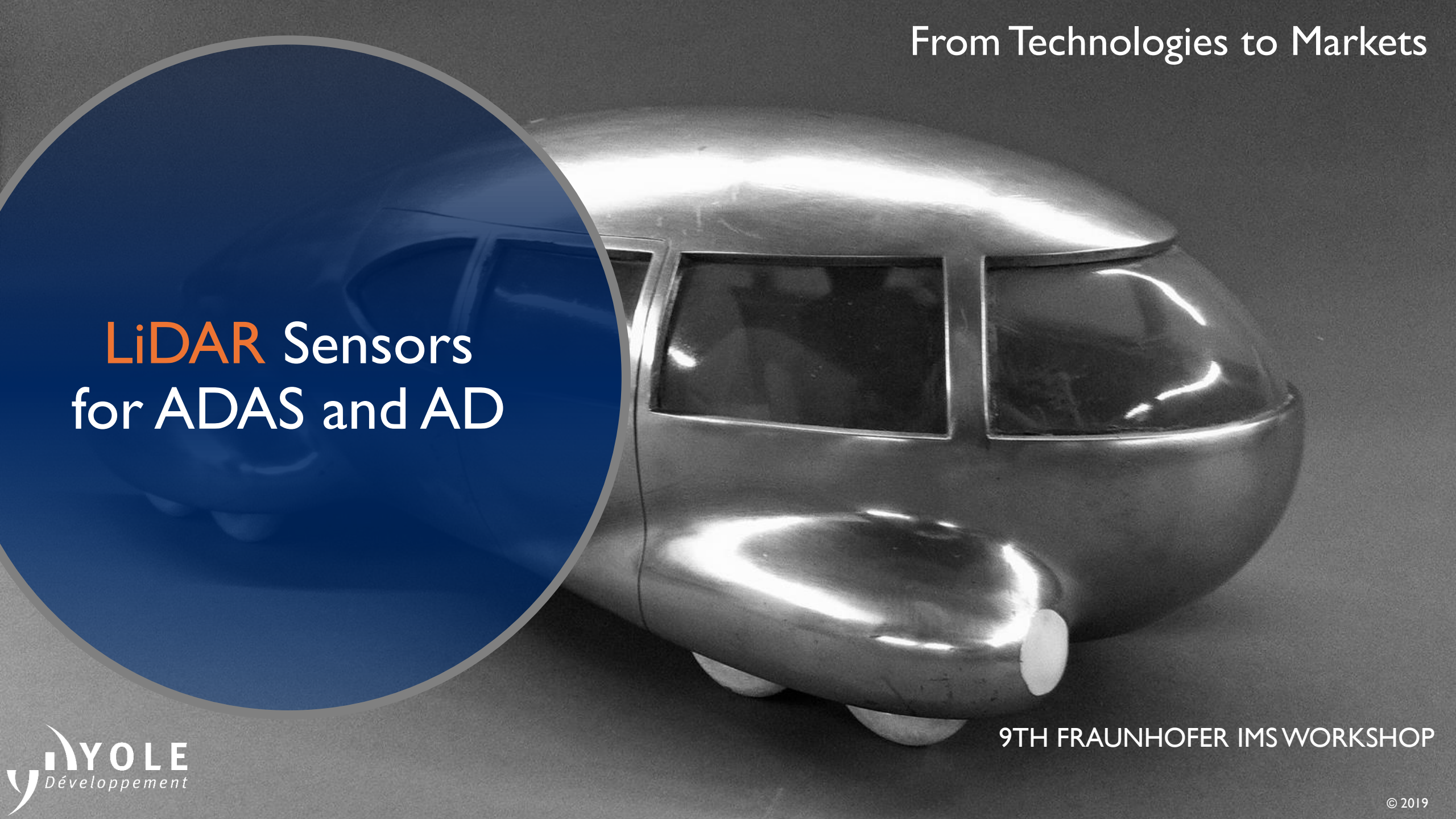
From Technologies to Markets

LiDAR Sensors for ADAS and AD



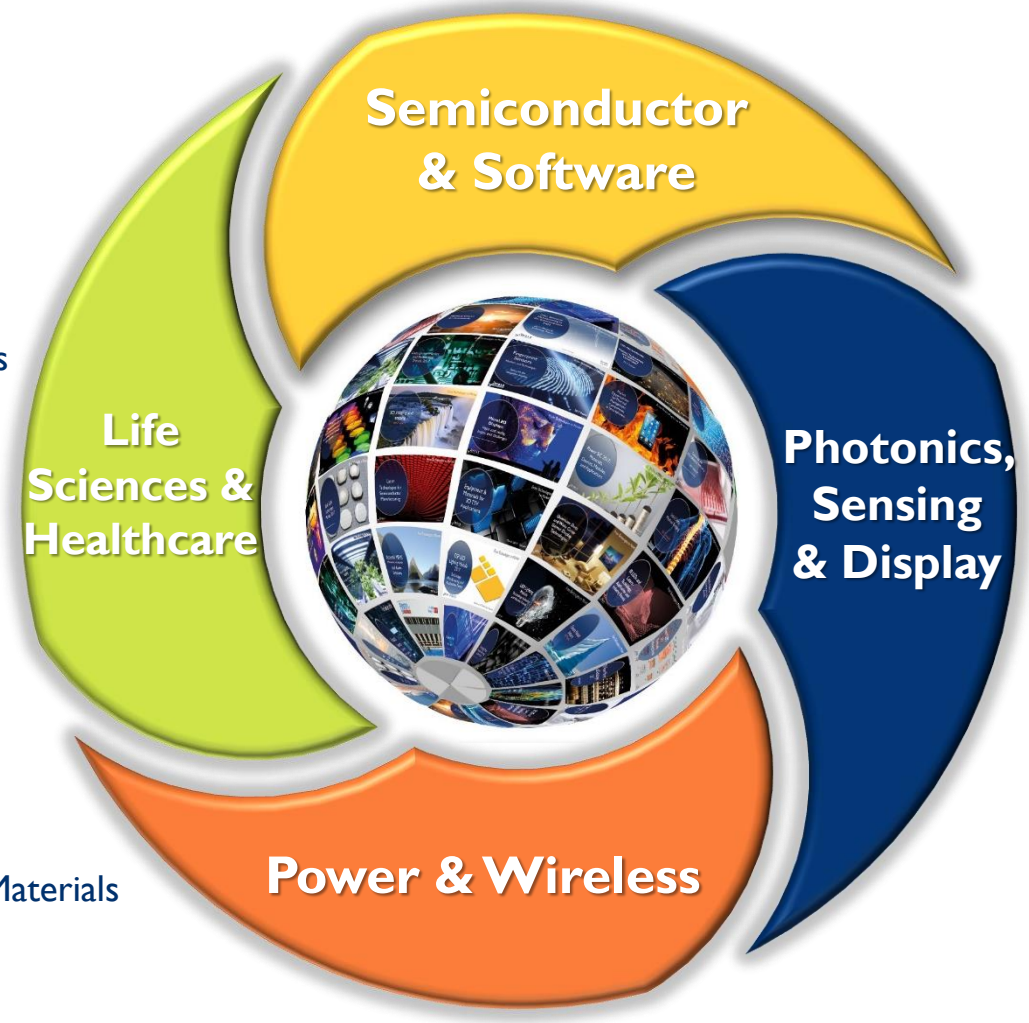
9TH FRAUNHOFER IMS WORKSHOP

YOLE Développement

YOLE DEVELOPPEMENT – FIELDS OF EXPERTISE

Life Sciences & Healthcare

- Microfluidics
- BioMEMS & Medical Microsystems
- Inkjet and accurate dispensing
- Solid-State Medical Imaging & BioPhotonics
- BioTechnologies



Semiconductor & Software

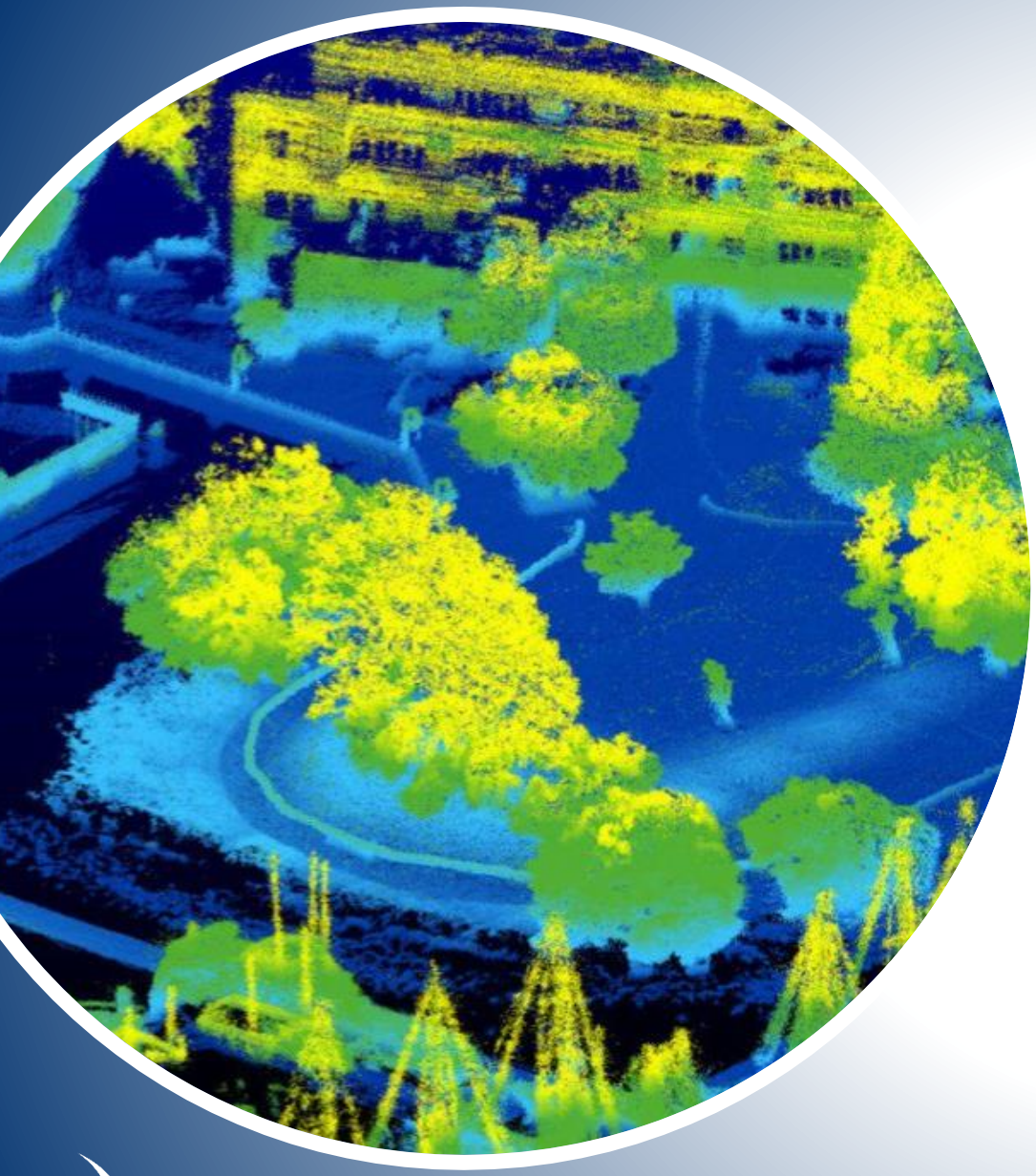
- Package, Assembly & Substrates
- Semiconductor Manufacturing
- Memory
- Software & Computing

Power & Wireless

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

Photonics, Sensing & Display

- Solid-State Lighting
- Display
- MEMS, Sensors & Actuators
- Imaging
- Photonics & Optoelectronics



Introduction

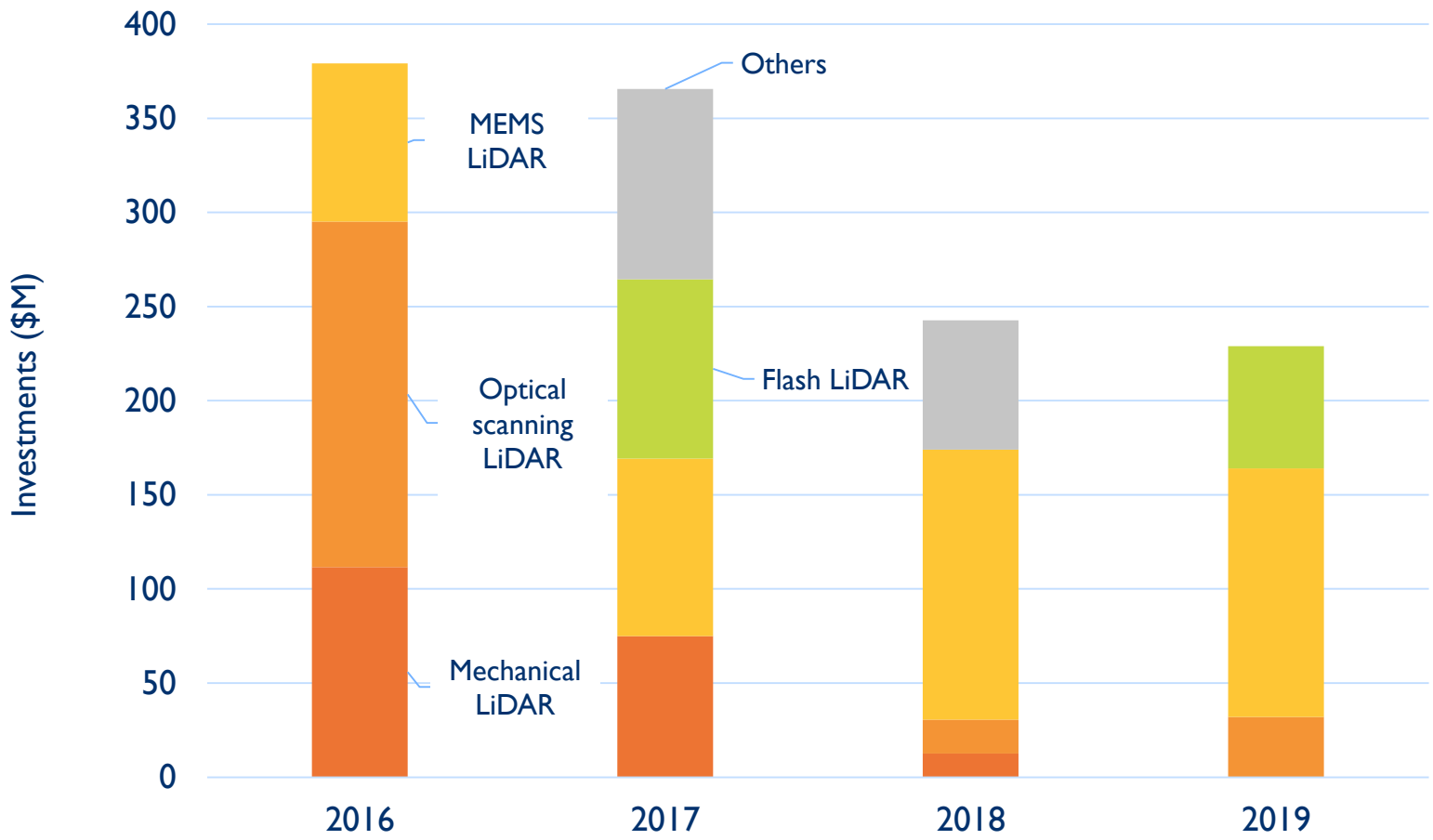
YOLE Développement

GREAT THINGS HAPPENING IN LiDAR

One billion dollar investment

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

Total private investments identified: **$1,216M**



GREAT THINGS HAPPENING IN LiDAR

High industrial involvement

Audi cars running with LiDAR — 2018

Valeo

The first LiDAR in an ADAS car

SYSTEMPLUS CONSULTING

Waymo selling LiDAR — 2019

laser bear honeycomb™ BY WAYMO

WAYMO

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

Innoviz readying the supply chain — 2021

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 $500M
- 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

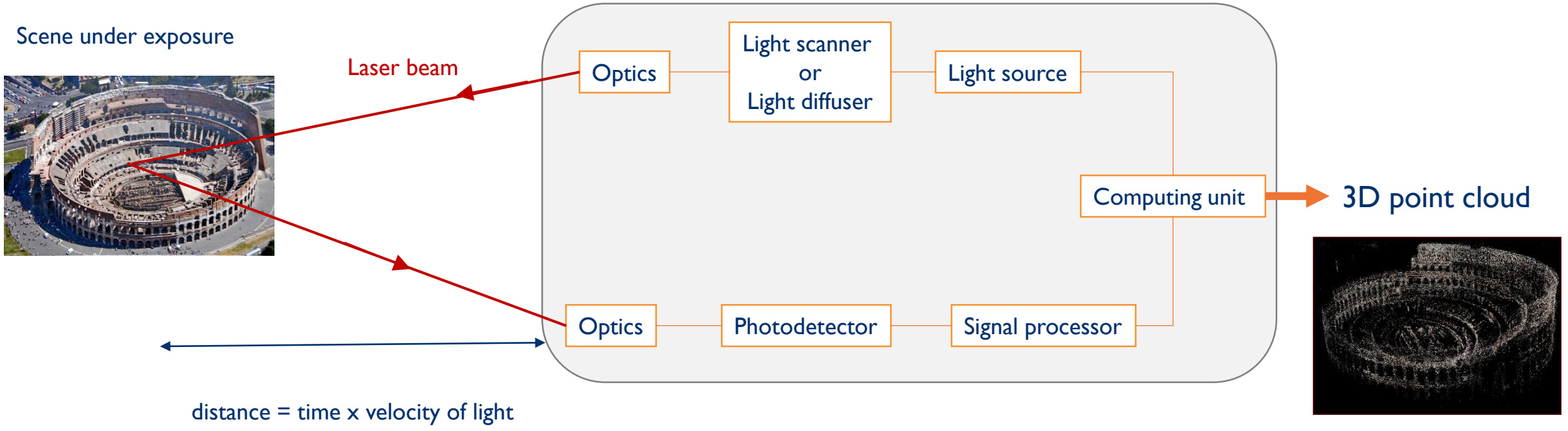
SiPM: Silicon Photomultiplier
VCSEL: Vertical-Cavity Surface-Emitting Laser

Technologies

YOLE Développement

LiDAR PRINCIPLE AND COMPONENTS

The basic working principle of the LiDAR is very simple.
A light source illuminates a scene. The light scattered by the objects of the scene is detected by a photodetector.
Measuring the time it takes for the light to travel to the object and back from it, allows to know its distance.

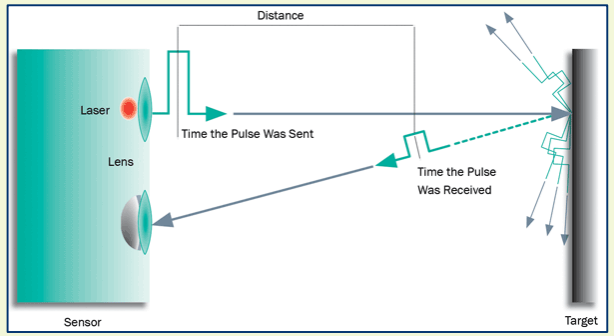


LiDAR system

LiDAR RANGING METHODS

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

Pulsed Time of Flight

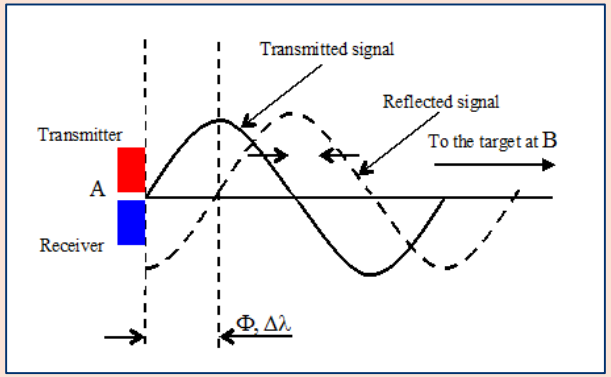


Pulsed Time of Flight (ToF) is a direct measurement of the time of flight of light from the emitter to the scene and then to the photodetector.

This technique allows to measure several reflections.

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

Phase Shift

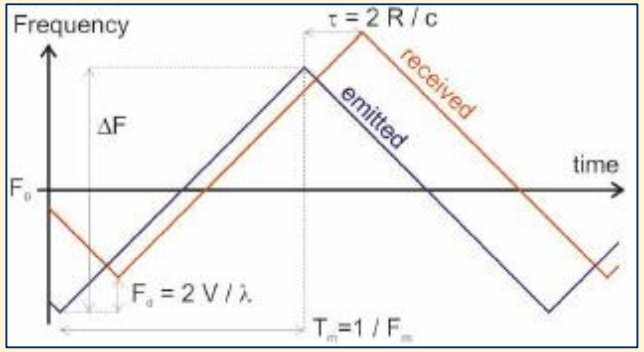


In phase shift time of flight, continuous waves are used and the time of flight is measured as a phase difference.

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.

Frequency Modulation



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

As 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.

IMAGE FORMATION IN LiDAR

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

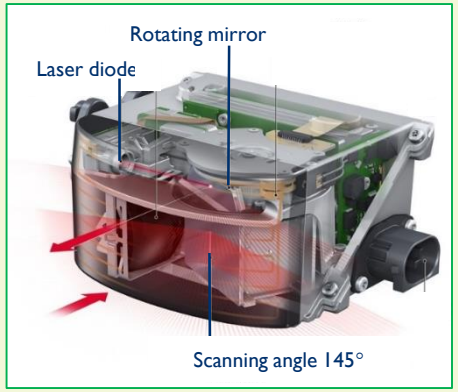
Mechanical LiDAR

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

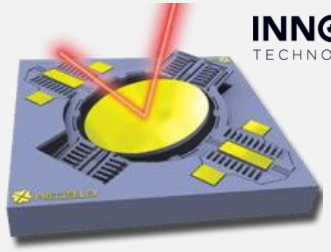
CEPTON

LUMINAR

1550 nm

Solid-state LiDAR

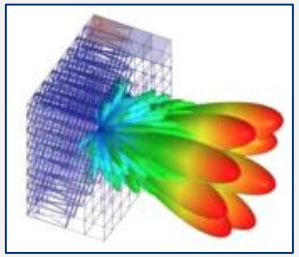
MEMS LiDAR



INNOVIZ TECHNOLOGIES

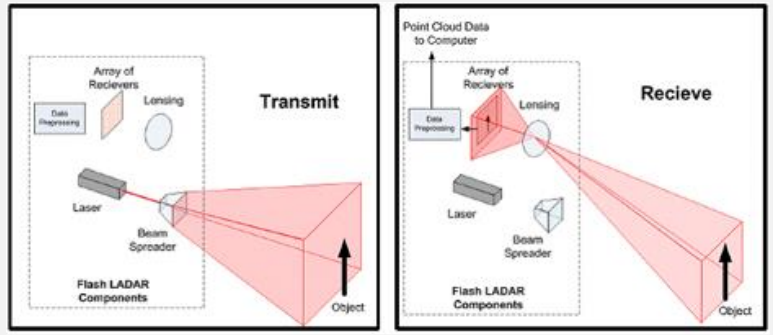
Courtesy of Preciseley Microtechnology Corp.

OPA LiDAR



Courtesy of Quanergy

Flash LiDAR



Courtesy of Advanced Scientific Concepts, Inc.

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	Continental 1064 nm, ZF, LeddarTech, tetravue, ARGO AI, sense photonics, 1350 nm
Phase shift			Benewake	Other optical based LiDAR: LUMOTIVE, BARAJA	Multi-Beam Flash LiDAR: ifm, OUSTER, XENOMATIX Automotive Vision Solutions
CW LiDAR					
FMCW				SiLC, blackmore 1550 nm	oryx 10 µm

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

2010~ 2017~ 2025~ 2035~

0 1 2 3 4 5

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.

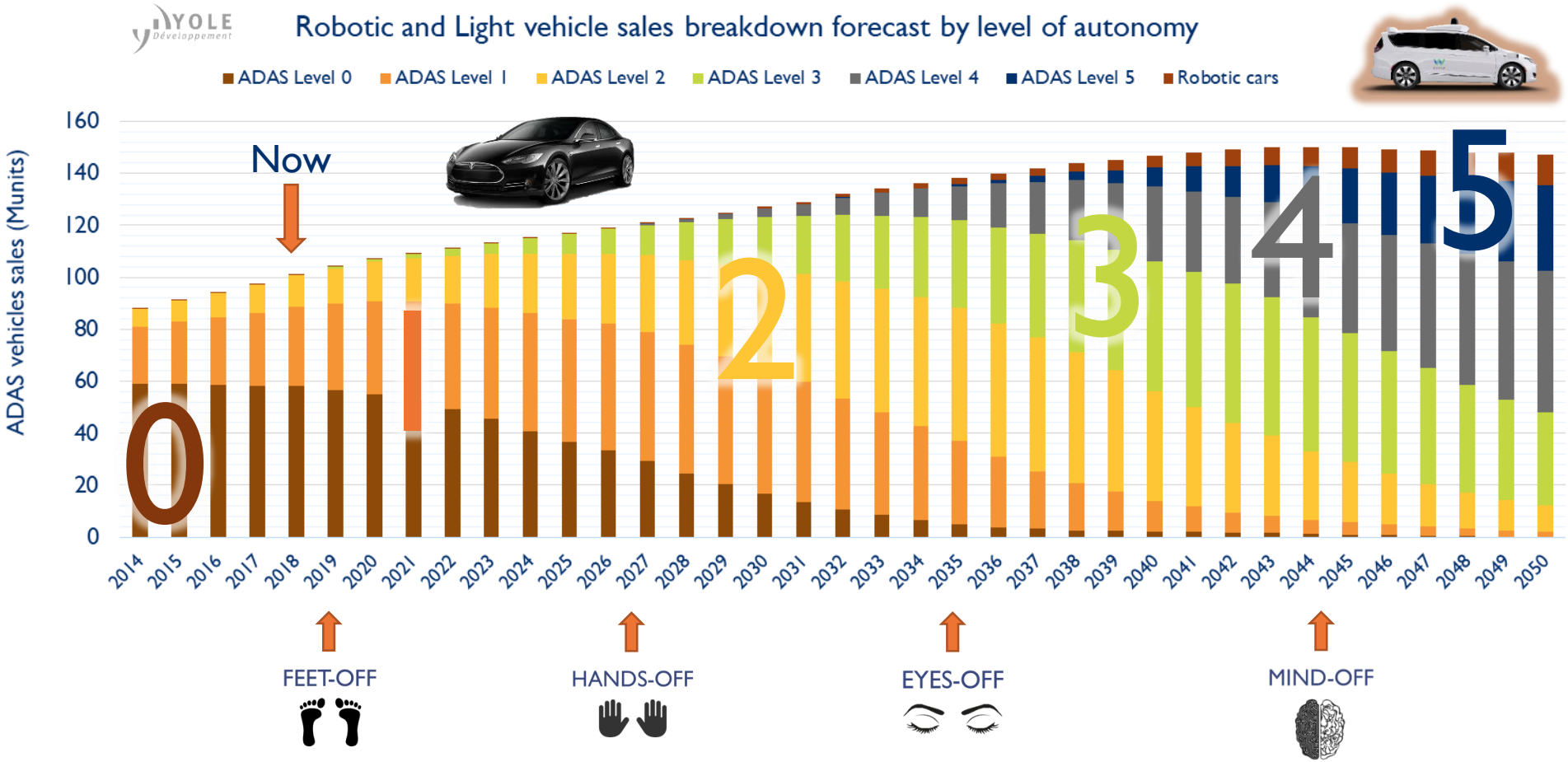
Fully autonomous vehicles in 2017

Robotic car players

WAYMO UBER TESLA lyft Baidu 百度

MARKET PENETRATION OF ADAS VEHICLES

By 2050, most cars should be above level 3!



ROBOTIC VEHICLE LIDAR MARKET

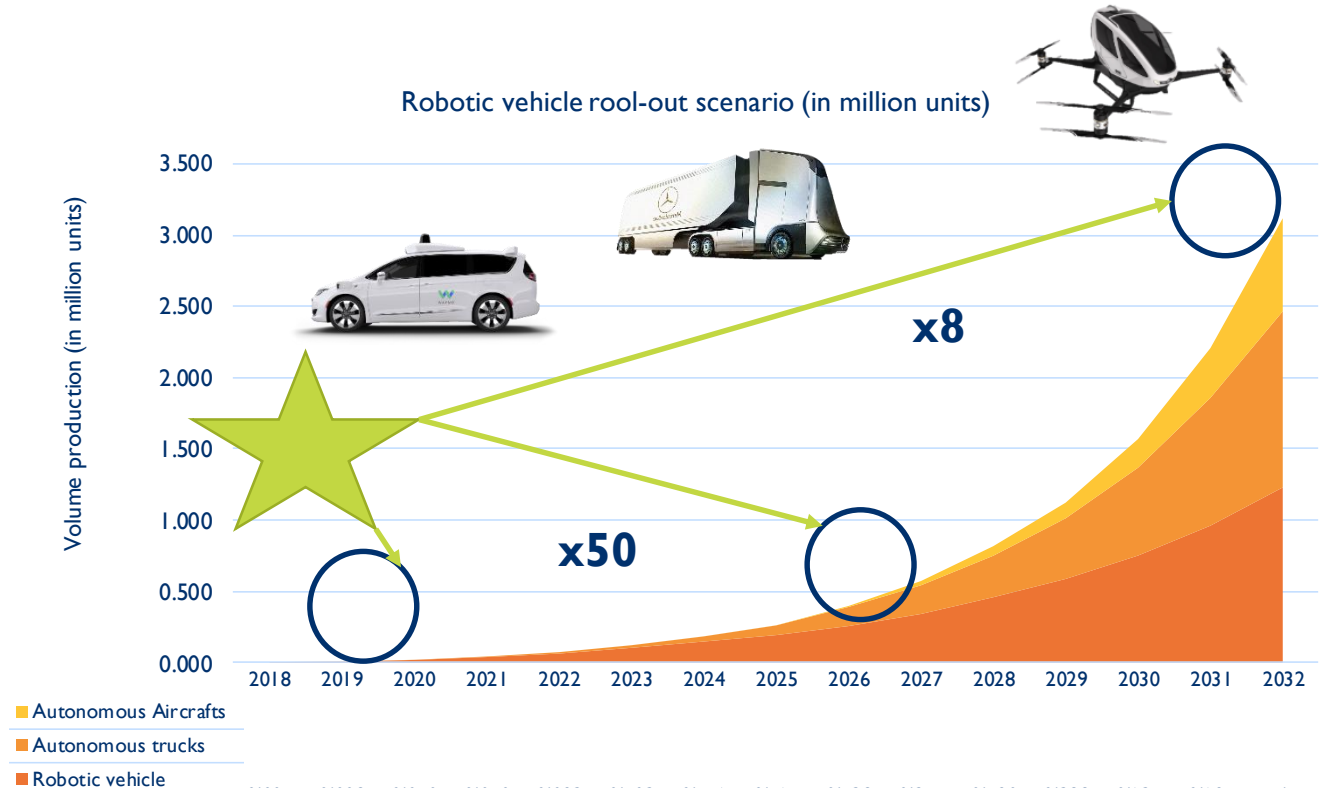
Robotic vehicle market trend

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.

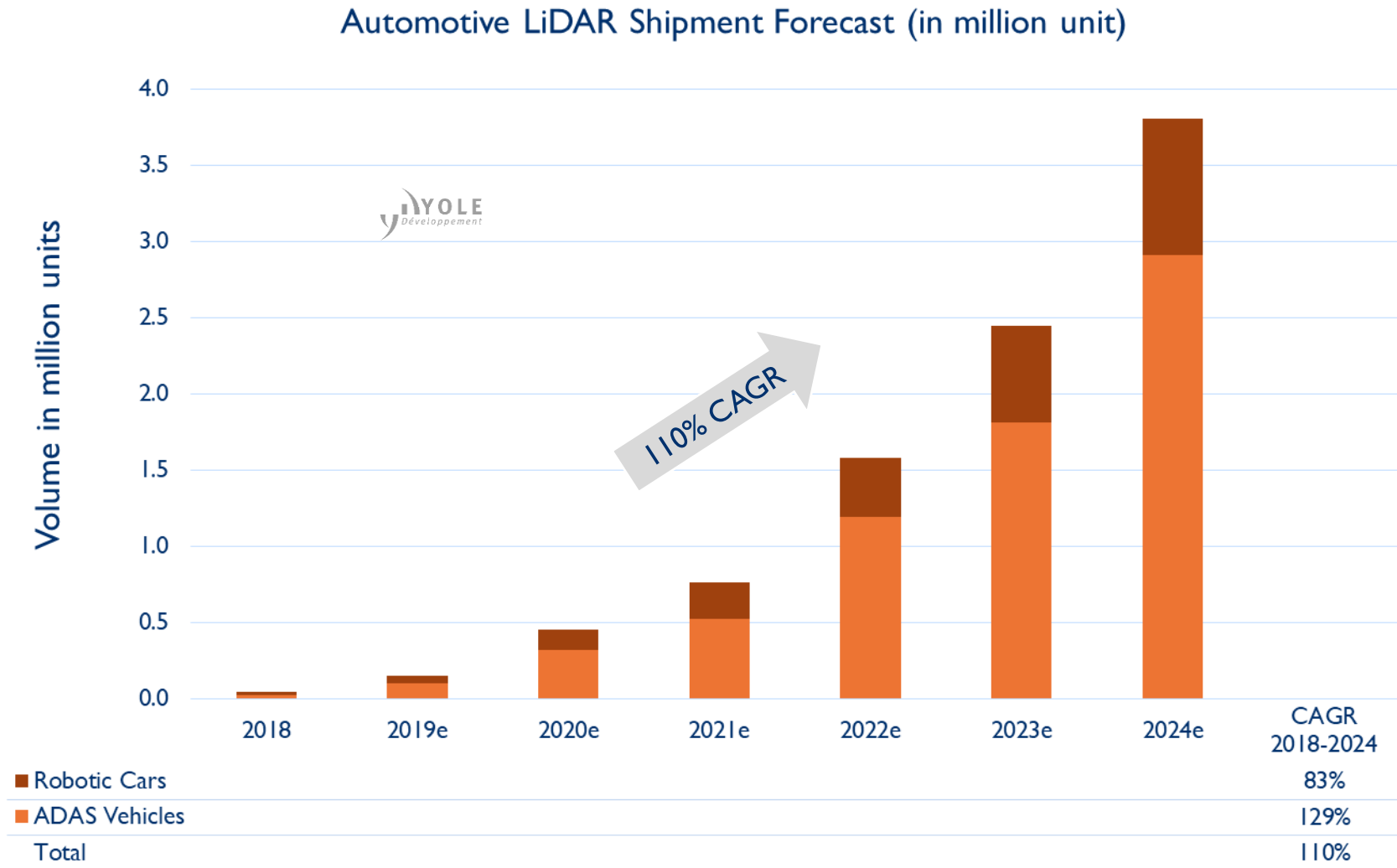


Autonomous aircrafts correspond to projects of flying taxis supported by Ehang in China, Airbus in France, and Rolls-Royce in UK.

AUTOMOTIVE LIDAR MARKET

Automotive LiDAR shipment forecast

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



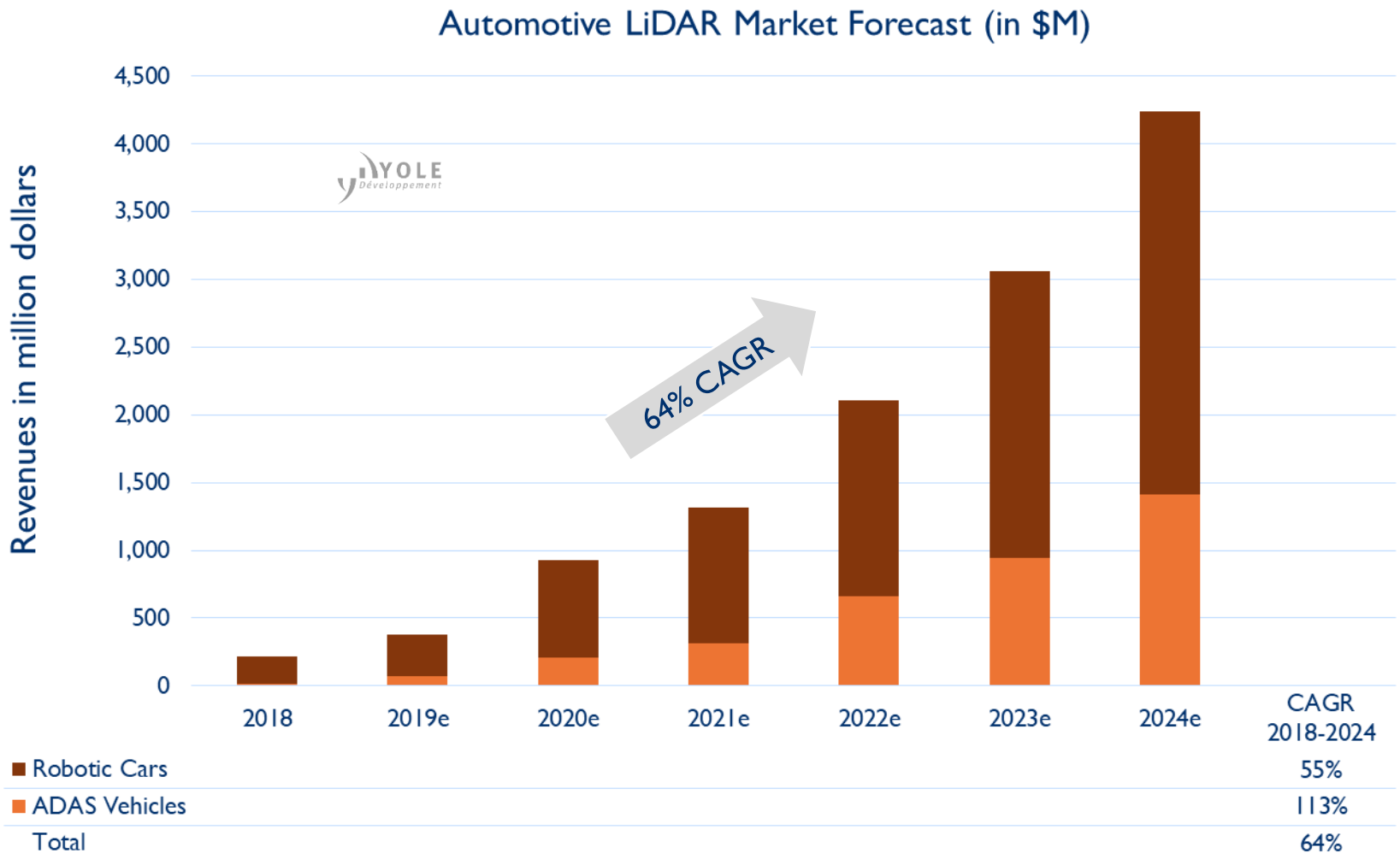
Note:

- 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.

trial Landscape

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.

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

INNOVIZ TECHNOLOGIES
CEPTON
XENOMATIX Automotive Vision Solutions
OUSTER
HESAI
EYE
SureStar
blackmore
Blickfeld LiDAR / scan your world
robosense
oryx
Benewake
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

The first LiDAR implemented in the Audi A8 in 2017 was a LiDAR from Valeo, using a mechanical scanning system.

Long range LiDAR are expected to use other mechanical scanning systems or MEMS scanning by 2020-2021.
In high automation configuration, short-/mid range LiDAR will be necessary and should be integrated in the corners of a vehicle. In this case, flash LiDAR should be implemented with VCSEL as a potential light source.

Optical phased array LiDAR are seen at long term as the power and therefore, the range is limited due to high components integration.

INDUSTRY: THE NEXT STEP FOR LiDAR?

Automation

Transportation

10 m

30 m

300 m

2 km

Factory Automation

Smart Buildings

Delivery Robots

Passenger Shuttle

AGV

Smart Farming

Autonomous bus

Mining

Robotic cars

Autonomous Trucks

Airport Safety

Autonomous Ships

Range

10m

100m

1km

10km

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