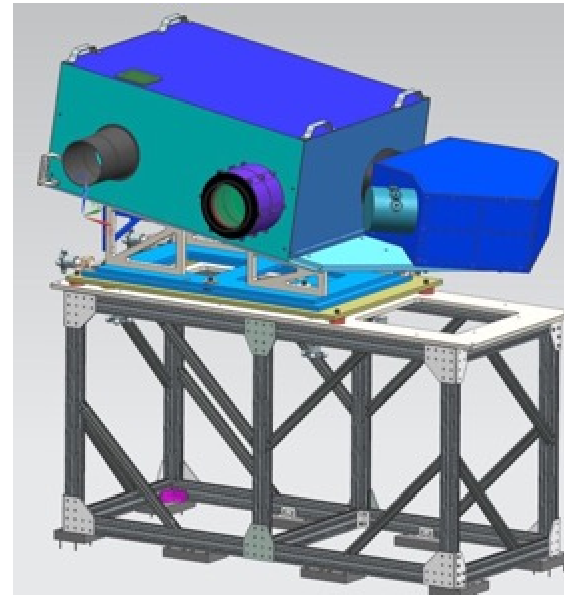
- Attenuates/stops and samples ATLAS laser beam
- Neutral Density filter stack
- Single mode fiber pick-off
- Integrating Sphere



MAAT

Main Alignment & Altimetry Target

- Retro-reflector & beam steering
- Laser Beam Diagnostics
  - Camera, Integrating Sphere, Fiber pickoff



Star Target

Fixed star pattern for LRS

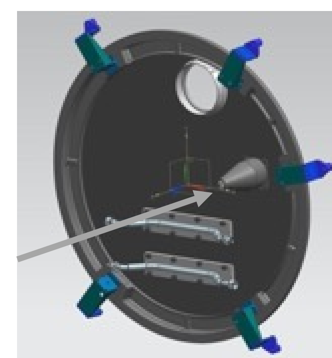
OTPSS

Optical Test Port Stimulator System

Diode laser sources, delay generators fiber coupled to ATLAS

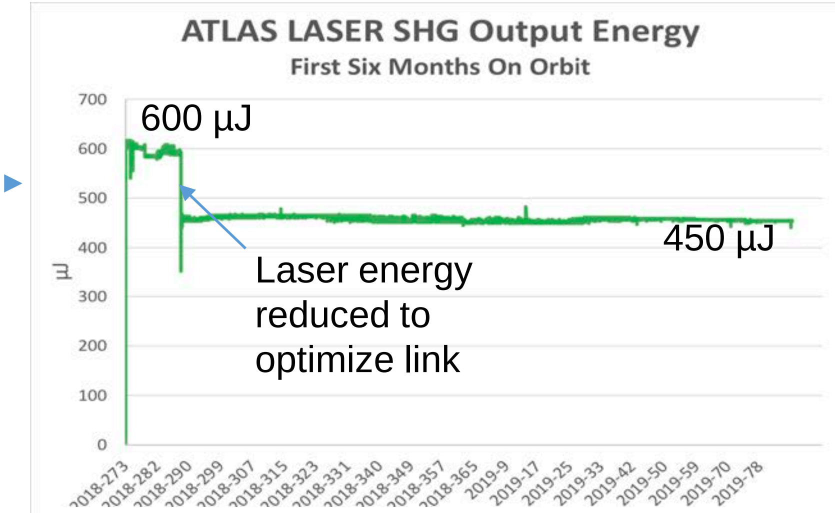
Receiver Telescope Aperture Cover

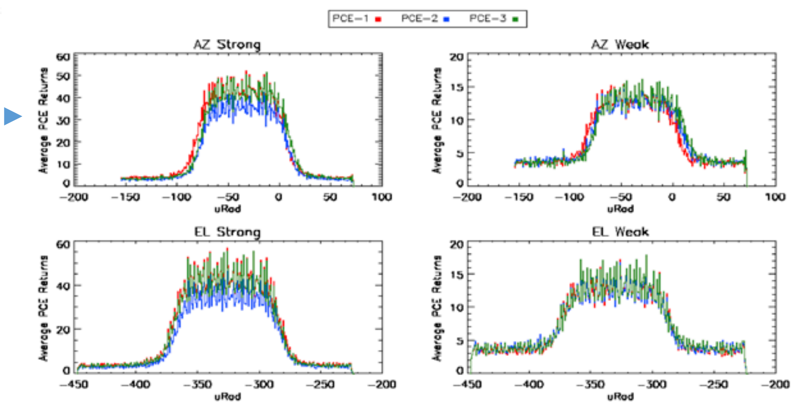
- Path for aperture signal sources
- Showerhead
- Thermal target
- Stray light block

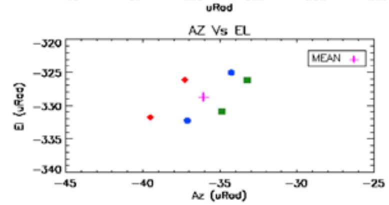


Launch on the last Delta-II

- Laser energy
  - Stable to within ±2% of ground test values
- Beam Quality
  - Nominal as indicated by slope of Alignment Monitoring and Control System (AMCS) sweeps
    - Plots show received beam convolved with RTA field of view
- Pointing
  - No change post-launch
  - Orbit variation ~30 μrad p-p



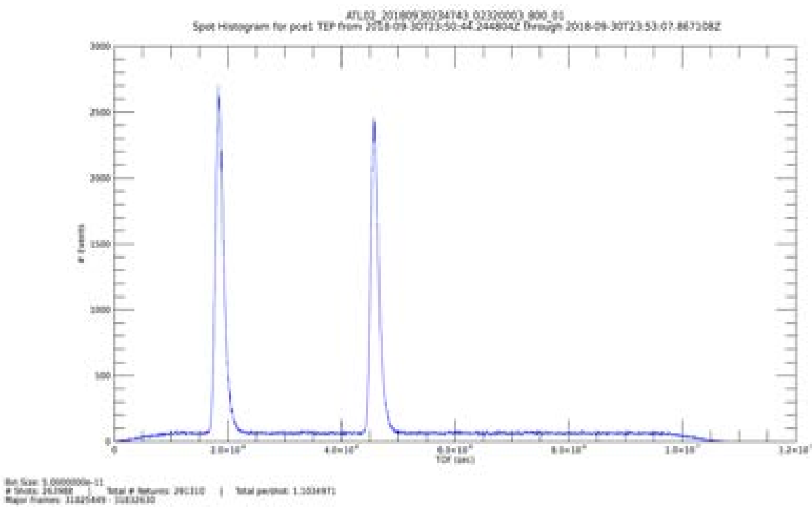




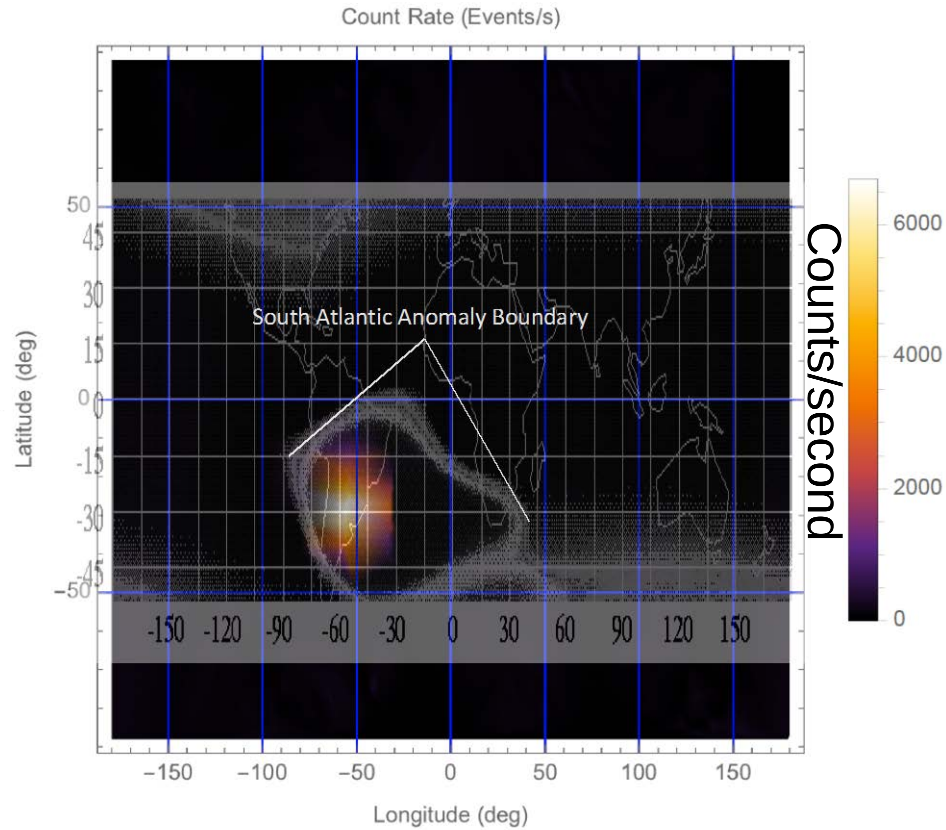
	Az (uRad)	El (uRad)	X	Y
Old AMCS Offset:	0.000	0.000		
Old BSM Offset(Raw):	32533.689	31554.590		
Old BSM Offset:	−40.718	−334.701		
PCE−1 Strong:	−37.297	−326.108	8.5769	3.4616
PCE−1 Weak:	−39.546	−331.771	2.9249	1.1861
PCE−2 Strong:	−34.281	−325.037	9.6342	6.4833
PCE−2 Weak:	−37.118	−332.223	2.4614	3.6122
PCE−3 Strong:	−33.254	−326.139	8.5268	7.5049
PCE−3 Weak:	−34.889	−330.871	3.8029	5.8473
Spots Average:	−36.064	−328.691		
New AMCS Offset:	5.988	4.683		

ATLAS Instrument Performance Receiver

- Receiver performance nominal
  - Impulse response as expected (Transmit Echo Pulse)
  - Solar background noise as expected



Transmit Echo Pulses



Photomultiplier responding to radiation over South Atlantic Anomaly prior to opening of aperture door. Counts are much lower than solar background rates

Receiver Algorithms On-Orbit Example Track over the Himalayas

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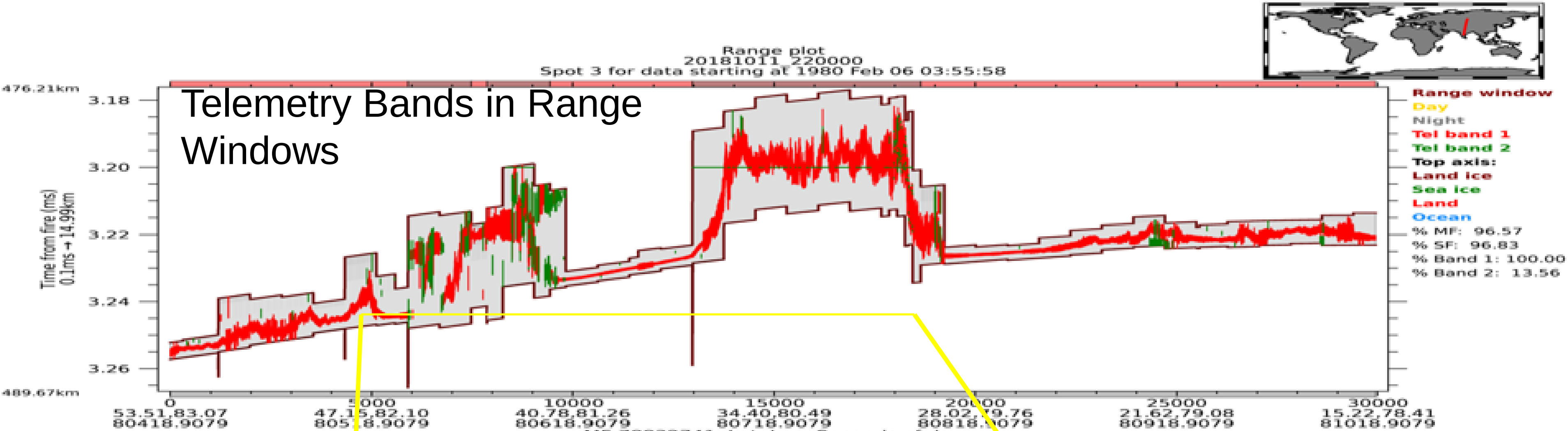

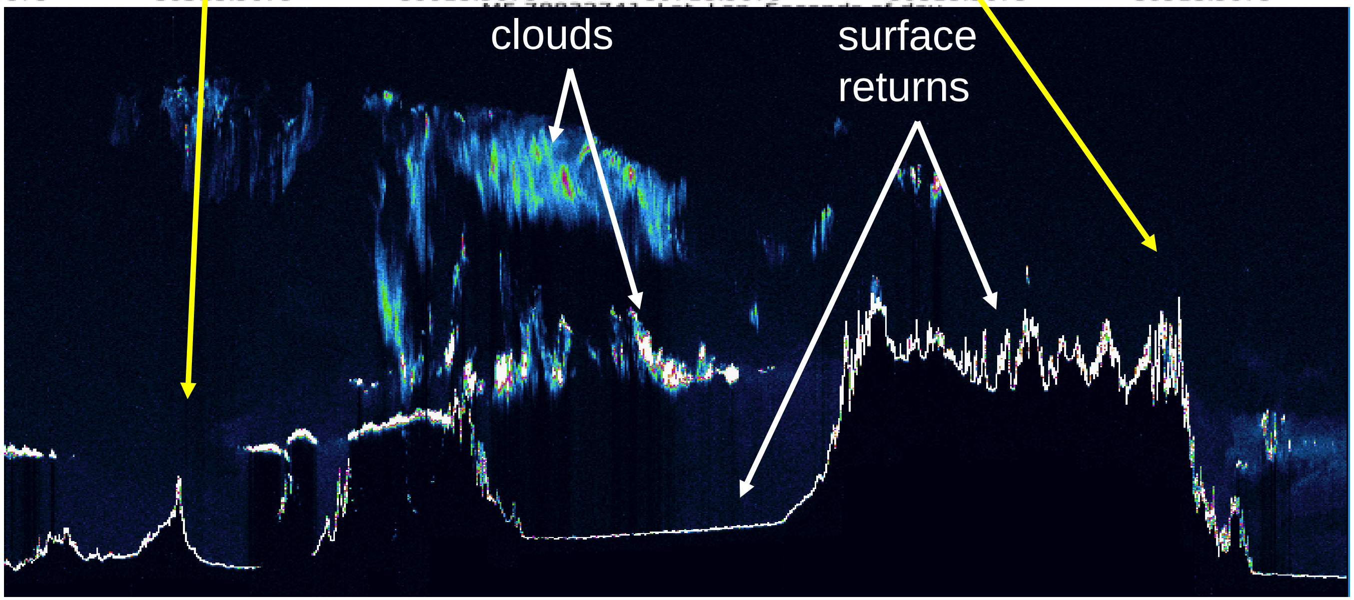

Atmospheric Histogram Plot

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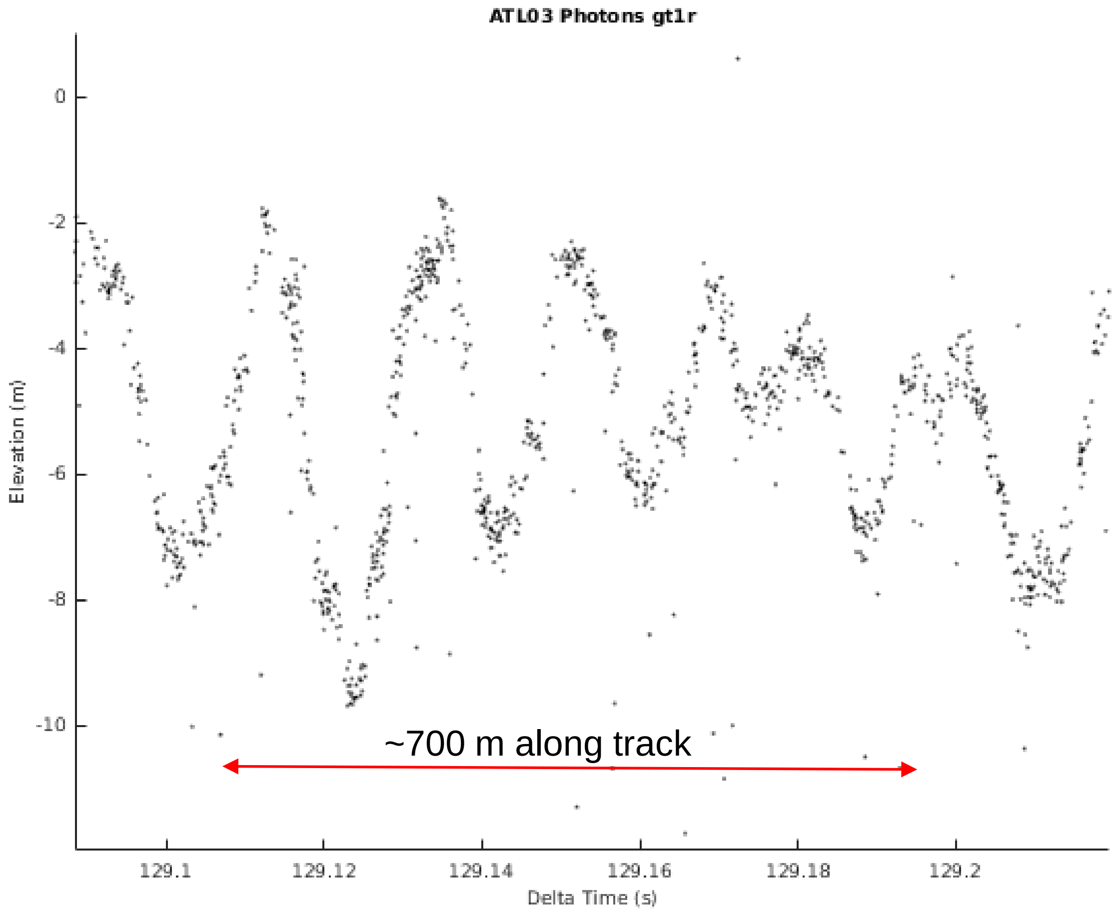

- With the strong beam, there is a well defined wave structure
- This example depicts wavelengths on the order of 140 m

Figure courtesy of Brad Klotz

ATLAS Observations
Trees in Russia, daytime acquisition

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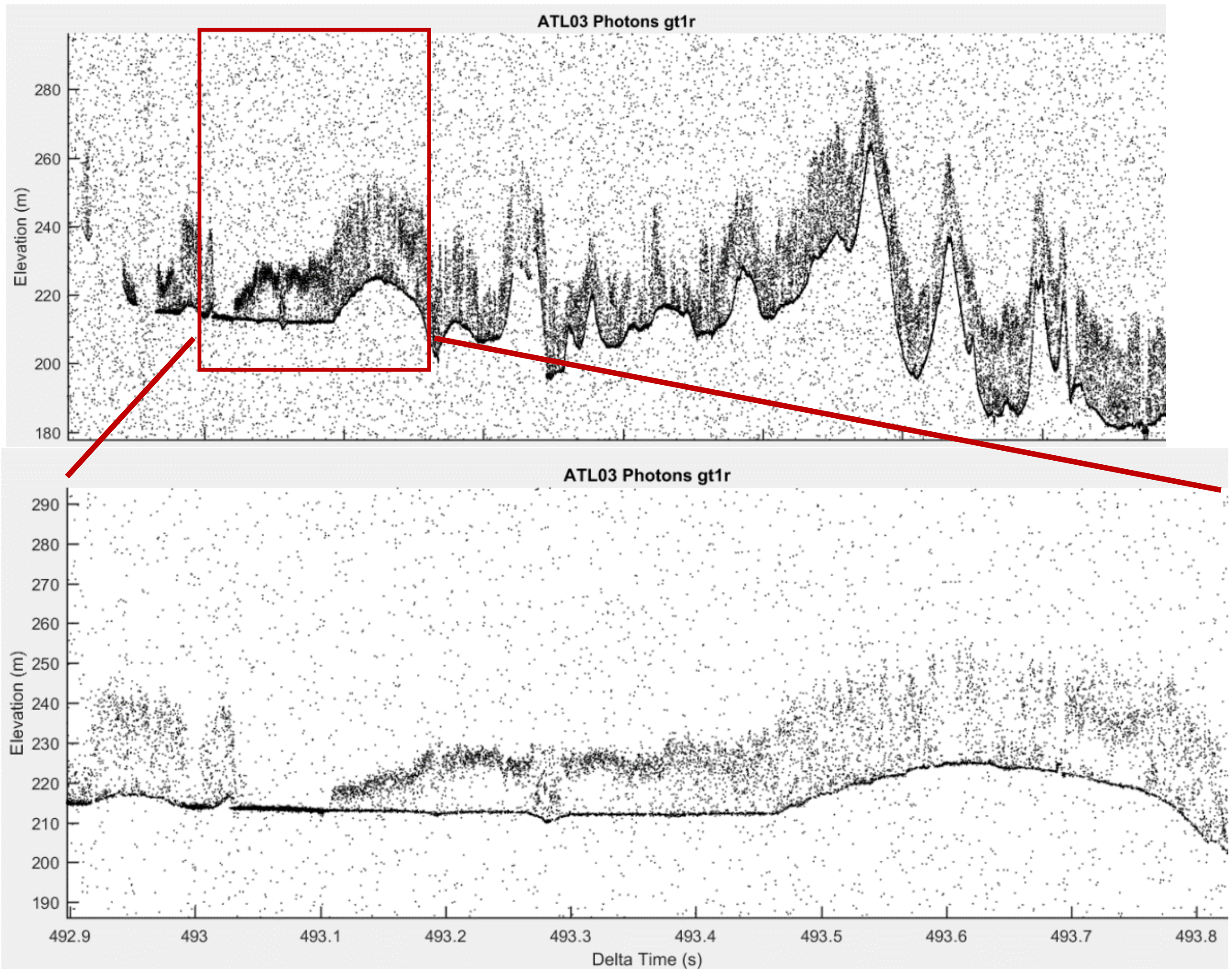
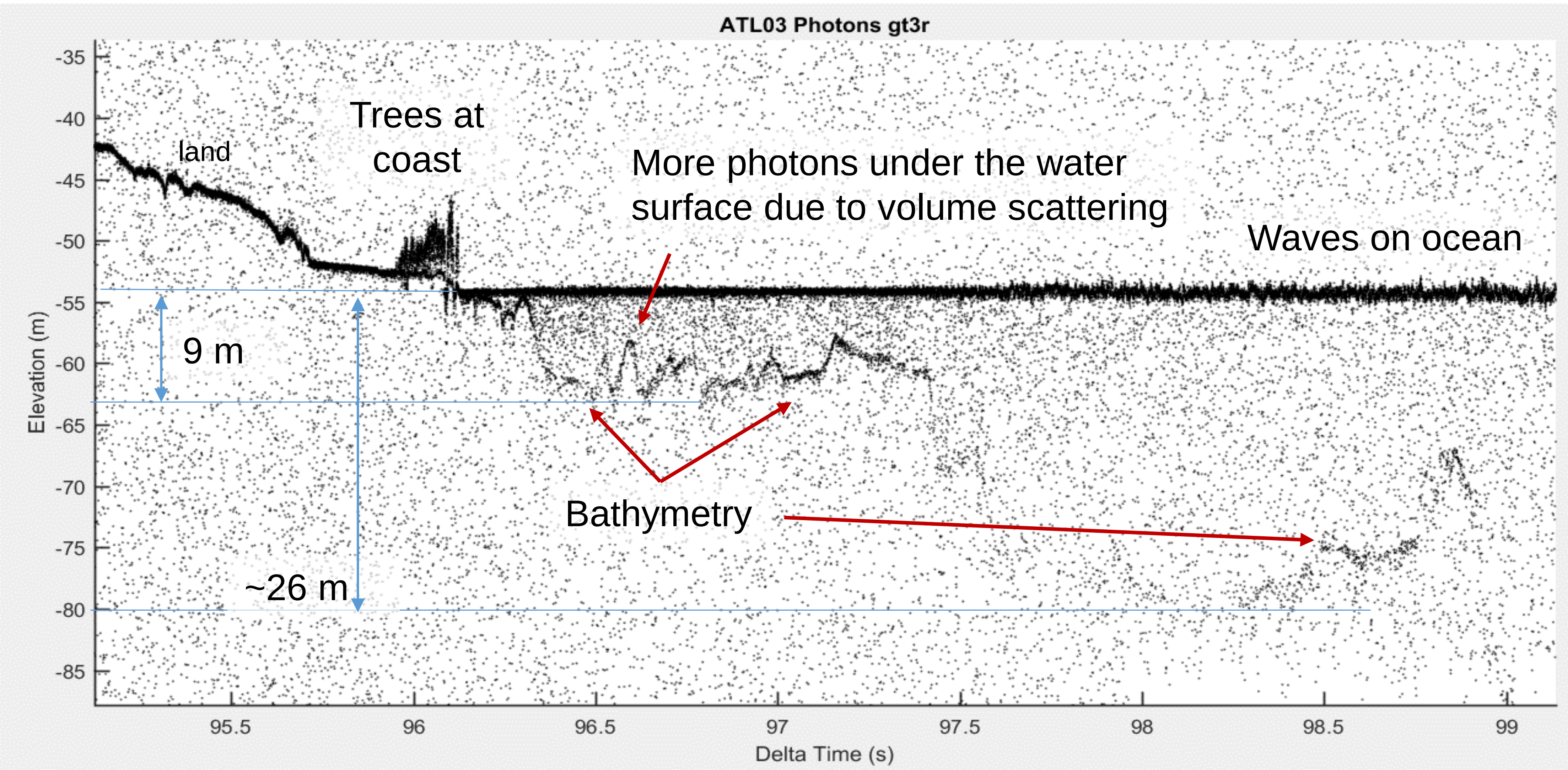


ATLAS Observations
Australian Coast (NW) ATL03 Transect



ATLAS Observations
Ice Sheet Elevation - Antarctica

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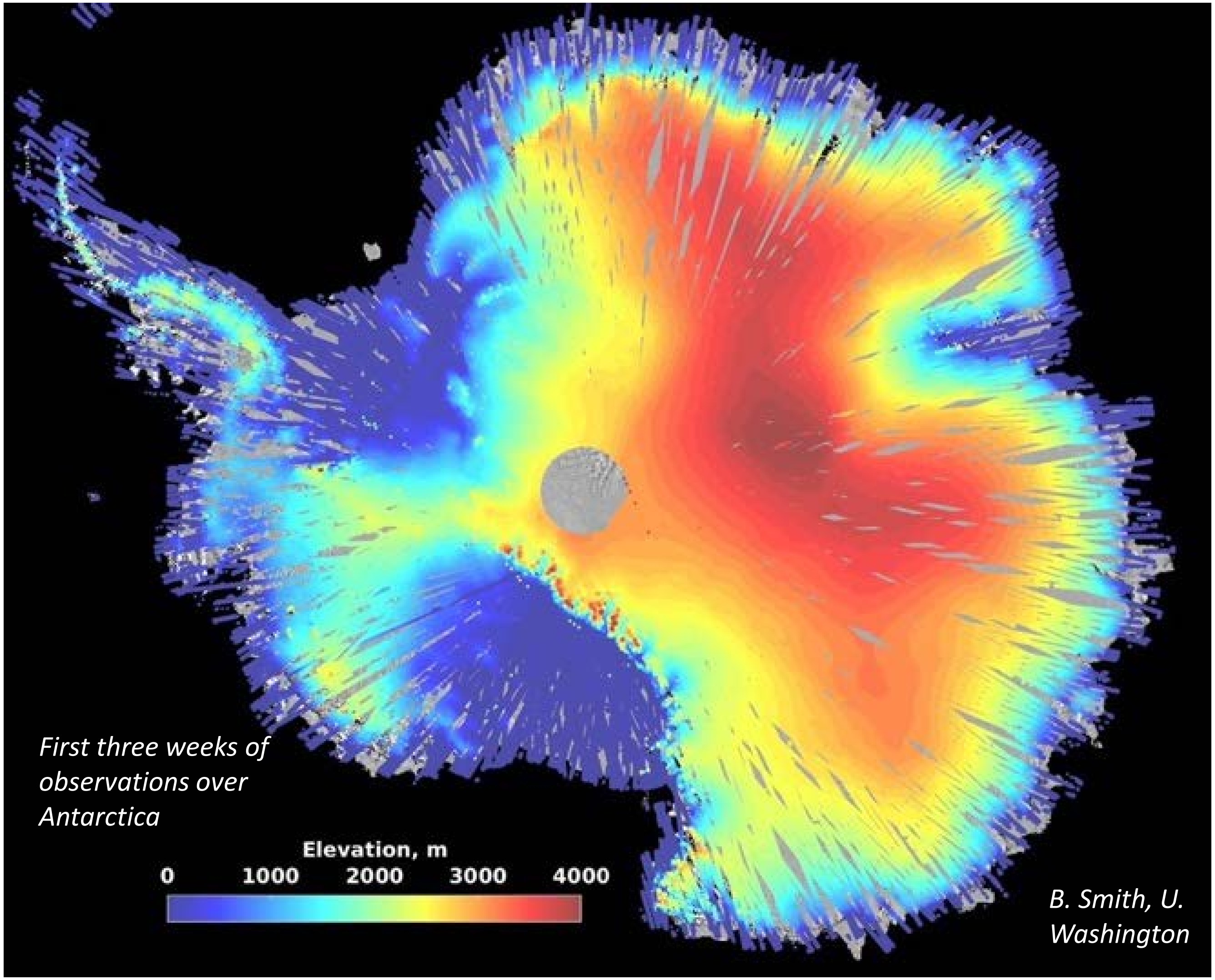
ICESat-2
ICE, CLOUD, AND LAND ELEVATION SATELLITE-2



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Atmospheric Observations
Smoke from California Fires

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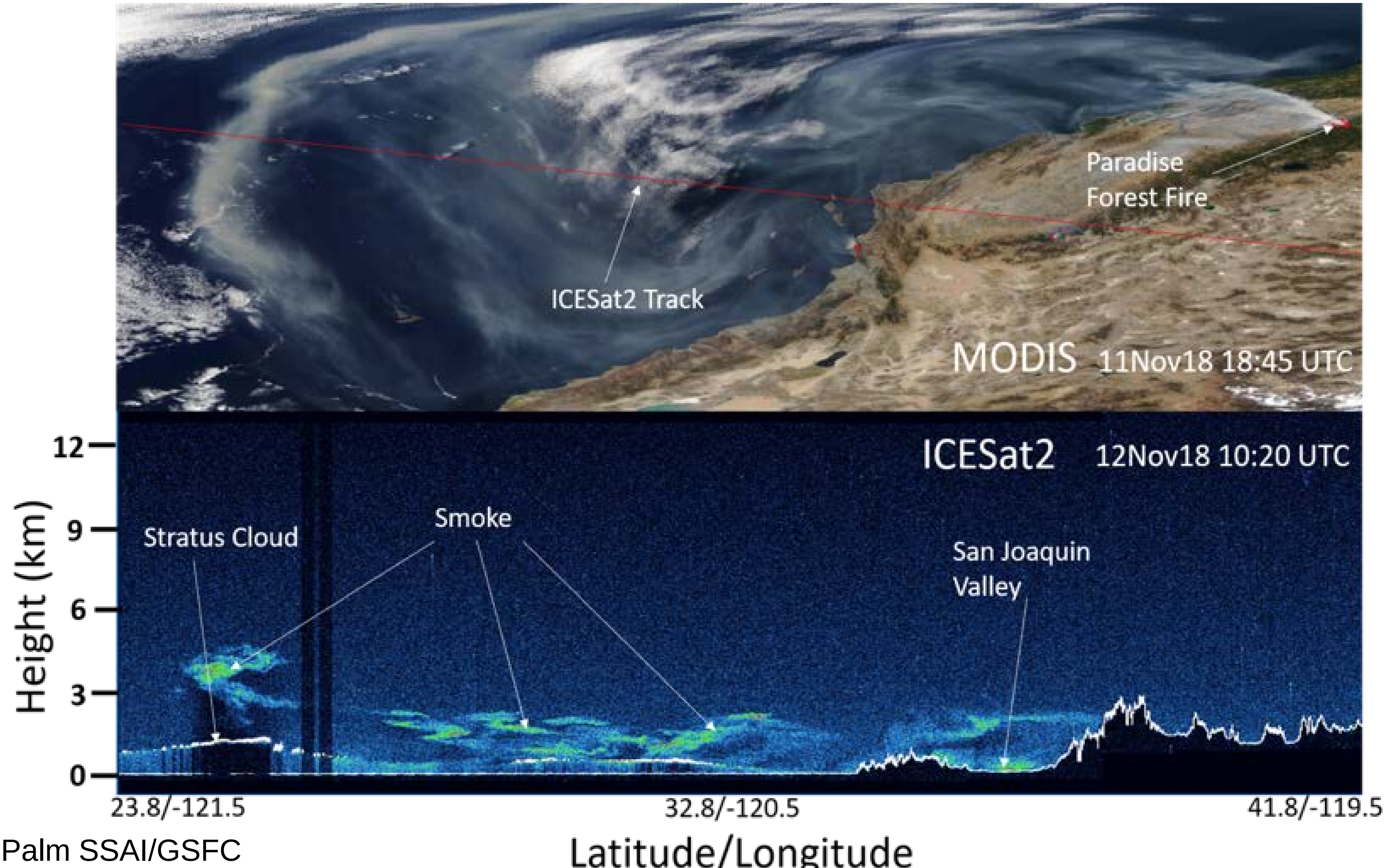

Steve Palm SSAI/GSFC
Yuekui Yang GSFC

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Northrop Grumman Gilbert Facility
ICESat-2 Spacecraft Integration & Test Location

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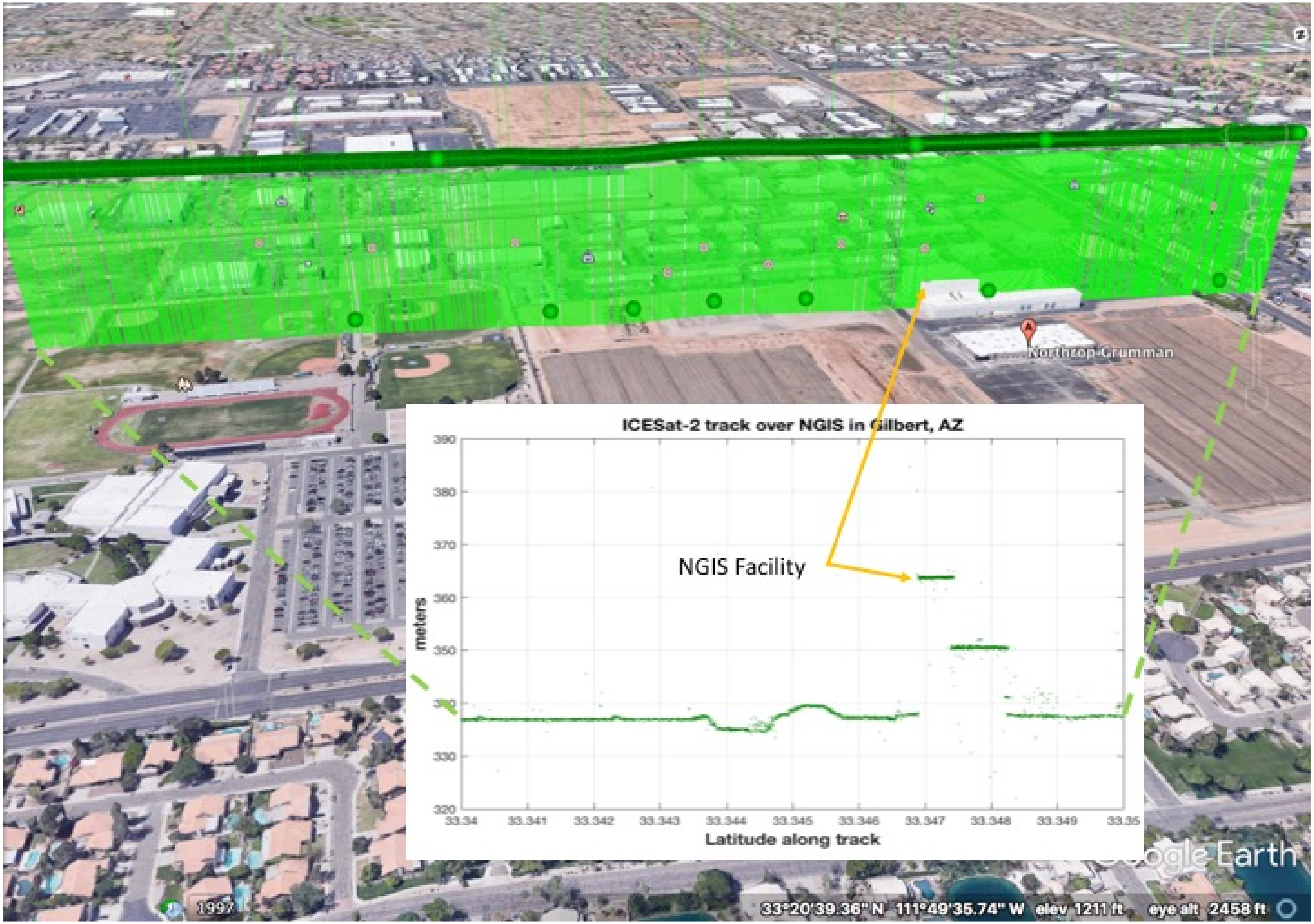

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Deepak Patel/NASA – Thermal Engineer

Luis Ramos-Izquierdo/NASA – Optics

Nick Sawruk/Fibertek - Laser

Oren Sheinman/NASA – Mechanical Systems

Kathy Strickler/Alcyon Tech. Services – I&T Manager

Joseph-Paul Swinski/NASA – Instrument Software

Elisavet Troupaki/NASA - Laser

Bonnieblue Valentin-Santiago/SGT - Contamination

Acronyms

AMCS	Alignment Monitoring and Control Subsystem
ATLAS	Advanced Topographic Laser Altimeter System
AZ	Azimuth
BCE	Bench Check-Out Equipment
BSM	Beam Steering Mechanism
CCHP	Constant Conductance Heat Pipe
CFD	Constant Fraction Discriminator
DAA	Detector Array Assembly
DEM	Detector Electronics Module
DOE	Diffractive Optical Element
DOM	Detector Optics Module
DRM	Digital Relief Model
EL	Elevation
FM	Fold Mirror
HV	High Voltage

ICESat-2	Ice Cloud and Land Elevation Satellite - 2
IMSC	Instrument-Mounted Spacecraft Components
LHP	Loop Heat Pipe
LRS	Laser Reference System
LSA	Laser Sampling Assembly
MOPA	Master Oscillator - Power Amplifier
Nd:YAG	Neodymium-doped Yttrium Aluminum Garnet
Nd:YVO4	Neodymium-doped Yttrium Orthovanadate
PBC	Polarization Beam Combiner
PMT	Photomultiplier
RTA	Receiver Telescope Assembly
SHG	Second Harmonic Generator
Si-APD	Silicon Avalanche Photodiode
SPCM	Single Photon Counting Module
TAMS-LS	Telescope Alignment Monitoring System Light Source
USO	Ultra Stable Oscillator