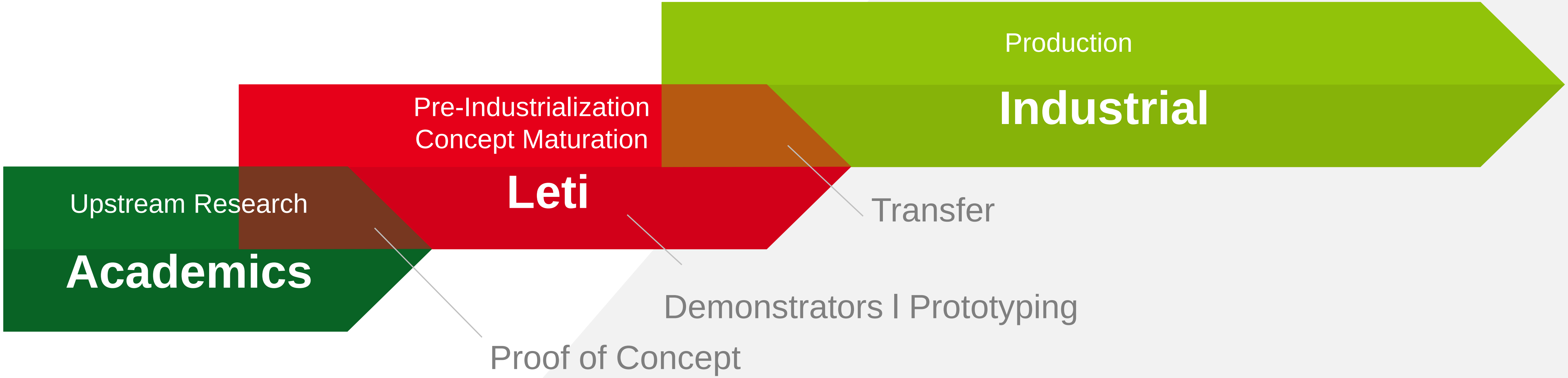
# Market challenges and opportunities : towards agile chip-scale low-cost LiDAR

**François Simoens**

Strategic Program Manager, CEA-Leti

# Leti offers a bridge between research and production of semiconductor technologies



Production

**Industrial**

Pre-Industrialization
Concept Maturation

**Leti**

Upstream Research

**Academics**

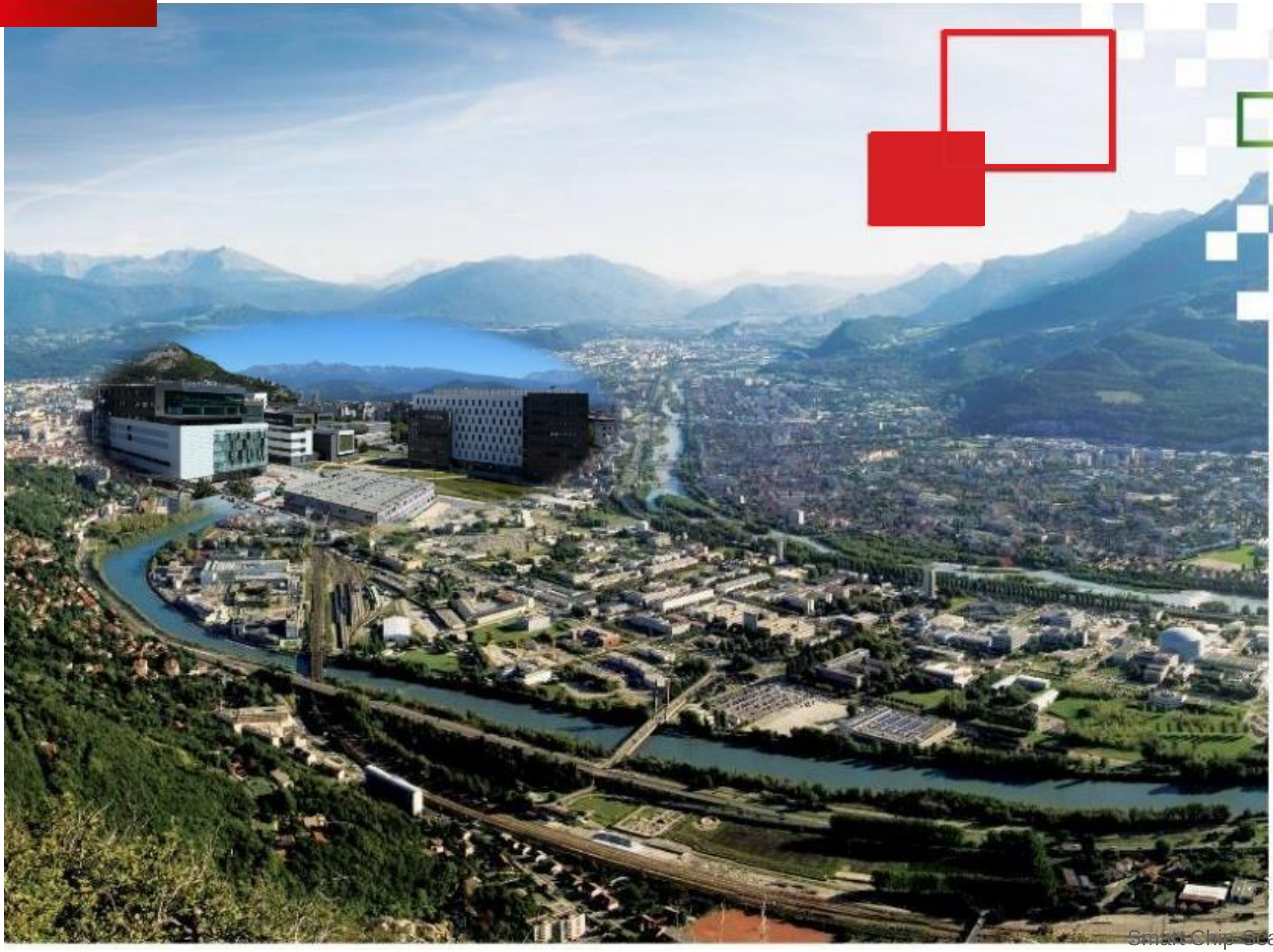
Transfer

Demonstrators I Prototyping

Proof of Concept

- **Long-term partnerships**
- **Milestones-oriented** to address partners issues
- **Project-oriented**, reactive and flexible

# KEY NUMBERS FOR LETI, A SEMICONDUCTOR-ORIENTED LAB



© Jacques-Marie FRANCILLON / CEA © Gérard COTTET/ CEA

Founded in **1967**

France, USA, Japan

**2,000** People

➢ **2,760** Patents in Portfolio

**> 40%** Under License Agreement

**350** Patents Granted per Year

**350** Industrial Partners

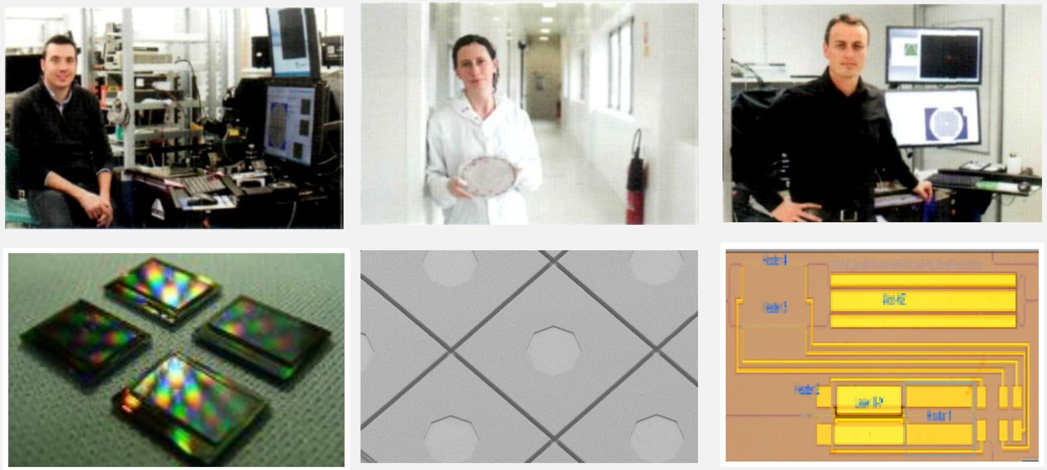
**> 65** Startups Created

**10,000 m²** Cleanroom 200-300mm

**315 M€** Budget

**85%** from R&D contracts

# OPTICS AND PHOTONICS DIVISION



Created in 1987
300 researchers, engineers and PhD students

500 patents in portfolio
81 new patents in 2018

~60 M€ budget
90% from external revenue

## DEDICATED OPTICS AND PHOTONICS FACILITY

**Clean rooms** from 100 to 300 mm wafers
**Electro-optical test and characterization** facilities
**Design and simulation** capabilities (process, growth, optics …)

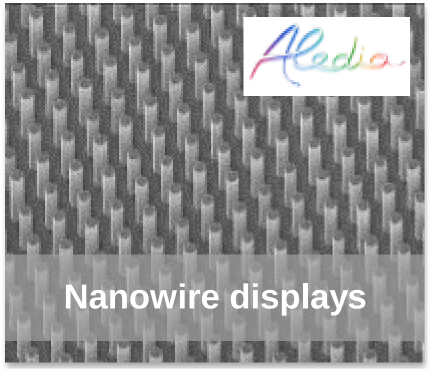
# LETI TECHNOLOGIES IN PRODUCTS OF OUR PARTNERS

IR image sensors

Thermal image sensors

CMOS image sensors

SOI substrates



Nanowire displays

Gas analyzers

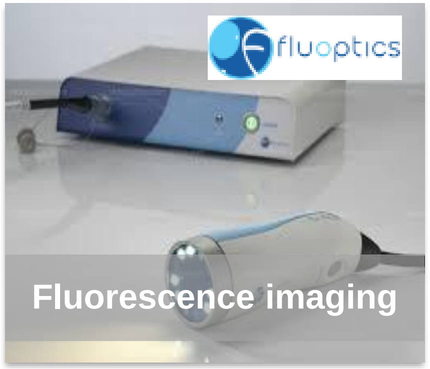
OLED displays

PACS camera

Gas sensors

X-Ray Imaging

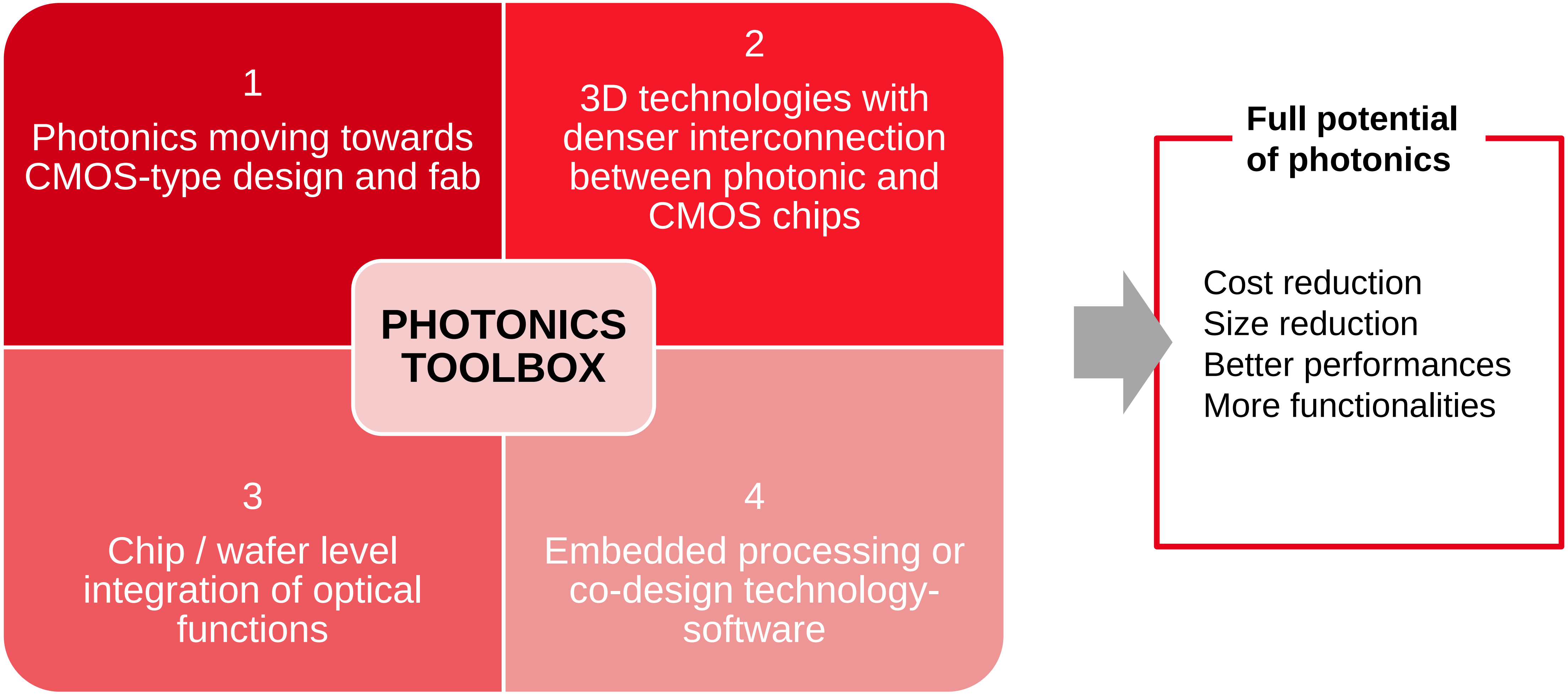
LiFi



Fluorescence imaging

Leti has created companies, transfered technologies to fabs and foundries and brought differentiation to its industrial partners.

# CONVERGENCE OF PHOTONICS AND ELECTRONICS : A HIGH OPPORTUNITY FOR LIDARS



1

Photonics moving towards CMOS-type design and fab

2

3D technologies with denser interconnection between photonic and CMOS chips

**PHOTONICS TOOLBOX**

3

Chip / wafer level integration of optical functions

4

Embedded processing or co-design technology-software

**Full potential of photonics**

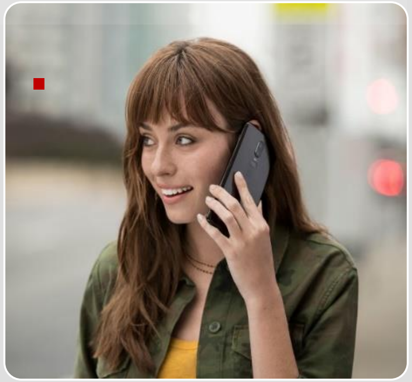
Cost reduction
Size reduction
Better performances
More functionalities

# LIDAR MARKET

- A WIDE RANGE OF APPLICATIONS

COST & SIZE REDUCTION

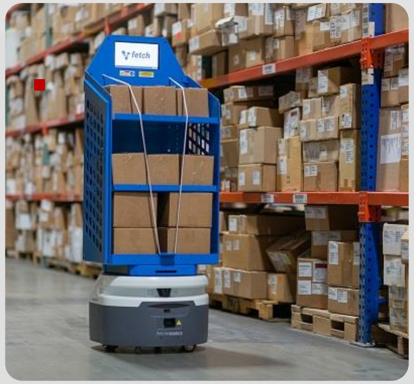
## CONSUMER



1D RANGE FINDER

LOW COST

## INDUSTRY

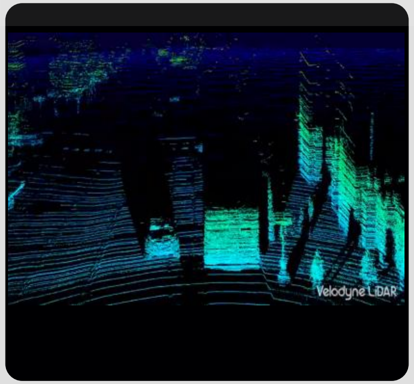


fetch robotics

ROBOTICS

REAL-TIME

## MOBILITY

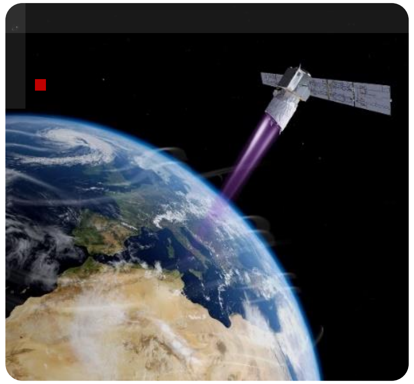


## ENGINEERING

3D MAPPING

ACCURACY

## SPACE/SCIENCE



REMOTE SENSING

PERFORMANCE

# LIDAR MARKET CHALLENGES

- STILL 2 MAJOR OBSTACLES TO LARGE MARKET ADOPTION: COST & SIZE

**Price**

Scalability / Availability

- Product or Power

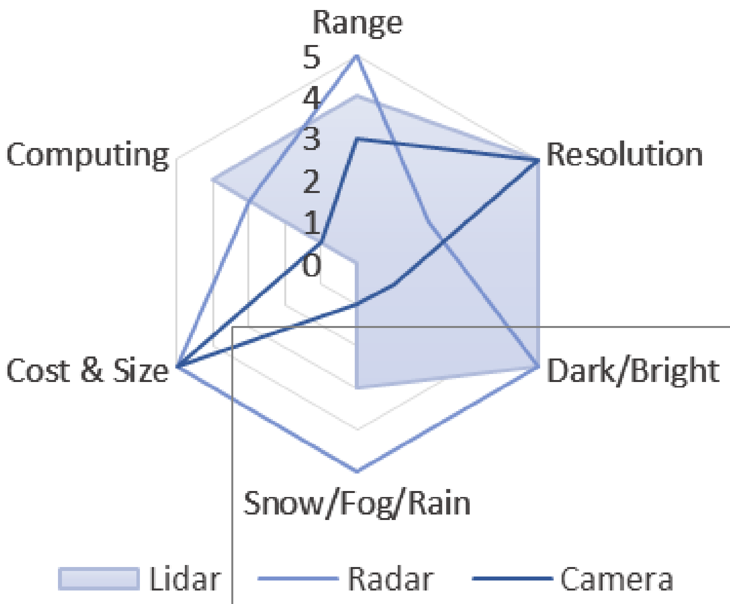
**Computing**

**Manufacturability**

**Maintenance**

**Form factor**

- Size
- Mass



**Performances**

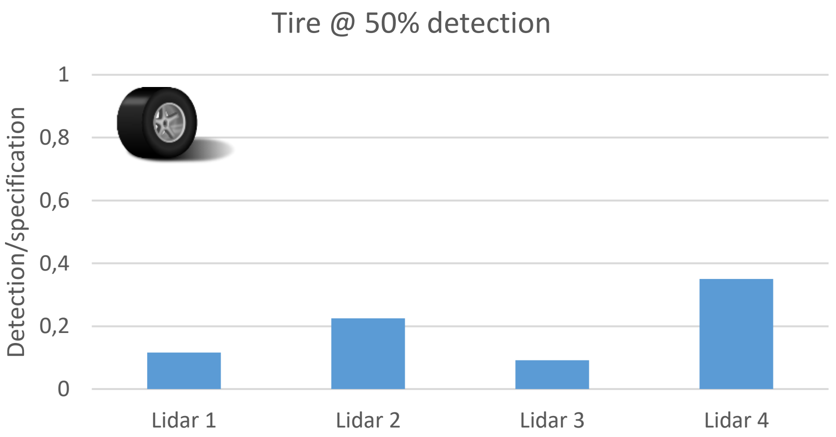
- Range
- Angular resolution (H / V)
- Spatial resolution
- Spatial accuracy – any 'blooming' artifacts etc…
- Scan rate / frame rate (per sec, in Hz)
- Range repeatability
- **Immunity to other LiDARs**

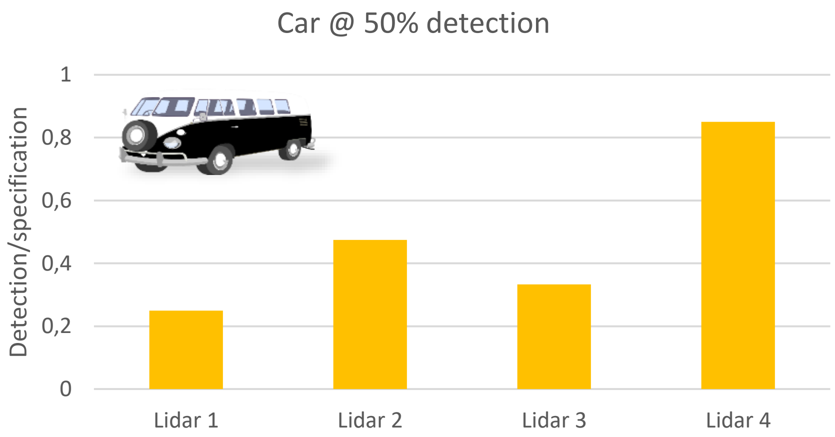
**Environmental conditions**

- Environment variability (temperature range, peak sun, fog-snow-rain…)
- Functionality amidst window obstruction
- Quality reliability
- Shock : Vibe / Jitter
- Thermal range & cycling
- Corrosion

# LIDAR MARKET CHALLENGES

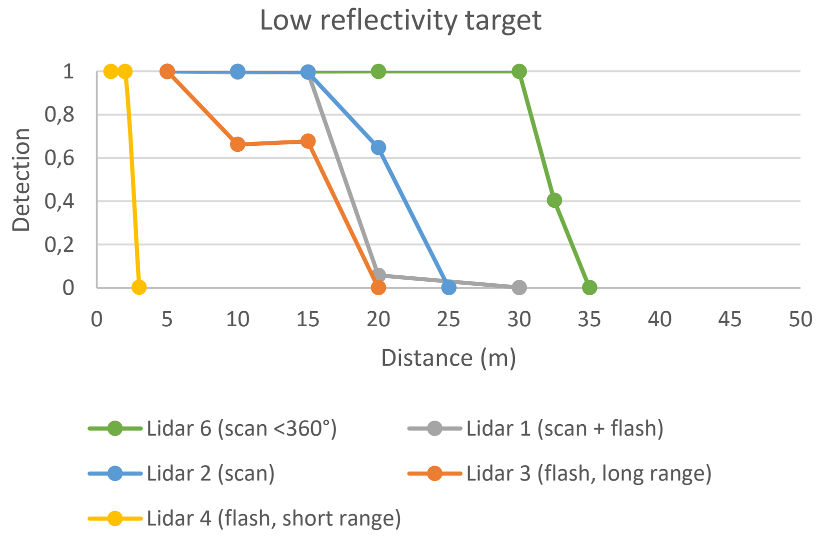
- TESTS OF COMMERCIAL LIDARS. LACK OF STANDARDIZATION ?

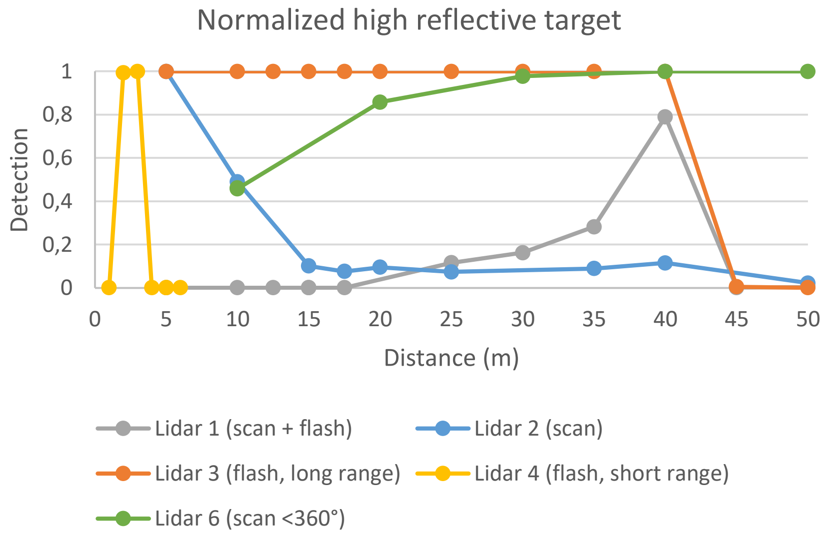

Tire @ 50% detection


Car @ 50% detection

http://www.leti-cea.com/cea-tech/leti/english/Pages/What's-On/Press%20release/Leti-Transdev-IRT-Nanoelec-Announce-Pilot-Program-To-Assess-New-Perception-Sensors-For-Autonomous-Vehicles.aspx

http://www.cea-tech.fr/cea-tech/english/Pages/ec_2018/evaluating-perception-sensors-autonomous-vehicles.aspx


Low reflectivity target


Normalized high reflective target

# LIDAR OPPORTUNITIES

- FUTURE TRENDS IN LIDAR TECHNOLOGY

## Towards Smart miniaturized low cost LiDAR

### Miniaturized

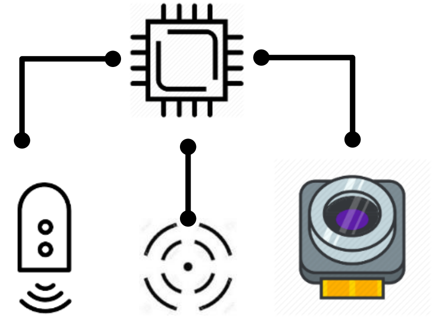
Infrared chip-scale LiDAR

### Low cost

Fully CMOS-compatible technologies

### Agile

driven by embedded computing that processes data fusion



# TOWARDS AGILE LOW-COST CHIP-SCALE LIDAR

## PHOTONICS

**Low cost technologies & integrated on chip**

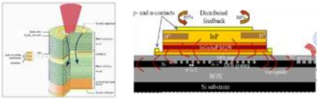
## ELECTRONICS

**Heterogeneous integration & 3D assembly with electronics**

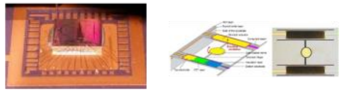
## SOFTWARE

**Operation derived from data fusion & AI**

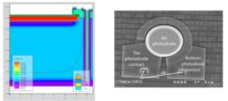
**Source**
Lasers

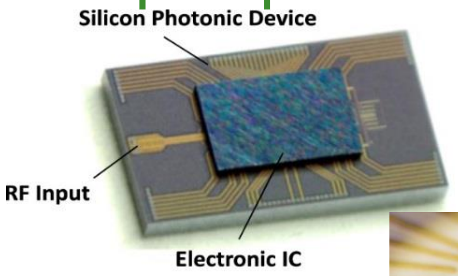


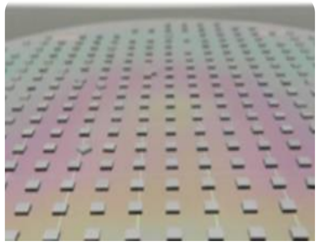
**Beam steering**
OPA / MEMS
µMIRROR

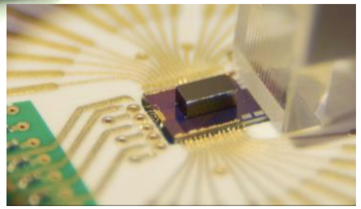


**Receiver**
III-V, Si, Ge PiN,
APDs, SPADs

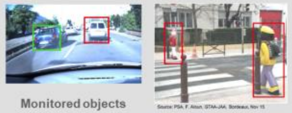








**Object fusion**



Source: PSA, F. Aioun, GTAA-JAA, Bordeaux, Nov 15

**Monitored objects limited** by computing power

Fault detection issues

*Objective* : Object recognition

*Algorithm* : AI, learning based on a finite list of objects…

*Sensor* : Image

**Map fusion**

Every location, **obstacles & free** space, is monitored

*Objective* : Construction of a map model of the environment

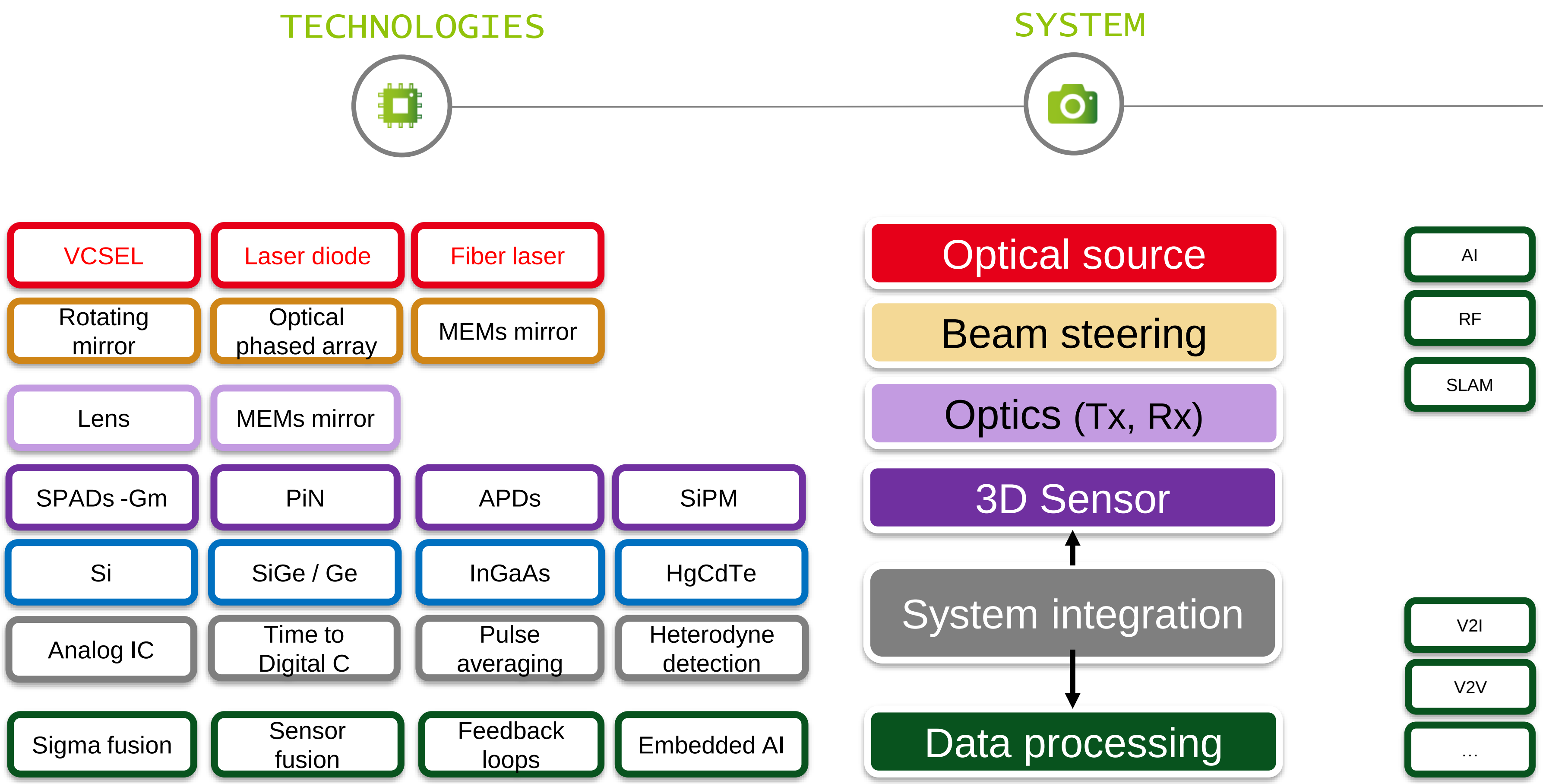
*Algorithm* : Fusion approaches, filtering, localization…

*Sensor* : Distance…

- *Silicon photonics enables high density integration of photonics functions*
- *Fully compatible with state-of-the-art CMOS foundries*

# TOWARDS AGILE LOW-COST CHIP-SCALE LIDAR

- CEA-LETI PORTFOLIO



TECHNOLOGIES

VCSEL | Laser diode | Fiber laser

Rotating mirror | Optical phased array | MEMs mirror

Lens | MEMs mirror

SPADs -Gm | PiN | APDs | SiPM

Si | SiGe / Ge | InGaAs | HgCdTe

Analog IC | Time to Digital C | Pulse averaging | Heterodyne detection

Sigma fusion | Sensor fusion | Feedback loops | Embedded AI

SYSTEM

Optical source

Beam steering

Optics (Tx, Rx)

3D Sensor

System integration

Data processing

CPS

AI

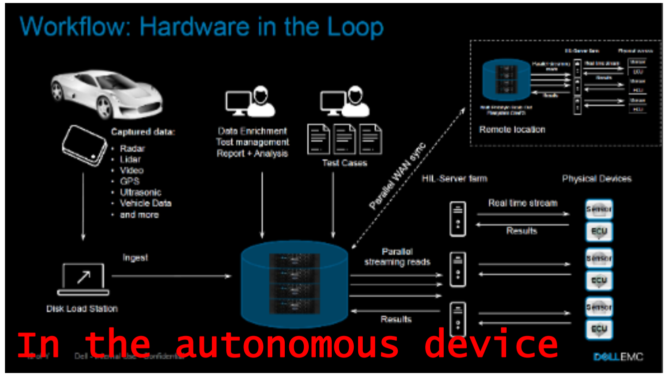
RF

SLAM

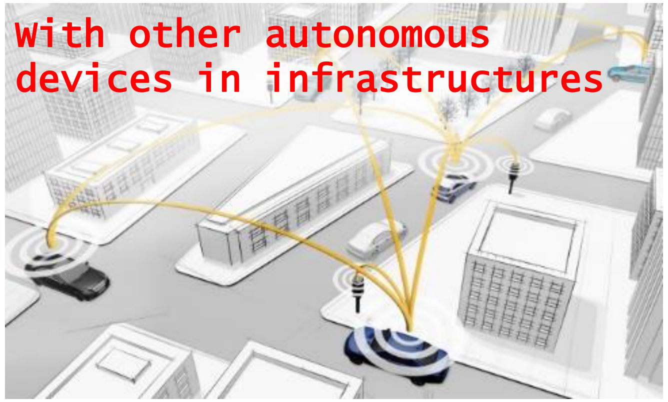
V2I

V2V

…



In the autonomous device



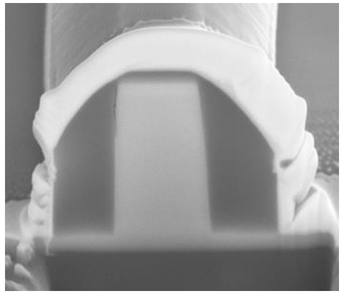
With other autonomous devices in infrastructures

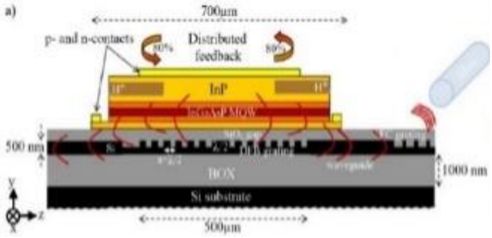
# TOWARDS AGILE LOW-COST CHIP-SCALE LIDAR

- LETI'S KEY PHOTONICS TECHNOLOGIES FOR CHIP-SCALE LIDAR

## OPTICAL EMITTER

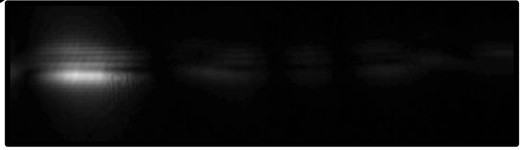
### CMOS-COMPATIBLE HYBRID III-V ON SI LASER





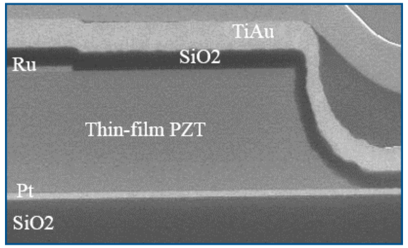
## BEAM STEERING

### OPTICAL PHASED ARRAYS

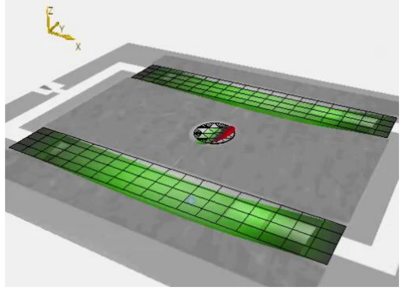


1D ±10° BEAM STEERING AT 900NM USING AN INTEGRATED OPA

### MEMS MIRRORS



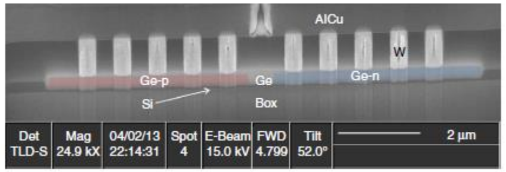
8" THIN-FILM PIEZOELECTRIC MATERIAL & TECHNOLOGY



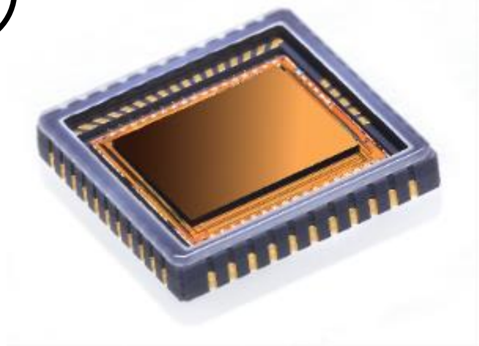
RESONANT ASYMMETRIC MICRO-MIRROR WITH PZT ACTUATION

## OPTICAL RECEIVER

### SIGE / SI PHOTODIODES

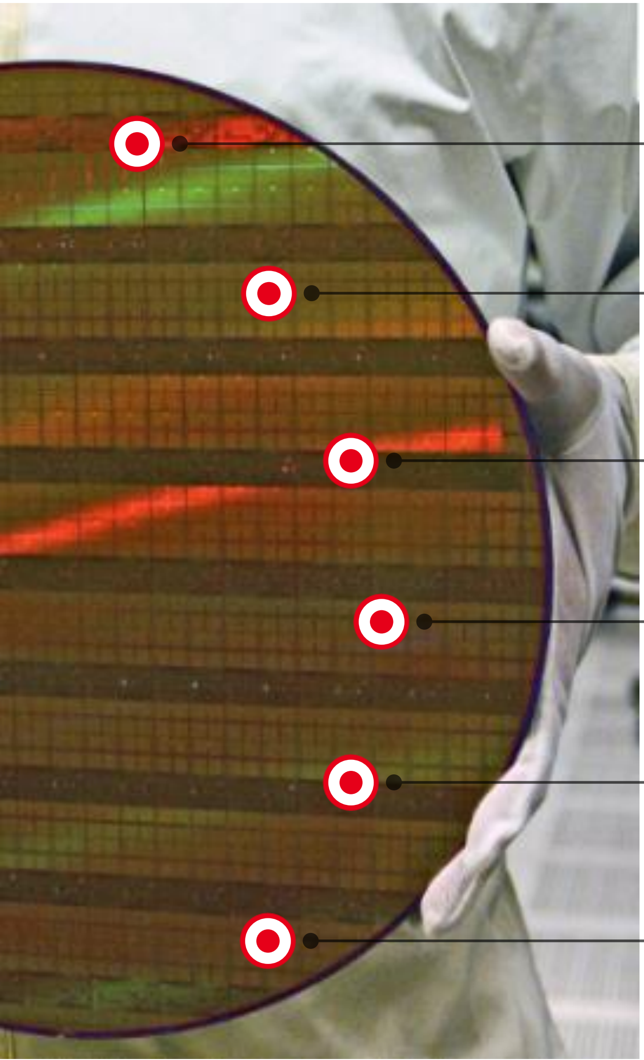


### INGAAS PHOTODIODES



# TOWARDS AGILE LOW-COST CHIP-SCALE LIDAR

- LETI’S STATE-OF-THE-ART INTEGRATED SILICON PHOTONICS PLATFORM



FIBER GRATING COUPLER

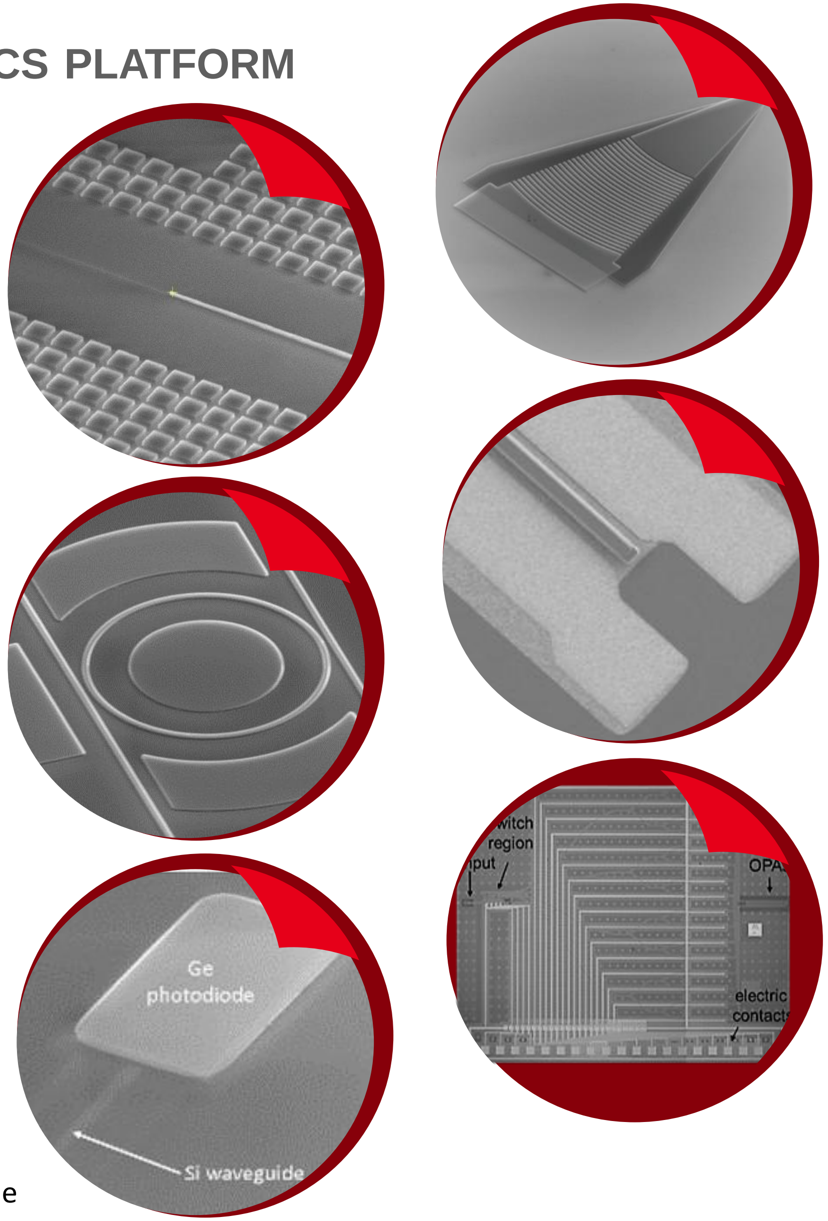
SI-SIN TRANSITION

HYBRID INP/SI LASER

MODULATOR

OPTICAL PHASED ARRAY

PHOTODETECTOR



Szelag et al., ” CMOS compatible 200mm silicon photonic platform suitable for high bandwidth applications” SSDM, 2017

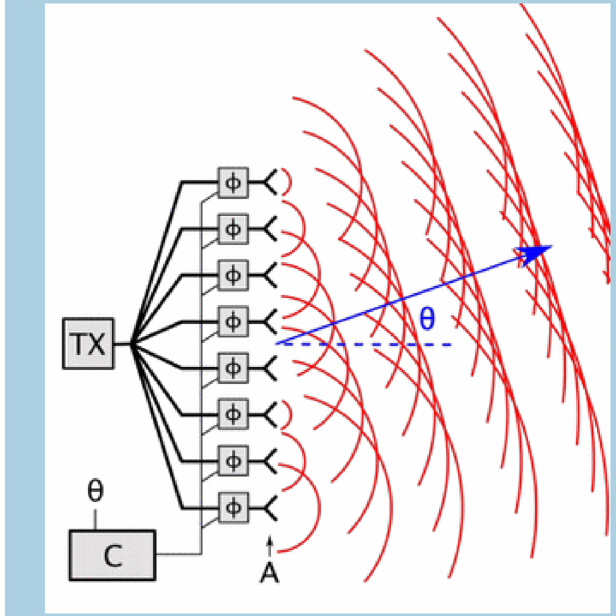
# TOWARDS AGILE LOW-COST CHIP-SCALE LIDAR

- FOCUS ON BEAM STEERING WITH NO MECHANICAL ELEMENTS

- Mechanical scanning RADAR

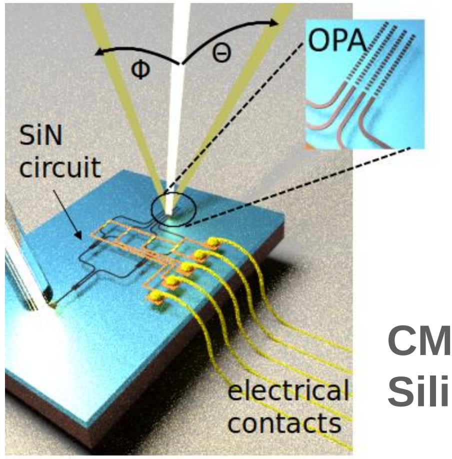
- Mechanical scanning LIDAR

**NO MECHANICAL ELEMENTS**



- Phased array RADAR

## Optical Phased array- based LIDAR



**OPA**

CMOS compatible
Silicon photonics

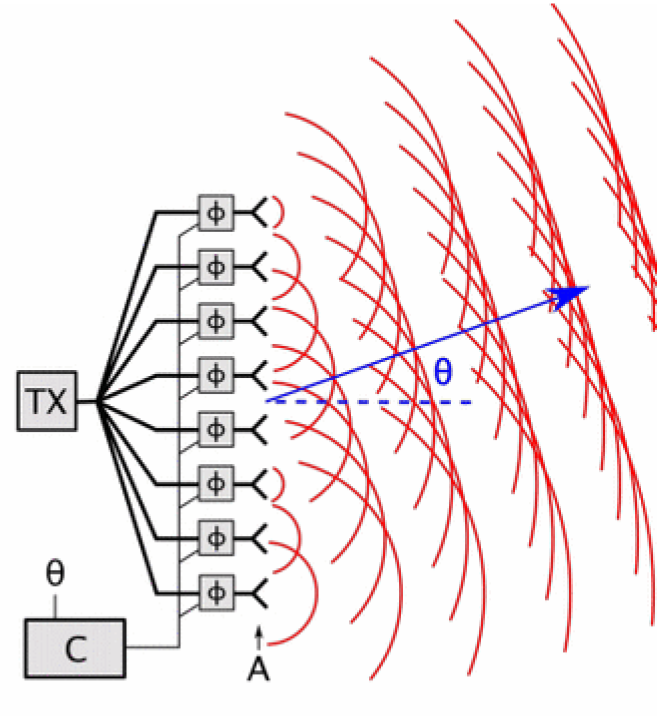
# TOWARDS AGILE LOW-COST CHIP-SCALE LIDAR

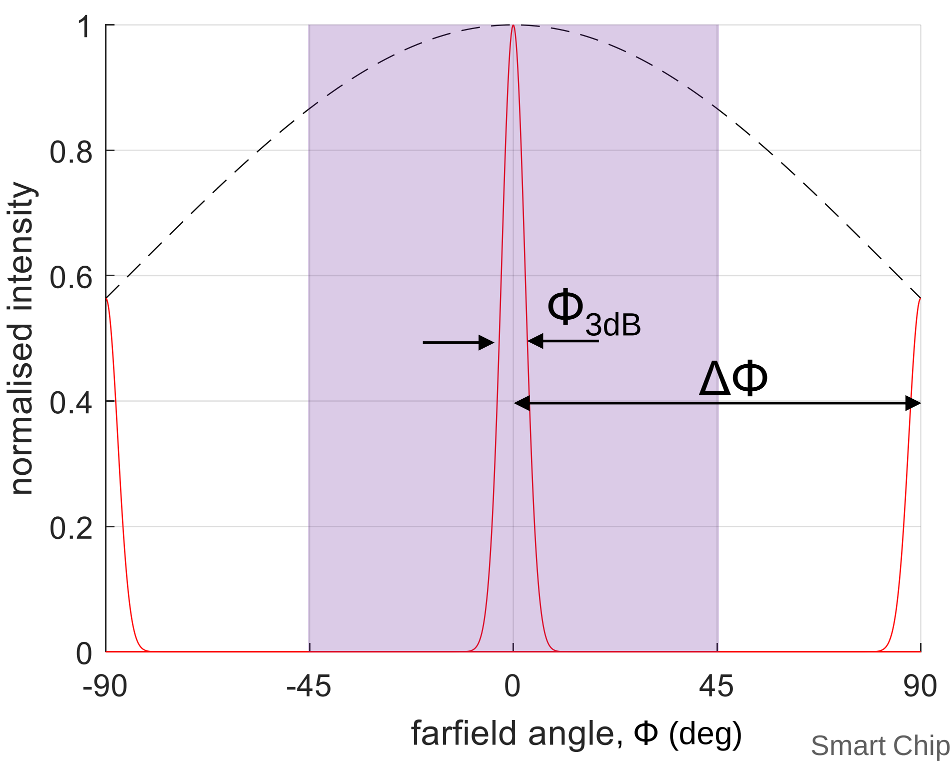
## SOME NUMBERS ON OPTICAL PHASED ARRAY FOR BEAM STEERING

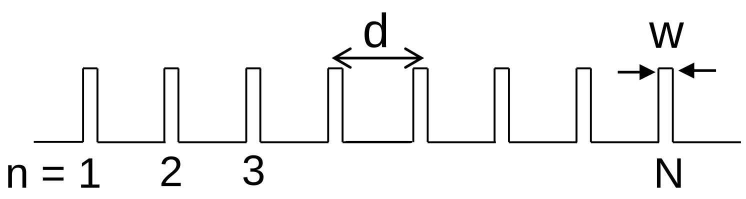
- Operating wavelength, λ = 1µm
- 10cm object at 100m
- Unambiguous sweeping range +/-45°

Beam divergence ~ 1mRad ~ 0,05°

>90° between diffraction orders







ΔΦ = 90°, d = λ/sin(ΔΦ) = λ

$\Phi_{3dB}$ = 1mRad,

N.d = 1,22λ/ $\Phi_{3dB}$ = 1220 x λ

**We need ~1000 sources, separated by 1µm**

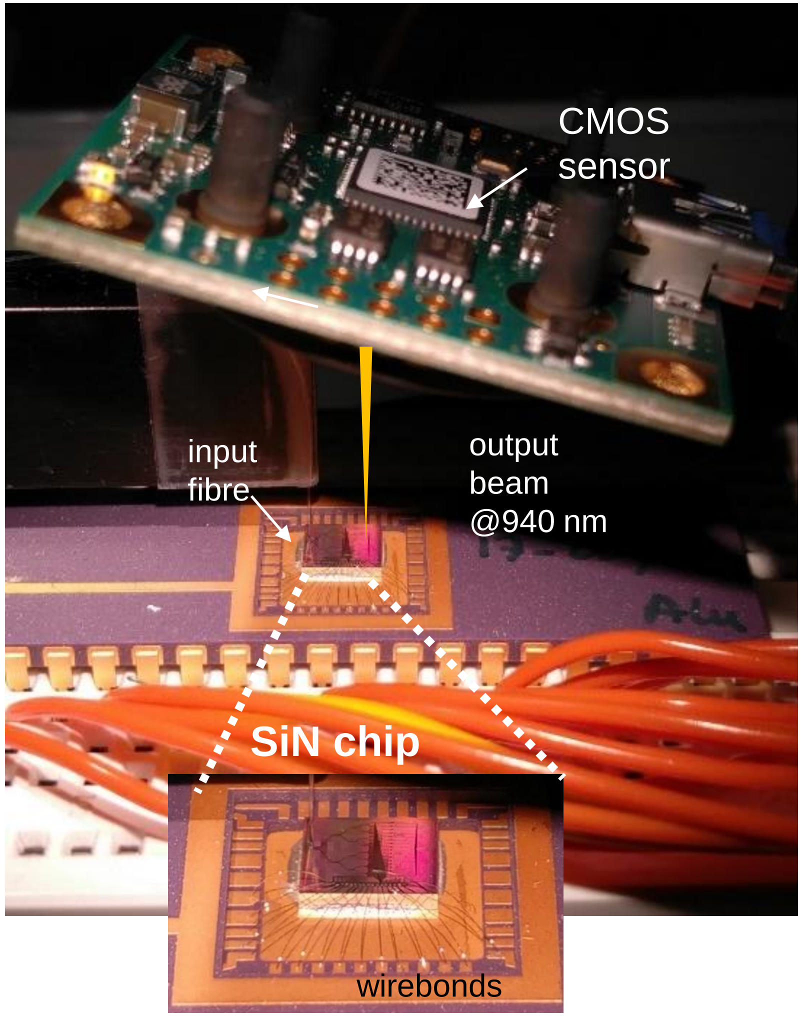
# TOWARDS AGILE LOW-COST CHIP-SCALE LIDAR

- Focus on Optical Phased Array for beam steering

**Silicon photonics:**

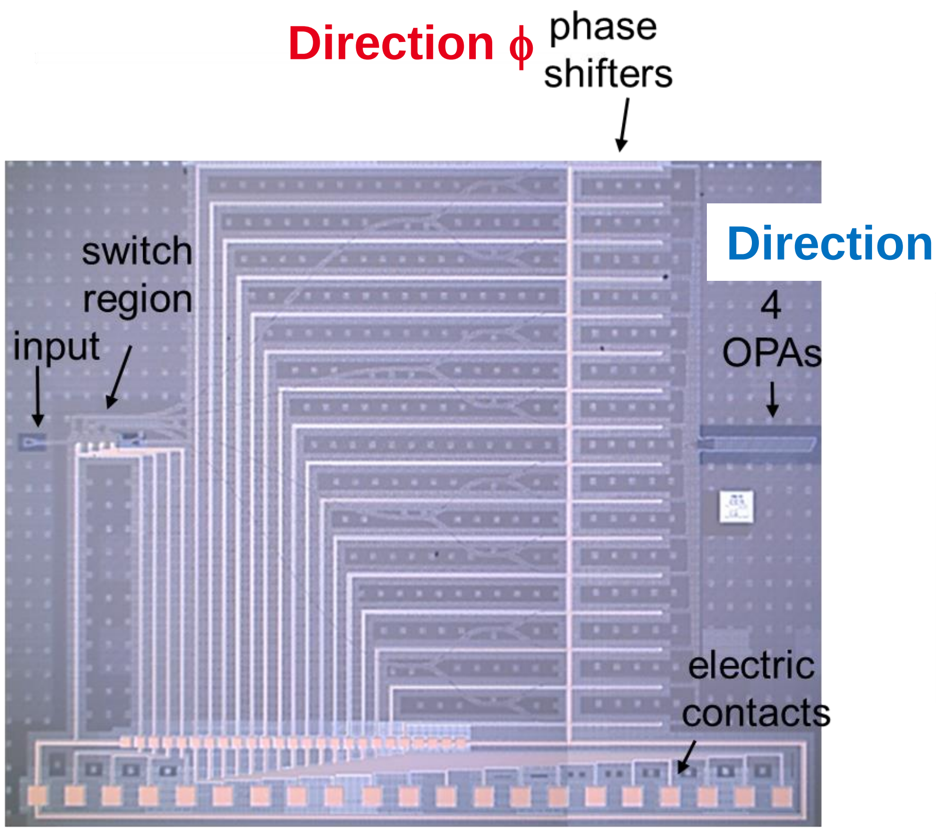
- Operating λ=0,5-4µm
- **Suited to high component density**
- **CMOS compatible for high-volume/low cost production**

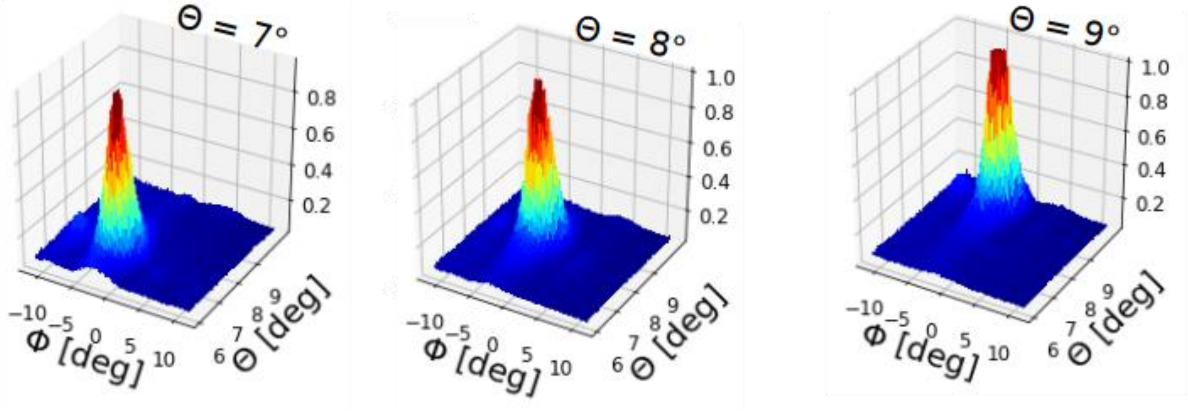
- Demonstrator of 1D ±10° beam steering at 900nm



# TOWARDS AGILE LOW-COST CHIP-SCALE LIDAR

- **FOCUS ON OPTICAL PHASED ARRAY FOR BEAM STEERING: DEMONSTRATION OF 2D SCANNING OPA**



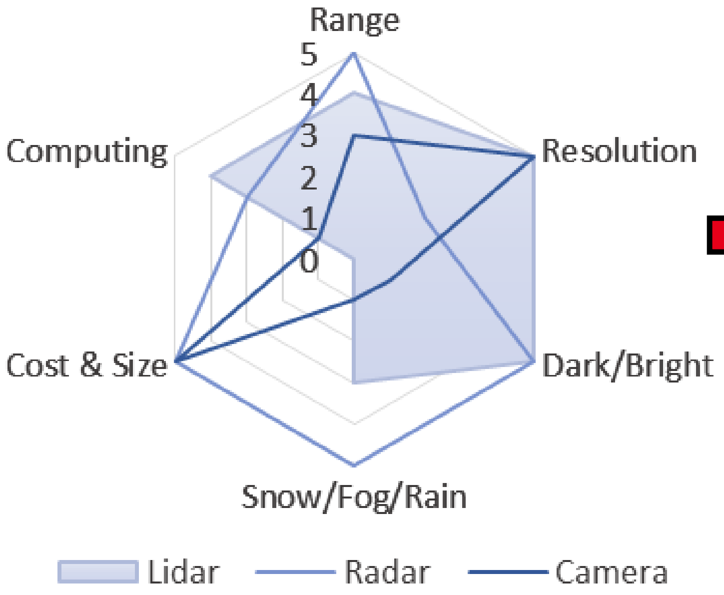


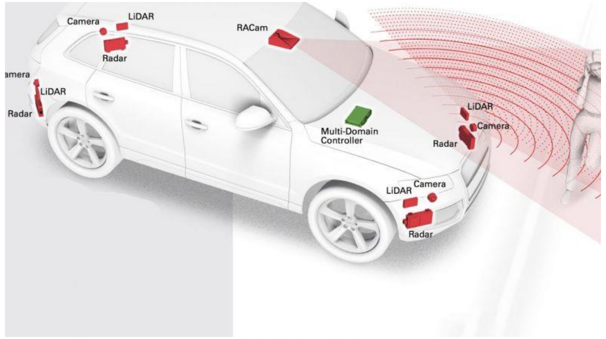
- 905nm OPA based on SiN waveguides/devices

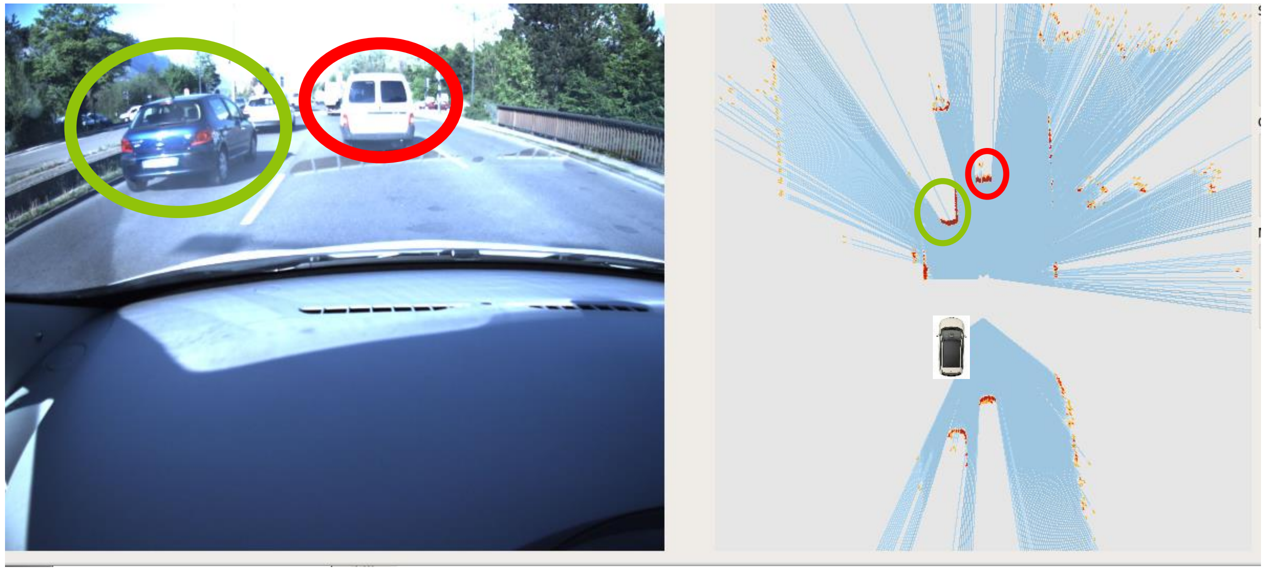
N. A. Tyler *et al. Optics Express*, Feb. 2019.
Tyler, N. A., et al. CPMT Symposium **BEST PAPER AWARD**

# TOWARDS AGILE LOW-COST CHIP-SCALE LIDAR

- LIDAR PROVIDES 3D PERCEPTION COMPLEMENTARY TO OTHER SENSORS







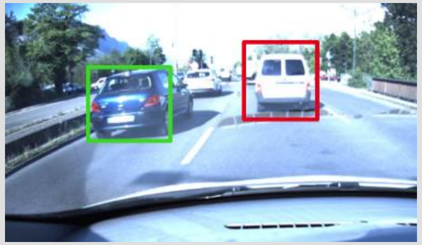
- **All obstacles** in the surroundings are detected in a unique environment model (in red)
- **Free space** is also detected (in blue)

# TOWARDS AGILE LOW-COST CHIP-SCALE LIDAR

- Leti’s key know-how in Perception computing: complementary approaches

**SigmaFusion™**

## Object fusion



**Monitored objects limited** by computing power

Source: PSA, F. Aïoun, GTAA-JAA, Bordeaux, Nov 15

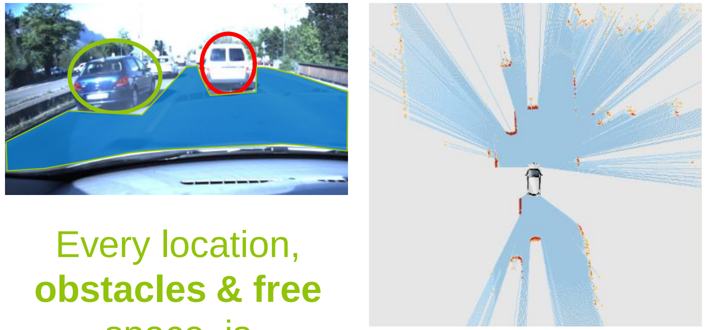
**Fault detection** issues

***Objective :*** **Object recognition**

***Algorithm :*** **AI, learning based on a finite list of objects…**

***Sensor :*** **Image**

## Map fusion



Every location, **obstacles & free** space, is monitored

***Objective :*** **Construction of a map model of the environment**

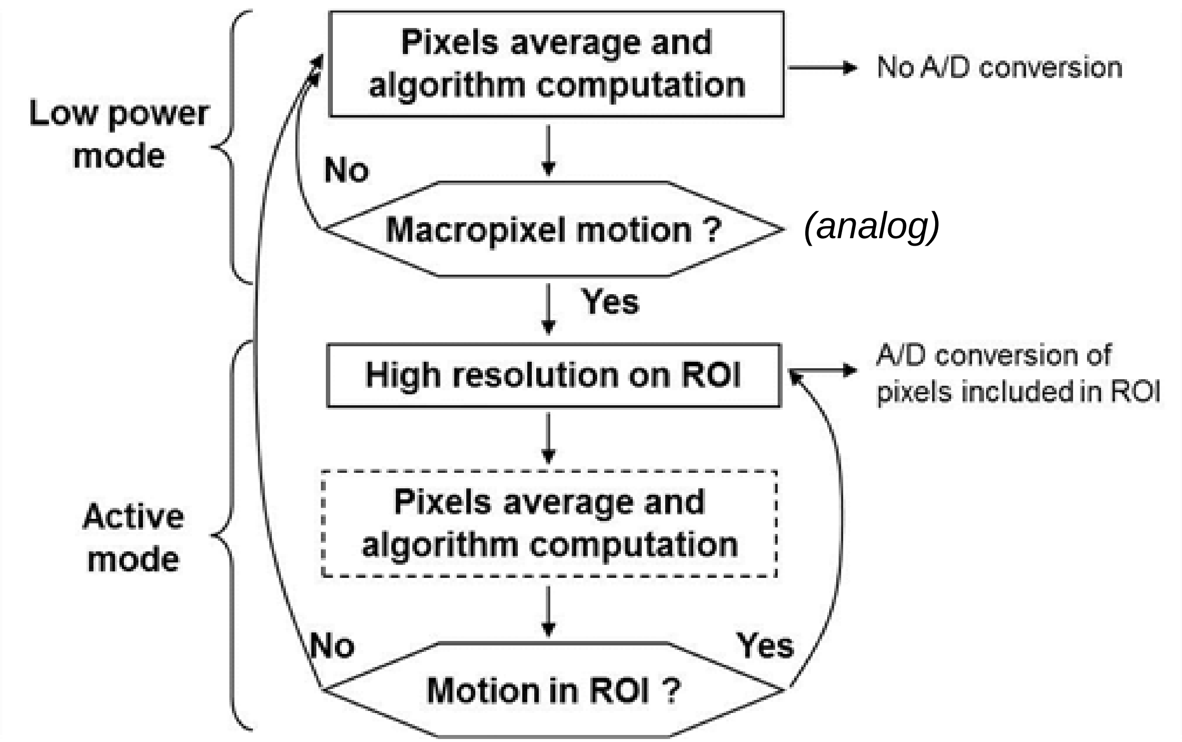
***Algorithm :*** **Fusion approaches, filtering, localization…**

***Sensor :*** **Distance…**

# TOWARDS AGILE LOW-COST CHIP-SCALE LIDAR

## LETI’S KEY KNOW-HOW IN EMBEDDED INTELLIGENCE

- Example of a sensor that wakes up on moving parts of the scene (ROI)



Low power mode

Pixels average and algorithm computation → No A/D conversion

Macropixel motion ? (analog)

No

Yes

Active mode

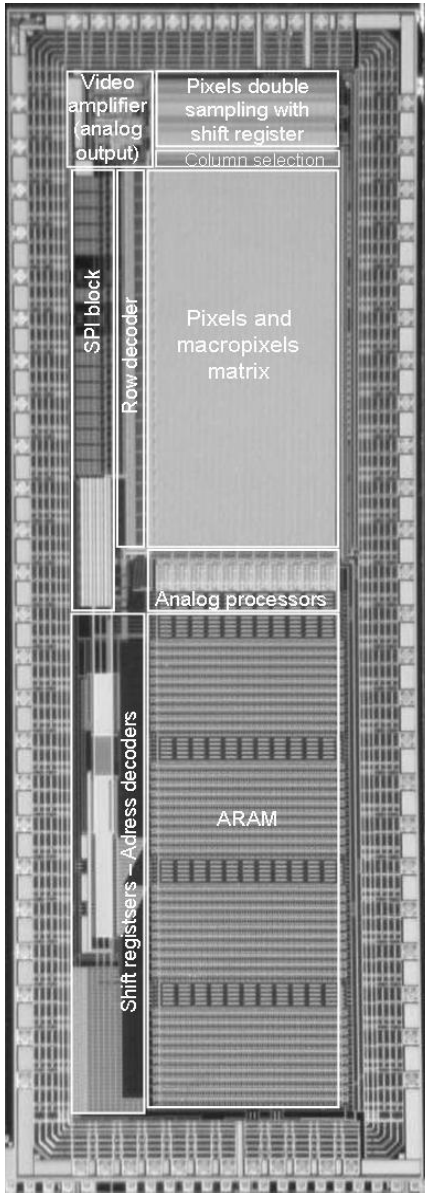
High resolution on ROI → A/D conversion of pixels included in ROI

Pixels average and algorithm computation

Motion in ROI ?

No

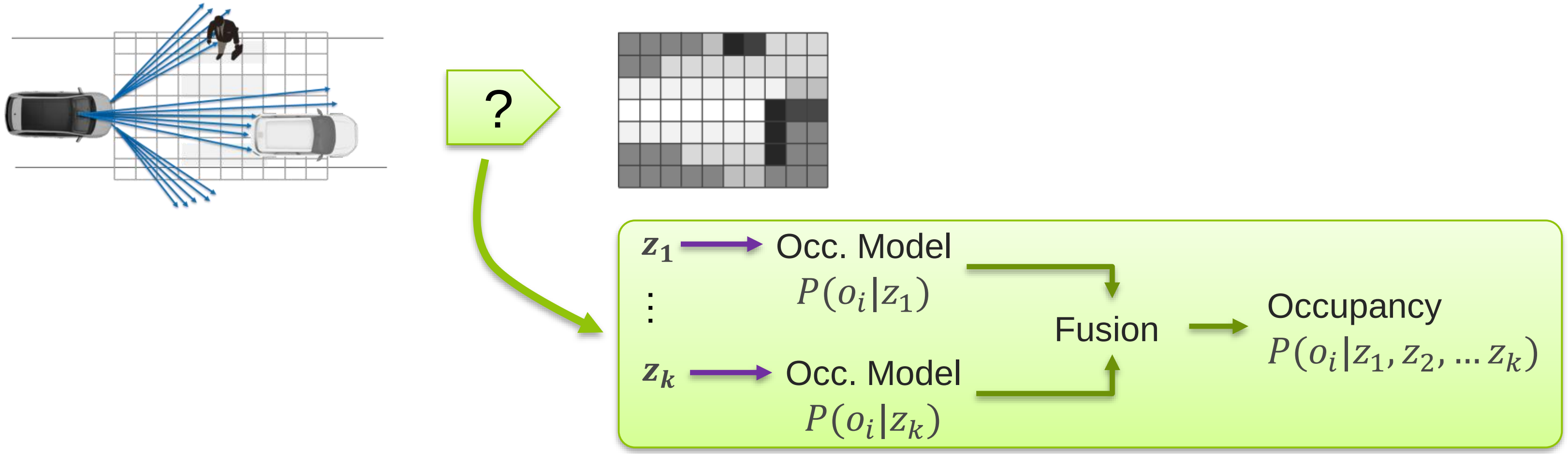
Yes



Motion detection is performed before A/D conversion ⬄ Power saving

# TOWARDS AGILE LOW-COST CHIP-SCALE LIDAR

- LETI'S KEY KNOW-HOW IN PERCEPTION COMPUTING: SIGMAFUSION™
  BUILD THE OCCUPANCY GRID FROM DIFFERENT MEASUREMENTS



$z_1$ → Occ. Model $P(o_i|z_1)$

⋮

$z_k$ → Occ. Model $P(o_i|z_k)$

Fusion → Occupancy $P(o_i|z_1, z_2, \ldots z_k)$

- **Use Bayesian Fusion**
  - only **integer arithmetic**
  - Compatible with **µC hardware (no Floating-Point Unit)**
  - Suitable for **embedded SW** or HW implementations

**→ Rethink arithmetic!**

# TOWARDS AGILE LOW-COST CHIP-SCALE LIDAR

## LETI'S KEY KNOW-HOW IN PERCEPTION COMPUTING: SIGMAFUSIONTM DEMO

- **Perception for autonomous vehicles**
  - 2x Velodyne VLP 16 LIDARs
    - 600000 data points per sec
    - 16 Mbits/sec data bandwidth (Ethernet)
  - 77GHz IFX Radar prototype
  - Environment model
    - ~1M cells
    - real-time computing (40 ms)
  - Hardware used:
    - **Infineon AURIX TriCore TC29x & TC39x**
    - **Ready for ISO26262 ASIL-D certification**

World First

icra 2016

DESIGN AUTOMATION CONFERENCE 2016

IFAC 2017

embedded world Exhibition&Conference ... it's a smarter world 2018

embedded world Exhibition&Conference ... it's a smarter world 2019

SEMICON EUROPA 2016

VISION 2016

12th ITS EUROPEAN CONGRESS ITS BEYOND BORDERS Strasbourg, France | 19-22 June 2017 2017

CES 2017

CES 2018

CES 2019

# CONCLUSION

- GREAT OPPORTUNITY WITH 3RD GENERATION

## PHOTONICS

**LOW COST TECHNOLOGIES & INTEGRATED ON CHIP**

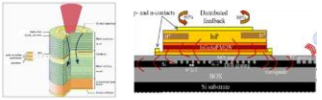
## ELECTRONICS

**HETEROGENEOUS INTEGRATION & 3D ASSEMBLY WITH ELECTRONICS**

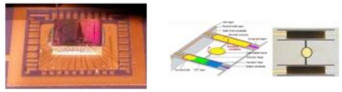
## SOFTWARE

**OPERATION DERIVED FROM DATA FUSION & AI**

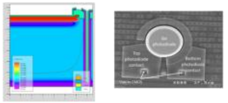
**SOURCE**
LASERS

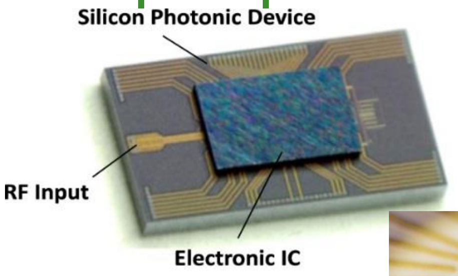


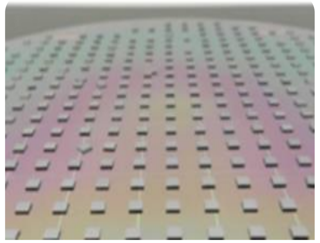
**BEAM STEERING**
OPA / MEMS µMIRROR

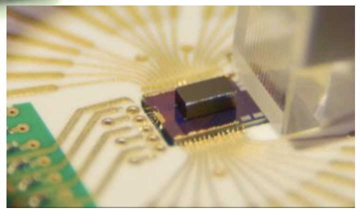


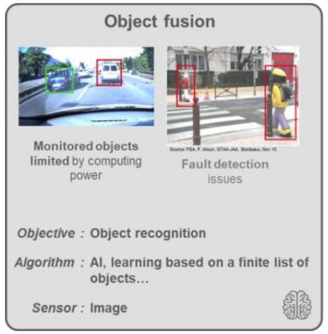
**RECEIVER**
III-V, SI, GE PIN, APDS, SPADS











**Object fusion**

Monitored objects limited by computing power

Fault detection issues

Source: PSA, F. Aioun, GTAA-JAA, Bordeaux, Nov 15

*Objective :* Object recognition

*Algorithm :* AI, learning based on a finite list of objects…

*Sensor :* Image

**Map fusion**

Every location, **obstacles & free** space, is monitored

*Objective :* Construction of a map model of the environment

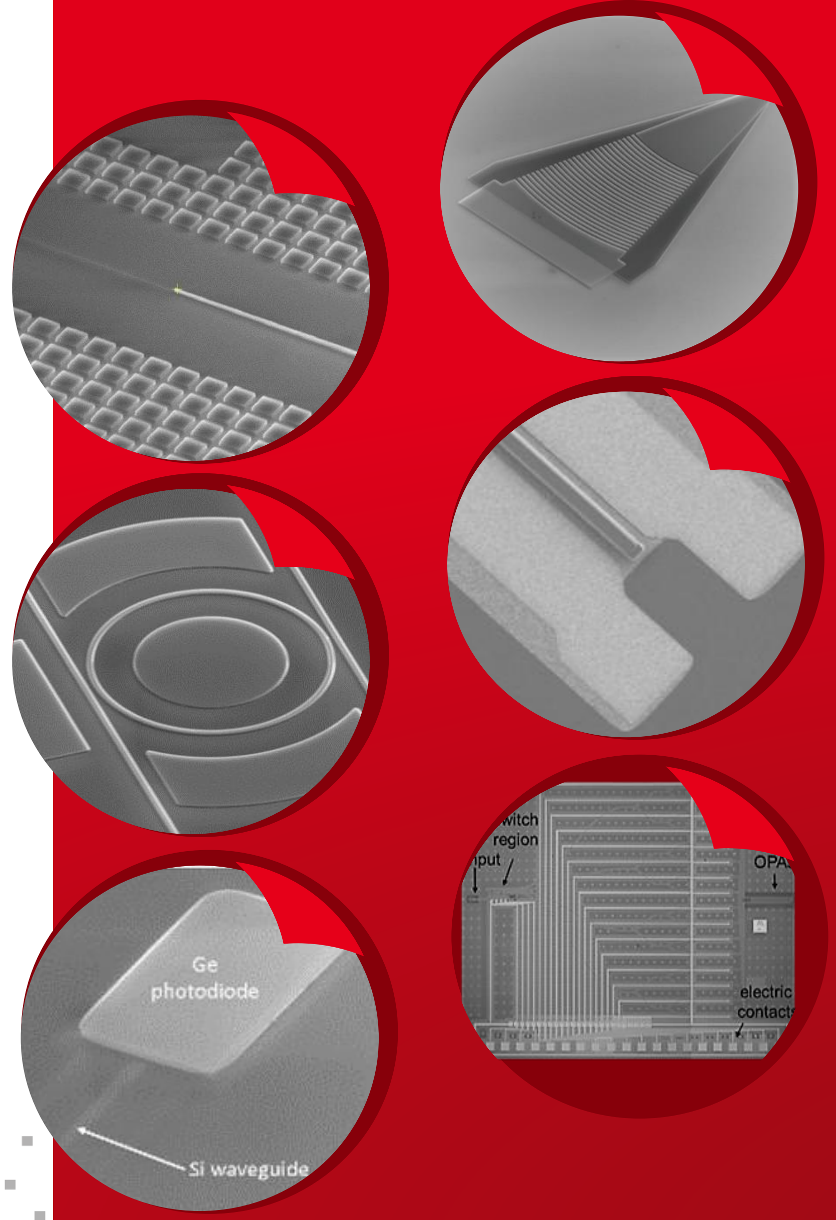
*Algorithm :* Fusion approaches, filtering, localization…

*Sensor :* Distance…

LOW-COST MINIATURIZED

SMART

# Questions ?



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