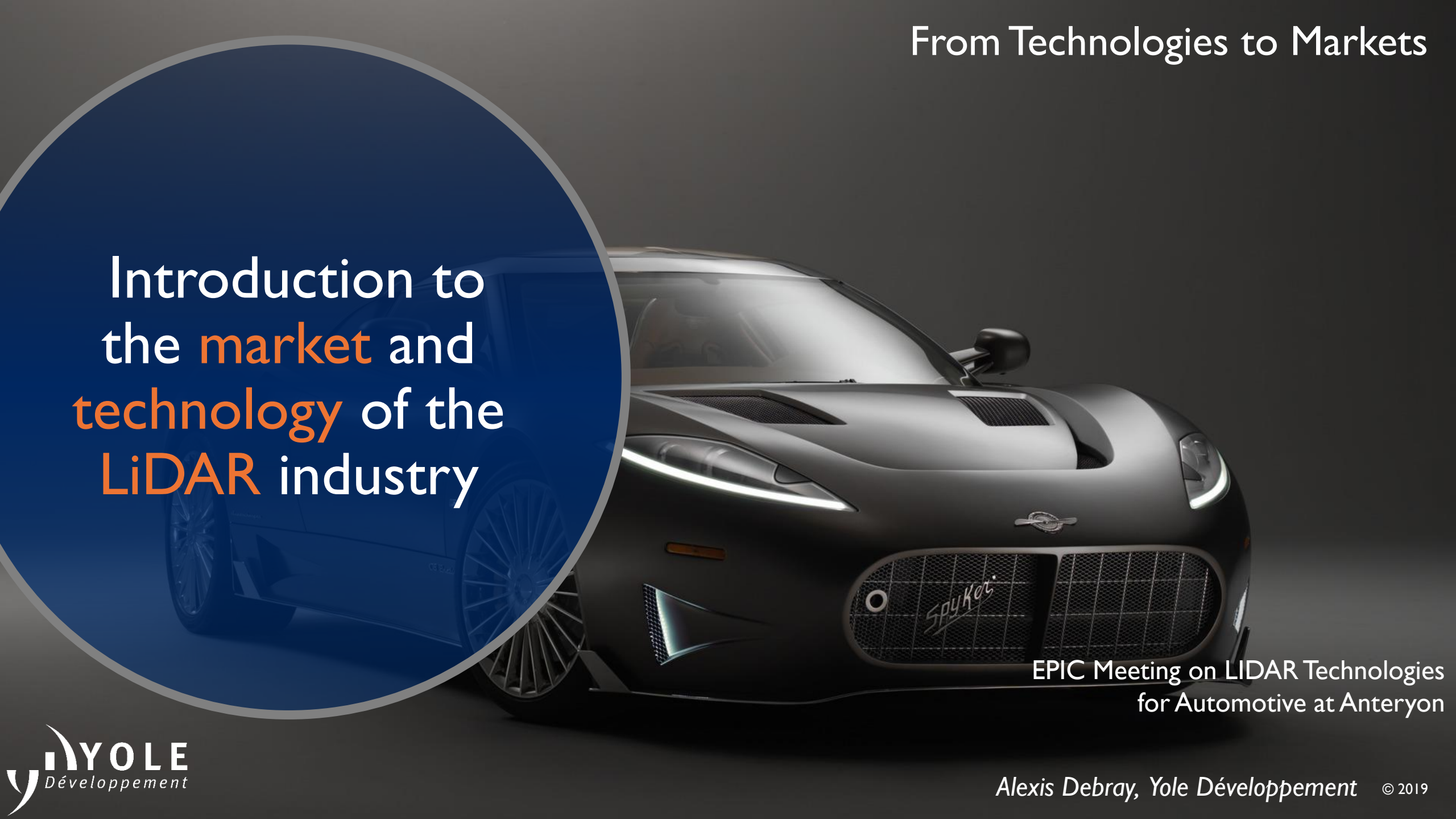
From Technologies to Markets

Introduction to the market and technology of the LiDAR industry



EPIC Meeting on LIDAR Technologies for Automotive at Anteryon

YOLE Développement

Alexis Debray, Yole Développement

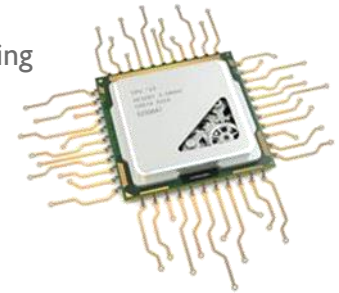
YOLE DEVELOPPEMENT – FIELDS OF EXPERTISE

Photonics & Sensing

- Photonics
- Lighting
- Imaging
- Sensing & Actuating
- Display

Semiconductor Manufacturing & Computing

- Advanced Packaging, Assembly & Substrates
- Semiconductor Manufacturing
- Memory
- Computing



Power & Wireless

- RF Devices & Technologies
- Compound Semiconductors & Emerging Materials
- Power Electronics
- Batteries & Energy Management

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Due diligence

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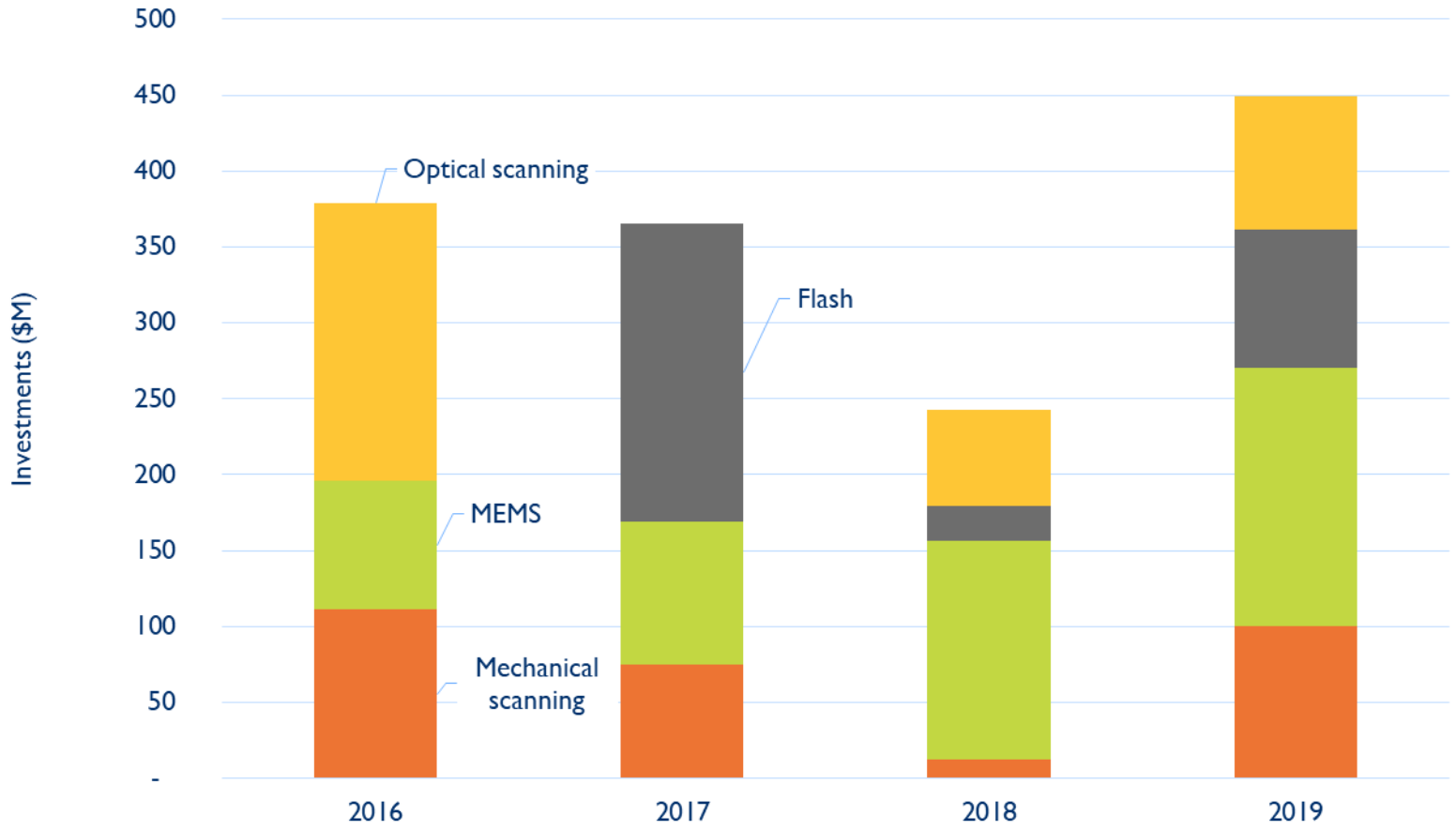
Introduction

GREAT THINGS HAPPENING IN LiDAR

One billion dollar investment

Private investments in the LiDAR industry since 2016 – Split by technology

Total private investments identified: **$1,437M**



GREAT THINGS HAPPENING IN LiDAR

High industrial involvement

2018 — Audi cars running with LiDAR

Valeo

The first LiDAR in an ADAS car

SYSTEMPLUS CONSULTING

2019 — Waymo selling LiDAR

laser bear honeycomb™ BY WAYMO

WAYMO

- More than 10 million kilometers
- More than 200 patents
- Several partnerships with OEM

2021 — Innoviz readying the supply chain

INNOVIZ TECHNOLOGIES

MAGNA

Tier I

BMW

OEM

LiDAR: FROM TECHNOLOGIES TO APPLICATIONS

Technologies

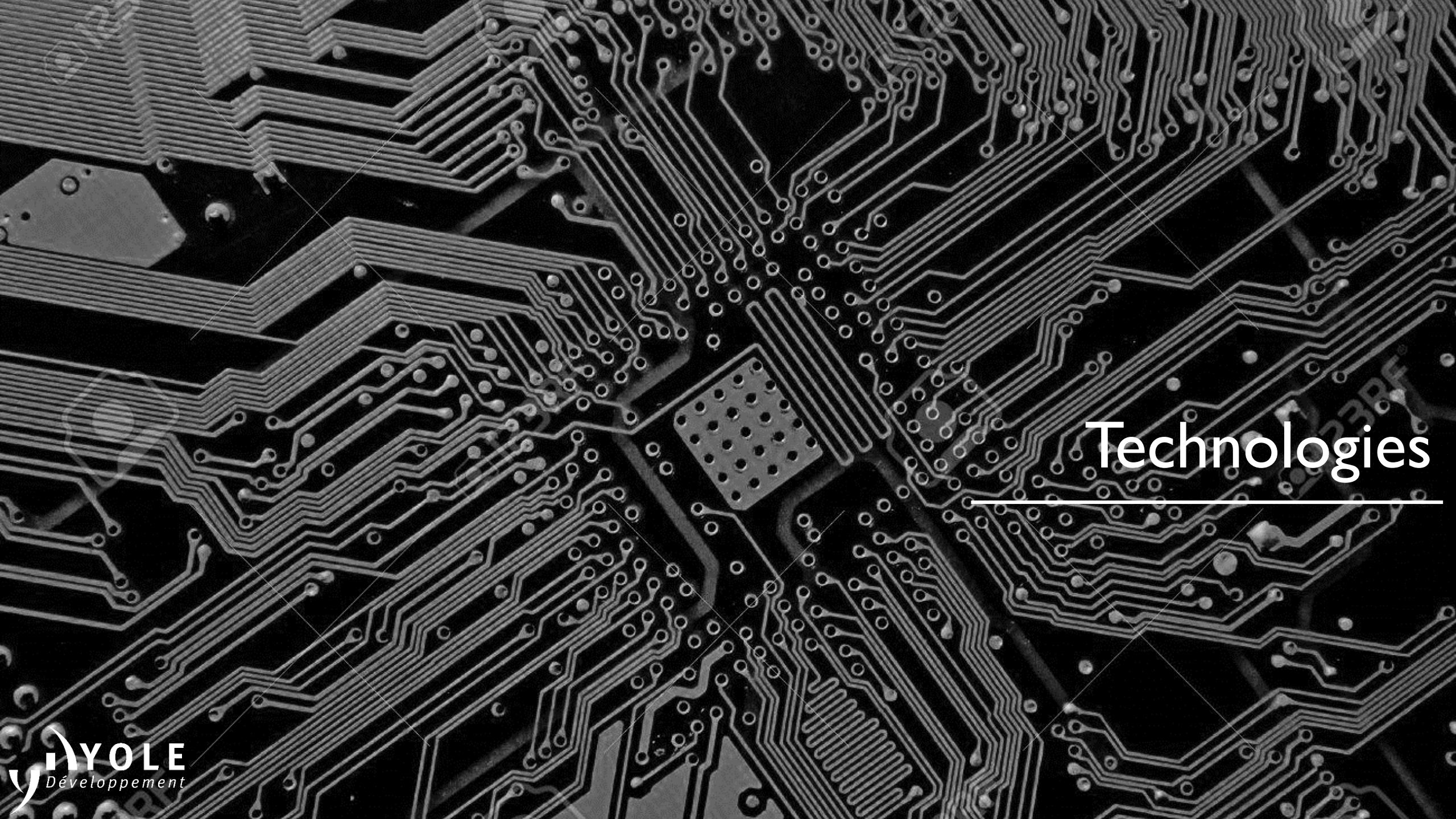
- Consumer optics
- OCT
- Fiber-optic communication
- Optical packaging
- MEMS scanner
- Laser diode
- VCSEL
- SiPM
- PET
- Image processing
- Cloud data
- Geographic Information System
- Automatic target recognition

LiDAR

Applications

- Space — Up to $M 500
- Topography — $10 000 $1 000 000
- Wind — $30 000 $500 000
- Logistics/Industry — $2 000 $100 000
- Transportation — $500 $75 000
- Robots — $1000
- Consumer — $1 $10

OCT: Optical Coherence Tomography
PET: Positron Emission Tomography
SiPM: Silicon Photomultiplier
VCSEL: Vertical-Cavity Surface-Emitting Laser



Technologies

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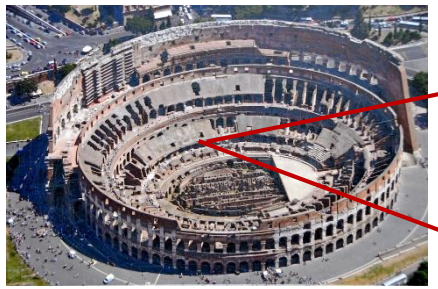
LiDAR PRINCIPLES AND COMPONENTS

The basic working principle of LiDAR is very simple.
A light source illuminates a scene. The light scattered by the objects of the scene is detected by a photodetector.
By measuring the time it takes for light to travel to the object and return from it, the distance can be calculated.

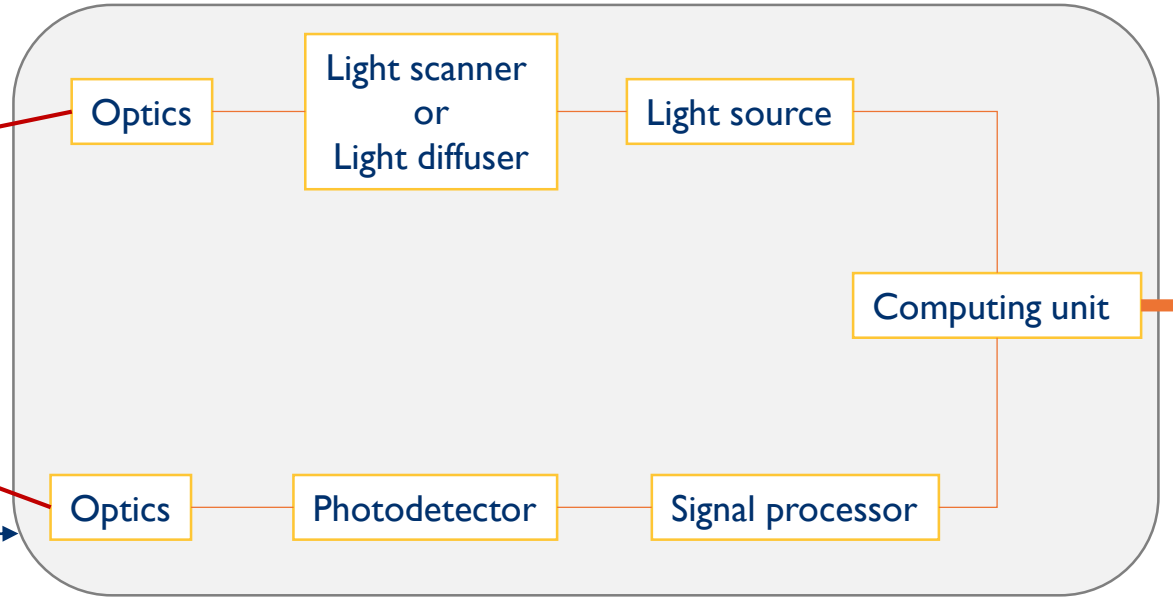
LiDAR is a system, with various components.

Scene under exposure



Laser beam

distance = time x velocity of light



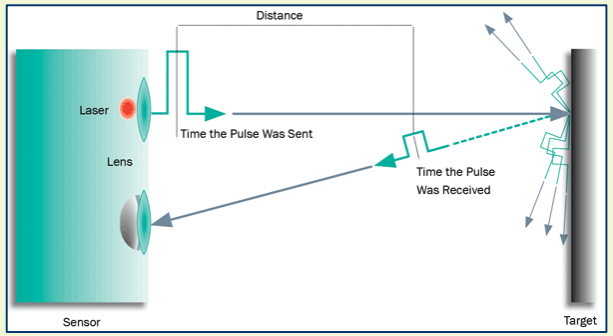
3D point cloud

LiDAR system

LiDAR RANGING METHODS

There are **three** LiDAR ranging methods: pulsed time of flight, phase shift, and frequency modulation.

Pulsed Time of Flight



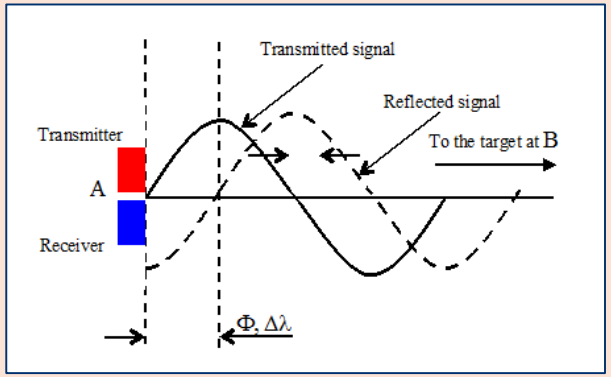
Pulsed Time of Flight (ToF) is a direct measurement of the time of flight of light from the emitter to the scene and then to the photodetector.

This technique allows measurement of several reflections.

It relies heavily on Time to Digital converters (TDC) which transform the pulse arrival timing into digital signals.

This is the most popular in LiDAR (easiest).

Phase Shift



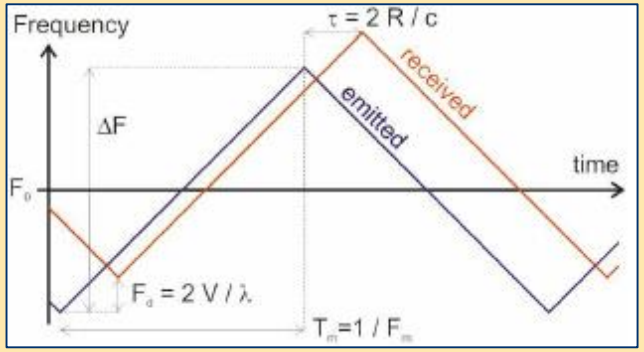
In phase shift time of flight, continuous waves are used and the time of flight is measured as a phase difference.

The use of continuous waves allows for heterodyne detection which is much more sensitive than direct detection.

However, the maximum range is limited by phase wrapping.

Limited range

Frequency Modulation



In frequency modulation, a continuous wave is modulated in frequency and the time of flight is measured as a frequency difference.

As with phase shift, continuous waves allow for heterodyne detection. Moreover, radial velocity can be easily measured.

However, a highly coherent source is needed to use heterodyne detection.

The future

IMAGE FORMATION IN LiDAR

There are basically **three** methods for forming an image in LiDAR.

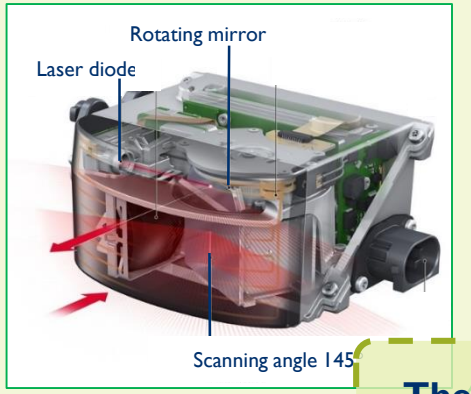
Mechanical LiDAR

Mechanical LiDAR for ADAS

Valeo

ibeo

Audi



Mechanical LiDAR for Robotic cars

Velodyne

Valeo

robosense 速腾聚创

Other mechanical LiDAR

neptec Technologies Corp

CEPTON

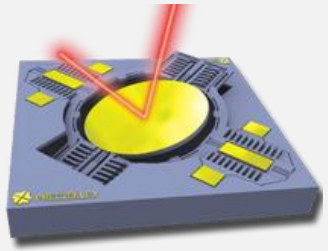
LUMINAR

1550 nm

The present

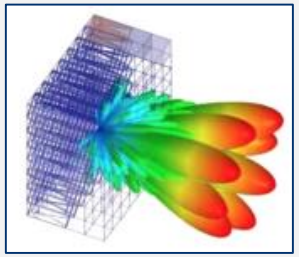
Solid-state LiDAR

MEMS LiDAR



Courtesy of Preciseley Microtechnology Corp.

OPA LiDAR

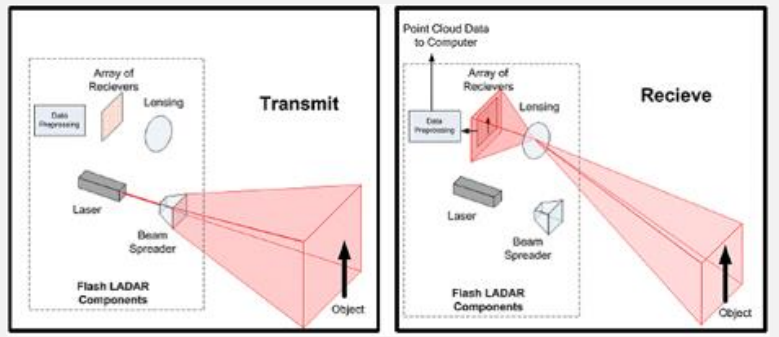


Courtesy of Quanergy

2020-2021

The future (may be)

Flash LiDAR



Courtesy of Advanced Scientific Concepts, Inc.

2020-2021

OPA: Optical-Phased Array

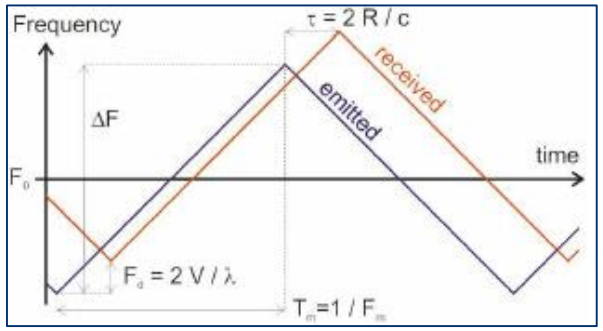
FMCW LiDAR

Frequency Modulated Continuous Wave

FMCW is expected to be the third generation of 3D real time LiDAR.

Principle of FMCW

- Ranging method commonly used in radar.



Advantages of FMCW

- 10 to 100 higher sensitivity thanks to heterodyne detection.
- Suited for 1550nm (higher power density available).
- Suited for OPA (scanning with no moving part).
- Leveraging Photonic IC.
- Instant radial velocity measurement (Doppler effect).

FMCW Players

AEVA, Analog Photonics, intel, Blackmore, SiLC, Insight LiDAR, oryx, OURS, STROBE, Voyant Photonics, Rockley Photonics, Bridger Photonics

OPA: Optical Phased Array

TECHNOLOGY/PLAYER SEGMENTATION FOR AUTOMOTIVE LiDAR

	Multi-channels Macro-mechanical scanning	Other mechanical scanning	MEMS LiDAR	Optical-phased array LiDAR	Flash LiDAR
Pulse LiDAR	Velodyne, WAYMO, Valeo, robosense, HESAI, SureStar, 镭神智能 LeiShen Intelligent System, OUSTER	CEPTON, LUMINAR 1550 nm, Panasonic, mirada Technologies, Inc.	Velodyne, Valeo, INNOVIZ, Blickfeld, robosense, Pioneer, LeddarTech, Infineon, SOS LAB, AEYE 1550 nm	robosense, AMIGOCAR, SK Участник, QUANERGY; Other optical based LiDAR: LUMOTIVE, BARAJA	Continental 1064 nm, ZF, LeddarTech, tetravue, ARGO AI, sense photonics, 1350 nm; Multi-Beam Flash LiDAR: OUSTER, XENOMATIX Automotive Vision Solutions, ibeo automotive
Phase shift			Benewake		ifm
CW LiDAR				SiLC 1550 nm, ANALOG PHOTONICS 1550 nm, blackmore 1550 nm, VOYANT PHOTONICS 1550 nm	oryx 10 µm
FMCW					

A wide range of technologies are under consideration by LiDAR companies.

Except when noted, wavelength is between 830 nm and 940 nm.

CW: Continuous Wave
FMCW: Frequency Modulated Continuous Wave

Market Trends

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DRIVER FOR AUTOMOTIVE LiDAR

Traditional car makers

ADAS Levels

0	1	2	3	4	5
		2010~	2017~	2025~	2035~
		FEET-OFF	HANDS-OFF	EYES-OFF	MIND-OFF

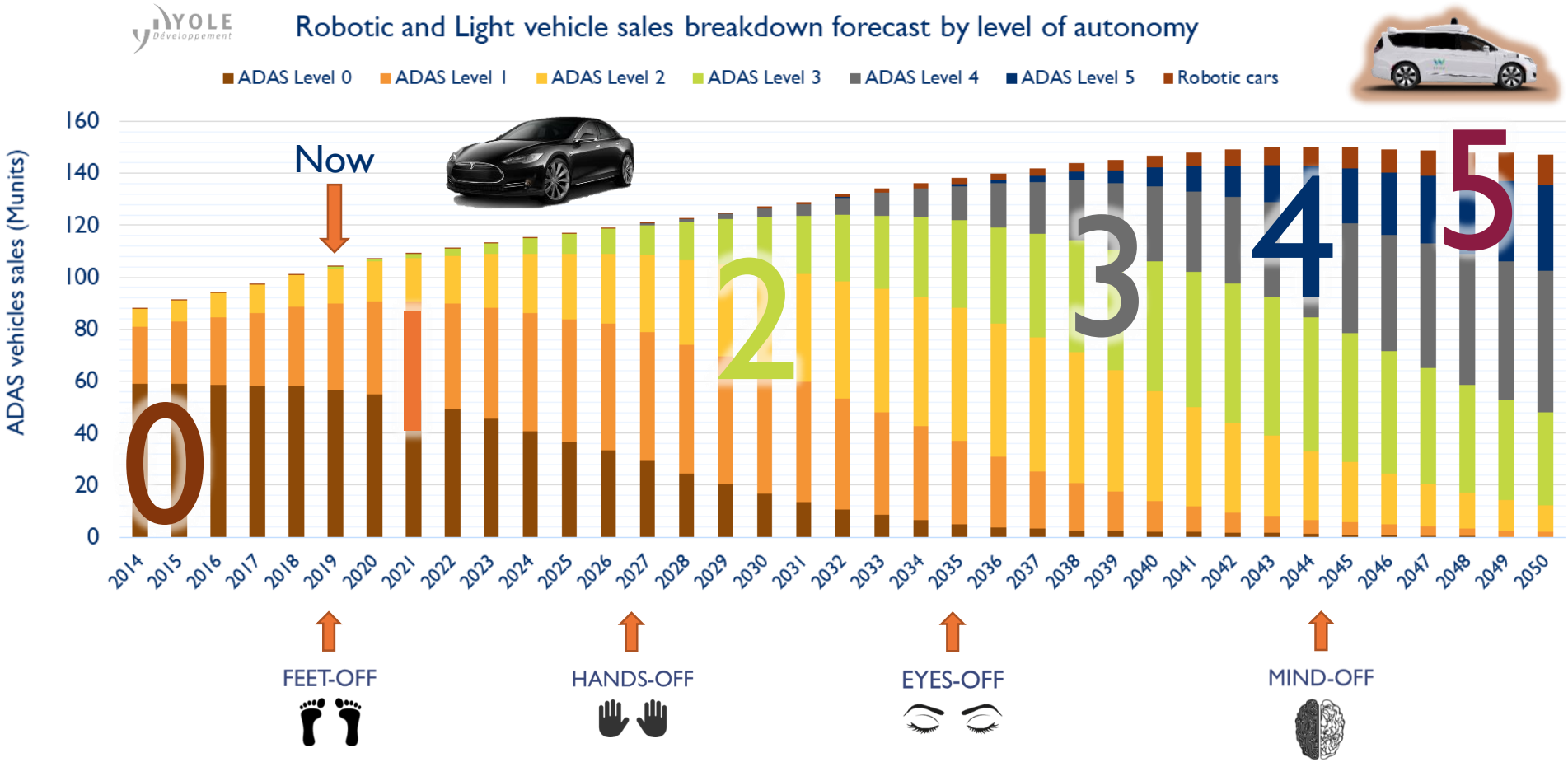
While traditional car makers are integrating autonomous functions in consumer cars little by little, new-comers have challenged this approach by short-cutting technological developments and proposing a new business model: transportation as a service. This move has triggered new investments in LiDAR technologies.

Fully autonomous vehicles in 2017

Robotic car players

MARKET PENETRATION OF ADAS VEHICLES

By 2050, most cars should be above level 3!



ROBOTIC VEHICLE LIDAR MARKET

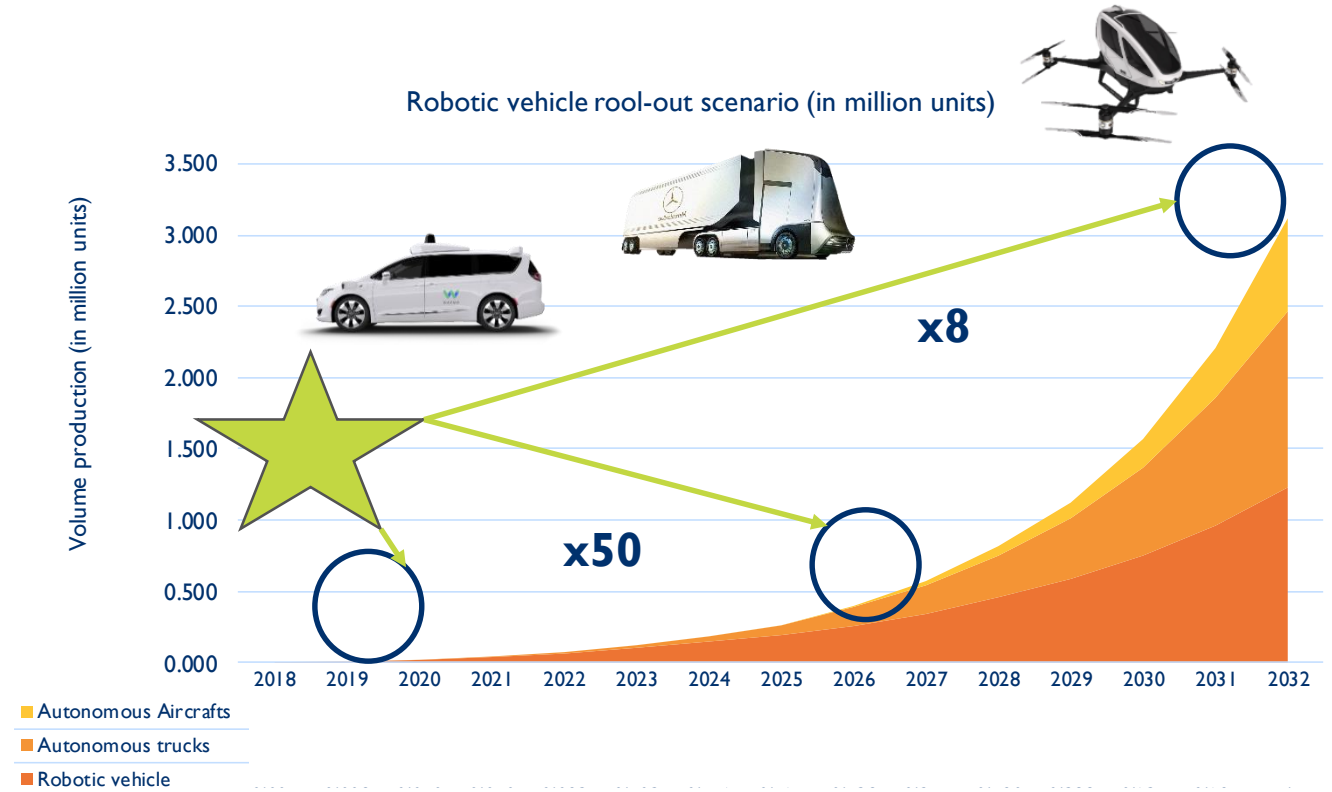
Robotic vehicle market trend

In 2032, we expect 5M robotic vehicles on the road.

Until 2032, the production of robotic vehicles will increase 3 orders of magnitude

4ku	in 2018	
44ku	in 2021	3 years
400ku	in 2026	5 years
3.1Mu	in 2032	6 years

Life cycle of each vehicle will be relatively short, in the order of 5 years.

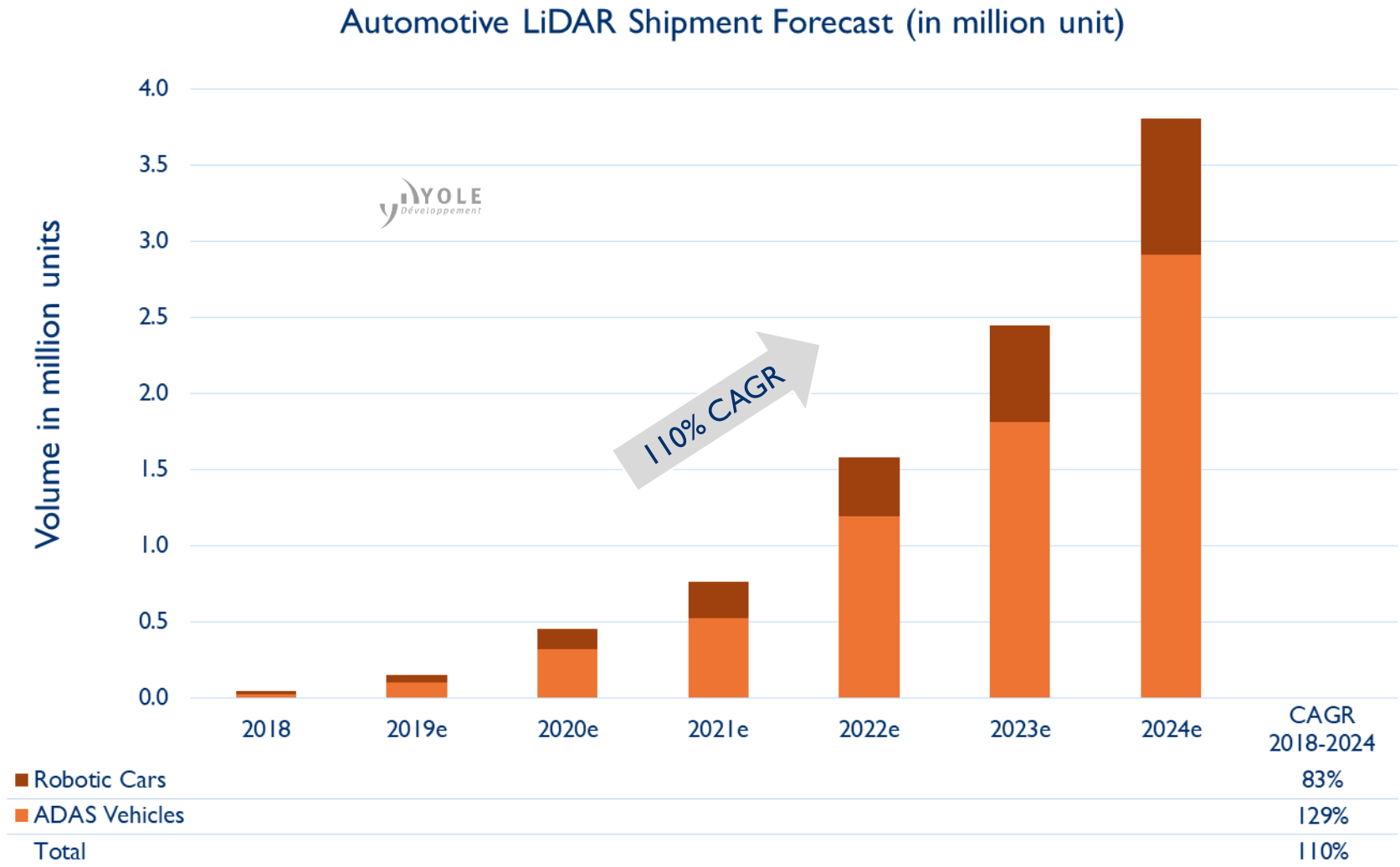


Autonomous aircrafts correspond to projects of flying taxis supported by Ehang in China, Airbus in France, and Rolls-Royce in UK.

AUTOMOTIVE LIDAR MARKET

Automotive LiDAR shipment forecast

ADAS vehicles will be responsible for massive LiDAR shipments in the next years.



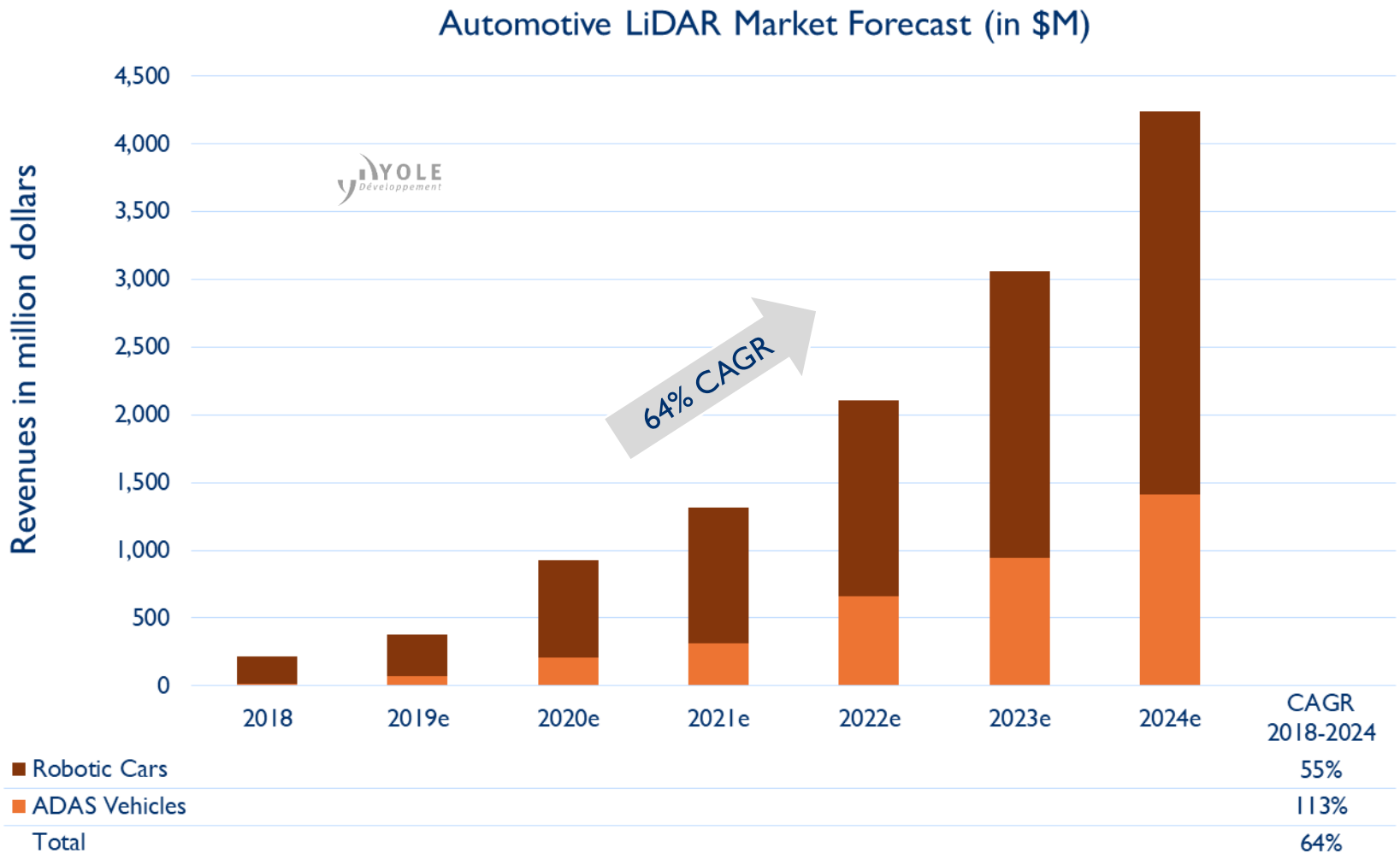
Note:

- Robotic vehicles includes cars, trucks, and aircrafts.
- ADAS includes levels 3, 4, 5.

AUTOMOTIVE LIDAR MARKET

Automotive LiDAR market forecast

The LiDAR market forecast is expected to reach $4.2B in 2024 with LiDAR in robotic vehicles representing two thirds of the revenues.



Note:

- Robotic vehicles includes cars, trucks, and aircrafts.
- ADAS includes levels 3, 4, 5.

Industrial Landscape

Jan van Goyen

YOLE Développement

TECHNOLOGICAL READINESS FOR AUTOMOTIVE LiDAR

It should be noted that all players are not working on the same technology or at the same industrial scale.

ADAS vehicles

Because the qualification is easier for robotic vehicles which are still at an experimental stage, most players have a higher TRL in robotic vehicles.

Pioneer
LUMOTIVE
sense photonics
SureStar
robosense *MEMS
Velodyne *MEMS
OUSTER
INNOVIZ TECHNOLOGIES
LUMINAR
XENOMATIX Automotive Vision Solutions
blackmore
Continental
CEPTON
AEYE
Blickfeld LIDAR / scan your world
Valeo

Robotic vehicles

A the present time, Waymo and Velodyne are the most successful companies for robotic vehicle LiDAR tests, though products from other companies are being also considered.

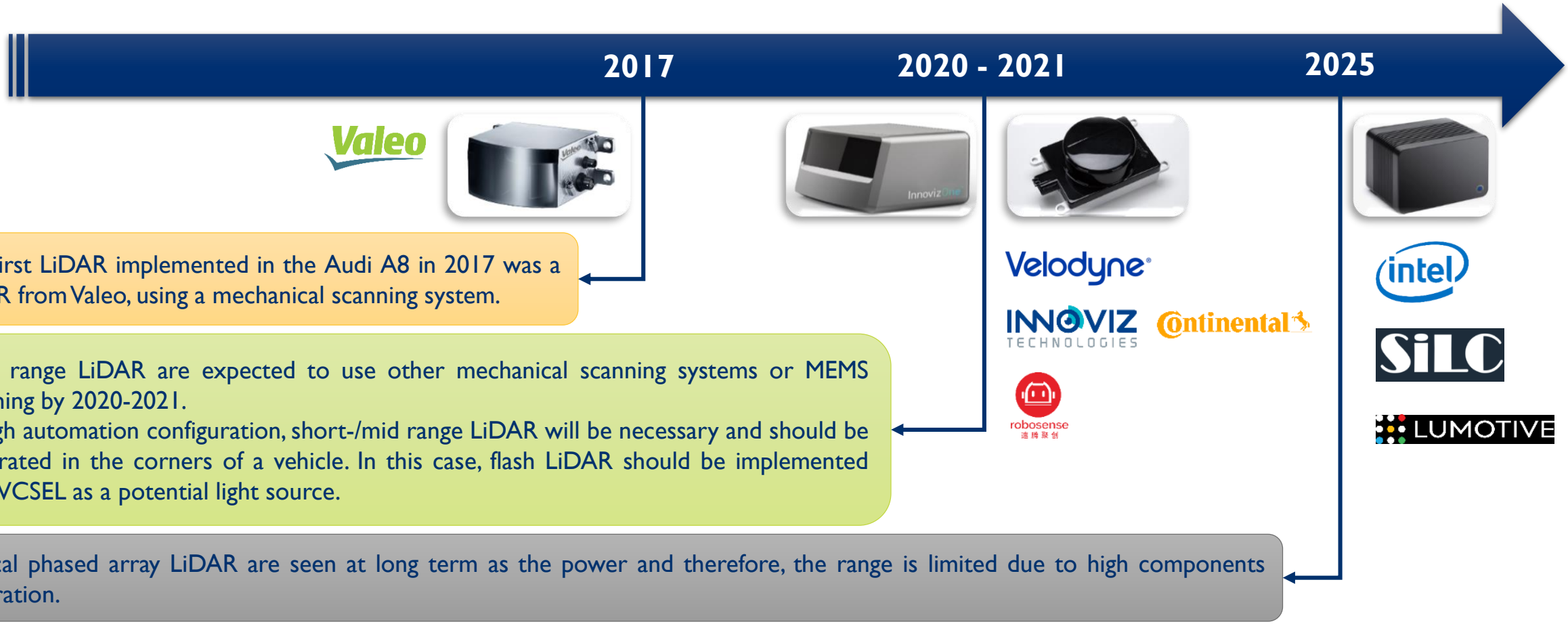
oryx
Benewake
INNOVIZ TECHNOLOGIES
CEPTON
XENOMATIX Automotive Vision Solutions
OUSTER
HESAI
AEYE
SureStar
blackmore
Blickfeld LIDAR / scan your world
robosense
Velodyne *Macro mechanical
WAYMO

TRL: Technological Readiness Level

TRL 1	2	3	4	5	6	7	8	TRL 9
Basic properties	Invention begins	R&D started	Pieces work together	"High fidelity" laboratory integration	Prototype is tested in relevant environment	Prototype is working in relevant environment	Technology is proven to work	Successful operation

TIME-TO-MARKET ANALYSIS

LiDAR for ADAS vehicles – technological roadmap



LiDAR EXPENDING INTO OTHER APPLICATIONS

System TAM per Year

Logistics | Construction | Smart building

Mobility | Manufacturing

Timing

Volume

Autonomous ships
200 units/year
Starting 2035

Office monitoring
10M units/year
Starting 2025

Flying taxis
600k units/year
Starting 2030

Autonomous trucks
600k units/year
Starting 2021

Terminal AGV
550 units/year
Starting 2017

Mining trucks
2000 units/year
Starting 2008

Delivery robots
30k units/year
Present

Autonomous forklift
300k units/year
Starting 2019

Robotic cars
1M units/year
Present

Warehouse AGV
100k units/year
Present

Airborne LiDAR
50 units/year
Present

Mobile LiDAR
2000 units/year
Present

Static LiDAR
40k units/year
Present

CONCLUSIONS

LiDAR technology is expanding into mass market.

- LiDAR technology, which has been confined to scientific and space applications for decades, is now expanding into the mass market with applications in consumer and automotive segments.
- The LiDAR market for automotive will be $375M in 2019; growth is expected to be 64%. Our forecast is a revenue of $4.2B in 2024.
- Strong growth of LiDAR is expected in the transportation segment, both in robotic vehicles and in ADAS vehicles.
- LiDAR technology will continue to develop at all sizes. It is a key technology for depth and 3D perception of any machine and will expand in:
  - Wearables,
  - Mobiles,
  - Robots,
  - Transportation (from cars to commercial jets and spacecraft).

YOLE RELATED REPORTS

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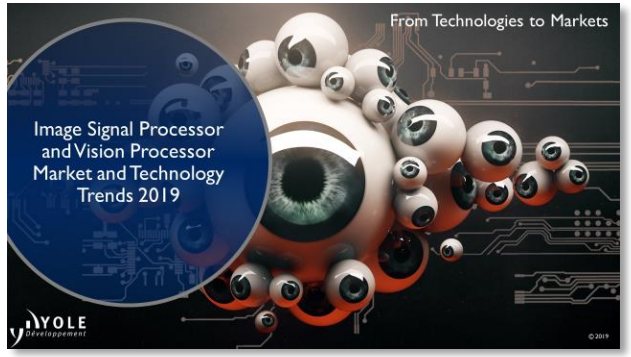

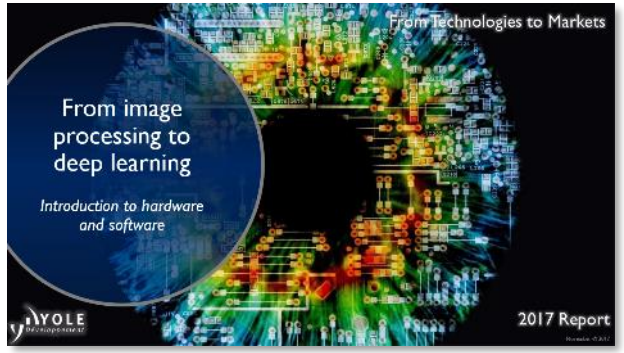

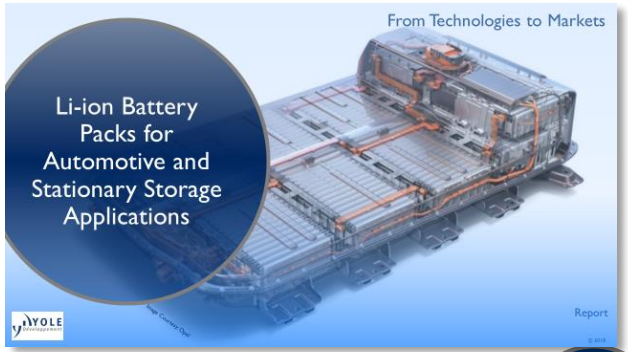

Thank you for your attention.

EPIC Meeting on LIDAR Technologies for Automotive at Anteryon

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