From Technologies to Markets

Evolution of the LiDAR industry towards driving automation

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Développement

DVN LiDAR Conference, Dec 3rd 2019

Pierrick Boulay, Yole Développement © 2019

AUTOMOTIVE MARKET MACROTRENDS

ADAS and AD are at the intersection of current automotive macro-trends

All trends lead to autonomous driving.

New players

New competition & regulation

Environmental Efficiency
- Lighter materials, recyclability
- Improved internal combustion engines
- Powertrain electrification

Shared Mobility
- Car sharing
- Car pooling
- On demand

Autonomous driving

Safety
- Computer design & simulation
- Braking assist
- Sensors

Robotic vehicle

ADAS

Digital Connectivity
- Entertainment
- Data handling
- Mapping

New business models
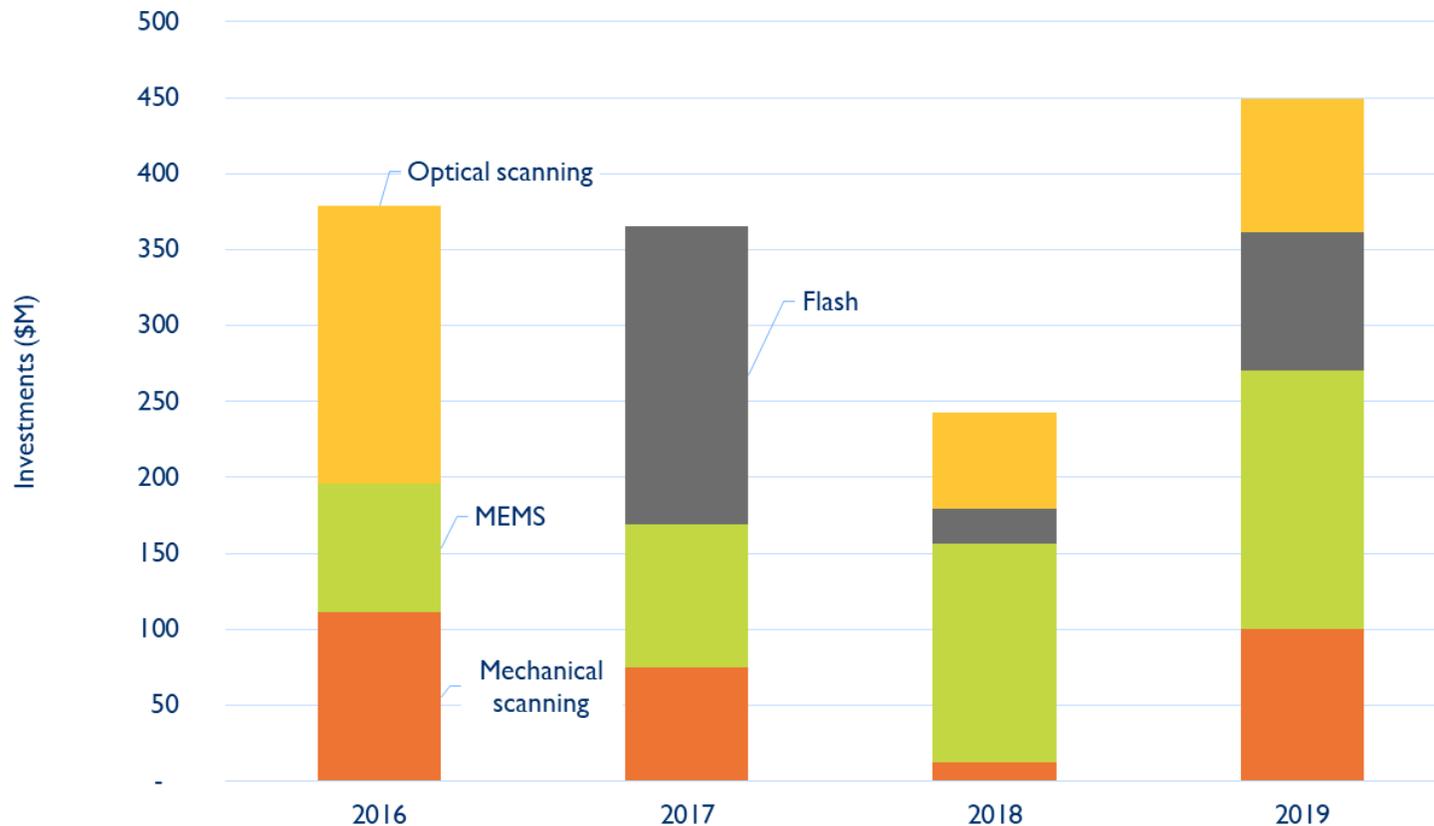
New players

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INVESTMENTS IN AUTOMOTIVE LIDAR

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

Since 2016, MEMS has been the technology that received the most investment, followed by flash and mechanical scanning.
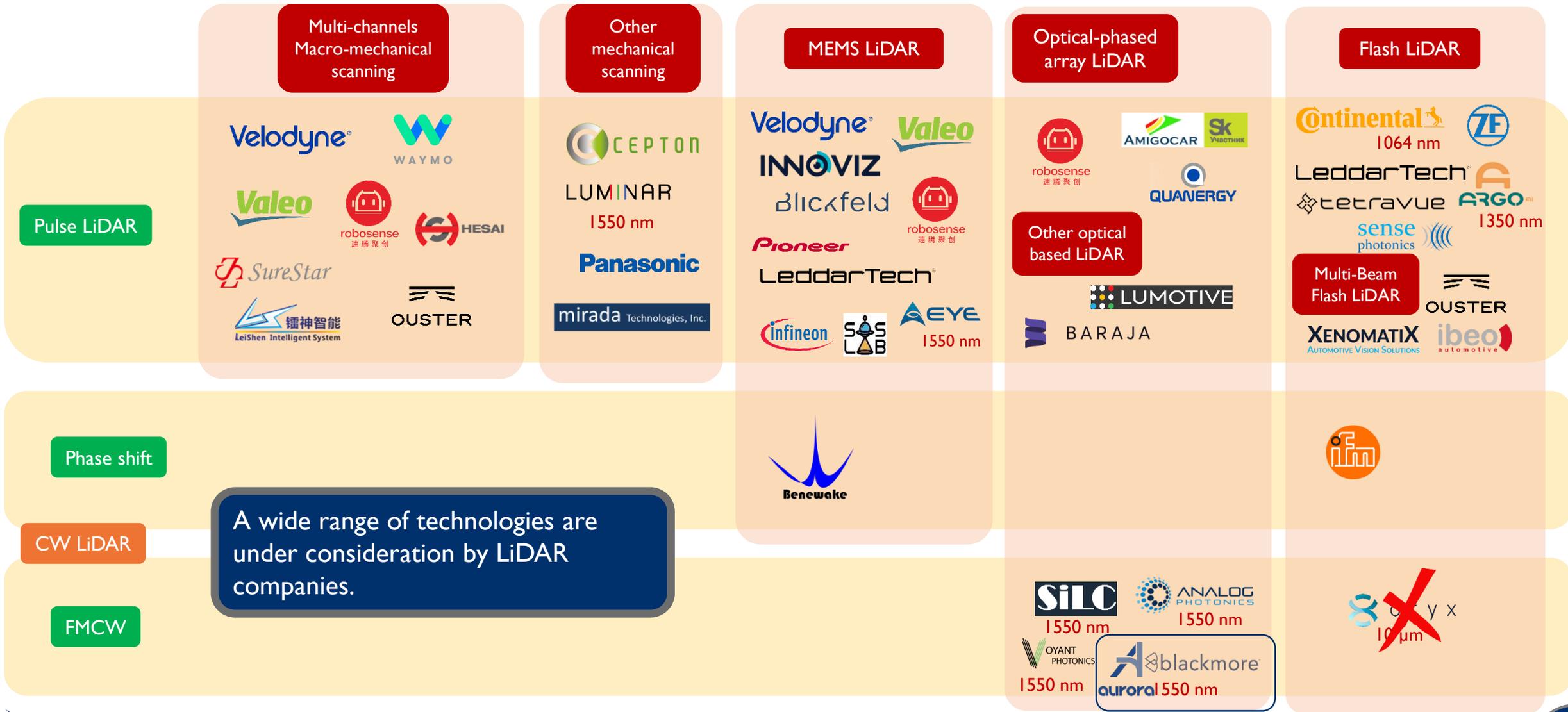
After a slowdown in 2018, investments have reached their highest level in 2019;

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

TOWARDS AUTOMATED DRIVING

Automotive LiDAR player landscape

Multi-channels Macro-mechanical scanning

Other mechanical scanning

MEMS LiDAR

Optical-phased array LiDAR

Flash LiDAR

Pulse LiDAR

Velodyne — WAYMO — Valeo — robosense 速腾聚创 — HESAI — SureStar — LeiShen Intelligent System 镭神智能 — OUSTER

CEPTON — LUMINAR 1550 nm — Panasonic — mirada Technologies, Inc.

Velodyne — Valeo — INNOVIZ — Blickfeld — robosense 速腾聚创 — Pioneer — LeddarTech — Infineon — SOS LAB — AEYE 1550 nm

robosense 速腾聚创 — AMIGOCAR — Sk Участник — QUANERGY — **Other optical based LiDAR** — LUMOTIVE — BARAJA

Continental 1064 nm — ZF — LeddarTech — tetravue — ARGO AI 1350 nm — sense Photonics — **Multi-Beam Flash LiDAR** — OUSTER — XENOMATIX Automotive Vision Solutions — ibeo automotive

Phase shift

Benewake

ifm

CW LiDAR

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

FMCW

SiLC 1550 nm — ANALOG PHOTONICS 1550 nm — VOYANT PHOTONICS 1550 nm — blackmore auroral 1550 nm

~~Oryx~~ 10 µm

TOWARDS AUTOMATED DRIVING

Image formation in LiDAR

From mechanical LiDAR to solid-state LiDAR.

Mechanical LiDAR for ADAS

Valeo

ibeo

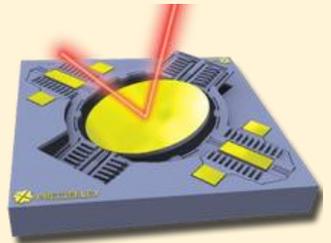Audi

- Rotating mirror
- Laser diode
- Scanning angle 145°
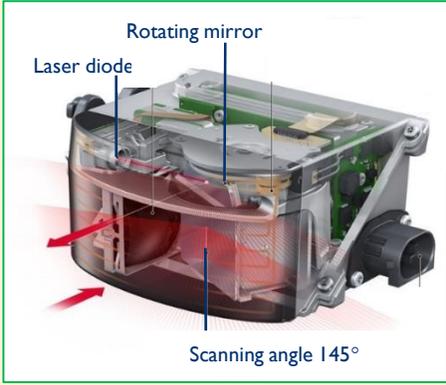
Mechanical LiDAR for Robotic cars

Velodyne

Valeo

robosense

Other mechanical LiDAR

NEPTEC Technologies Corp

CEPTON
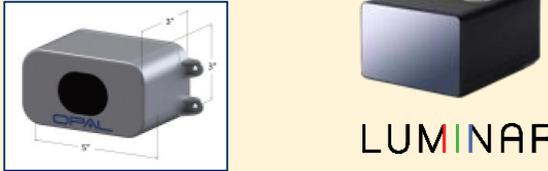
LUMINAR

1550 nm

The present

MEMS LiDAR

Flash LiDAR

Array of Recievers

Lensing

Data Preprocessing

Transmit

Laser

Beam Spreader

Flash LADAR Components

Object

Point Cloud Data to Computer

Array of Recievers

Lensing

Data Preprocessing

Recieve

Laser

Beam Spreader

Flash LADAR Components

Object

OPA / FMCW

Frequency

$\tau = 2\,R\,/\,c$

ΔF

emitted

received

time

F_0

$F_d = 2\,V\,/\,\lambda$

$T_m = 1\,/\,F_m$
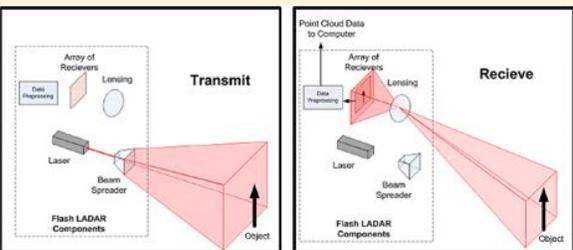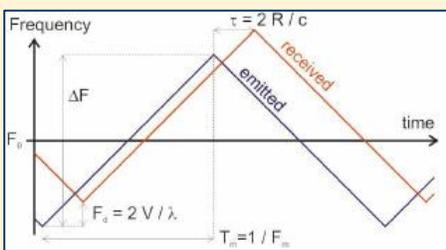
2020-2021

The future

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TOWARDS AUTOMATED DRIVING

Player positioning

More than 50 LiDAR companies

Limited number of OEMs

There are too many LiDAR companies compared to the OEMs willing to implement LiDAR.

TECHNOLOGY UPDATE AND ROADMAP

Potential winner in the next five years?

In the next five years most of available LiDAR should be based on 905nm and use pulse ToF principle.

2017   2018   2019   2020   2021   2022   2023   2024

Credits: Valeo Scala®

The second generation will be released by 2020.

Credits: Valeo Scala® Gen2

Credits: Innoviz

In 2021, BMW will start implementing LiDAR from Innoviz into its vehicles.

Similarities:
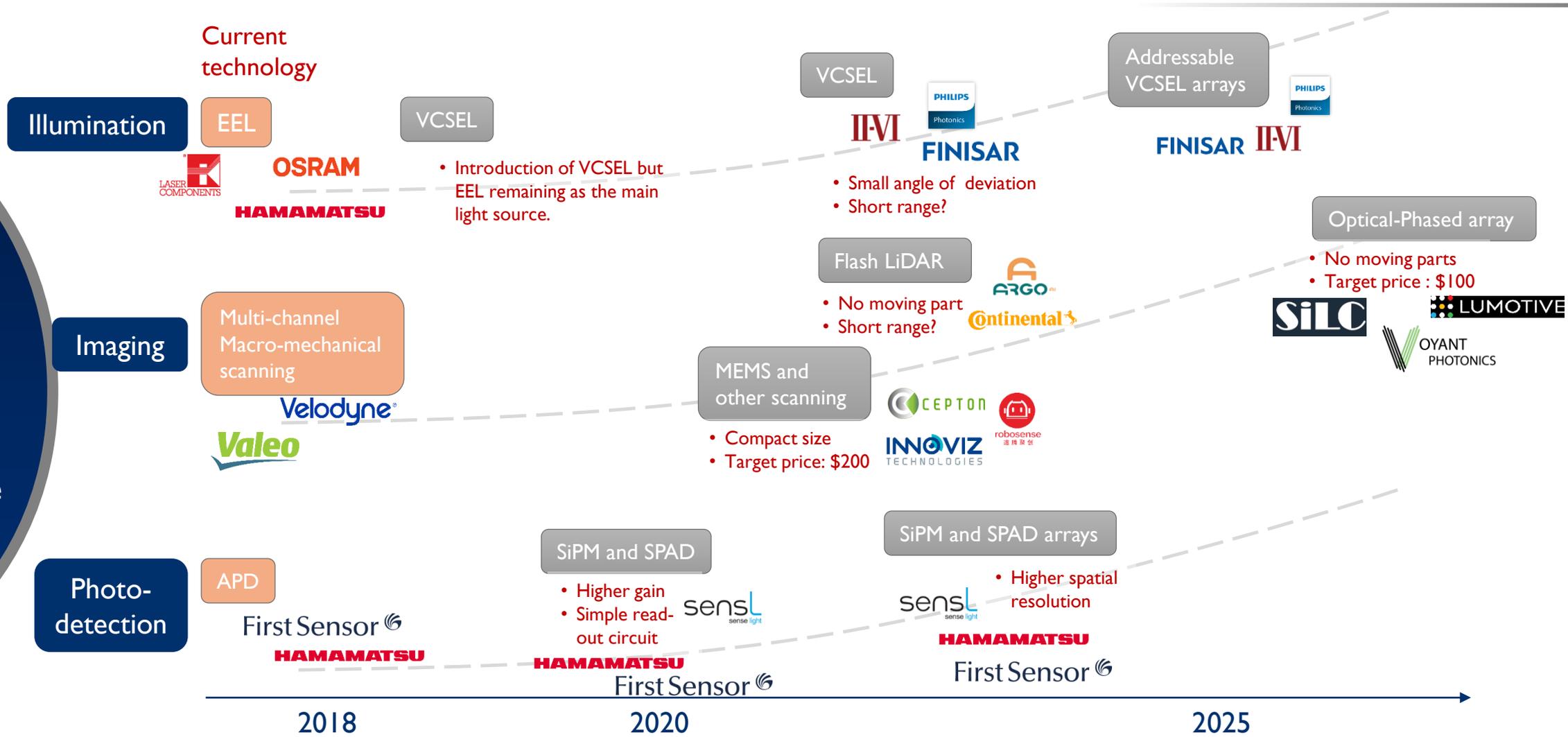
905nm EEL

Pulse Time of Flight

Silicon-based sensor

- Most popular ranging method (easiest)
- Lower cost of components

TECHNOLOGY UPDATE AND ROADMAP

Potential winner at long term?

2024   **?**   **2030**

905nm based systems should continue to be used to due to its low cost but FMCW LiDARs based on 1550nm could emerge at long term.

Credits: Ibeo

Credits: SOSLab

MEMS and flash LiDARs

Credits: Blackmore

Credits: Insight LiDAR

FMCW LiDARs

Suited for 1550nm

Credits: Analog Photonics

Credits: SILC Technologies

OPA LiDARs

Credits: Voyant Photonics

Similarities:

905nm based systems

Increasing use of VCSELs and SPADs

Coherent detection

Radial velocity measurement

Alternative to mechanical or MEMS scanning

Still not ready for industrial applications

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TECHNOLOGY UPDATE AND ROADMAP

How technologies could evolve?

VCSELs and SPADs are expected to become main components.

OPA imaging could emerge at long term.

Current technology

Illumination — EEL

LASER COMPONENTS
OSRAM
HAMAMATSU

VCSEL

- Introduction of VCSEL but EEL remaining as the main light source.

VCSEL

II-VI
PHILIPS Photonics
FINISAR

- Small angle of deviation
- Short range?

Addressable VCSEL arrays

PHILIPS Photonics
FINISAR II-VI

Imaging

Multi-channel Macro-mechanical scanning

Velodyne
Valeo

Flash LiDAR

ARGO AI
Continental

- No moving part
- Short range?

MEMS and other scanning

CEPTON
INNOVIZ TECHNOLOGIES
robosense

- Compact size
- Target price: $200

Optical-Phased array

- No moving parts
- Target price : $100

SiLC
LUMOTIVE
VOYANT PHOTONICS

Photo-detection — APD

First Sensor
HAMAMATSU

SiPM and SPAD

- Higher gain
- Simple read-out circuit

sensL sense light
HAMAMATSU
First Sensor

SiPM and SPAD arrays

- Higher spatial resolution

sensL sense light
HAMAMATSU
First Sensor

2018   2020   2025

5 years

APD: Avalanche Photodiode
EEL: Edge-Emitting Laser
MEMS: Micro-Electro-Mechanical System
PD: Photodiode

SiPM: Silicon Photomultiplier
SPAD: Single-Photon Avalanche Diode
VCSEL: Vertical Cavity Surface-Emitting Laser

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INTEGRATION OF LIDAR IN ADAS VEHICLE

The difference between robotic and ADAS vehicles

Contrary to robotic vehicles, the integration of sensors in ADAS vehicles is mandatory.

Robotic vehicles

- Level 4/5 of autonomy are targeted
- Plenty of sensors are used to scan the environment: LiDAR (x7) + radar (x7), cameras (x20) for the Ford Fusion example.
- Low/No need to integrate sensors

VS

ADAS vehicles

- Level 3 of autonomy is firstly targeted
- Multiple sensors are used to scan the environment: LiDAR (x1) + radar and cameras
- High need to integrate sensors

LiDAR integration in ADAS vehicles
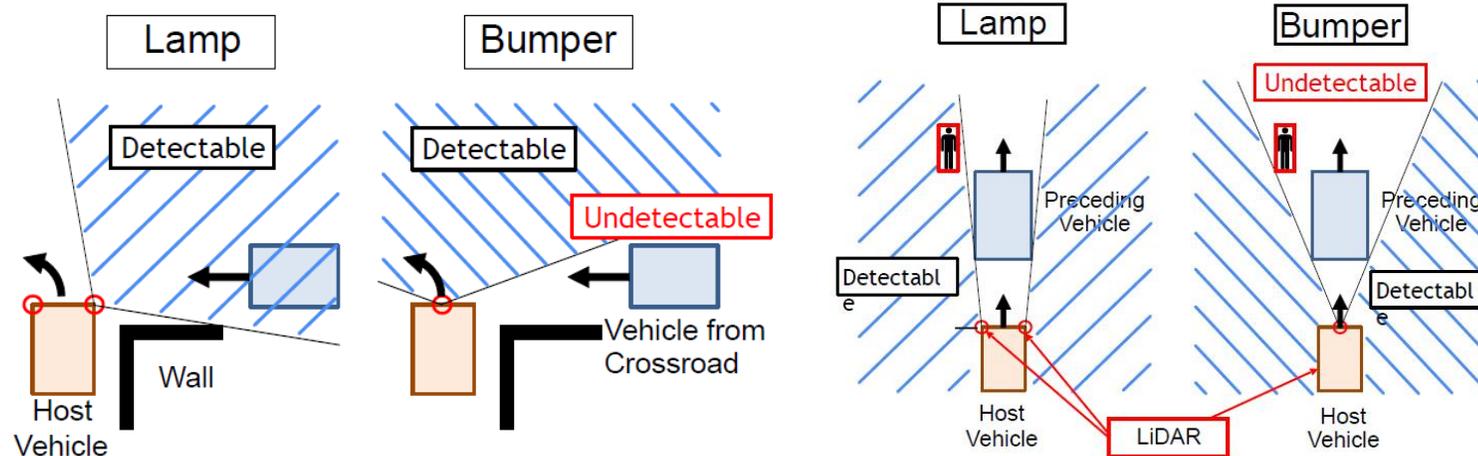
Integration challenges:
- Aesthetic
- Cleaning
- Heat management
- Optics

While camera, radar and ultrasonic sensors are already well integrated in the car body, a good position has to be found for LiDAR.

Behind the windshield
- Easy cleaning
- Possible obstruction of driver's view

In the grille
- Good position for front LiDAR
- Heat from the engine
- Difficulty of cleaning

IR Transparent Materials
Image deformation must be avoided.

Ceramic Packaging
Can be key for heat management

In headlights
- Easy integration
- Good for corner (short-range) LiDAR
- Photonic pollution
- Heat management

In bumper
- Easy integration
- Low position ⇒ More dirt
- Absence of bumper?
- Difficulty of cleaning

INTEGRATION OF LIDAR IN ADAS VEHICLE
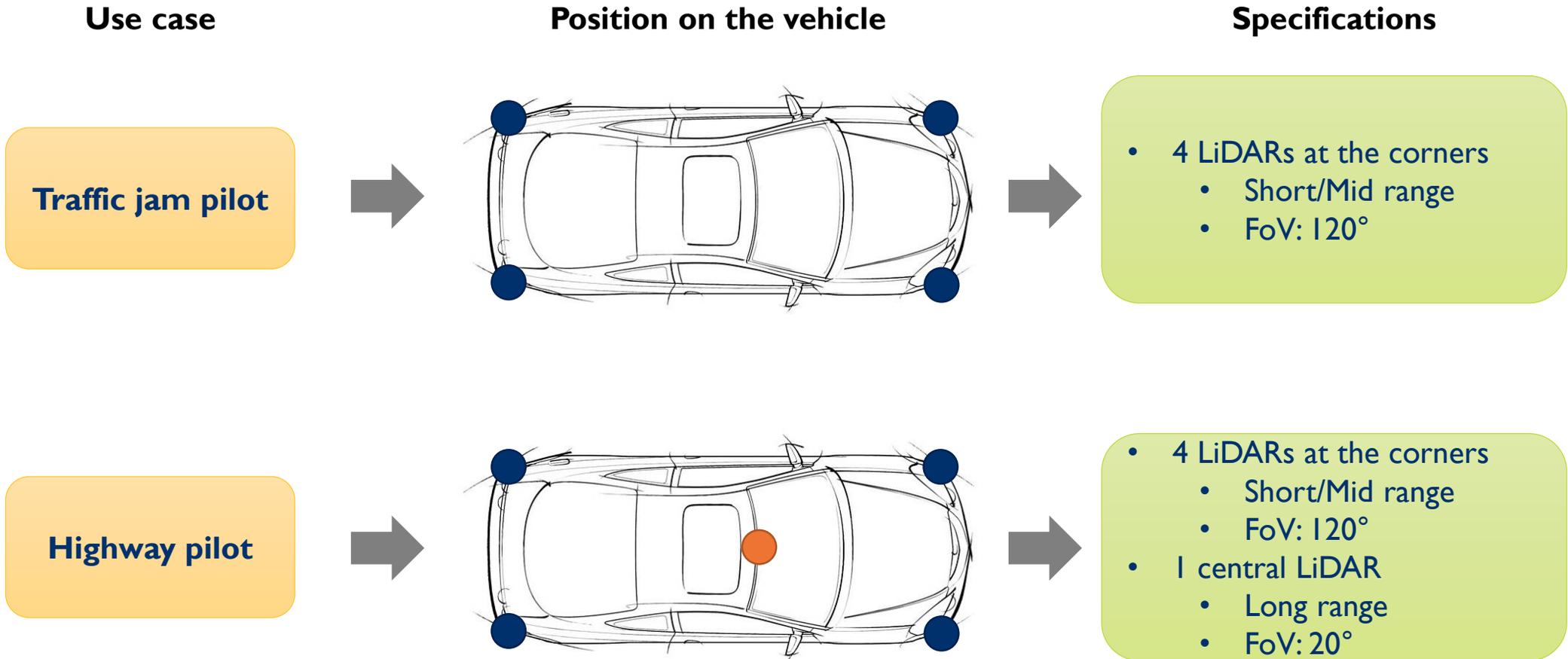
Positioning of LiDAR

The position of LiDAR in the corners of vehicles seems to have good detection performance in a wide range of cases.

Comparison of LiDAR position: headlamp vs bumper

Source: Koito

LiDAR position: behind the windshield

Source: Hella

- The LiDAR position in the corners of a vehicle could detect front and rear objects in a wide range of cases.
- Higher position, such as on the roof, would enable to detect objects over surrounding obstructions in some cases. But it would appear difficult to detect a child near the host vehicle.
- There is not one position that fits all use cases but the use case will define the position of the LiDAR(s).

Impact of use case on LiDAR position(s) and specifications (examples)

Use case	Position on the vehicle	Specifications

The use case has a direct impact on the position of the LiDAR(s) and on its specifications.

Traffic jam pilot →

→
- 4 LiDARs at the corners
  - Short/Mid range
  - FoV: 120°

Highway pilot →

→
- 4 LiDARs at the corners
  - Short/Mid range
  - FoV: 120°
- 1 central LiDAR
  - Long range
  - FoV: 20°

● Flash or Mechanical or MEMS at 905nm

● Mechanical or MEMS at 905nm (or 1550nm)

Sensor cleaning

Headlamps and sensors have to face severe environmental impacts and conditions. There are various synergies in terms of protection.

Environmental impacts on headlamps and sensors

Ice and snow	Rain
Insects	Dust
Scratches	Stone impact
Temperature	Road condition
Vibration	Moisture
Radiation	Material
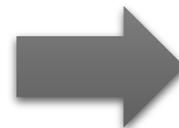
Possible solutions

Cleaning
(High pressure, wipers, coatings)

Housing
(Cover lens, Gluing, pressure equalization)

Thermal management
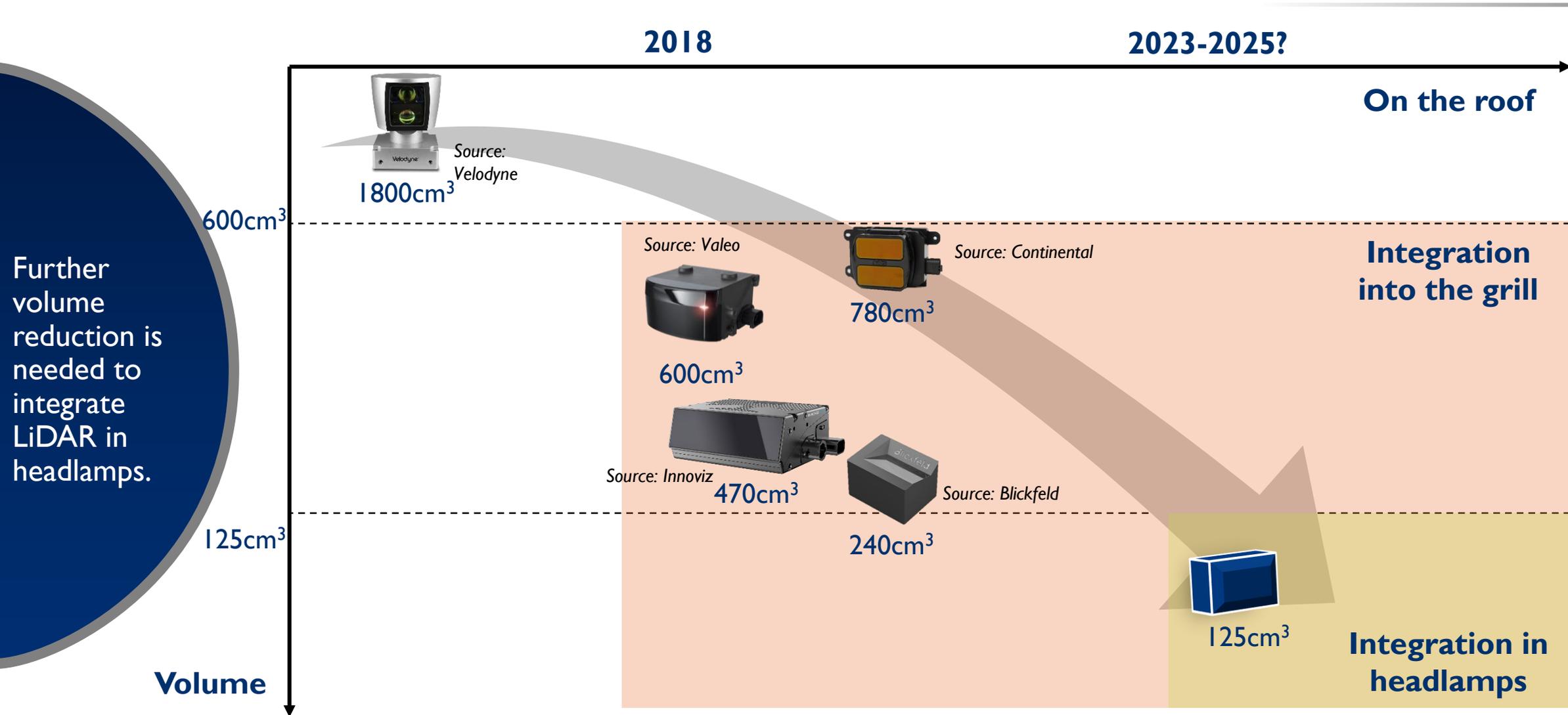(Active ventilation, heatsink, simulation)

Aiming
(Levelling actuator, adjustment, levelling sensor)

De-icing / Defrosting
(Wire heated lens, coating)

INTEGRATION OF LIDAR IN ADAS VEHICLE

Size evolution of LiDAR

2018

2023-2025?

On the roof

Source: Velodyne

1800cm³

600cm³

Source: Valeo

Source: Continental

780cm³

Integration into the grill

600cm³

Source: Innoviz

470cm³

Source: Blickfeld

240cm³

125cm³

Further volume reduction is needed to integrate LiDAR in headlamps.

125cm³

Integration in headlamps

Volume

INTEGRATION OF LIDAR IN ADAS VEHICLE

Comparison with the evolution of radar size

Over the last decade, radar size has shrunk by a factor of 2 - 3, depending on the manufacturer.
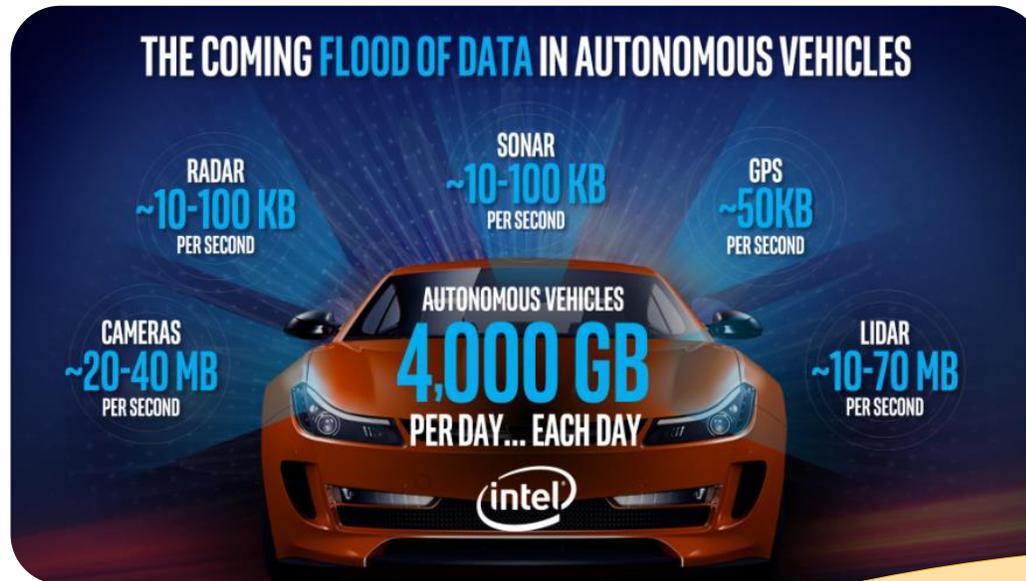
Ford has recently integrated a radar in tail lamps.
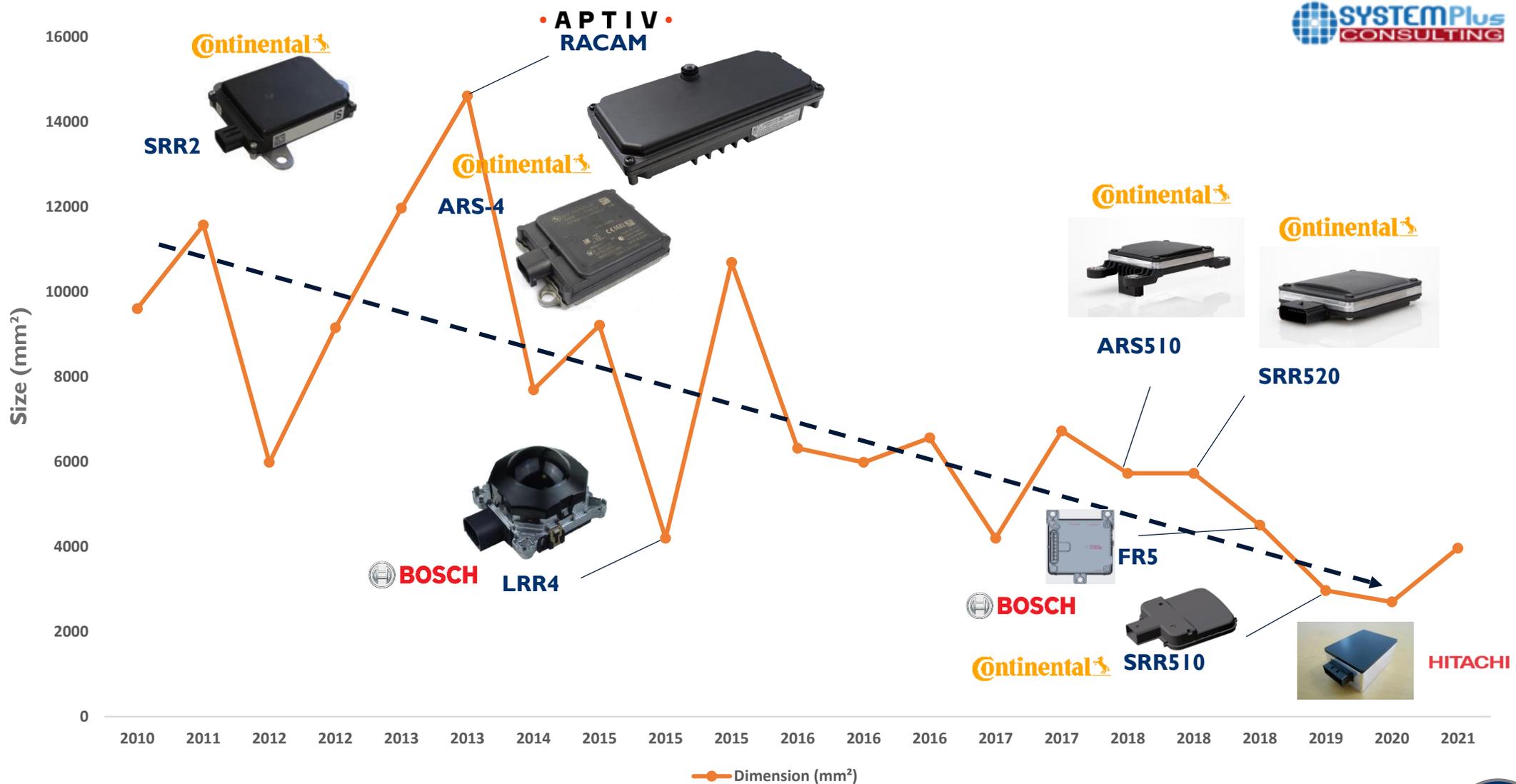
Expected developments needed for integration

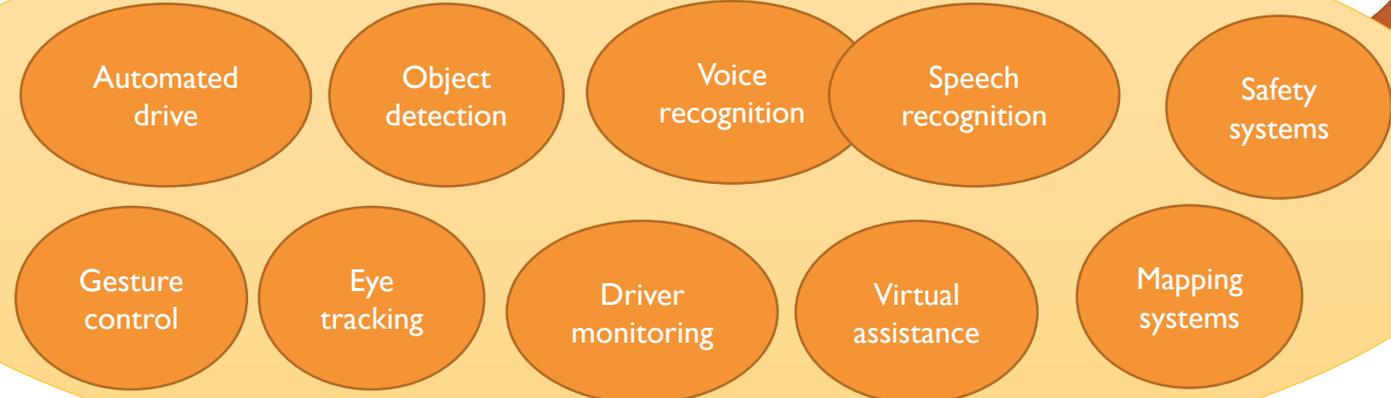An increasing number of sensors leading to a huge amount of data to be processed.

THE COMING FLOOD OF DATA IN AUTONOMOUS VEHICLES

RADAR
~10-100 KB
PER SECOND

SONAR
~10-100 KB
PER SECOND

GPS
~50KB
PER SECOND

CAMERAS
~20-40 MB
PER SECOND

LIDAR
~10-70 MB
PER SECOND

AUTONOMOUS VEHICLES
4,000 GB
PER DAY... EACH DAY

intel

Autonomy

Treatment

Input

AI-based functions in autonomous vehicles

- Automated drive
- Object detection
- Voice recognition
- Speech recognition
- Safety systems
- Gesture control
- Eye tracking
- Driver monitoring
- Virtual assistance
- Mapping systems

INTEGRATION OF LIDAR IN ADAS VEHICLE

From MCU to fusion platform

Utilization of the existing resources provided by the computing platform used for safety and autonomy.
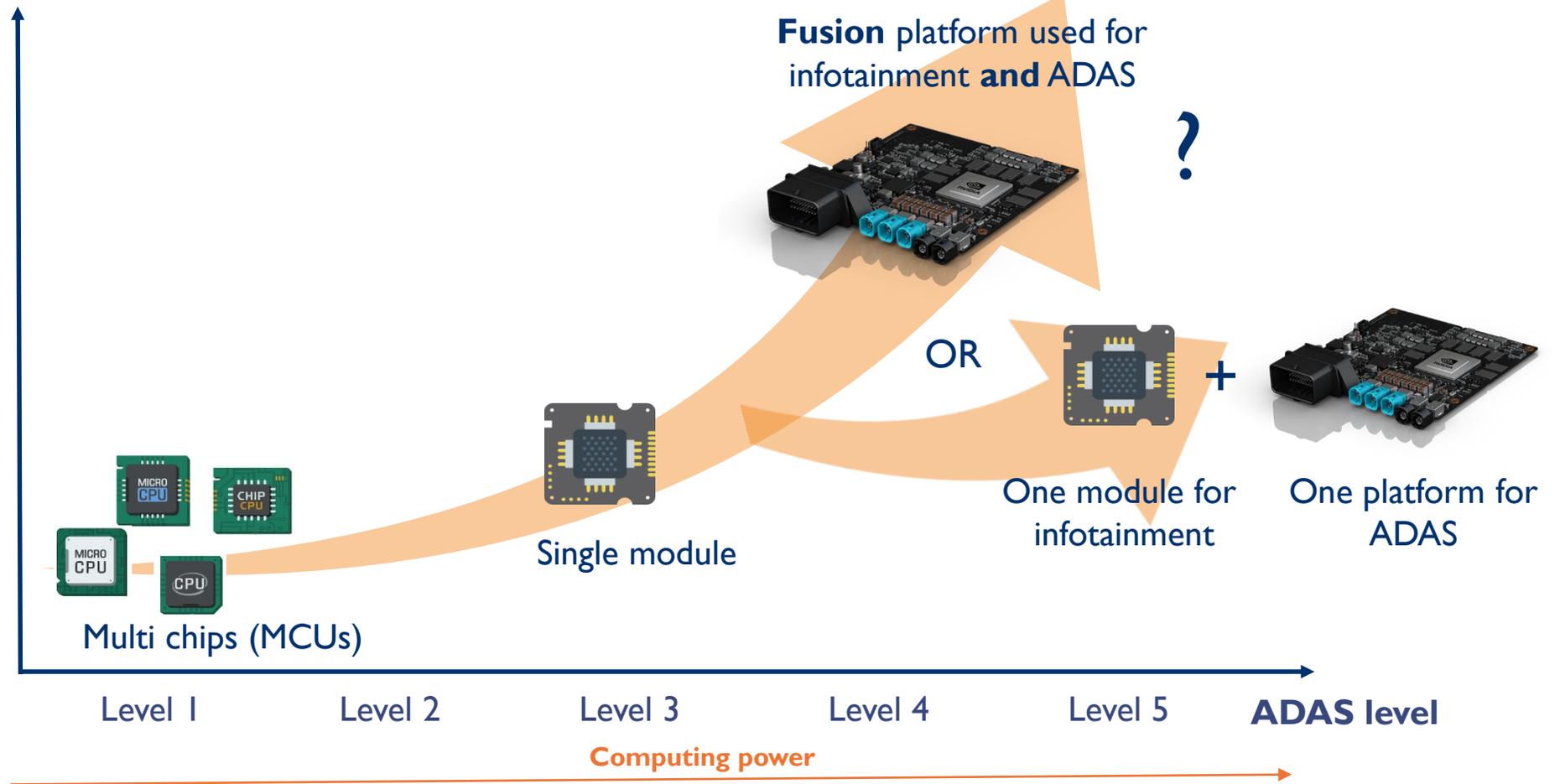

Intelligence

MIND-OFF

EYES-OFF

HANDS-OFF

FEET-OFF

Fusion platform used for infotainment **and** ADAS

?

OR

+

One module for infotainment

One platform for ADAS

Single module

Multi chips (MCUs)

Level 1   Level 2   Level 3   Level 4   Level 5   **ADAS level**

Computing power

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MAIN CHALLENGES OF DRIVING AUTOMATION

Performance & Safety:

- Under the responsibility of LiDAR manufacturer/tier-1/OEM.
- Make sure that performance meets safety requirements.

Customer trust:

- Will customers trust the vehicle?
- Depends on vehicle behaviour when detecting an obstacle and how it reacts during defined use cases.

Product liabilities:

- Who is responsible in case of accident under automation conditions, the OEM or the driver?
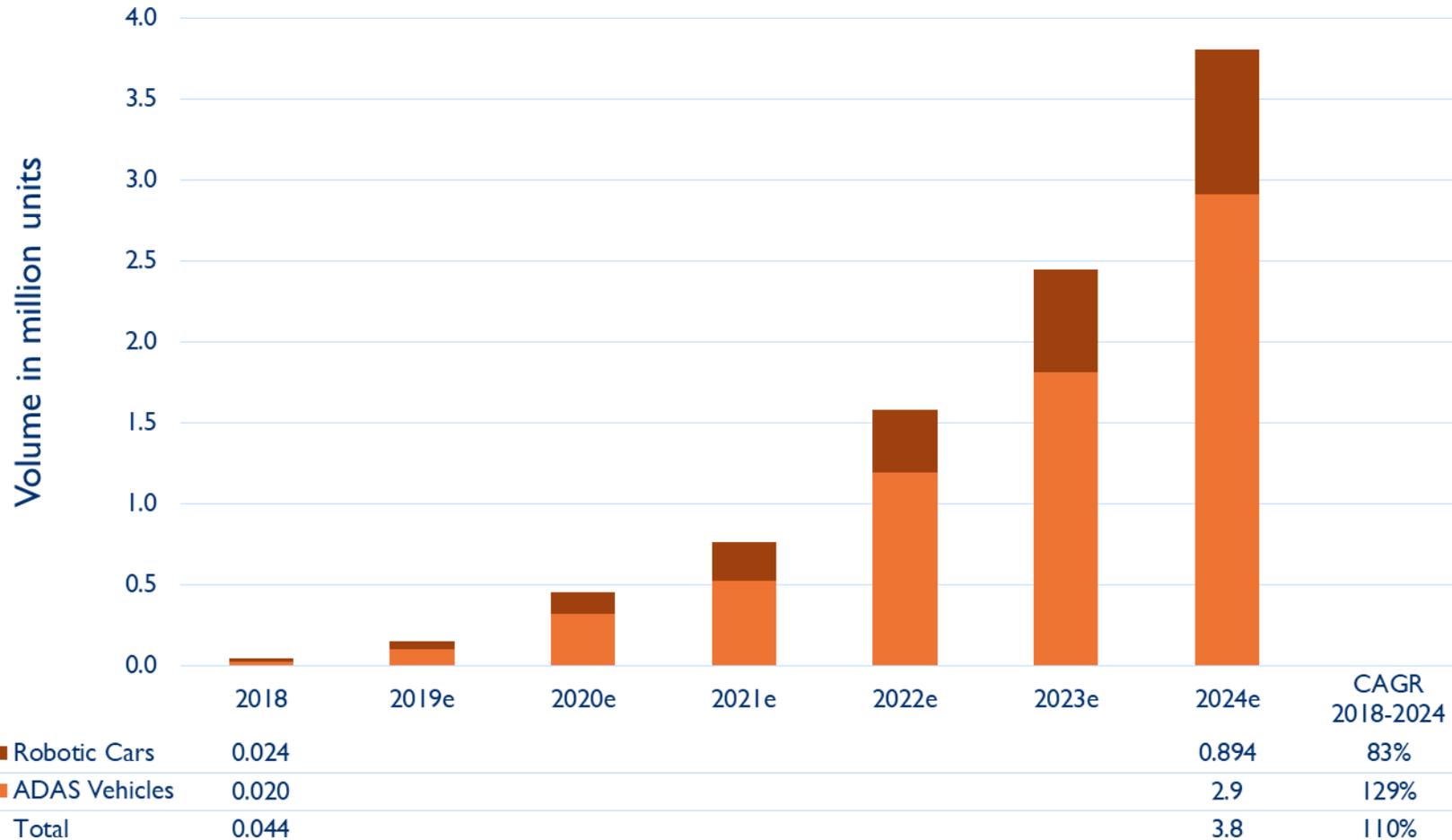- New insurance models/contracts are needed.

Performance & Safety

Customer Trust

Product Liability

Regulation

Regulations have to be defined for a large adoption

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Automotive LiDAR shipment forecast

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

### Automotive LiDAR Shipment Forecast (in million unit)

	2018						2024e	CAGR 2018-2024
■ Robotic Cars	0.024						0.894	83%
■ ADAS Vehicles	0.020						2.9	129%
Total	0.044						3.8	110%

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

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.

Automotive LiDAR Market Forecast (in $M)

	2018	2024e	CAGR 2018-2024
■ Robotic Cars	201	2,827	55%
■ ADAS Vehicles	15	1,411	113%
Total	216	4,238	64%
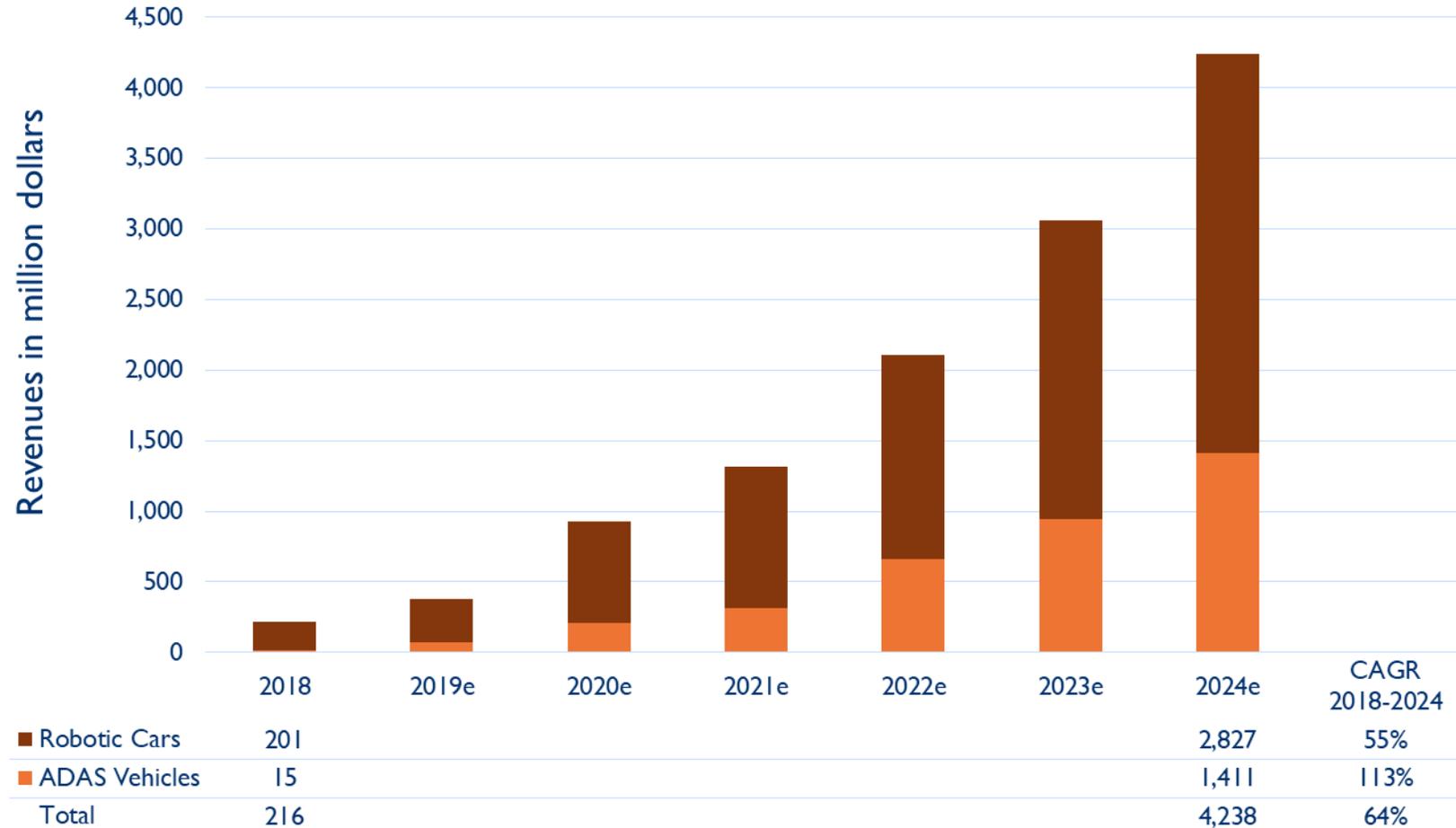
Note:
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Thank you for
your attention

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KHYZYL SALEEM