

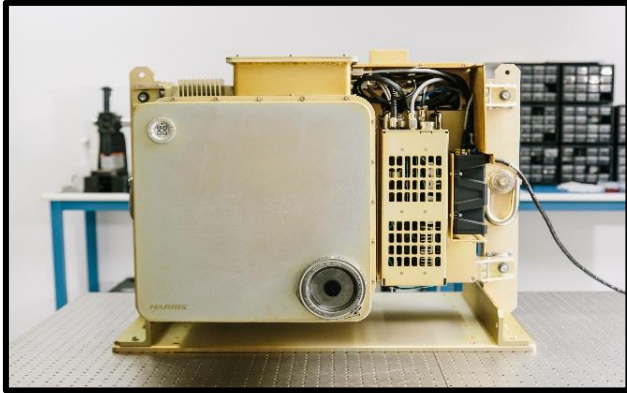
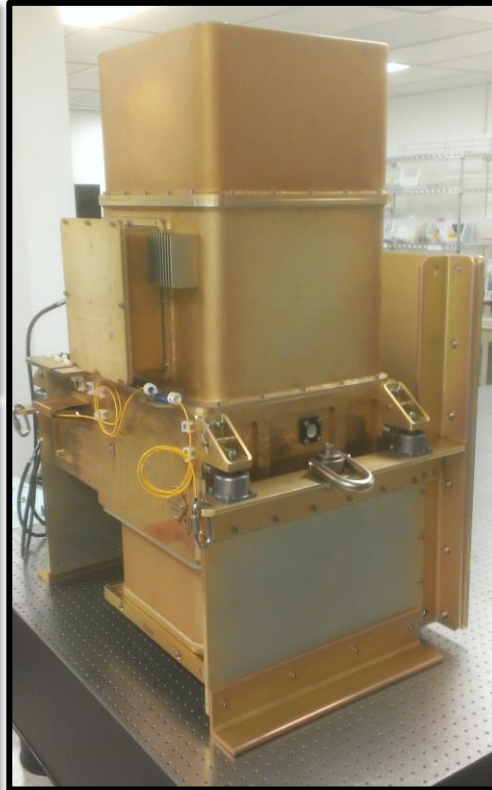
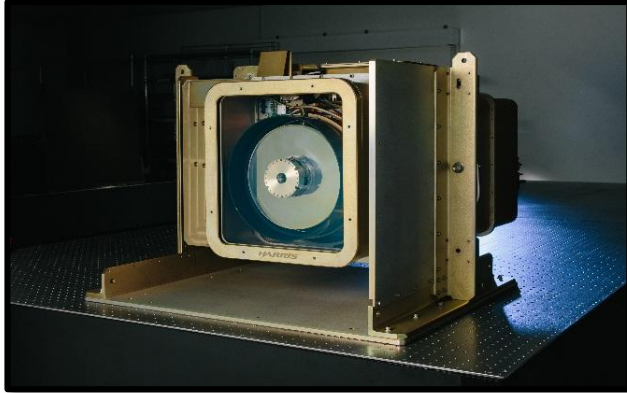
Commercial Geiger Mode LiDAR



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Geiger-mode (GmAPD) LiDAR sensor



**Geiger-mode
GmAPD
LiDAR Sensor**



Built specifically for wide-area, high-density collection

Geiger Mode LiDAR is a new technology

False - it been utilized successfully in the defense industry for over 15 years. It is only new to the commercial industry.

Why hasn't it been available before now?

Key components could not be sourced for commercial application until recently

Geiger Mode LiDAR data are noisy

False - in its raw (unprocessed) state it is noisier than linear systems however, this just means a different approach to processing is utilized to produce elevation data and derivative products.

Geiger Mode LiDAR will not work in daylight conditions

False – Commercial Geiger mode technology is designed to work in daylight (solar) conditions with a minimal decrease in performance.

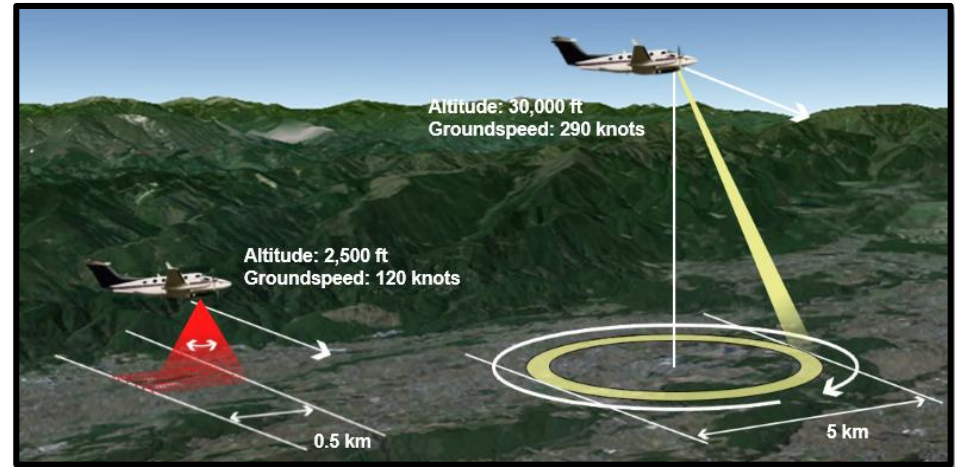
Years of proven performance in real world operations and applications

- Inefficient (Costly) at high resolutions
- Has inherent data occlusions
- Foliage penetration is limited
- Limited-range resolution (target separation)
- Low-sensitivity, high-power system

What's Different about Geiger-mode?



Harris Geiger –mode Specifications	
Mission	
Altitude range (AGL)	7,000 - >30,00 ft
Flight Speed	200 - 450knots
Swath Width	>20,000 ft
Palmer Scanner	
Scan Half Angle	15°
Aperture Diameter	27 cm
Transmit Laser	
Wavelength	1064 nm (Class IV)
Average Power	20 W
Pulse Width	550 ps
Pulse Repetition Frequency	50 kHz
NOHD/ENOHD	300m/2.2 km
GmAPD Receiver	
Array Size	32 x 128
IFOV	35 urads
PDE	30%
Timing Resolution	250-500ps
Coverage Rate (w 50% overlap)	
4 points per m²	1200 km²/hr
8 points per m²	1000 km²/hr
20 points per m²	700 km²/hr



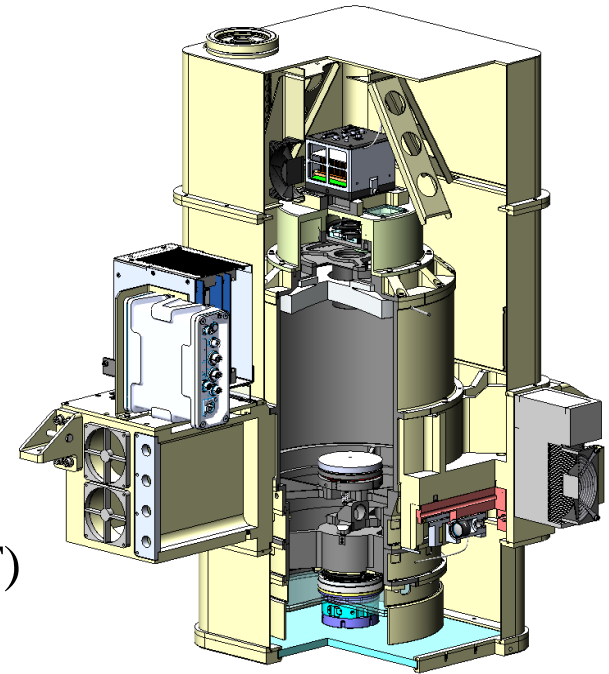
- High-sensitivity
- Low-power system
- Higher-resolution
- More accurate data
- Large-aperture Palmer scanner
- Multi-pulse-in-the-air
- Automatic range gate control
- Improved range separation
- Improved foliage penetration

Geiger-mode flies higher, and collects faster than current sensors

What is a GmAPD Sensor?



- Avalanche Photo Diode Array (4096 detectors)
- Photon counting device (Low light sensitivity enables use of low power laser)
- Capable of sub-ns operation (enables higher vertical measurement precision and vertical resolution)
- Supports high laser Pulse Repetition Frequencies (PRF)



Think of it as a 3D camera

Technology Comparison

Linear LiDAR



- Single pulse
- Single measurement
- Low sample rate

Approximately 500KHz for single scanner designs

Technology Comparison

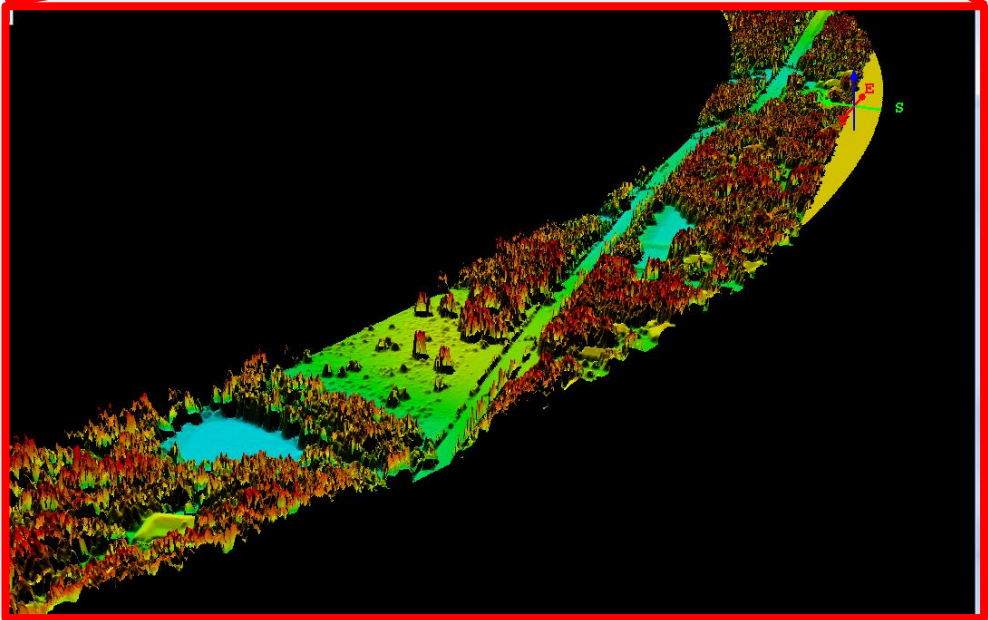
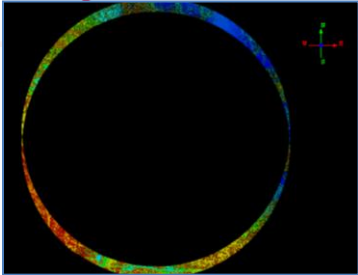
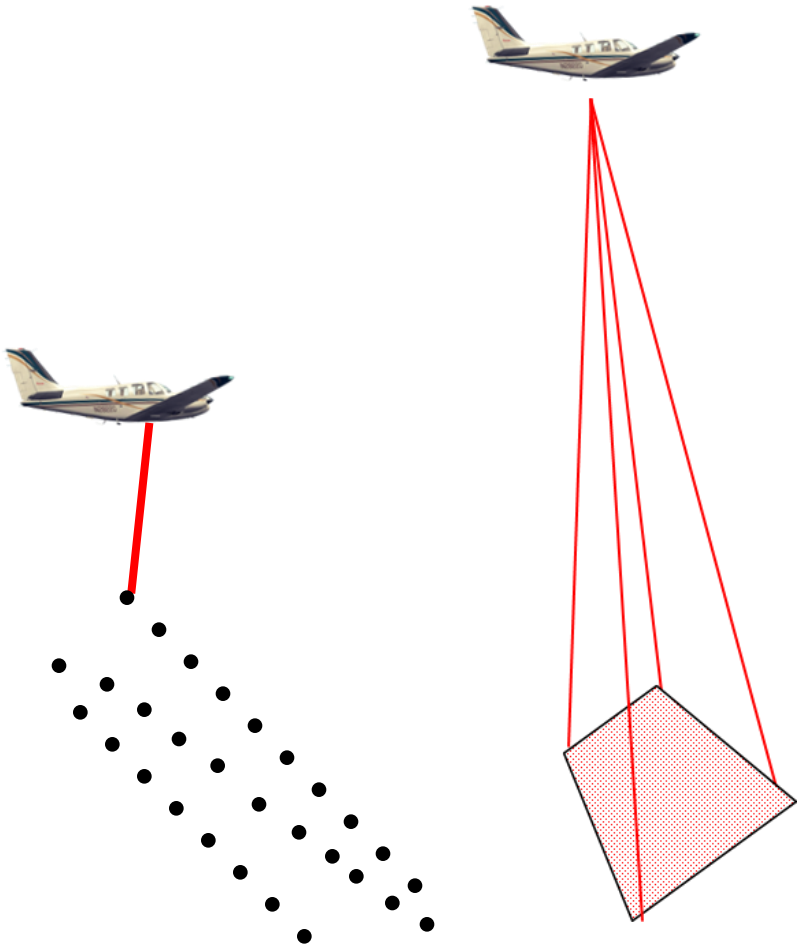
Geiger LiDAR

- Large array collection
- Collection from multiple angles
- High sample rate
(204 million samples per second)



200MHz vs. 500KHz

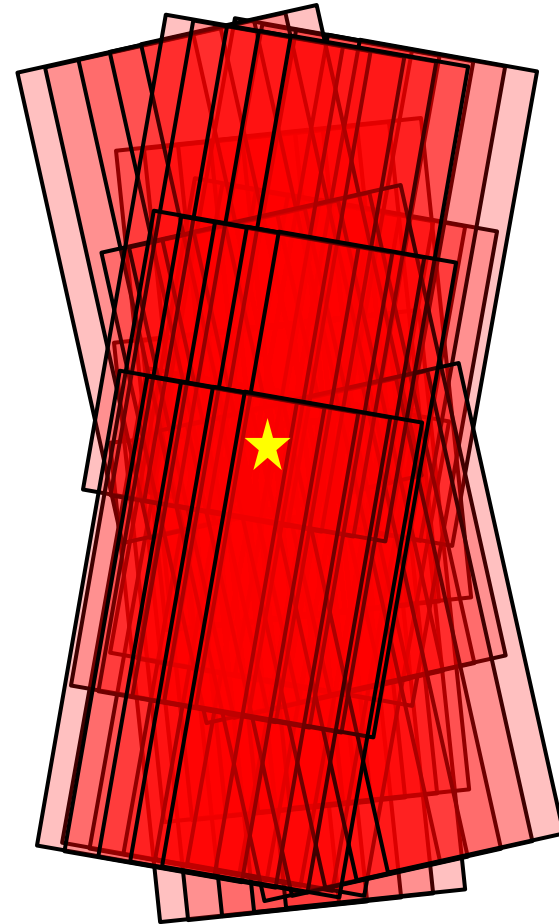
Geiger-mode vs. today's technology



Geiger-mode sensors sample the same spot on the ground multiple times

Multi-look approach

- 4096 measurements per laser flash
- 50,000 flashes per second
- Approx= 205 million elevation measurement per second
- Every spot illuminated 1000's of times
- The dozens of photon detections are processed to determine the real objects
- Programmable Forward/Sidelap



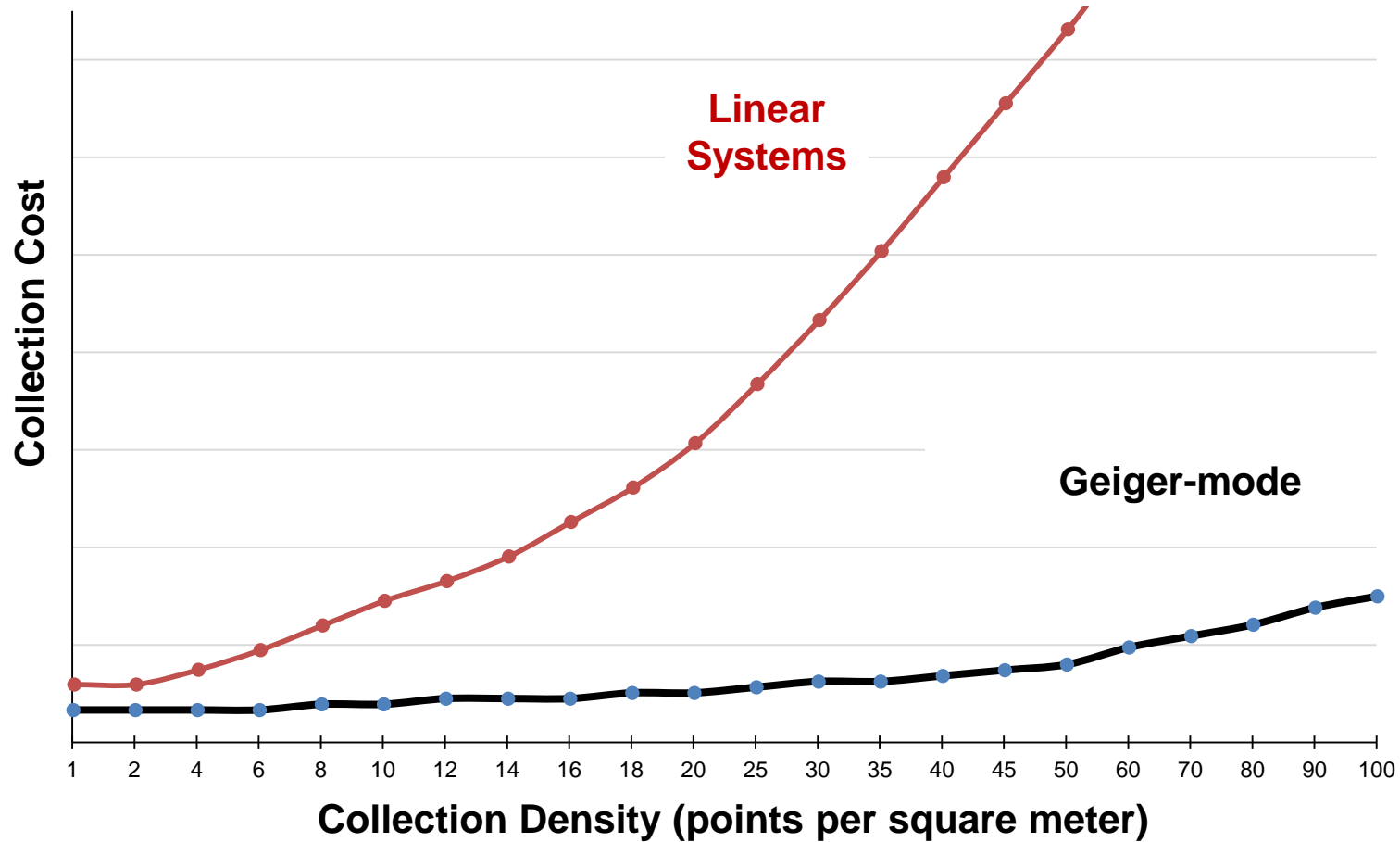
Speed of Collection Metrics @ 8PPM



8 points/m2 Collection	Current Linear Mode	Flash (Linear Array)	Photon Counting PMT	Harris Geiger-mode Sensors
Altitude (AGL)	150 - 1500m	500-2000m	1000-8500m	4000-11000m
Field of View	45-60°	5-10°	10-40°	30°
Flight Speed	50-100 kn	200-250 kn	100-200kn	200-450kn
Laser Power	200-500mW	120-400mW	1-2W	20-40W
PDE	N/A	N/A	10-15%	25-40%
Pulse Width (Resolution)	1 - 10 ns	5 - 10 ns	700-900ps	300-600ps
Timing Jitter (Precision)	50-500ps	50-500ps	50-100ps	250-500ps
Pulse Repetition Frequency	100 - 800kHz	20-30Hz	20-35kHz	50-90kHz
Detector Count	less than 10	16k	100	4096
Ground Samples/Second	100k-800k	325k-500k	200-350k	200M-400M
Return Surface(s)	1,4,Full Waveform	1, Multiple	Multiple	Multiple
Area Coverage Rate (w/ desired overlap)	50-180km²/hour	40-160km²/hour	170-500km²/hour	1000-1600 km²/hour
Operational Maturity	20-25 years of airborne operation; Evolutionary Improvements	Limited operations in airborne mapping; Technology undergoing incremental improvement	< 5 years in experimental mapping operations; Emerging technology undergoing rapid improvement	5-10 years in defense operations mapping hundreds of thousands of km²; Over 15 years in experimental use; Emerging technology undergoing rapid improvement

Geiger-mode sensors can collect 5x,10x, etc with increasing density

Reduced Cost at Higher Resolutions



Efficiency gains keep costs down at higher collection densities

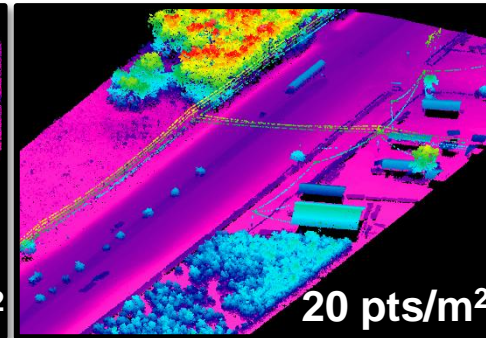
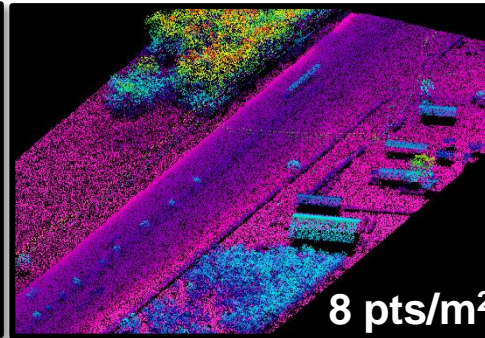
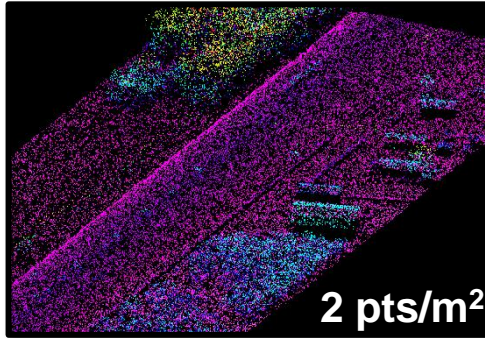
Superior Performance

	Linear LiDAR	Geiger LiDAR
Density (points per meter)	8	8
Instantaneous Coverage Rate (mi ² /hr)	50	850
RMSEz (cm)	9.25	9.25
Altitude (AGL ft)	3,200	27,000
Swath Width (ft)	3,300	16,000
Ground Speed (kts)	90	290

17X

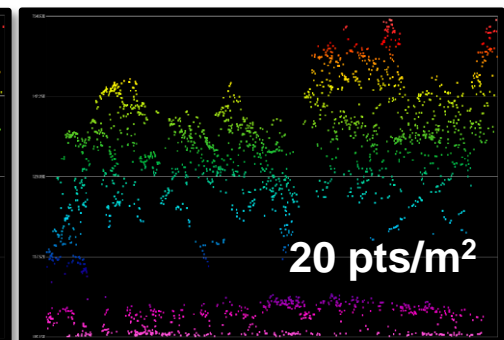
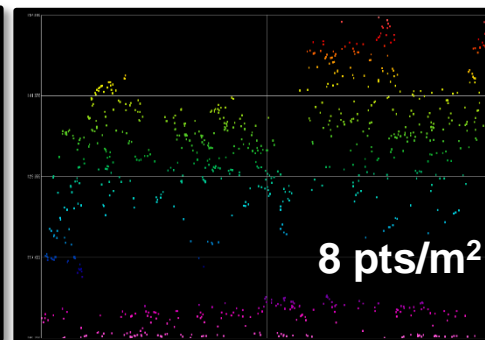
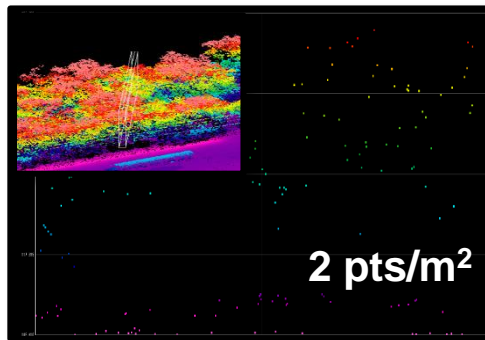
Higher the density greater the payback

Why do higher densities matter?



Infrastructure details better defined

Improves foliage penetration to better sample bare earth

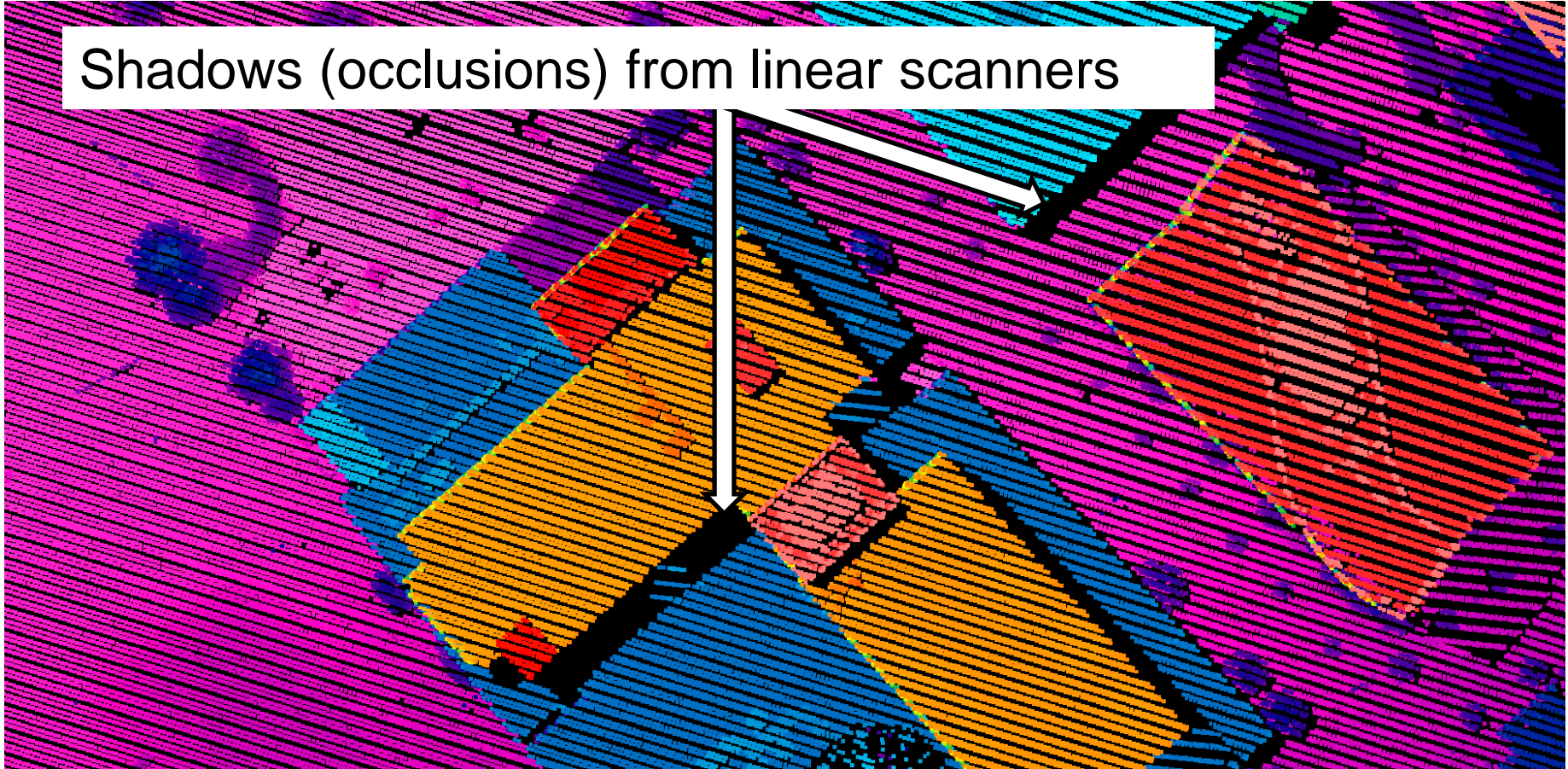


Improves accuracy and enables a high level of automation

Single Look Linear Artifact Example1



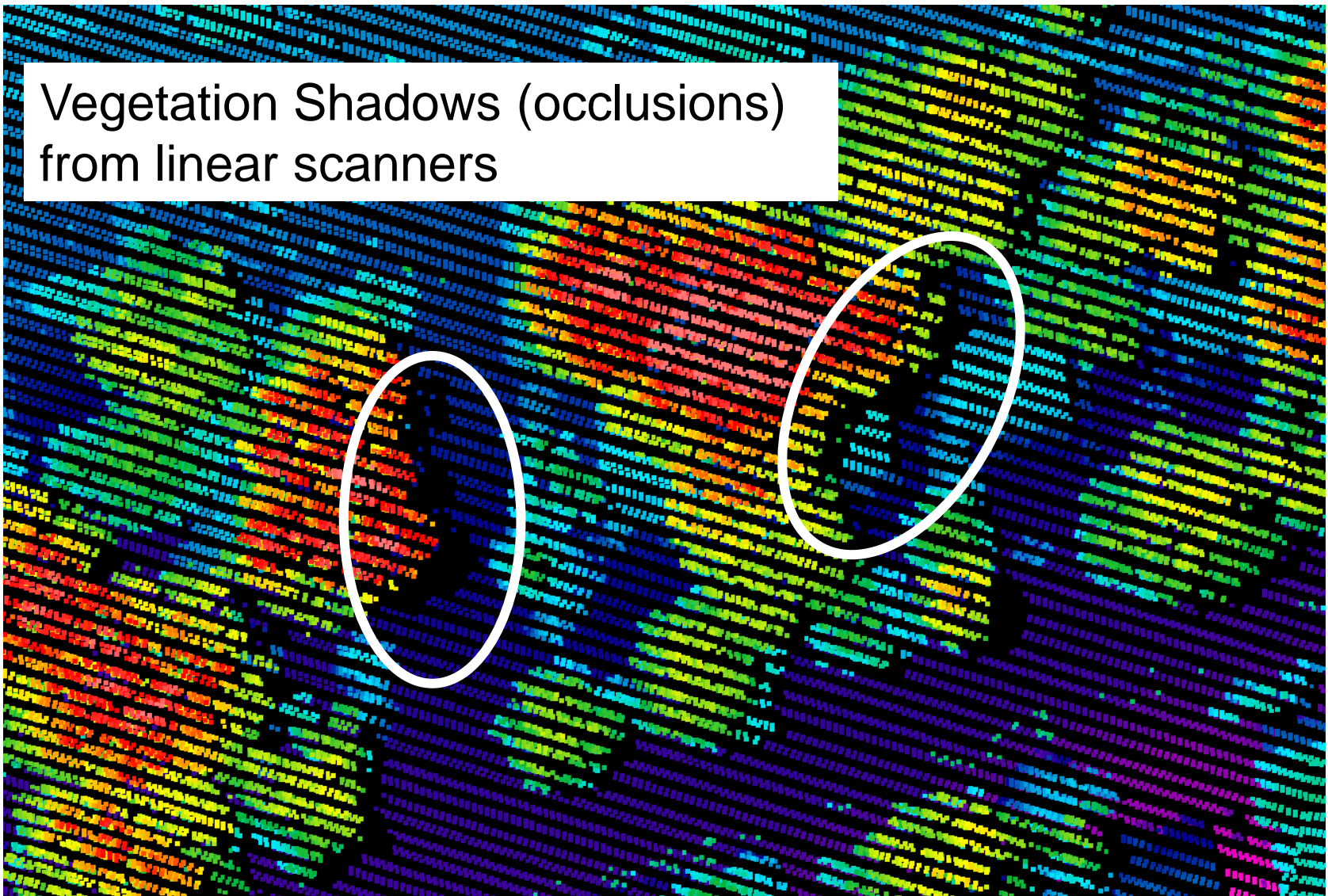
Shadows (occlusions) from linear scanners



Single Look Linear Artifact Example2



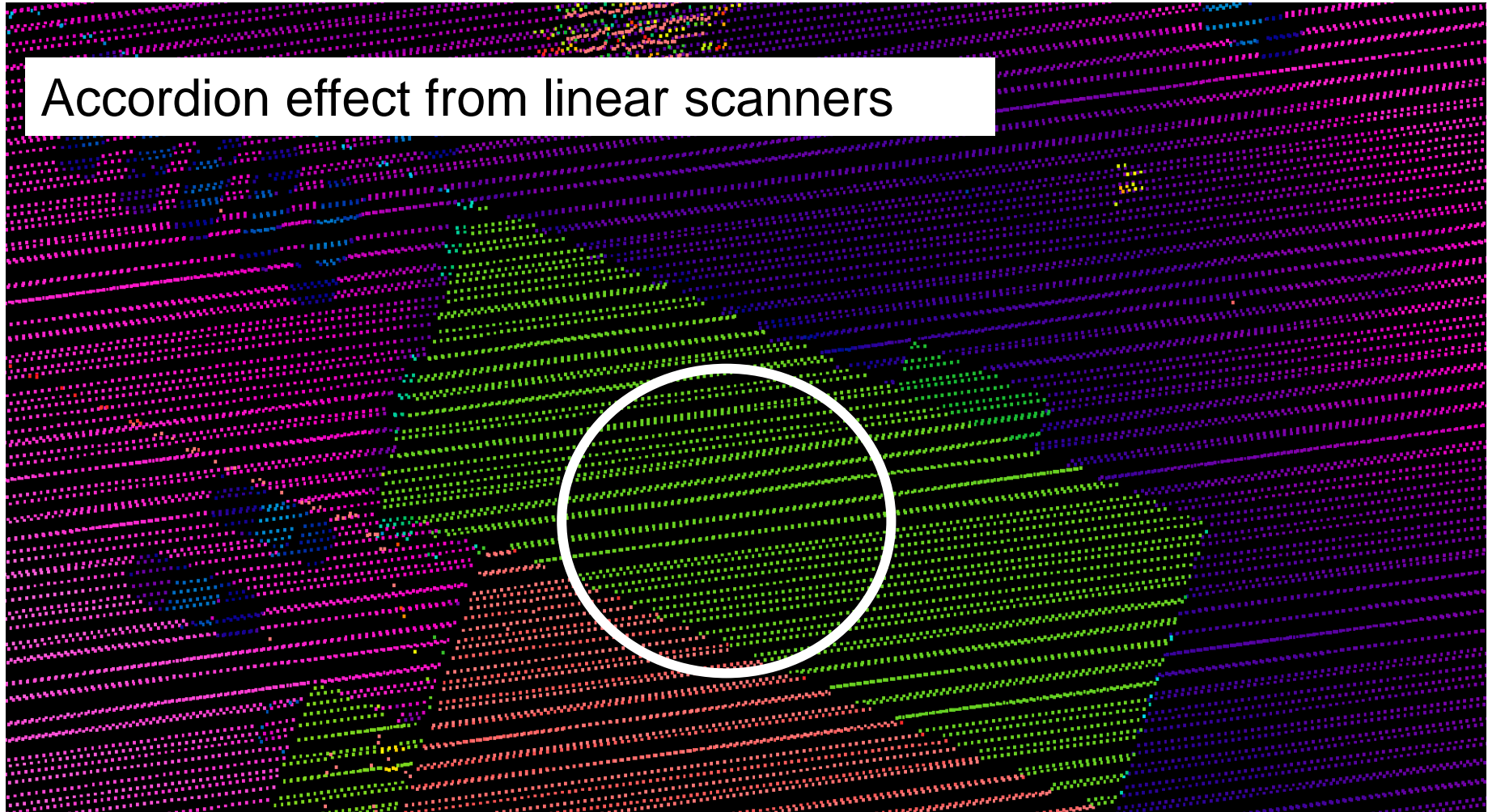
Vegetation Shadows (occlusions)
from linear scanners



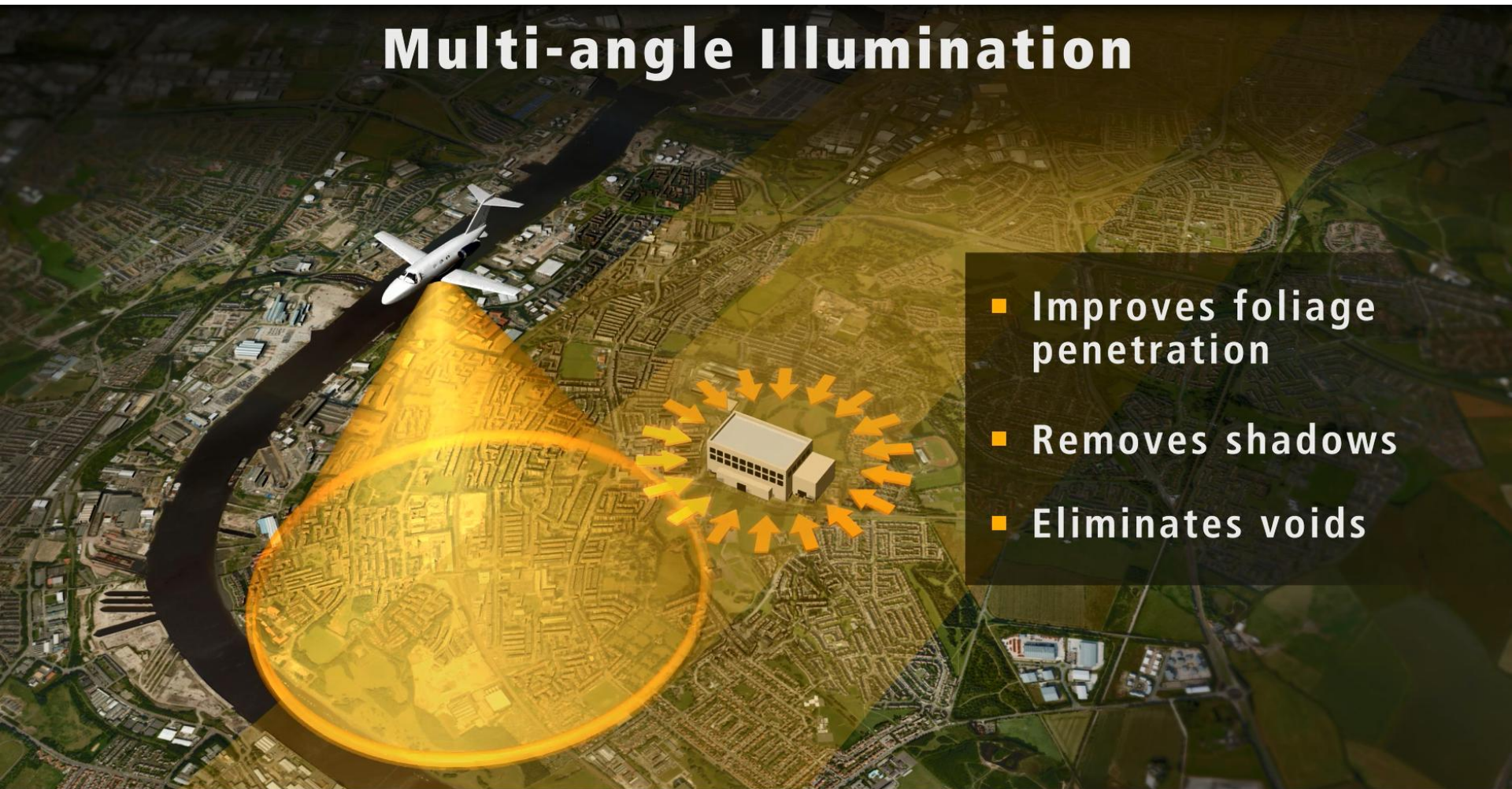
Single Look Linear Artifact Example3



Accordion effect from linear scanners



Multi-angle Illumination



- Improves foliage penetration
- Removes shadows
- Eliminates voids



Reduces Artifacts
and occlusions

Provides Highly Homogenous High-Density Accurate Data

Aggregating data requires accurate swath alignment

Utilize latest INS/GPS

Utilize horizontal and vertical ground control points

50% overlap swaths creates four looks (fore/aft <>fore/aft)

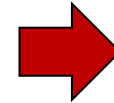
Perform bundle adjustment via data tie points correcting both horizontal and vertical alignment from multiple look angles.

True photogrammetric bundle adjustment to provide higher accuracy

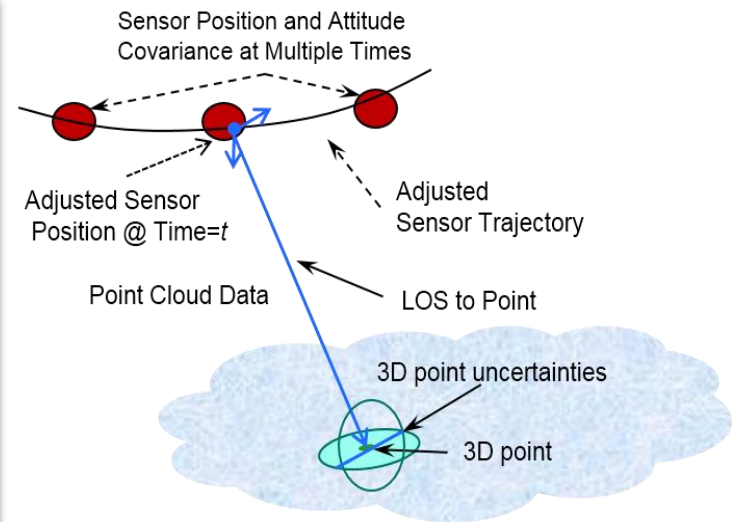
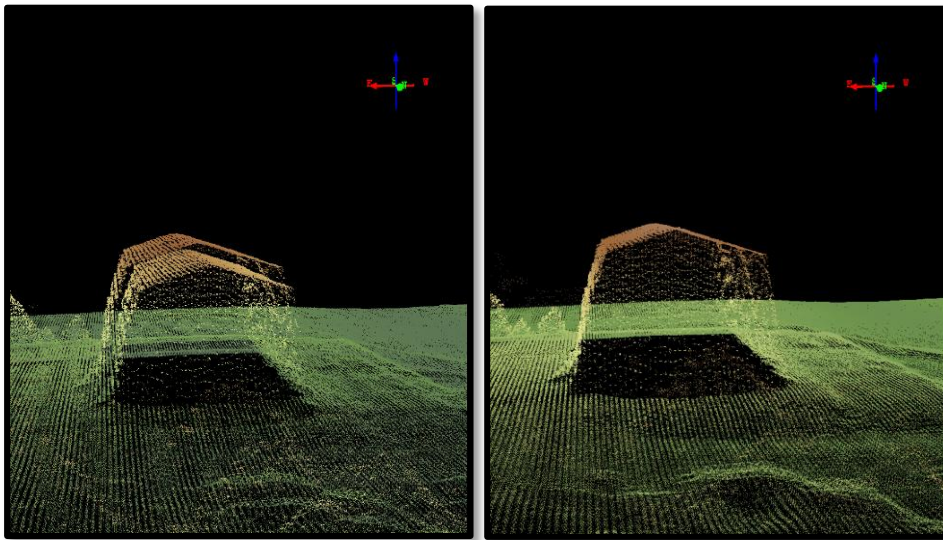
Accuracy Improves with Rigorous Bundle Adjustment



Multi-Swath Alignment via Sensor Based 3D Photogrammetric Bundle Adjustment



Enables Rigorous Accuracy Statements per Point



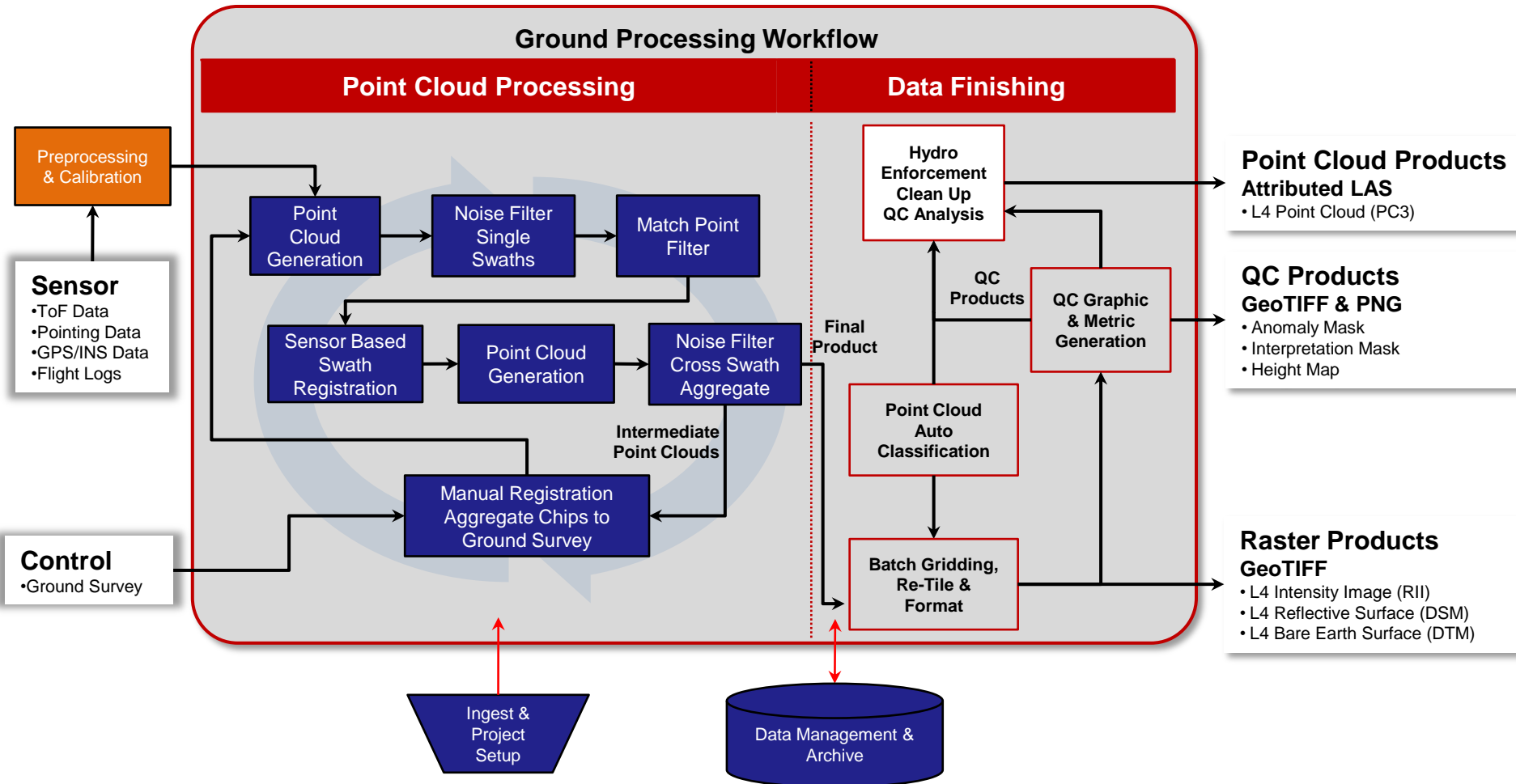
Sensor-based adjustment enables per point accuracy statements

What to do with all this data?



- Not for the workstation in raw form
- Terabytes to petabytes in data management and processing
- Requires high-speed, distributed, multi-core processing
- System has been highly evolved over 15 years
- Sorties are processed in <24 hours
- Total solution requires innovations in both hardware and software

Automated GmAPD Lidar Processing ...



Increased ground automation is critical for reducing production costs

- **Improves speed of collection**
- **Increased data density (resolution) at lower cost**
- **Improves foliage penetration**
- **Multi-look reduces shadows/voids (artifacts)**
- **Higher accuracy with robust bundle adjustment**
- **Improved vertical target separation**

Large area, high density collection leads to new adopters and opportunities

Will Geiger Mode LiDAR replace existing technology?

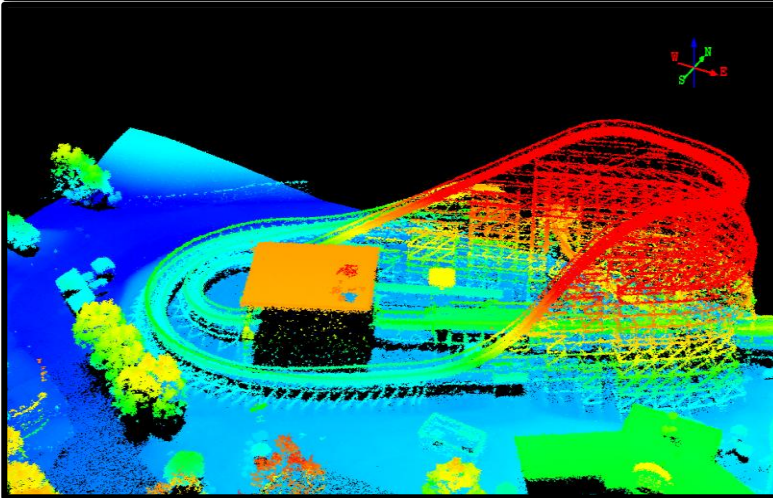
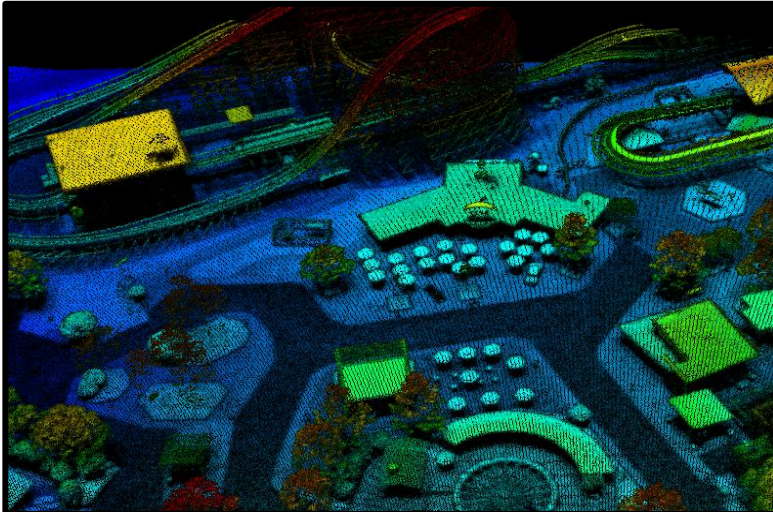
Like all new things change is often met with skepticism and fear its human nature. In the early 90's it was said that "LiDAR will never replace photogrammetry".

"Unnamed Photogrammetrist"

"Never say never"

Charles Dickens

Questions?



Examples from new Harris commercial Geiger Mode LiDAR