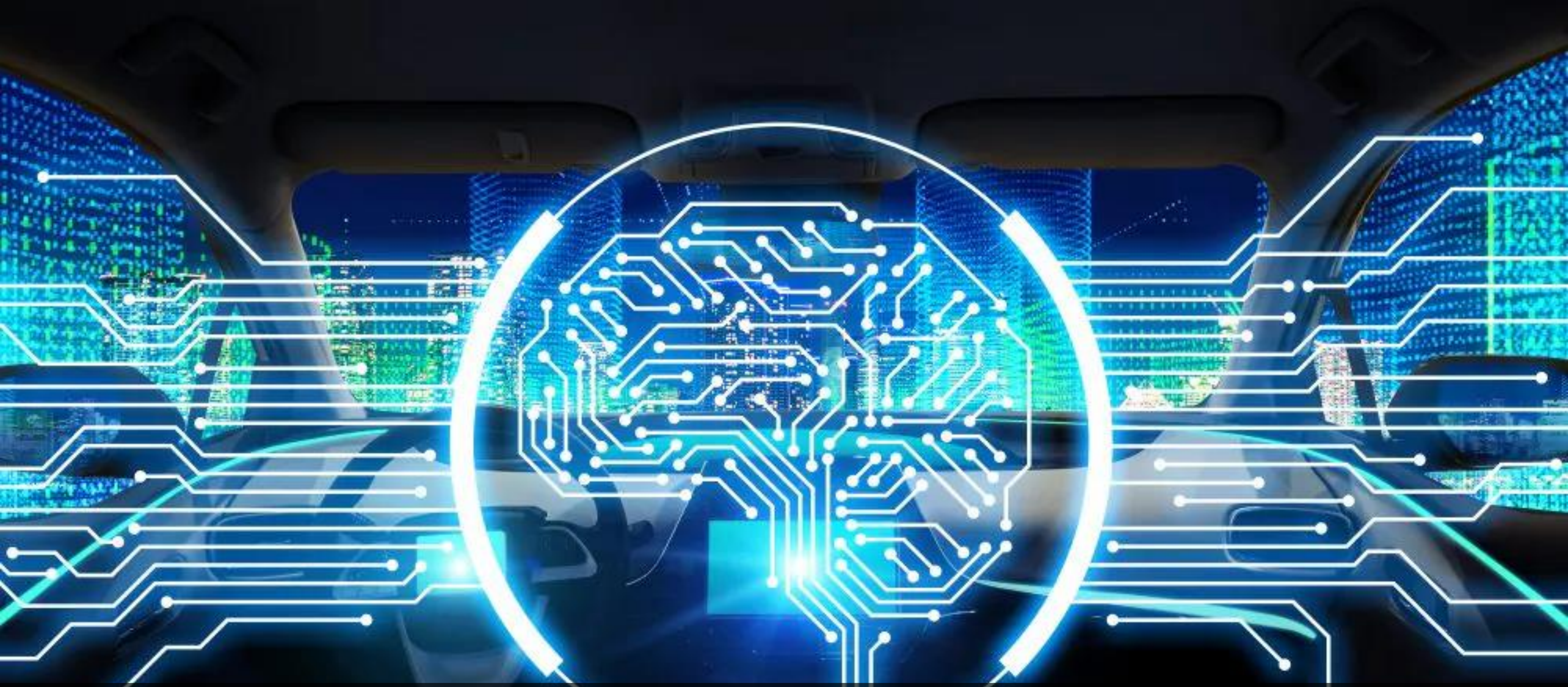
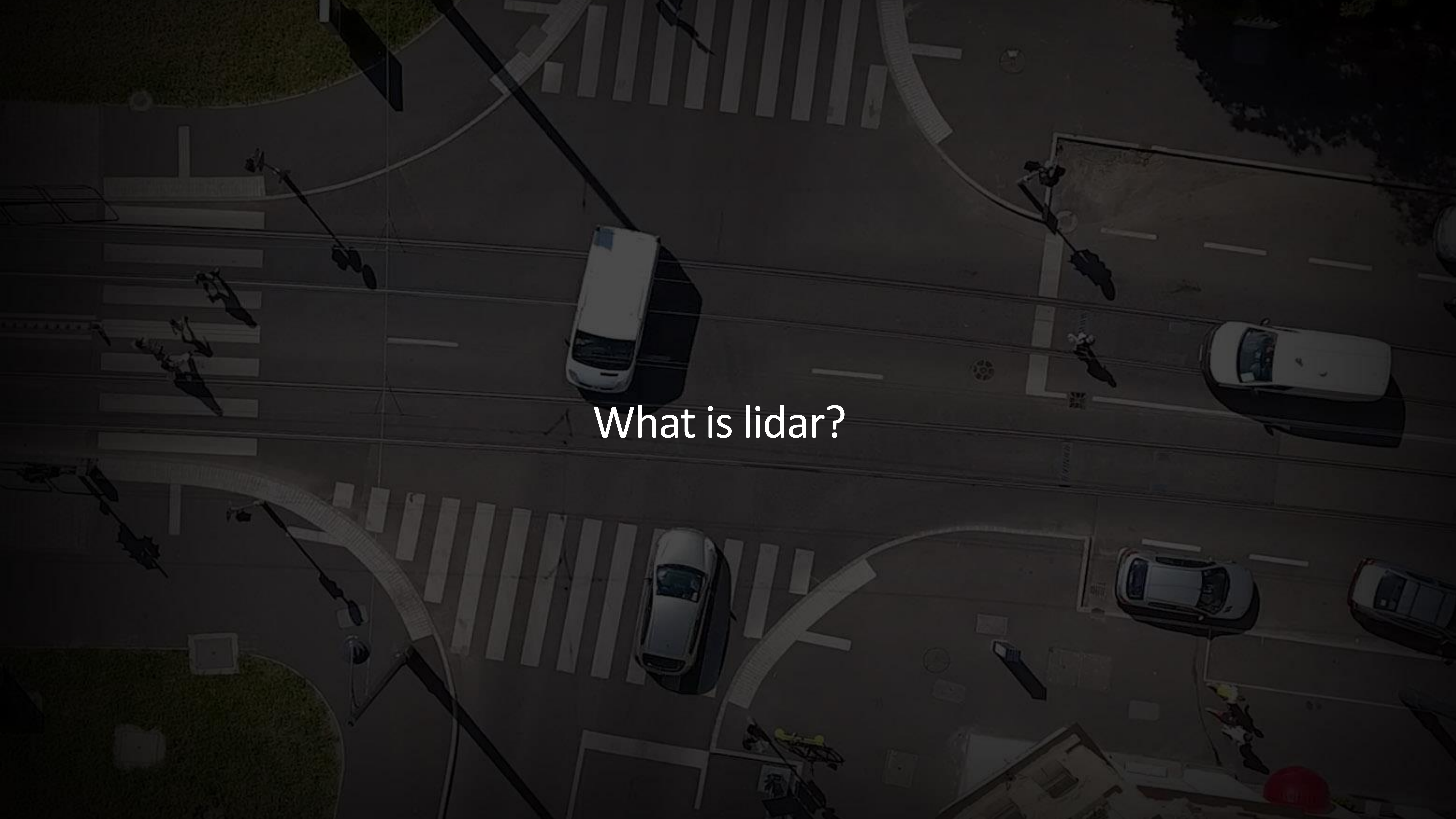


Lidar Sensors

Peter D. Kozma – ELTE IK

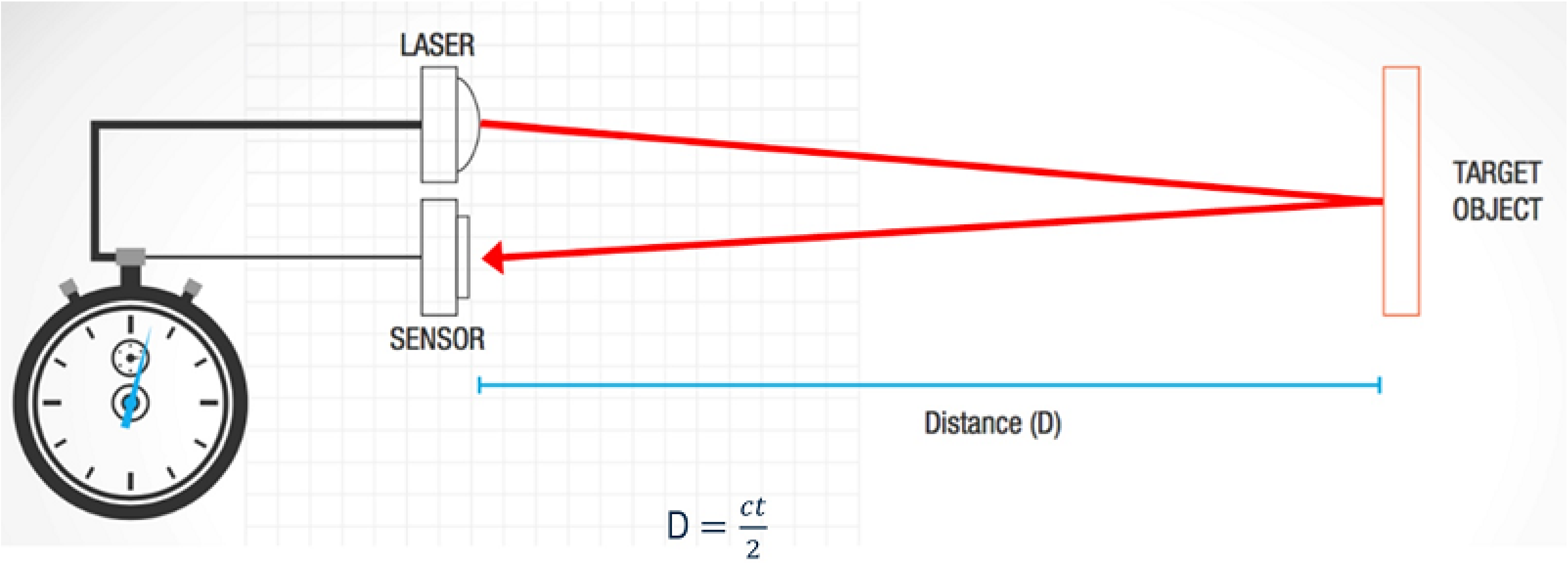
Content overview

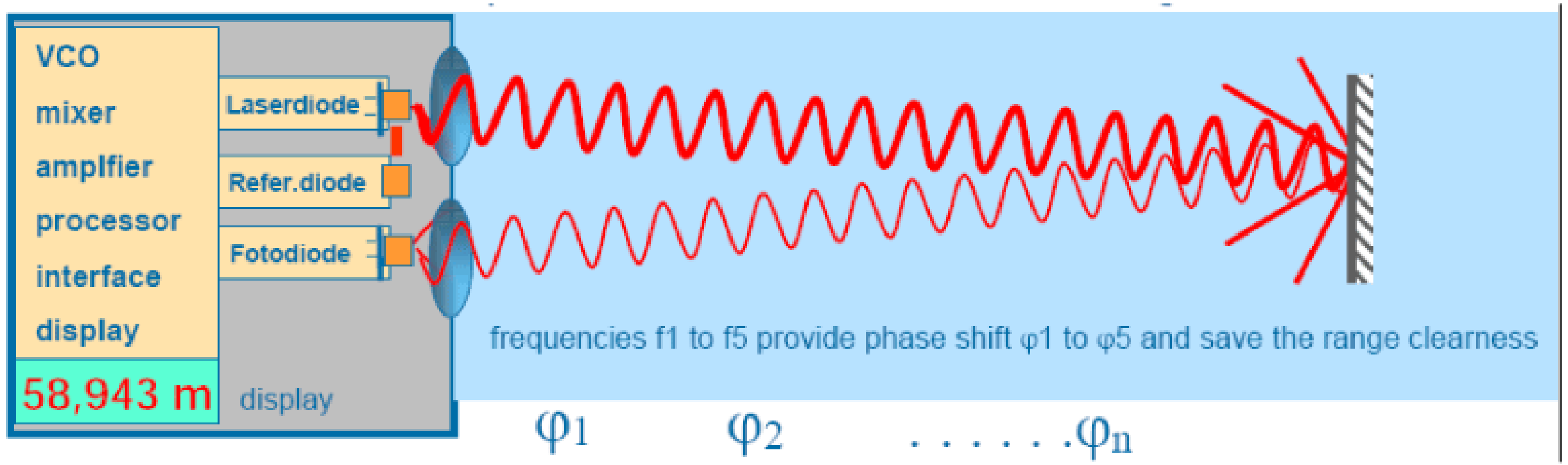


What is lidar?

Laser distance meter

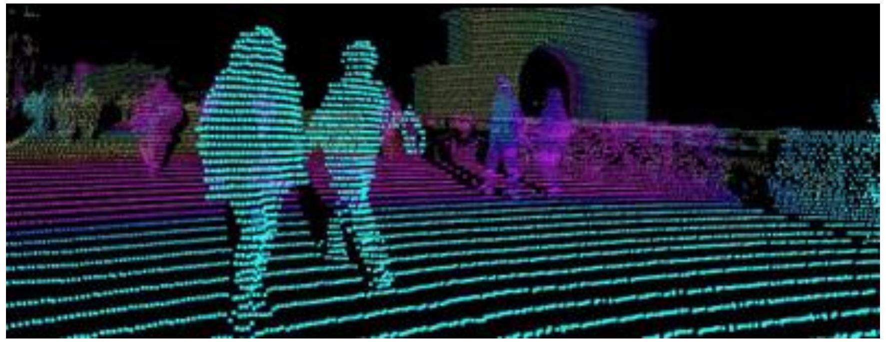
- Time-of-flight
  - Laser pulse emitted
  - Return signal collected
  - Time (t) measured
  - Distance (D) calculated
- Speed of light (c):
  - ~ 3 x 10^8 m/s
  - ~ 30 cm / ns
- Modulated laser beams
  - Beam modulation → phase (φ) difference
  - Higher accuracy and precision at lower cost

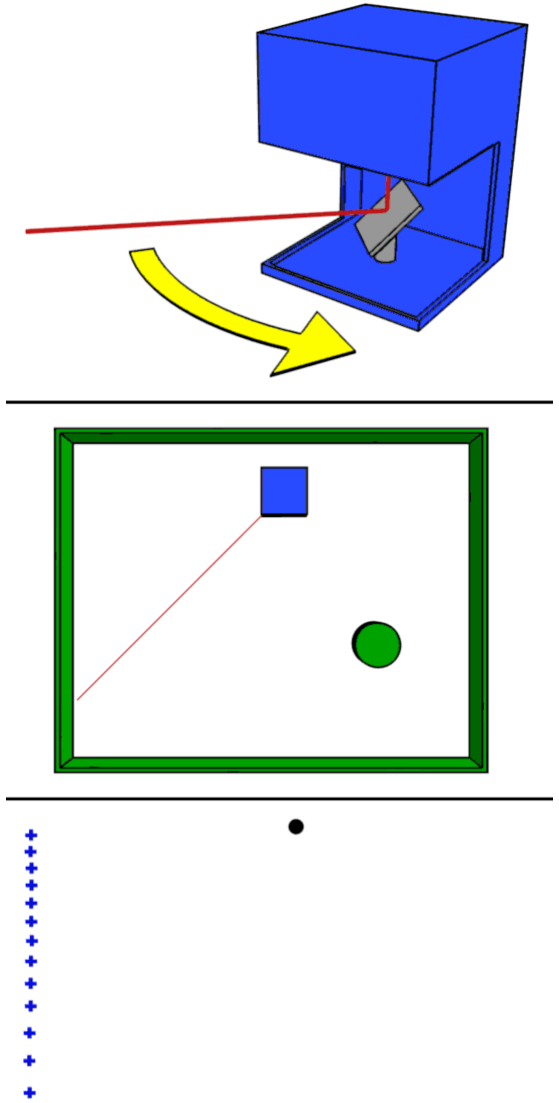




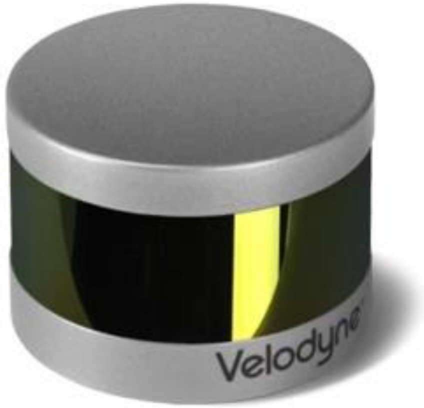
Lidar measurement

- Lidar (Light Detection and Ranging) scans the environment and measures
  - Relative position
  - Intensity
  - (Radial speed)
- Measurement methods
  - Time-of-flight
  - Amplitude modulation
  - Frequency modulation
- The output:
  - 2D or 3D lidar point cloud



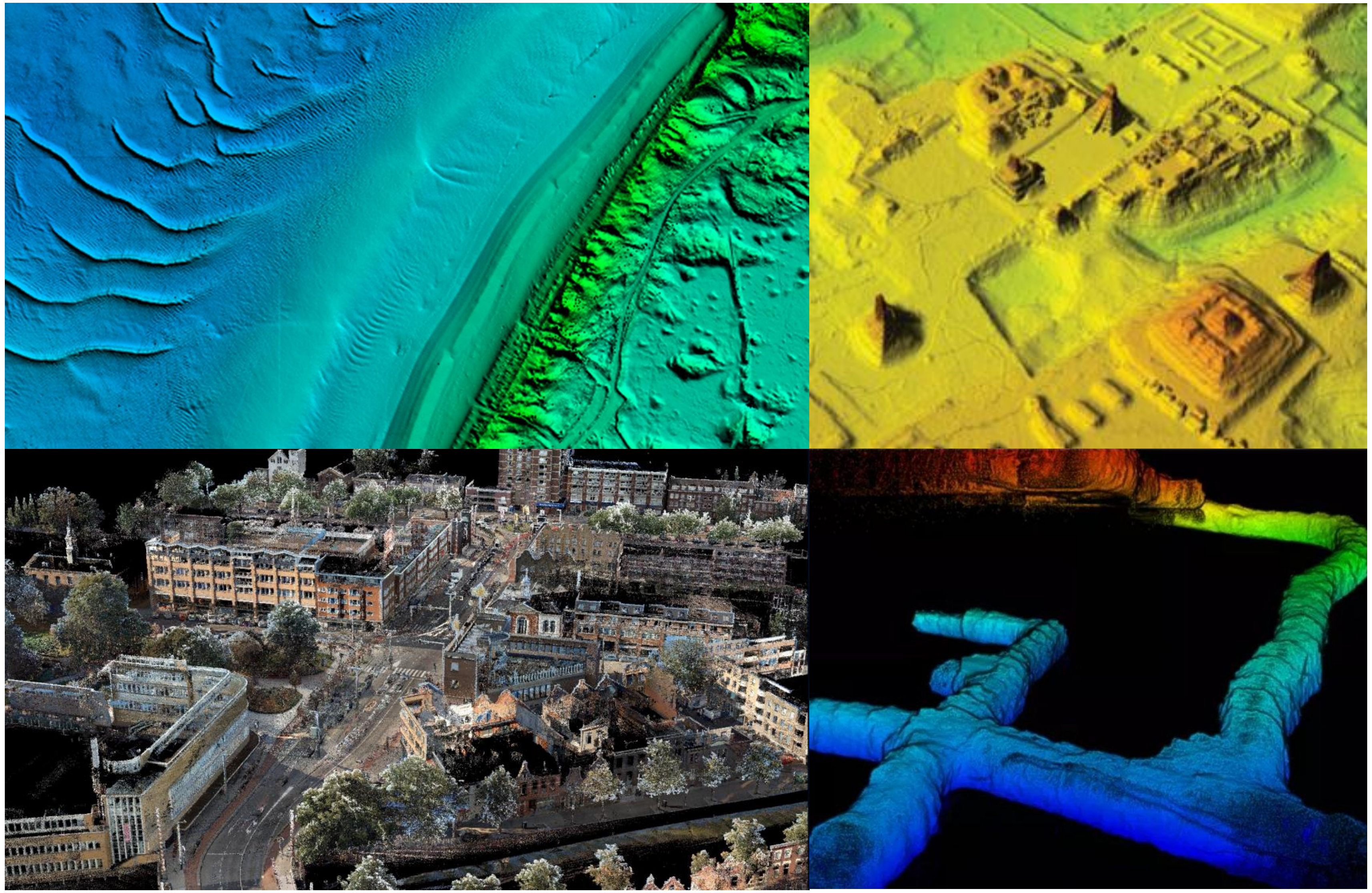


Different lidar models

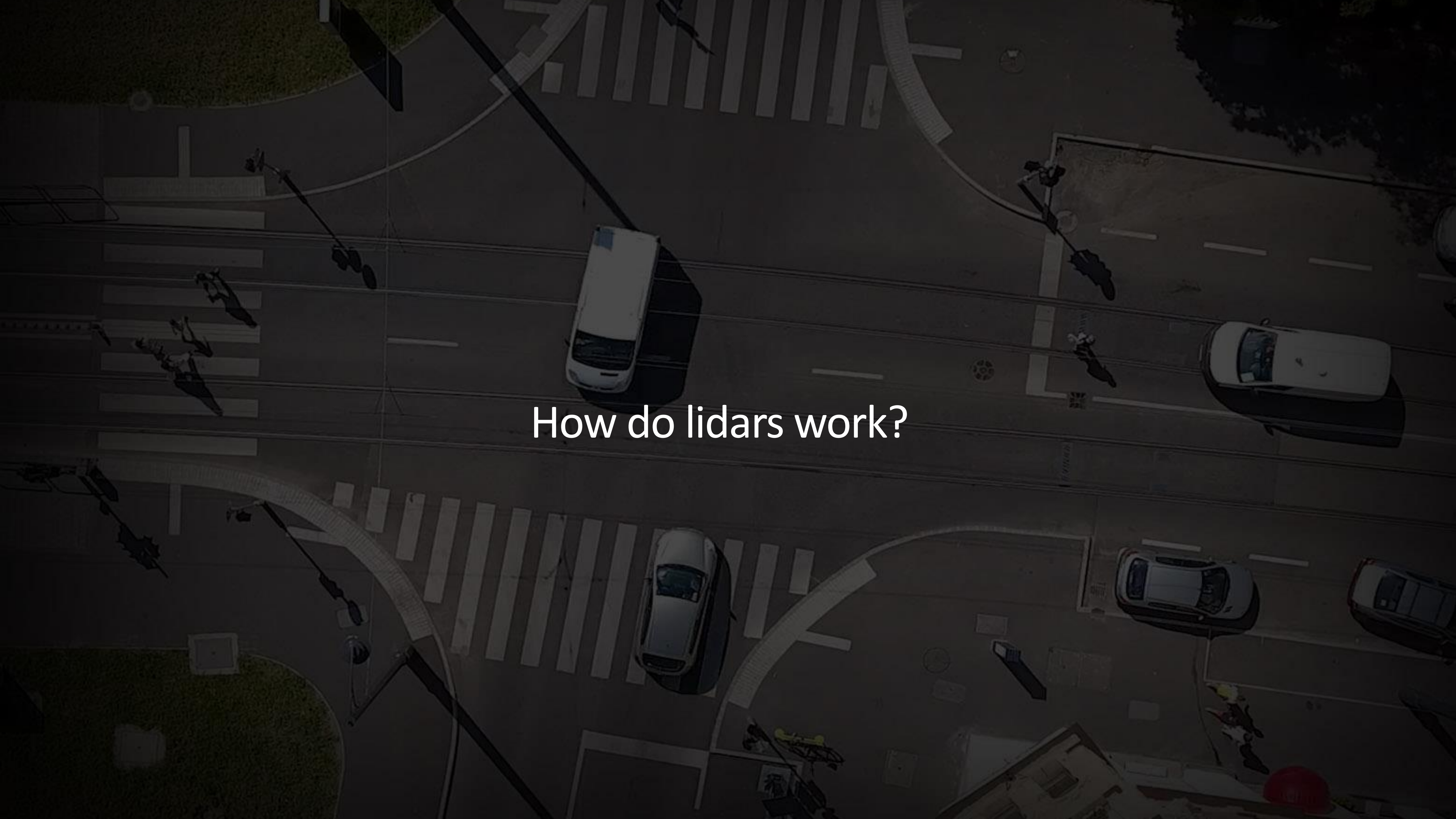


Applications

- Some relevant application fields
  - Robotics *
  - Mapping and surveying *
  - Urban planning and infrastructure *
  - Mining and construction
  - Archeology, geology
  - Forestry and agriculture
  - Coastal and oceanographic studies
  - Manufacturing
  - Security and defense
  - Consumer and entertainment electronics

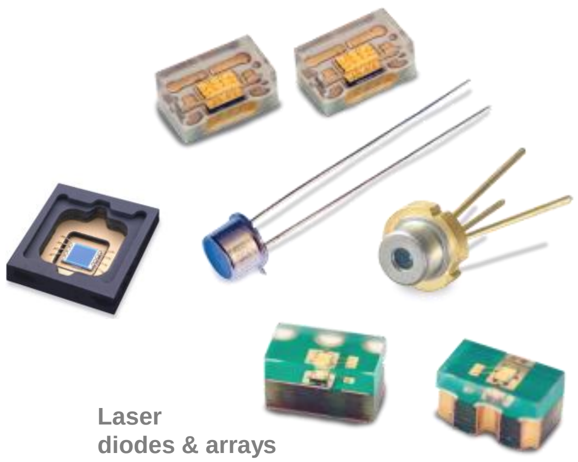


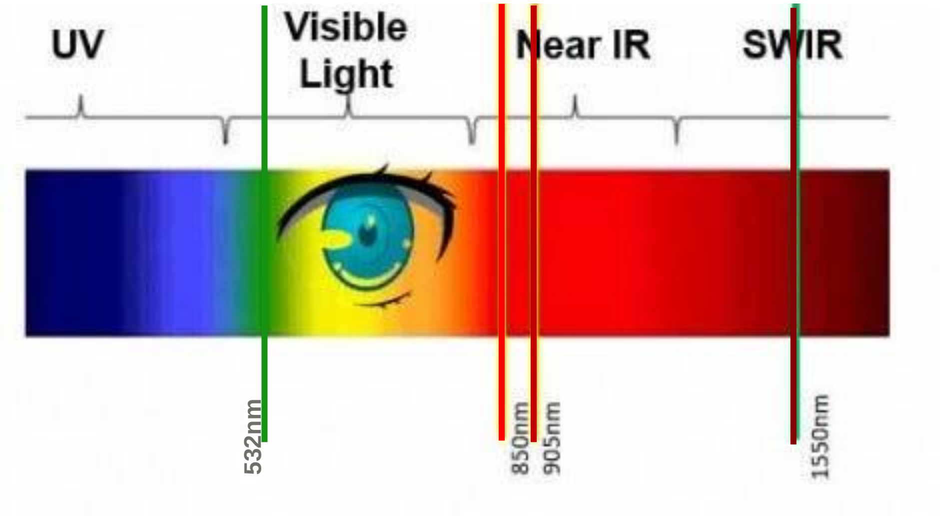
How do lidars work?

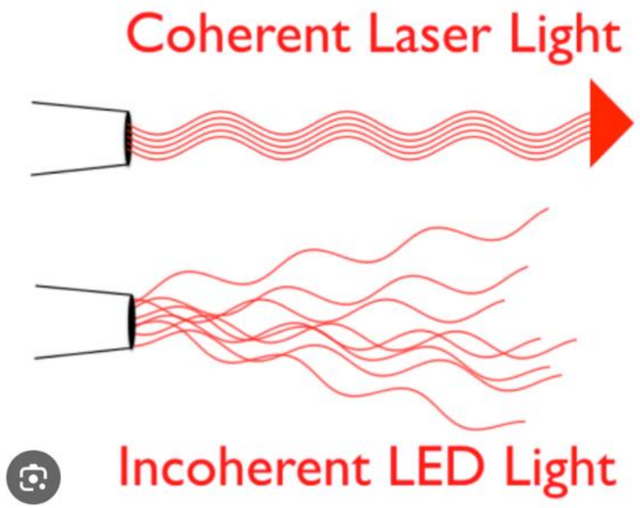


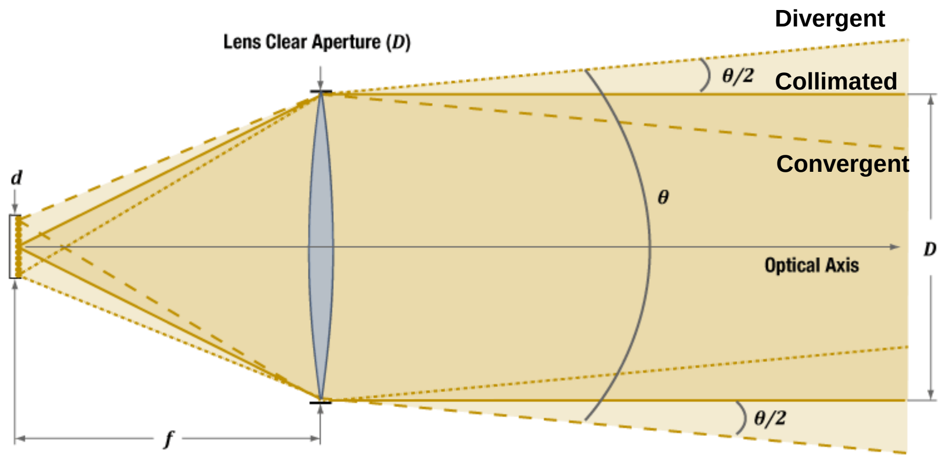
Light sources

- Lidar light sources
  - Near-infrared laser diode (array)
    - Typically 905 nm *
  - Short-wave infrared laser diode (array)
    - Typically 1550 nm *
  - Visible light laser diode (array)
    - Typically 532 nm
- Beam coherence
  - Coherent light sources *
  - Incoherent light sources
- Beam divergence
  - Highly collimated light sources *
  - Less collimated / divergent light sources









Measurement principles

- Time-of-flight
  - Laser pulse is emitted
  - Return signal is collected
  - Time (τ) is measured
  - Distance (r) is calculated

- Beam divergence
  - Pulsed lidars: Highly collimated beam
  - Flash lidars: collimated or divergent

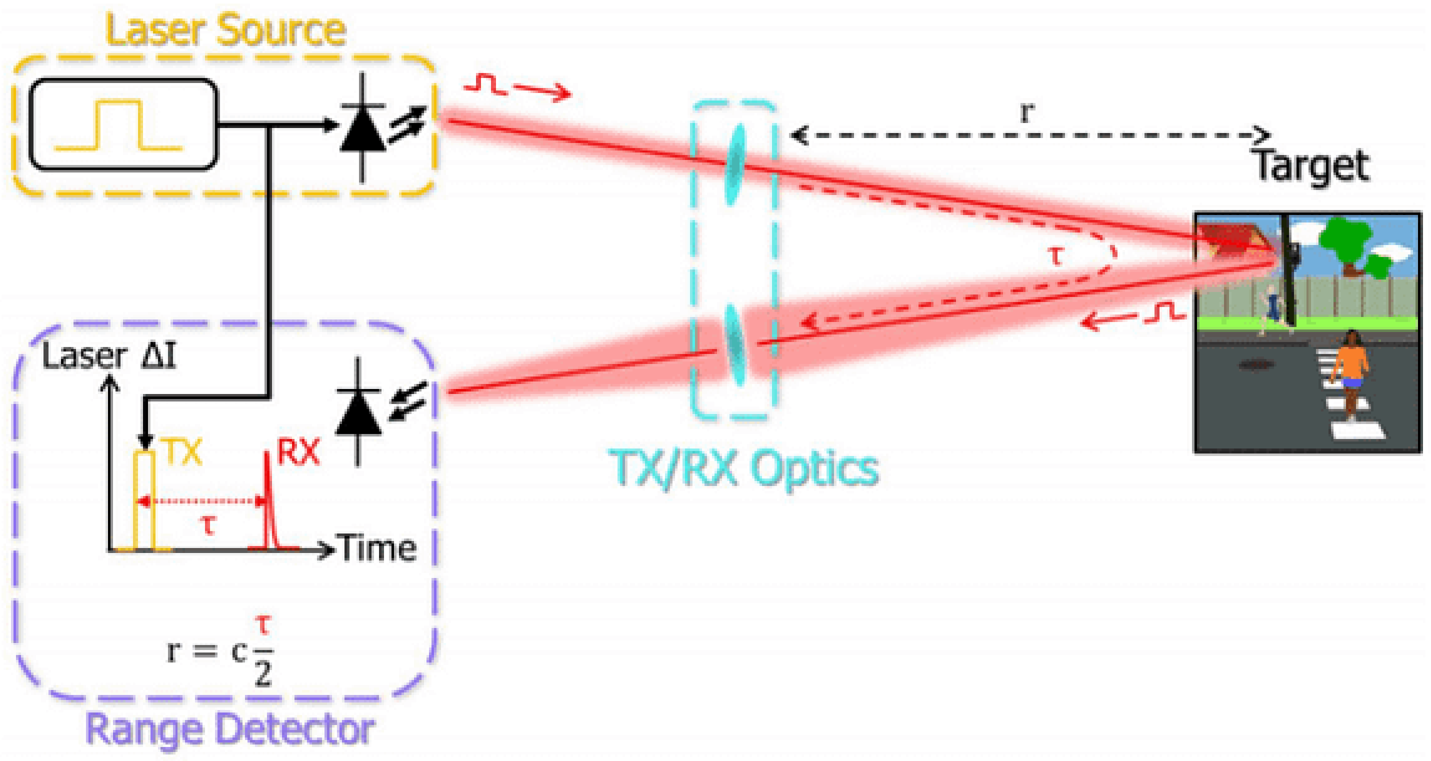


Fig. 1-1. Schematic for pulsed TOF lidar. A laser source transmits an optical pulse, which is reflected by a target surface. The difference between the transmit time and receive time encodes distance to the target.

Measurement principles

- Amplitude Modulated Continuous Wave (AMCW)
  - AMCW signal is emitted
  - Return signal is collected
  - Phase difference (ΔΦ) is measured
    - Lock-in detection method
  - Distance (r) is calculated

High noise immunity

- AMCW technique can be combined with ToF one
  - Pulse compression: typical in lidars
- Beam divergence
  - Highly collimated

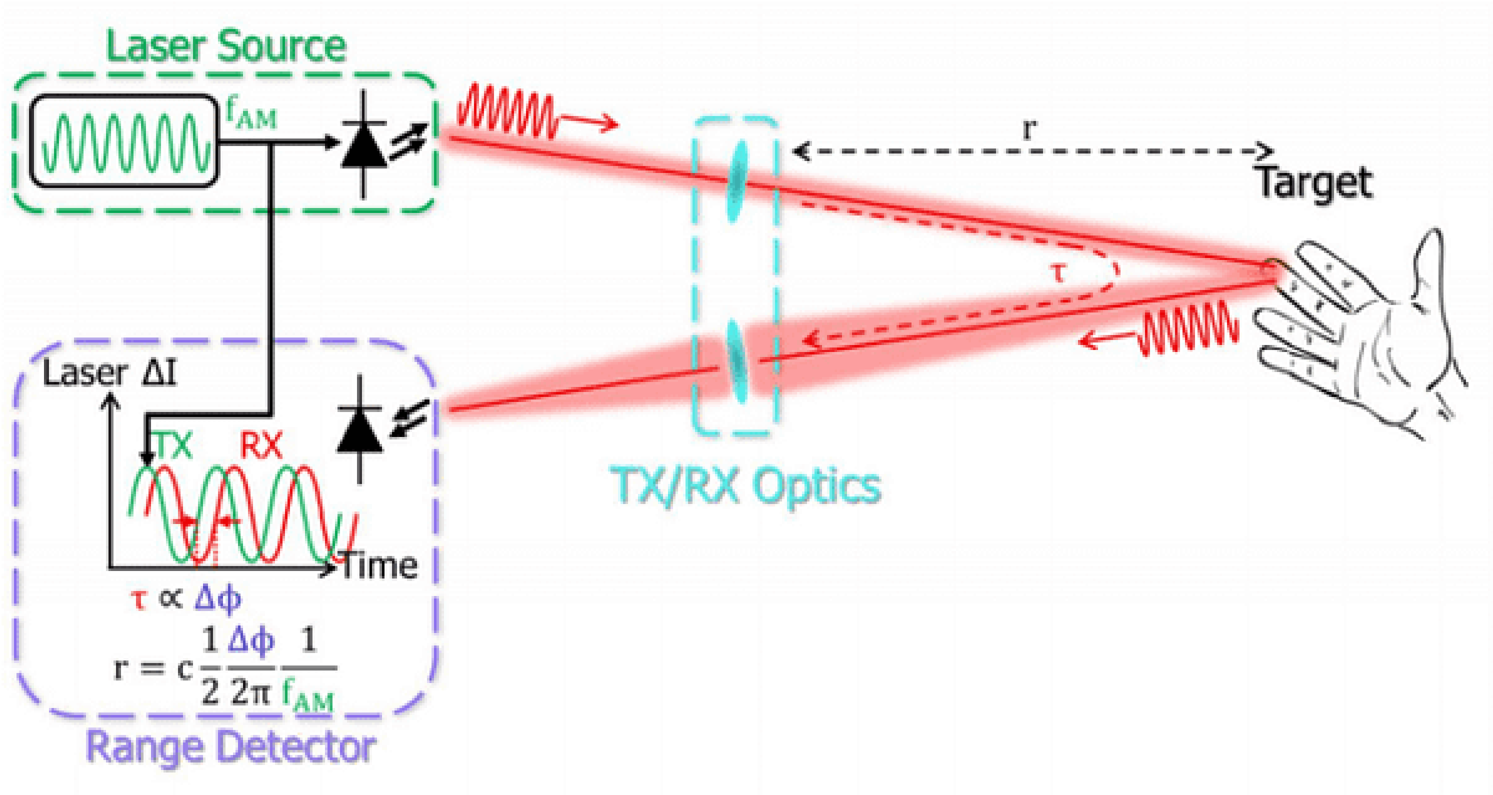


Fig. 1-2. Schematic for amplitude-modulated continuous-wave lidar. A laser source transmits an intensity modulated optical wave, which is reflected by a target surface. The difference between the transmitted signal phase and the received signal phase encodes distance to the target.

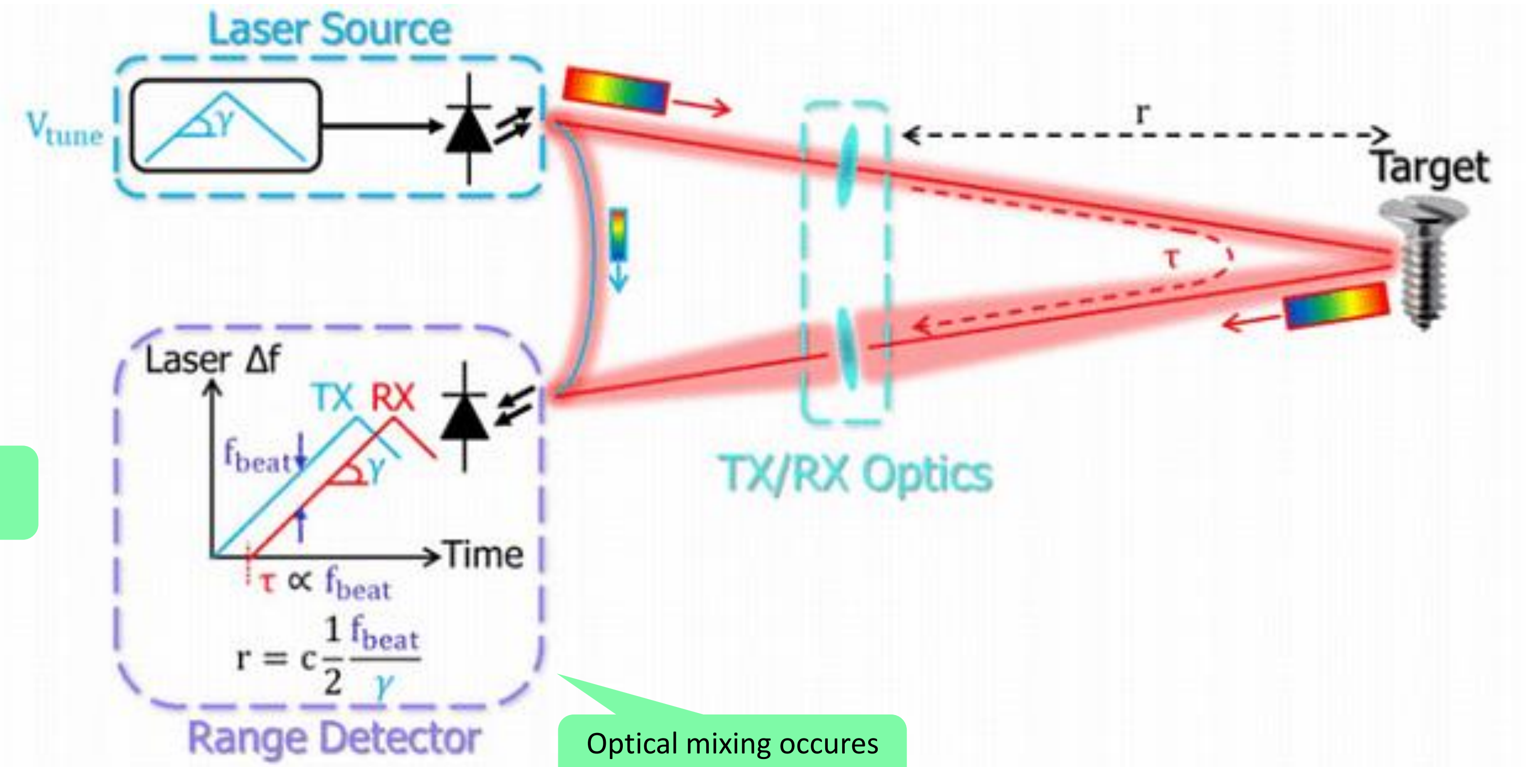
Measurement principles

- Frequency Modulated Continuous Wave (FMCW)
  - FMCW (chirp) signal is emitted
  - Return signal is collected
  - Beat frequency (f_{beat}) is measured
  - Doppler shift (f_d) is measured
  - Distance (r) and rel. radial speed (v) are calc.

High noise immunity

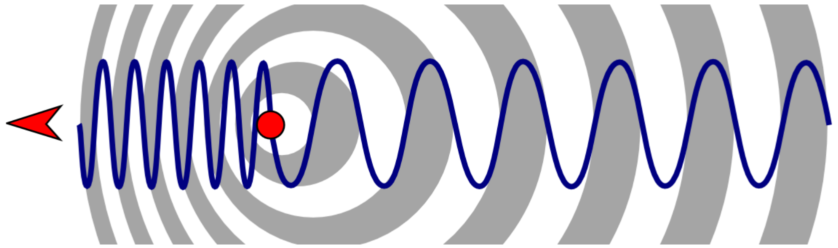
- FMCW technique can be combined with ToF one
  - Pulse compression: not typical in lidars

- Beam divergence
  - Highly collimated



Optical mixing occures on the detector

Fig. 1-3. Schematic for frequency-modulated continuous-wave lidar. A laser source transmits a frequency-modulated optical wave, which is reflected by a target surface. The beat frequency on the receiver photodiode encodes distance to the target.

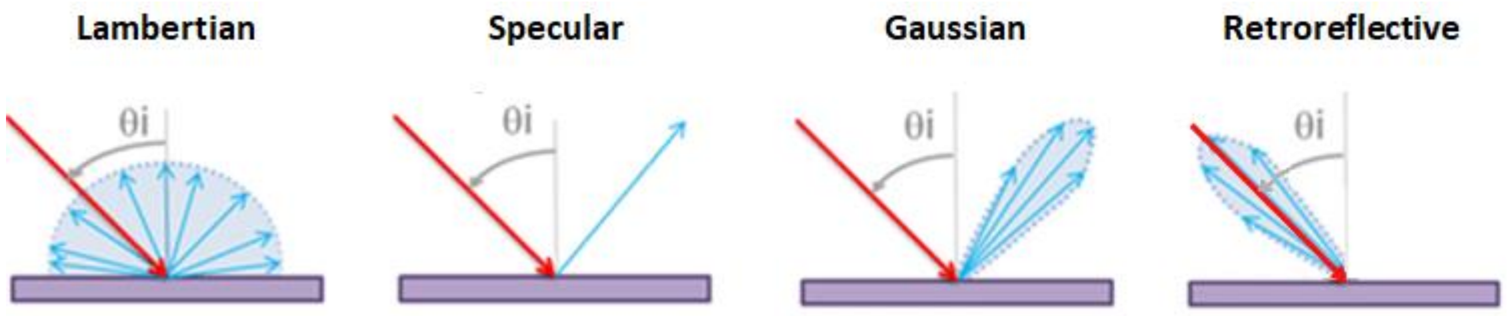


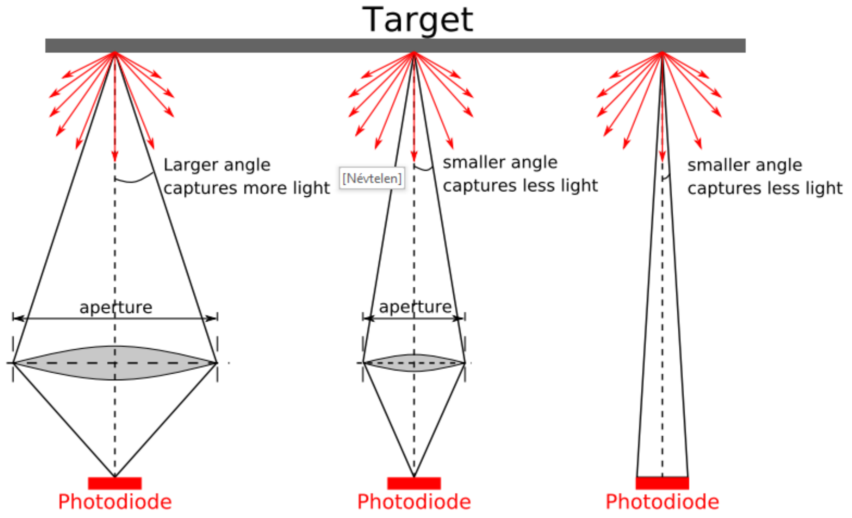
$$v = \frac{c}{2}\frac{f_d}{f_s}$$

Target and optics

- Target reflectivity model
  - Lambertian
  - Specular
  - Gaussian
  - Retroreflective

- Lidar optics
  - Aperture maximization
  - Fix focus
  - Large depth of field
  - Low aberrations
  - Optical coating (wavelength filtering)





Detectors

- Detectors
  - PIN photodiode
  - Avalanche Photodetector (APD)
  - Single Photon Avalanche Diode (SPAD)
  - Silicon Photomultiplier (SiPM)
    - = SPAD array
  - Balanced photodetector
- Lidar design specific selection of detectors

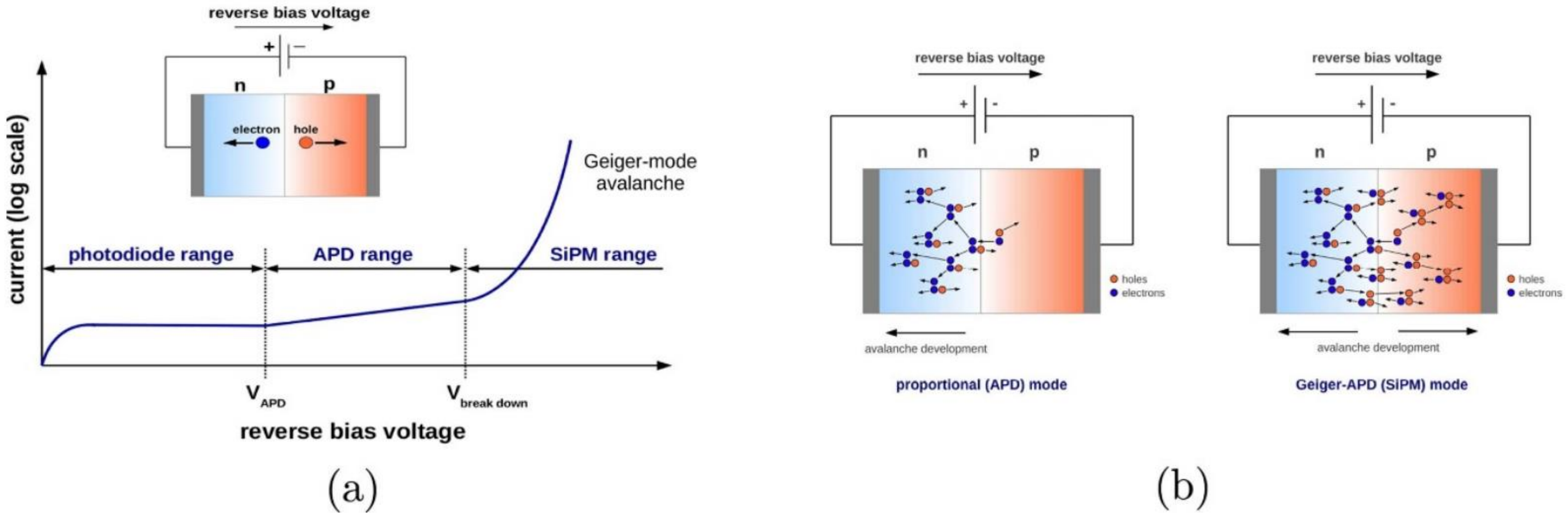
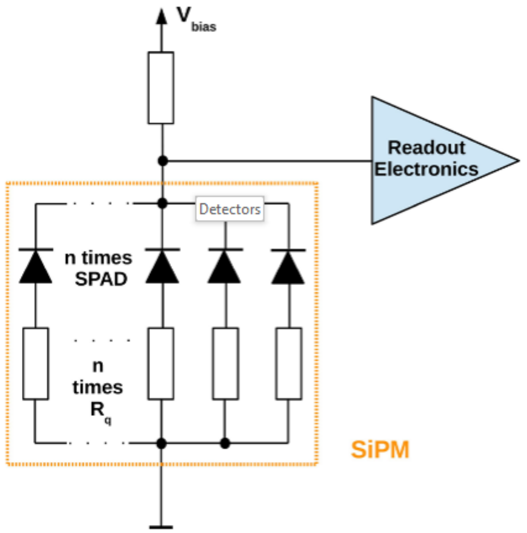
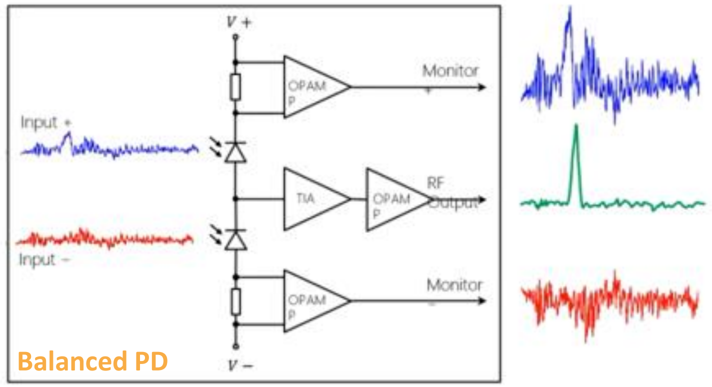


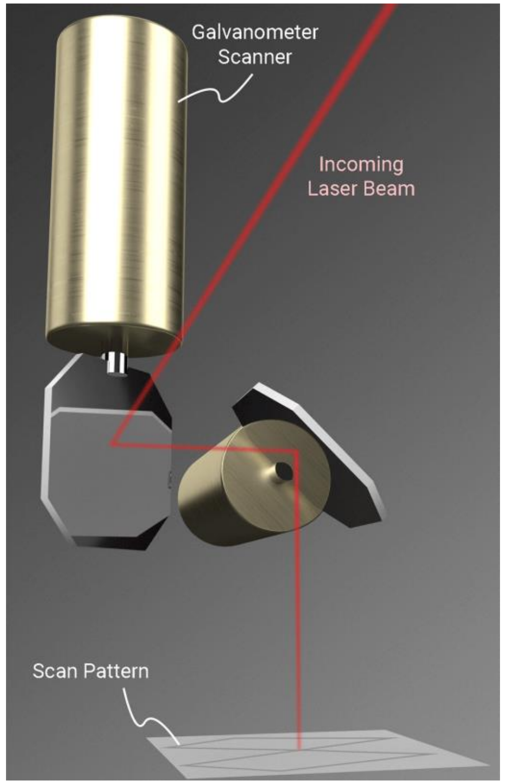
Figure 1. (a) Operation regimes of solid state p-n junction, i.e. photodiode, avalanche photodiode (APD) and SPAD or SiPM range. (b) In the APD only electrons can sustain the avalanche, whereas in a SPAD holes will perform impact ionization as well.

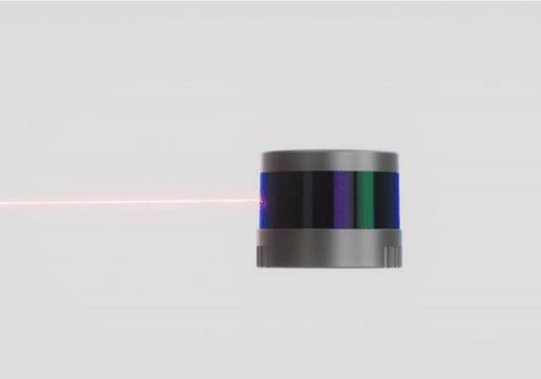


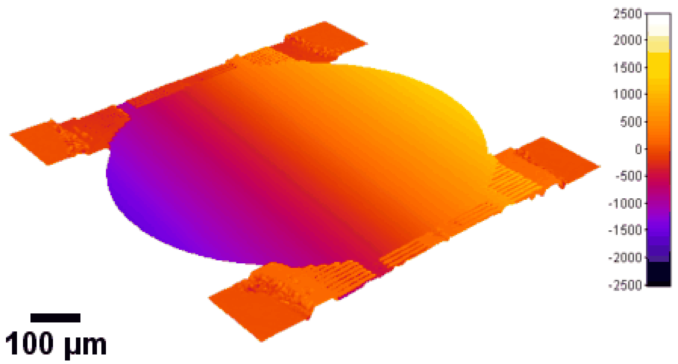


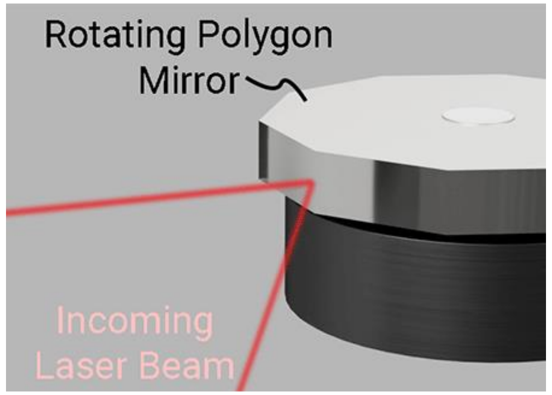
Beam steering mechanism

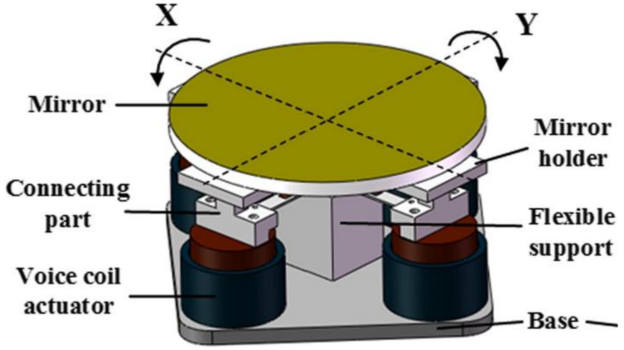
- Rotating lidar systems
  - Rotating mirrors
  - Rotating (multi-beam) lidar heads
- Scanning lidar systems
  - Galvanometer-Based Systems
  - Micro-Electro-Mechanical Systems (MEMS)
  - Vibrating Mirrors
  - Optical Phased Arrays (OPA)
  - Wavelength modulation
  - etc
- Flash lidar systems
  - Flash lidar

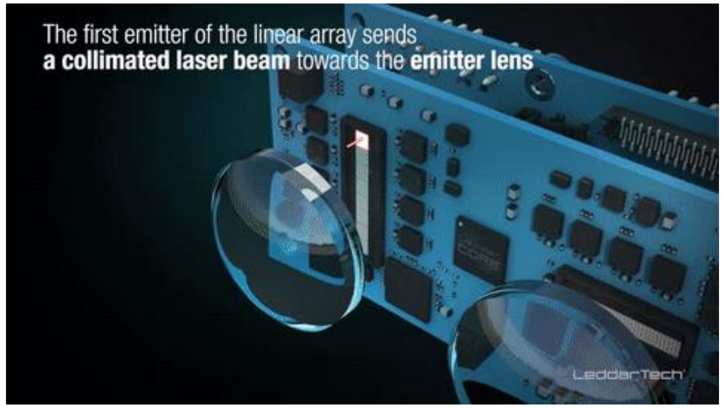


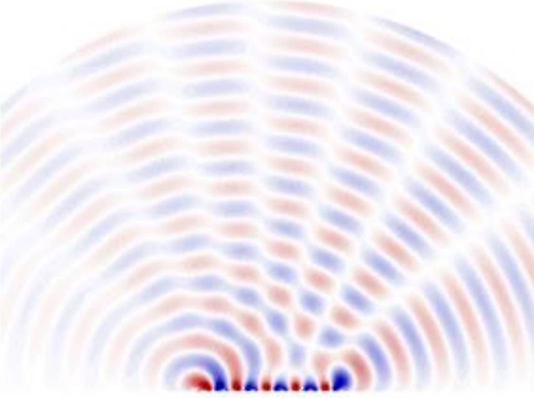


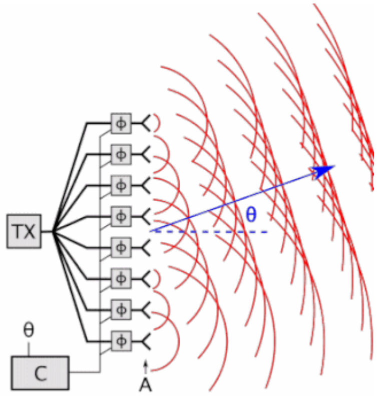






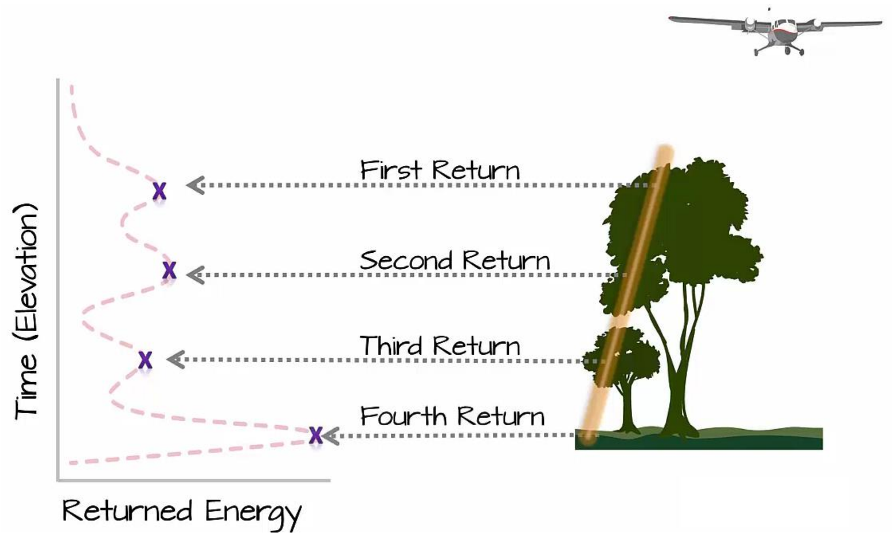






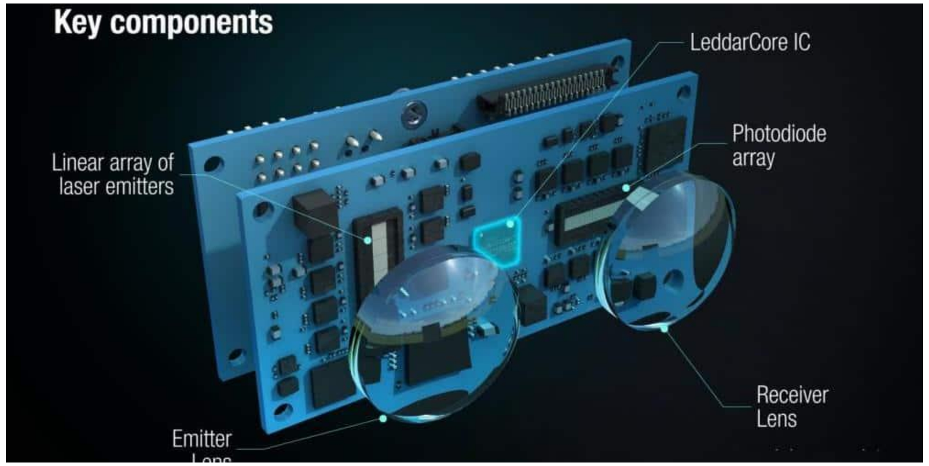
Signal returns

- Multiple returns of single laser pulse
  - First return
  - Intermediate returns (second, third, …)
  - Last return
  - Strongest return
  - Weakest return

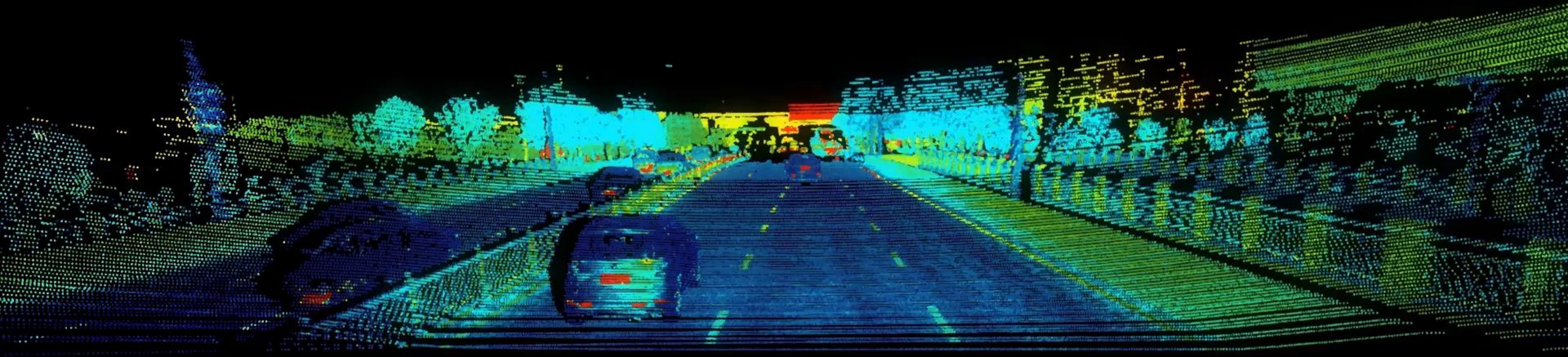


Electrical components

- Main electrical components
  - Light source
  - Detector
  - Beam steering
  - Lidar controller
  - Data processor
  - Communication interface
  - Power and thermal management
- Some relevant data interface protocols
  - Automotive ethernet *
  - Gigabit ethernet
  - USB
- TechInsights Teardown
  - Electronics360

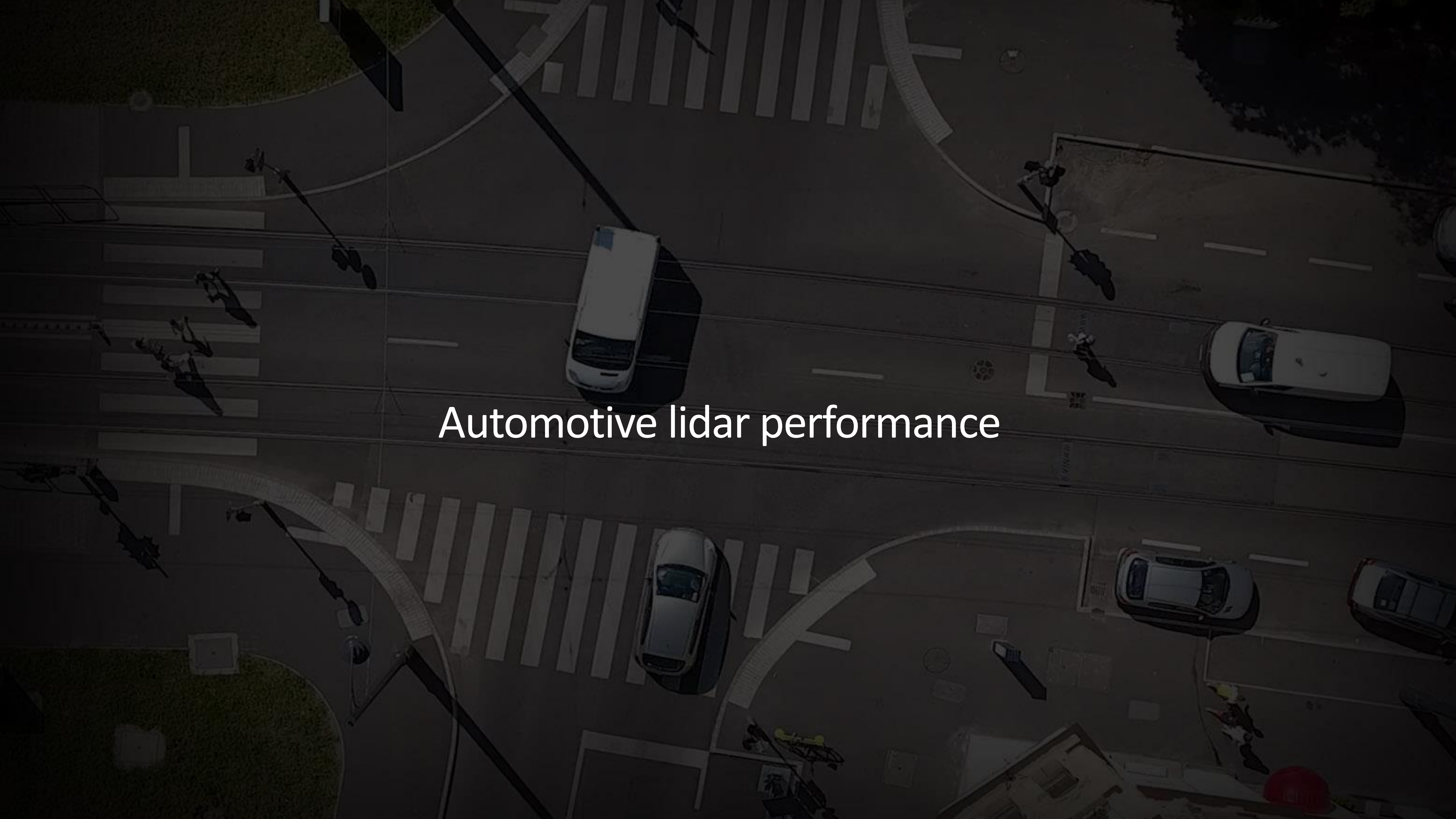


Data output – point cloud



Seyond Falcon - [link]

Automotive lidar performance



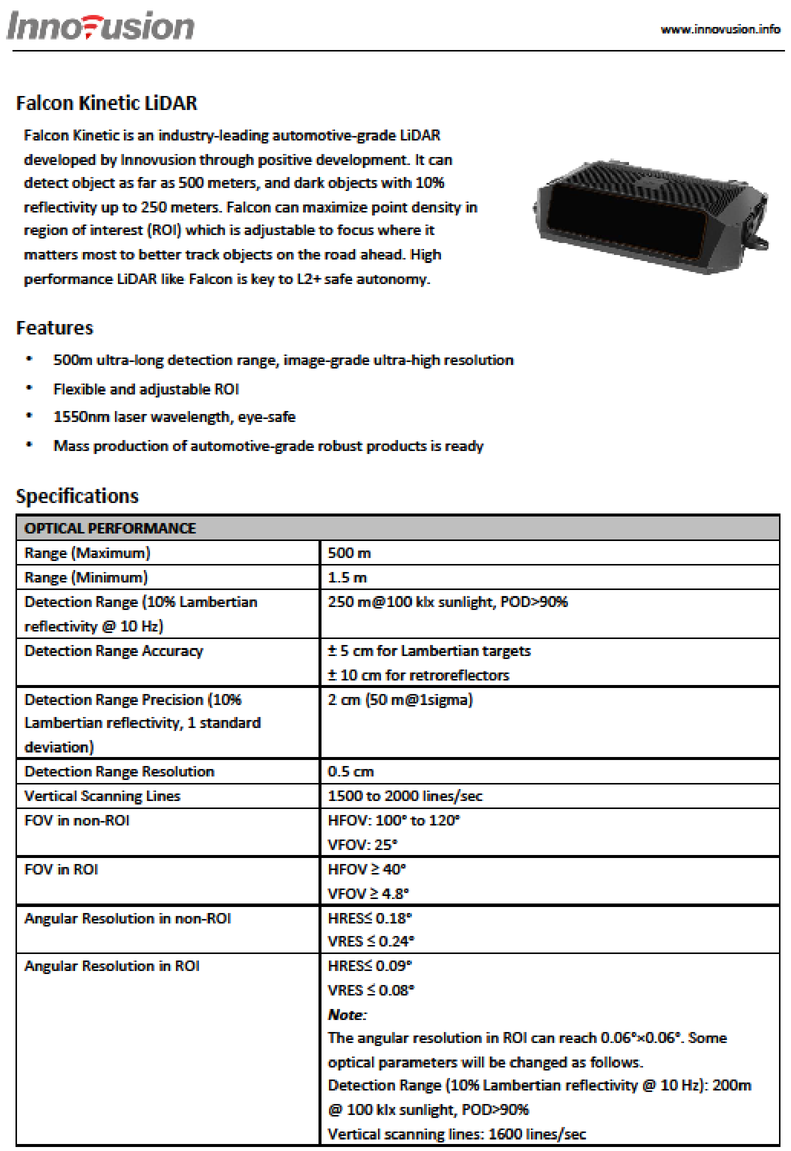
Performance metrics

- Some relevant performance metrics
  - Detection range (min, max)
  - Accuracy and precision
  - Field of view and resolution (H, V)
  - Frame rate and data rate
  - False positive rate

  - Wavelength, power, divergence
  - Scan pattern
  - # of returns
  - Time synchronization
  - Ingress protection rating (wiki)
  - Electro-mechanical design and resistance
  - Operating temperature
  - Communication interface
  - Compliance (ISO, IEC, RoHS, etc)

  \+

  - Extra features, e.g.
    - Speed measurement capability
    - Connecting Perception Software


InnoFusion www.innovusion.info

Falcon Kinetic LiDAR

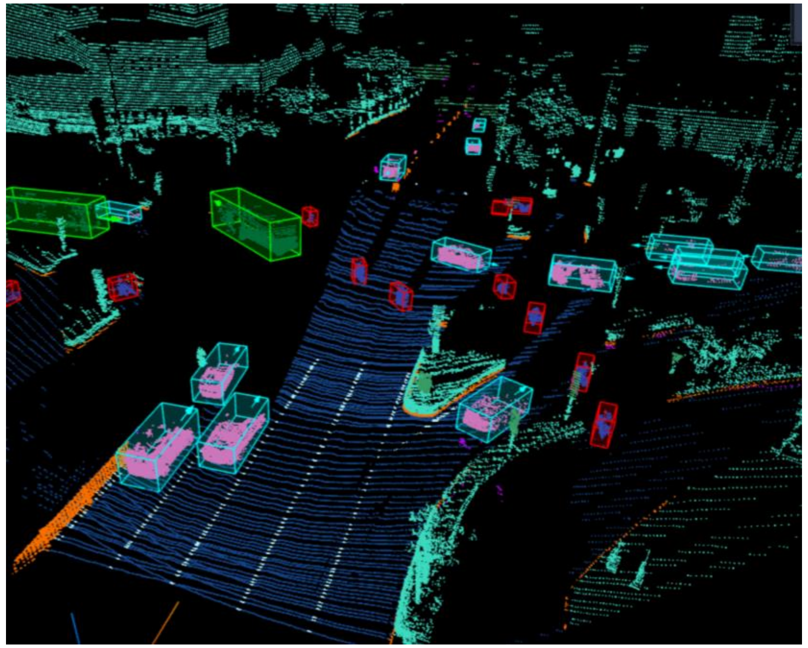
Falcon Kinetic is an industry-leading automotive-grade LiDAR developed by Innovusion through positive development. It can detect object as far as 500 meters, and dark objects with 10% reflectivity up to 250 meters. Falcon can maximize point density in region of interest (ROI) which is adjustable to focus where it matters most to better track objects on the road ahead. High performance LiDAR like Falcon is key to L2+ safe autonomy.

Features

- 500m ultra-long detection range, image-grade ultra-high resolution
- Flexible and adjustable ROI
- 1550nm laser wavelength, eye-safe
- Mass production of automotive-grade robust products is ready

Specifications

OPTICAL PERFORMANCE	
Range (Maximum)	500 m
Range (Minimum)	1.5 m
Detection Range (10% Lambertian reflectivity @ 10 Hz)	250 m@100 klx sunlight, POD>90%
Detection Range Accuracy	± 5 cm for Lambertian targets ± 10 cm for retroreflectors
Detection Range Precision (10% Lambertian reflectivity, 1 standard deviation)	2 cm (50 m@1sigma)
Detection Range Resolution	0.5 cm
Vertical Scanning Lines	1500 to 2000 lines/sec
FOV in non-ROI	HFOV: 100° to 120° VFOV: 25°
FOV in ROI	HFOV ≥ 40° VFOV ≥ 4.8°
Angular Resolution in non-ROI	HRES≤ 0.18° VRES ≤ 0.24°
Angular Resolution in ROI	HRES≤ 0.09° VRES ≤ 0.08° *Note:* The angular resolution in ROI can reach 0.06°×0.06°. Some optical parameters will be changed as follows. Detection Range (10% Lambertian reflectivity @ 10 Hz): 200m @ 100 klx sunlight, POD>90% Vertical scanning lines: 1600 lines/sec



Performance test

- Lidar performance tests standards
  - DIN SAE SPEC 91471
  - Unified test procedures
  - Developed by leading companies in 2023

- Individual, application-tailored evaluations, e.g.:
  - Park et al.
  - Haider et al.
  - Lambert et al.

May 2023

DIN SAE SPEC 91471

ICS 43.040.10

Bewertungsmethodik für LiDAR-Sensoren in Kraftfahrzeugen; Text Englisch

Assessment methodology for automotive LiDAR sensors;
Text in English

Méthodologie d'évaluation des capteurs LiDAR automobiles;
Texte en anglais

Zur Erstellung einer DIN SPEC können verschiedene Verfahrensweisen herangezogen werden:
Das vorliegende Dokument wurde nach den Verfahrensregeln einer PAS erstellt.

Gesamtumfang 46 Seiten

Dieses Dokument wurde durch die im Vorwort genannten Verfasser erarbeitet und verabschiedet.

www.din.de
www.beuth.de

3424993

1 Sensor specification

	Baraja Spectrum-Scan Lidar
Horizontal FOV	100°
Vertical FOV	25°
Angular resolution (horizontal)	0.05° - 0.2°
Angular resolution (vertical)	0.025° - 0.2°
Wavelength	1550nm
Framerate	6-40Hz
Range	0.01 - 300m
Range repeatability	9cm

Table 1: Basic parameters of Baraja Lidar sensor.

Figure 1: Baraja Lidar sensor.

Disclaimer: The following evaluation is based on demo data provided by Baraja. Our systematic tests with standard targets could not be performed.

2 Position measurement error

2.1 Plane fitting test

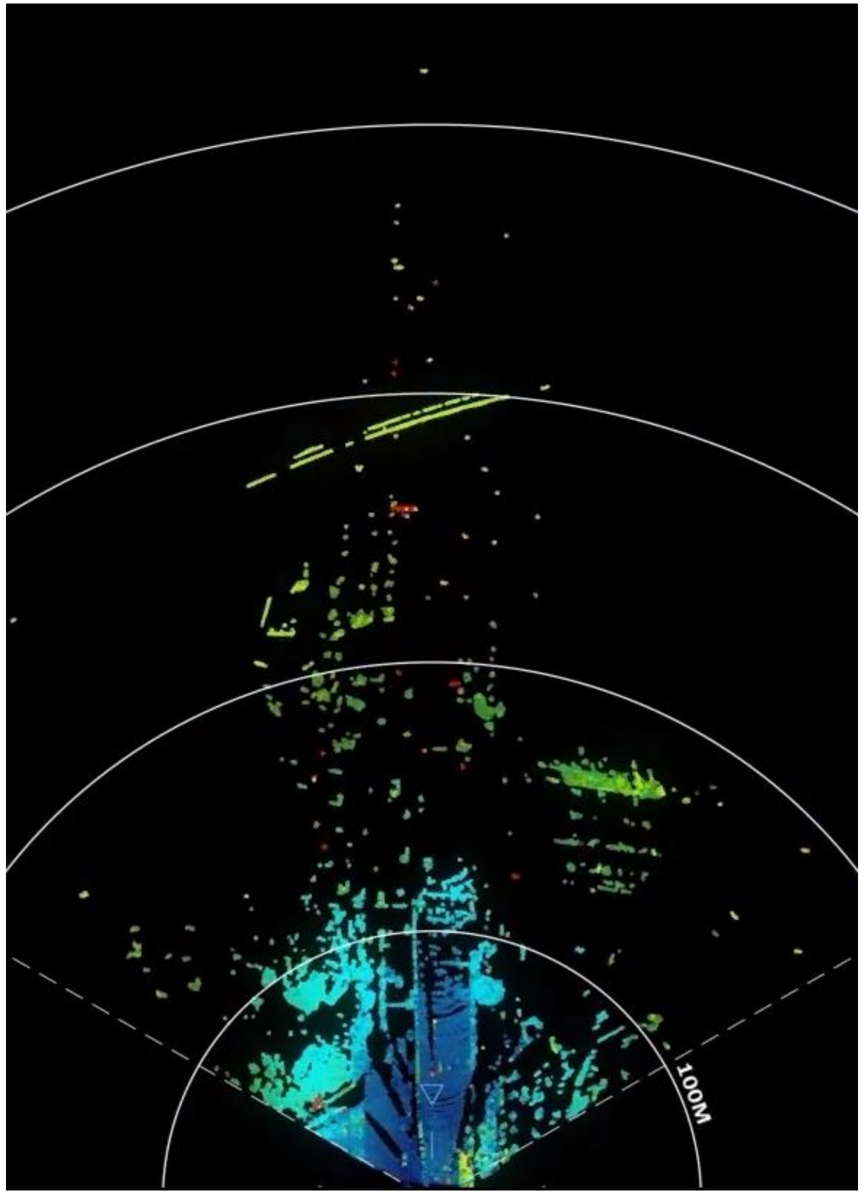
Test method:

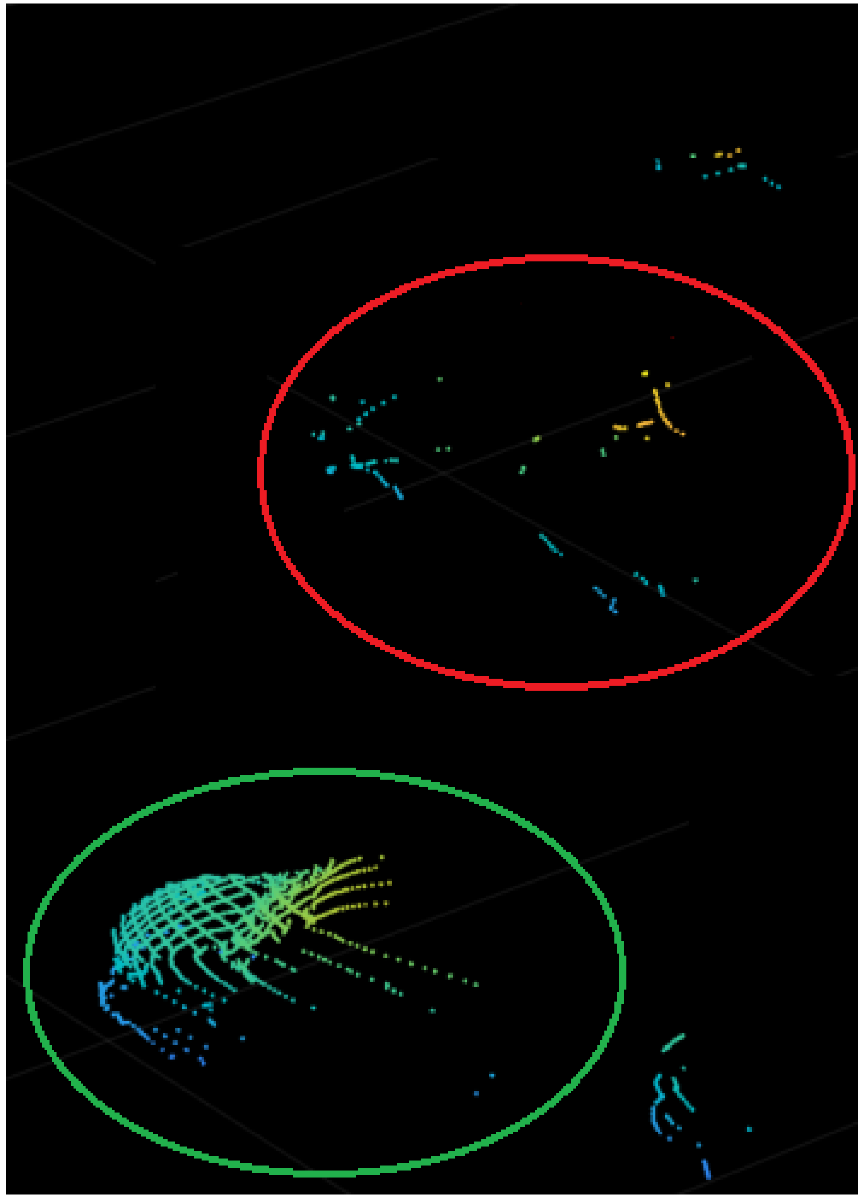
Using .pcap file as a source, lidar frames containing smooth surfaces were exported and a plane was fitted to the points of interest. Best quality surfaces are typically the roads. This approach reveals the error of distance measurement relative to a plain surface derived from the detections and gives an estimate of measurement precision.

The normal of the plane is determined by the first eigenvector of the selected point cloud's covariance matrix. The origin of the plane is given by the average of the points in the point cloud.

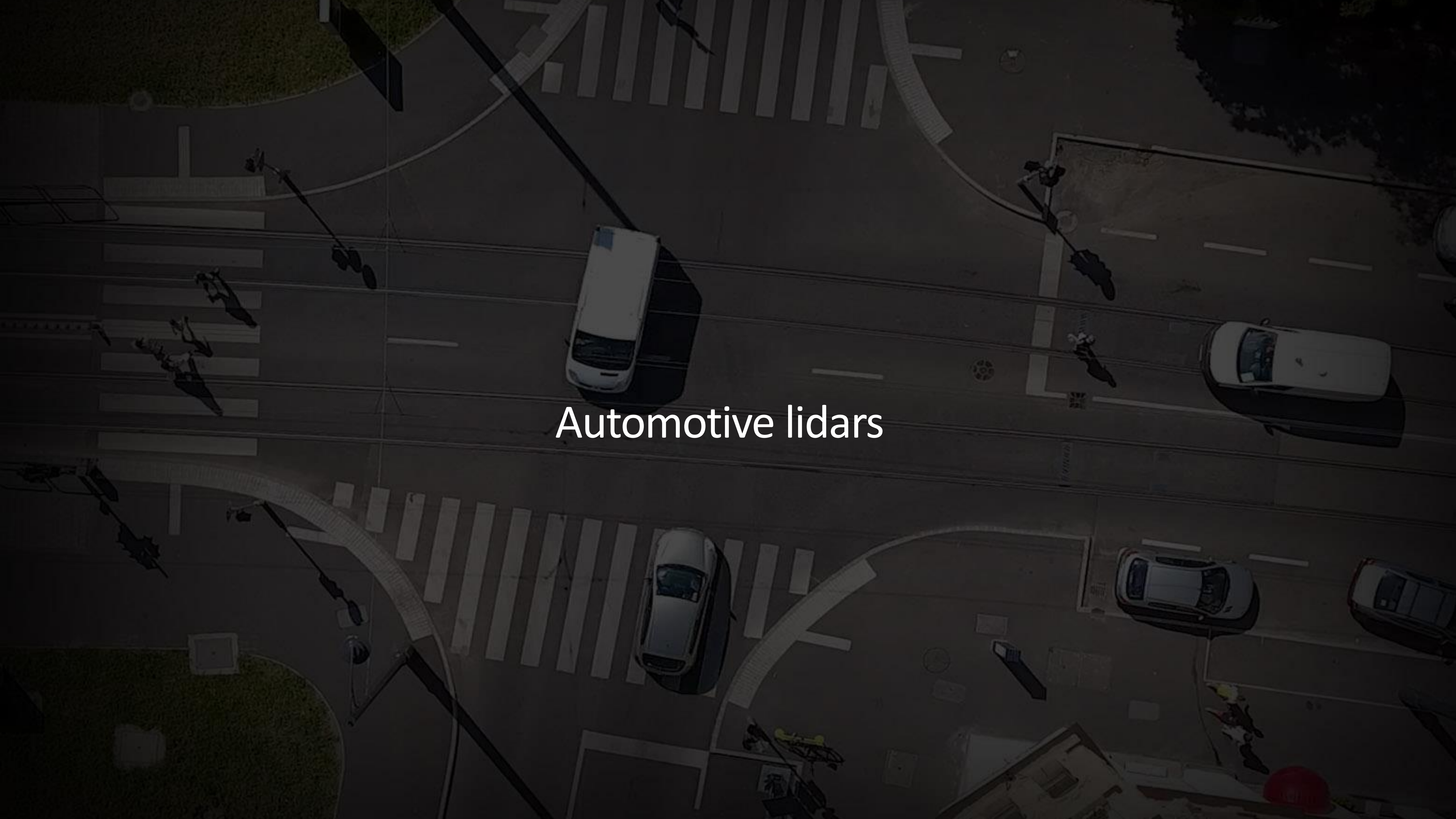
Performance limitations

- Resolution, range, field of view
- Frame rate and sweep / scan time
- Beam divergence
- Only one return measured
- Environmental conditions
- Target reflectance
- Reflections
- Interference and crosstalk
- Mechanical issues
- Data latency
- Eye safety regulations
- Power consumption



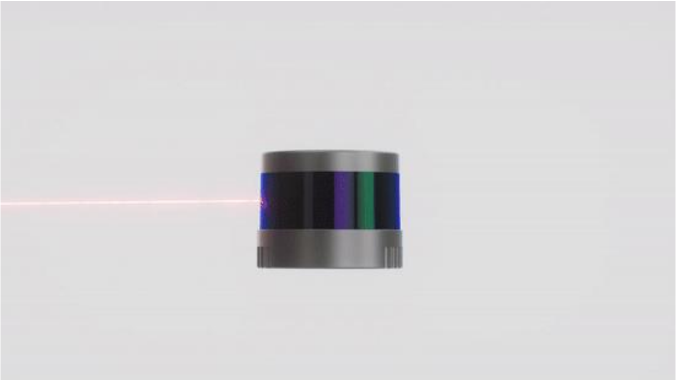


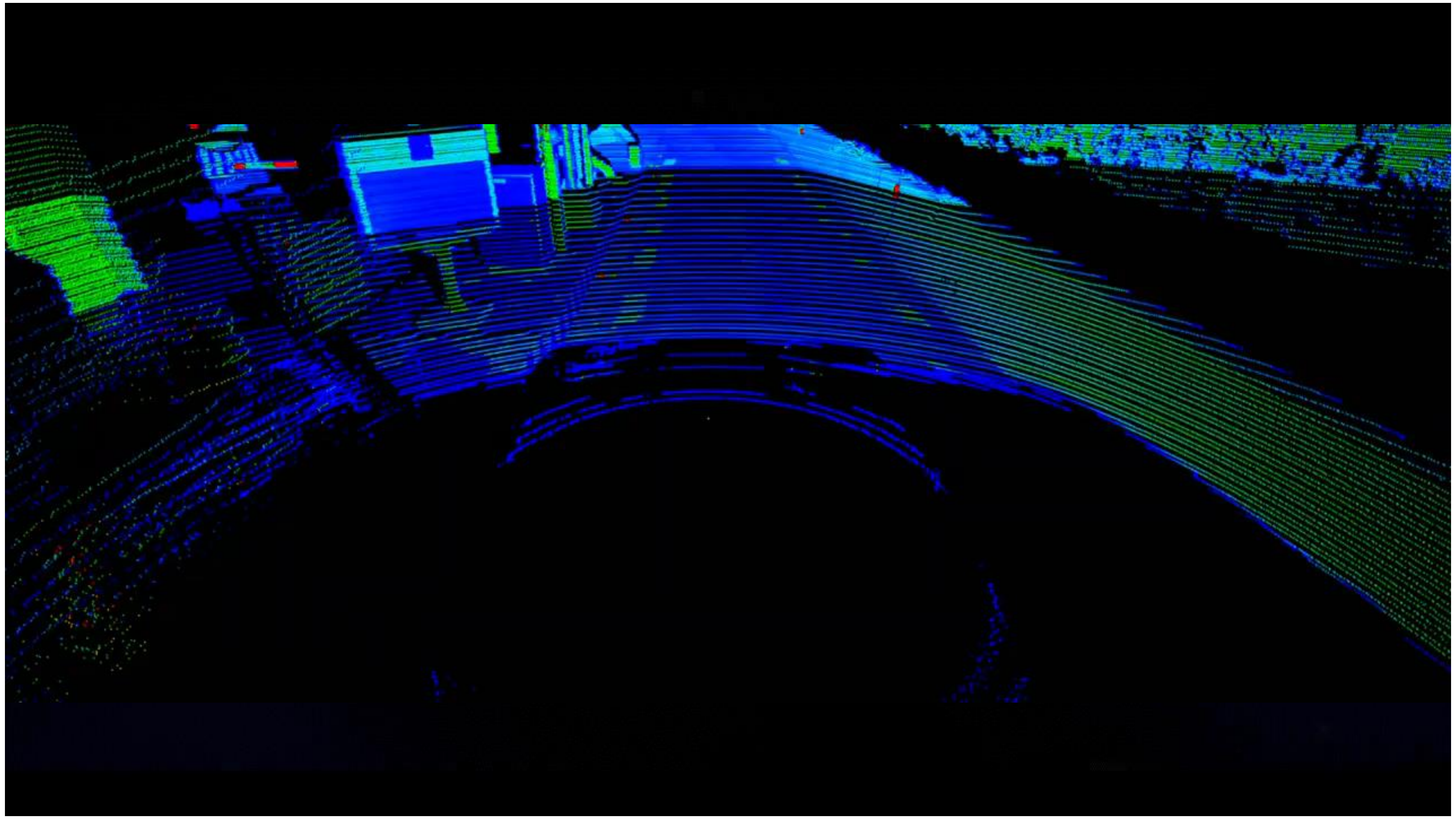
Automotive lidars



Classical rotating lidars

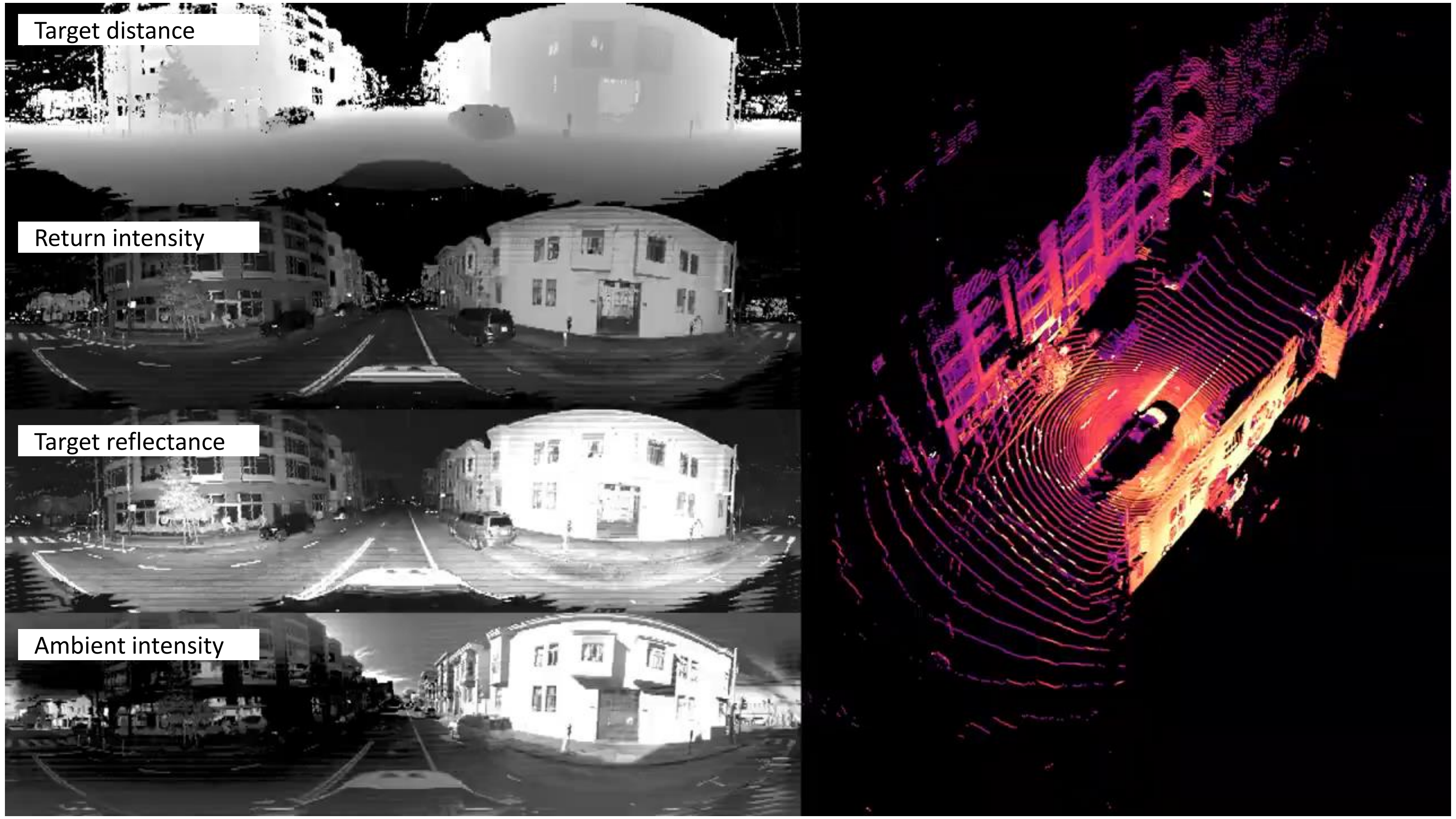
- Key features
  - 360° horizontal field of view
    - Mechanical rotation
  - Multiple vertical channels
    - 16 / 32 / 64 / 128 / 512
- Most relevant vendors
  - Hesai
  - Robosense
  - Velodyne (acquired by Ouster)





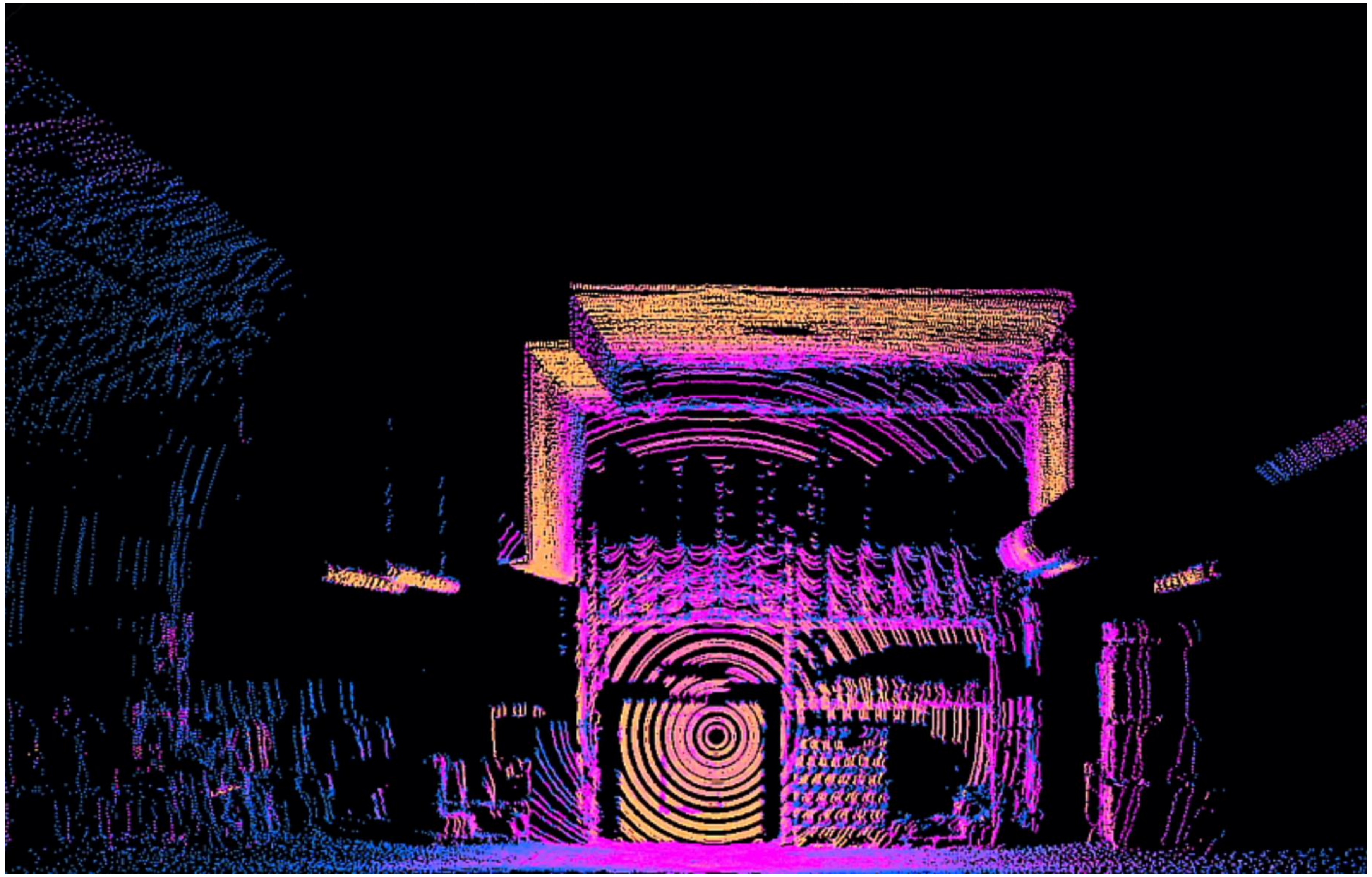
Rotating lidars with extra features

- Key features
  - 360° horizontal field of view
    - Mechanical rotation
  - Multiple vertical channels
    - 128
  - Rotating lidar as a camera
    - Also ambient intensity is measured
- Relevant vendors
  - Ouster



Rotating dome lidars

- Key features
  - 360° horizontal field of view
    - Mechanical rotation
  - Multiple vertical channels
    - 32 / 64 / 128
    - Extreme wide vFoV: 90°
  - Short range detection
- Relevant vendors
  - Ouster
  - Robosense

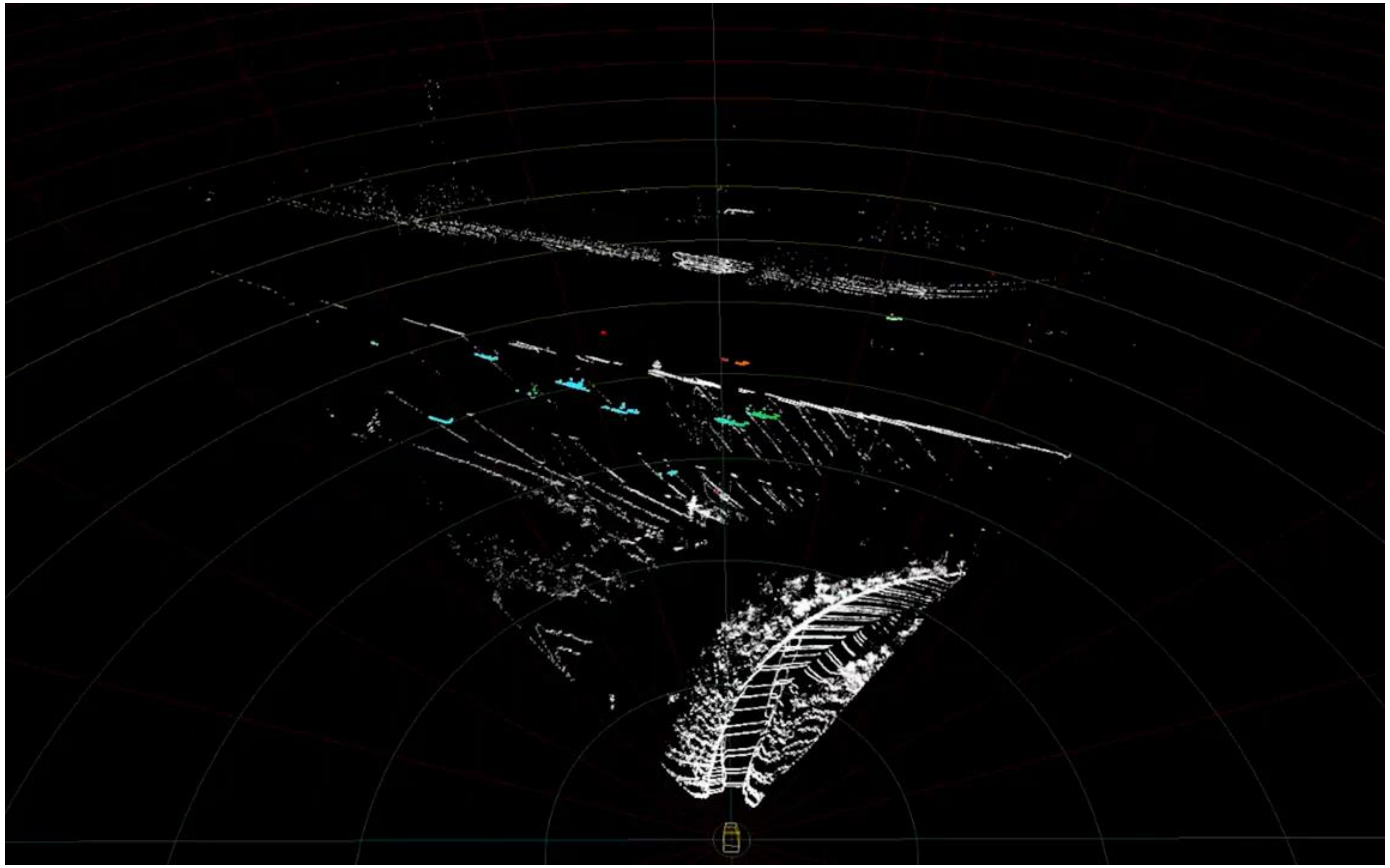


Solid state lidars

- Key features
  - Higher flexibility in configuration
  - Less or no moving components
  - Higher mechanical endurance
  - Better integrability to vehicles
  - Less complex manufacturing, better price
- Relevant vendors
  - Aeva
  - Aeye
  - Blackmore (acquired by Ambarella)
  - Cepton
  - Hesai
  - Innoviz
  - Livox
  - Ouster
  - Robosense
  - Seyond
  - Valeo
  - Velodyne

Solid state FMCW lidars

- Key features
  - Radial speed measurement
  - Easier clustering and tracking
- Relevant vendors
  - Blackmore (acquired by Aurora)
  - Aeva
  - Mobileye

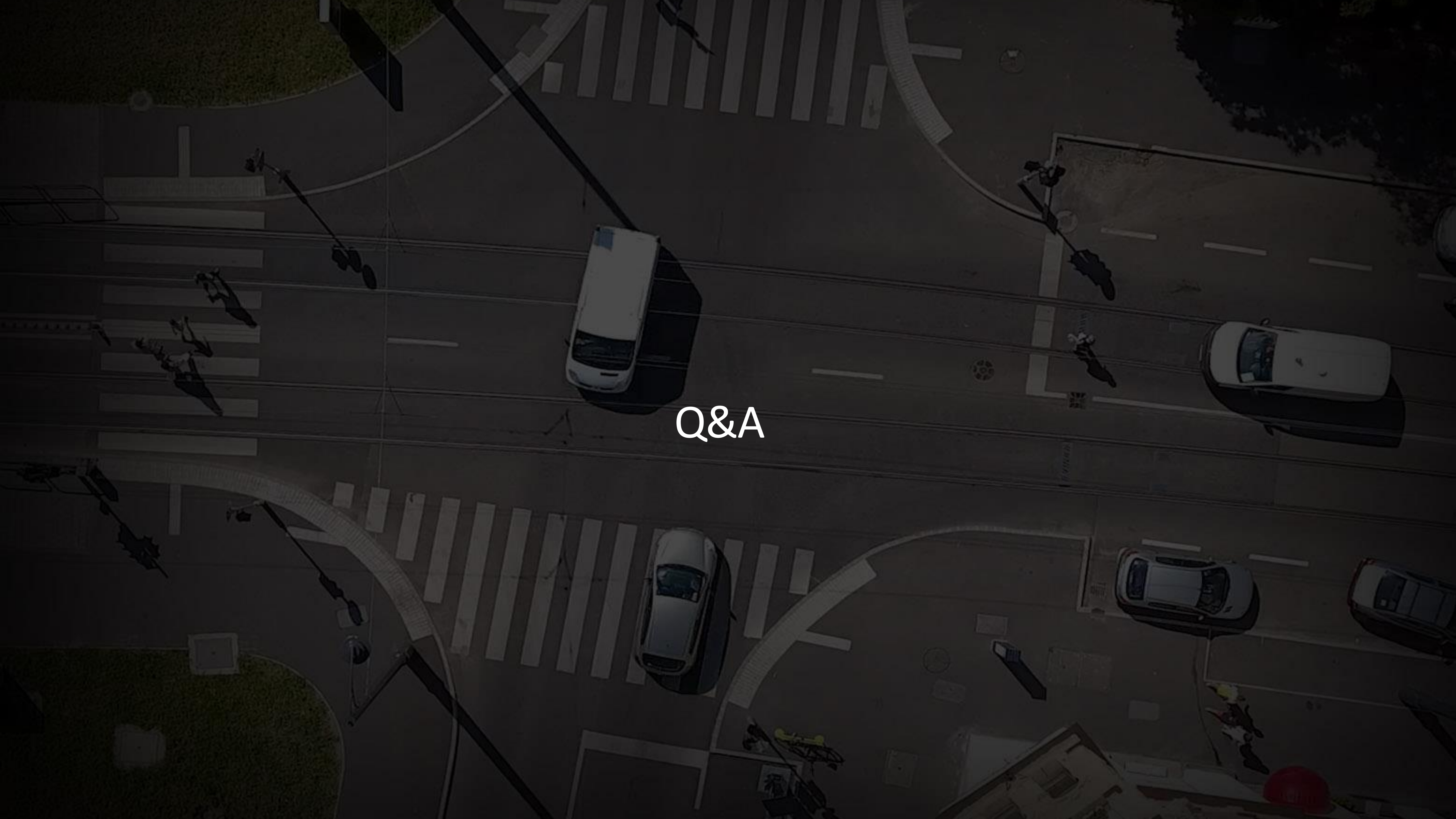


Solid state flash lidars

- Key features
    - Even less or no moving components
    - More parallelized measurements
        - Even global shutter
- Relevant vendors
    - Continental
    - Ouster
    - Sense Photonics

Profilers

- Key features
  - Sub-millimeter accuracy and precision
  - High angular resolution: ~0.01
  - ~ 200 rotation per min
  - Less intensity inhomogeneity issues
  - Less intrinsic calibration issues
  - Mobile mapping applications
- Relevant vendors
  - Faro
  - Leica Geosystems
  - Z+F (Zoller+Fröhlich)



Q&A