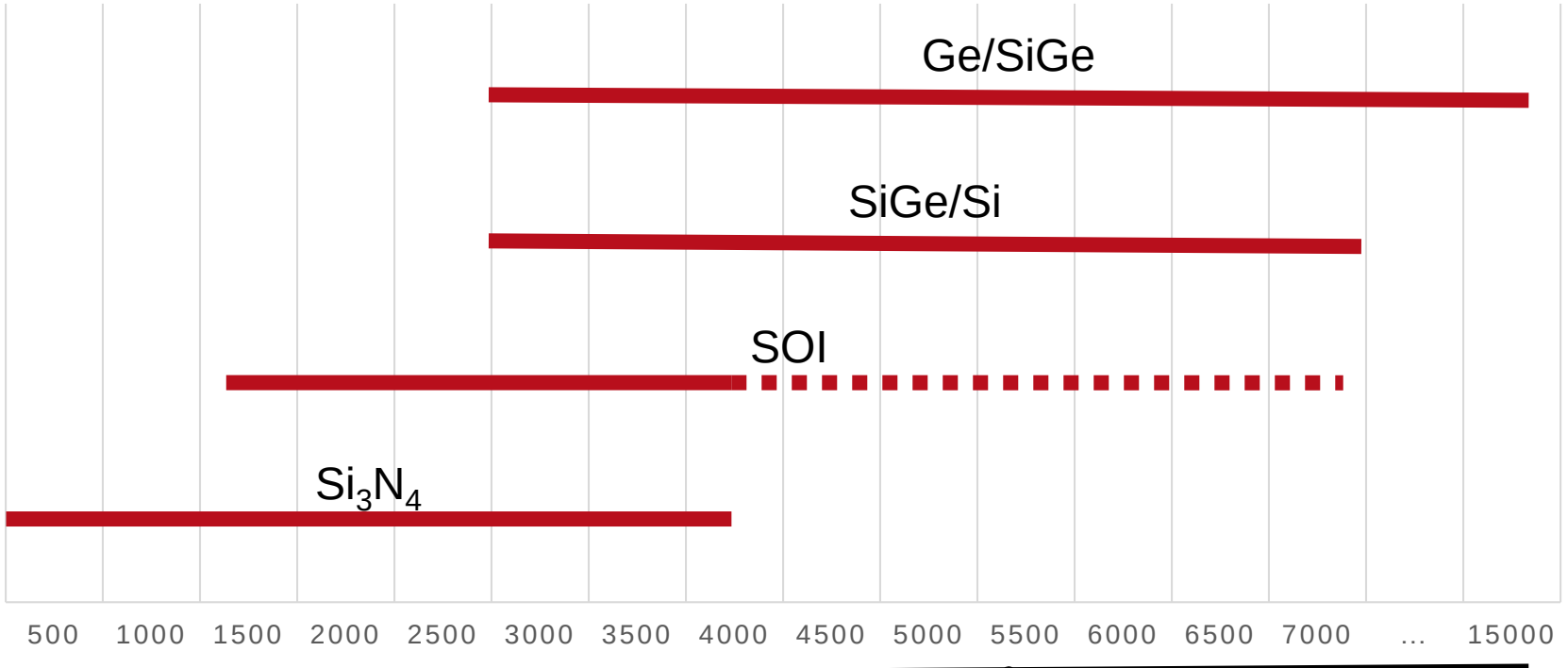
Photonique integrée :
Les nouvelles applications

INTEGRATED PHOTONICS
CEA-LETI'S PLATFORMS



AR/VR

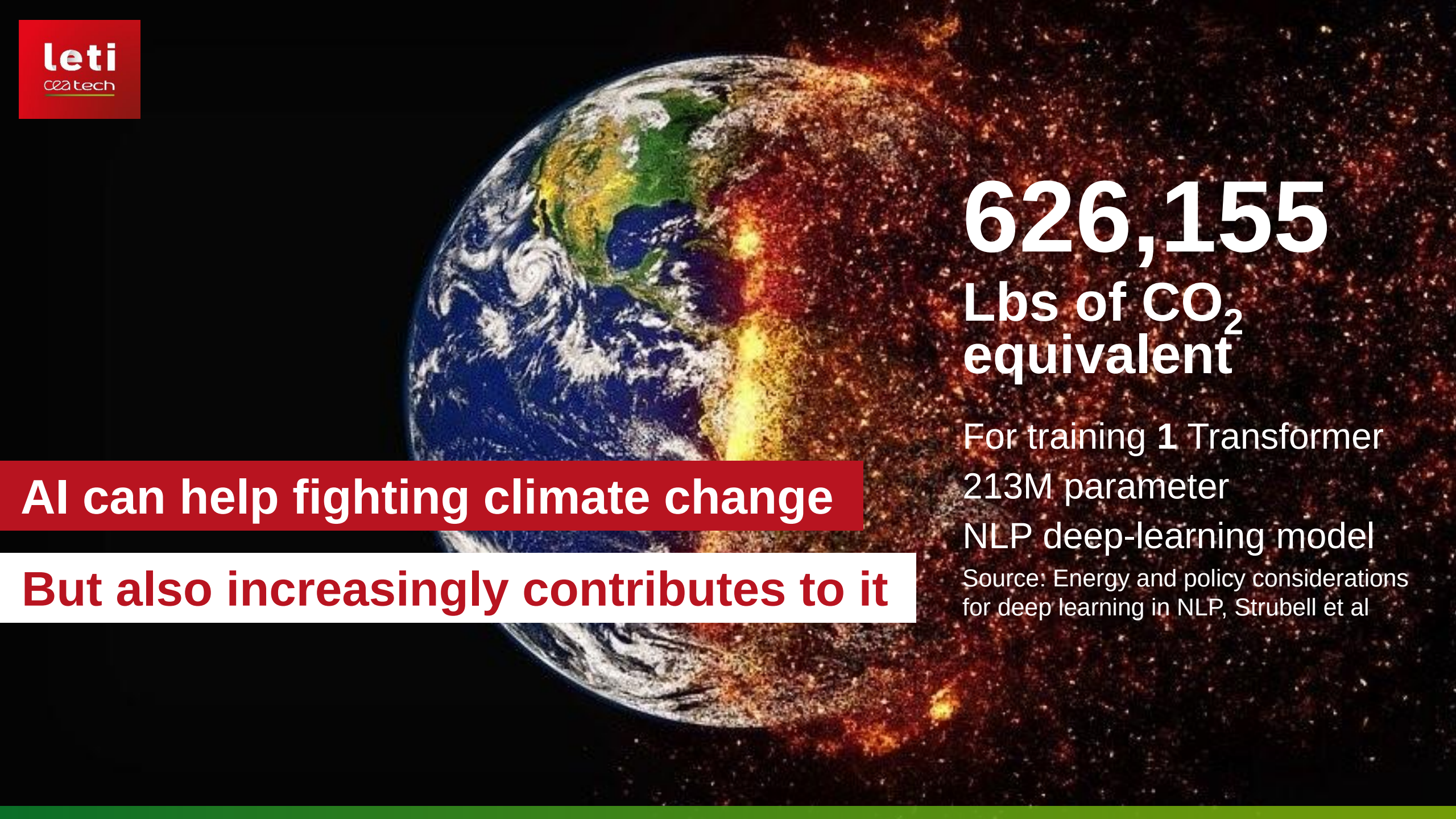
Com & computing

Health

Chemical Sensing

Photonics-based AI

leti
ceatech
35%
of lung nodules are missed at the initial screening
Source: Nature outlook - lung cancer, 2020
Beyond making our lives easier
AI is helping us to solve
some of the world's biggest challenges



626,155

Lbs of CO_2 equivalent

For training **1** Transformer
213M parameter
NLP deep-learning model

Source: Energy and policy considerations for deep learning in NLP, Strubell et al

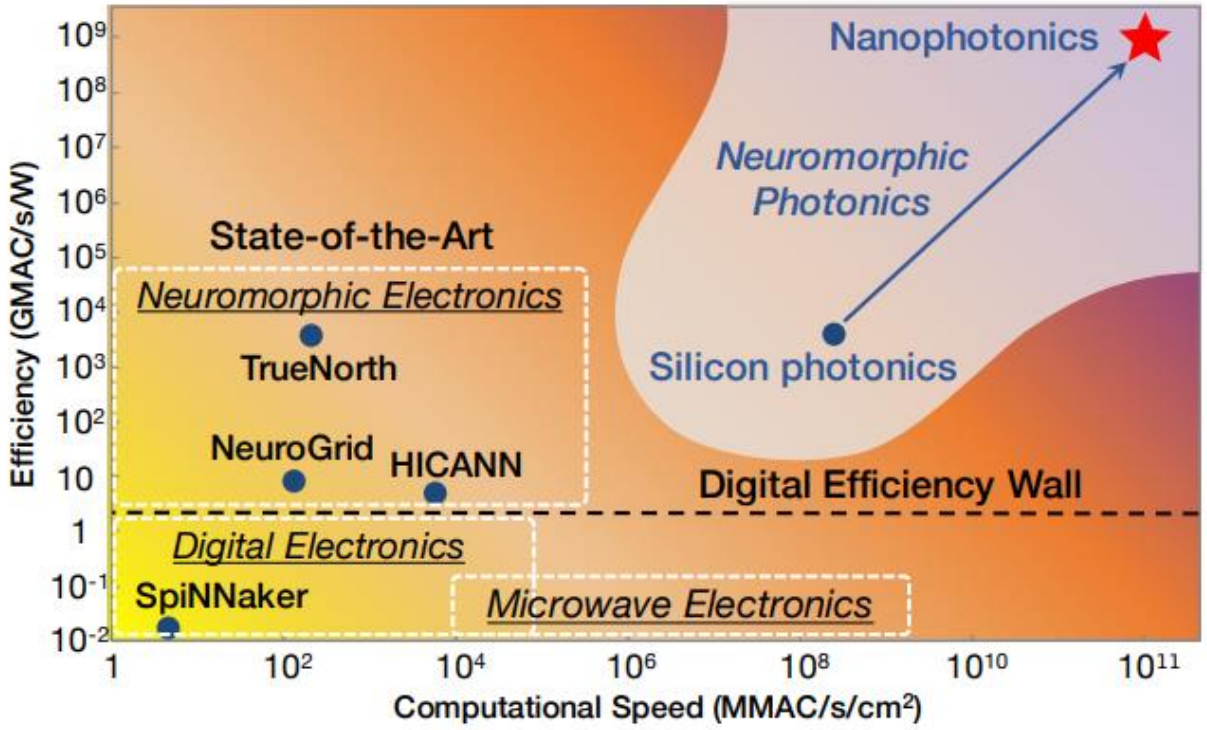
AI can help fighting climate change

But also increasingly contributes to it

PHOTONICS IN AI AND ML

Expectations:

- ❑ High speed data processing
- ❑ Lower energy consumption per operation



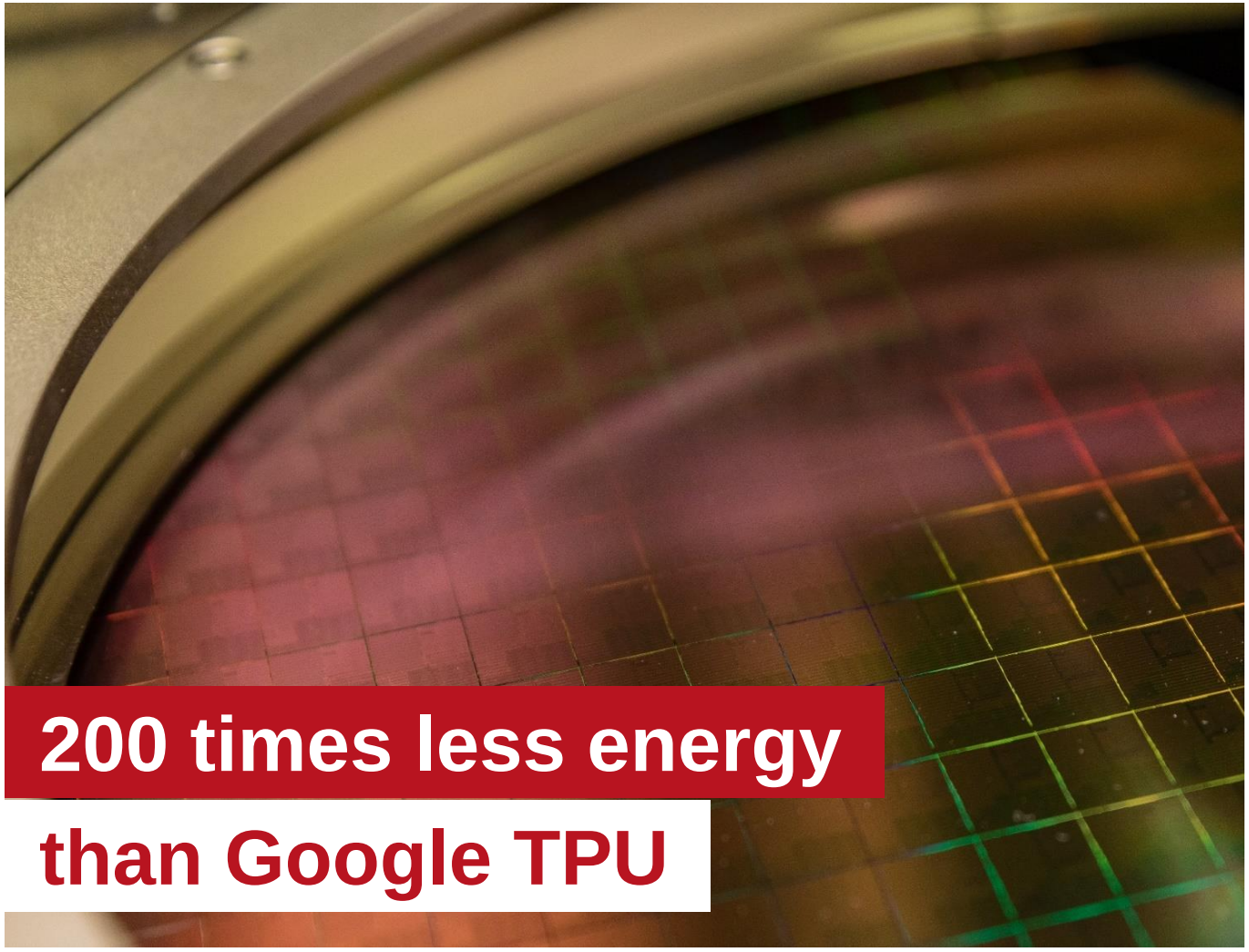
Photonics' advantage:

- ✓ Linear combinations are "lossless"
- ✓ Reduced latency

Source : Neuromorphic Photonics, Nahmias *et al*

AI HARDWARE THAT REQUIRES LESS ENERGY

› Silicon photonics



200 times less energy than Google TPU

Neuromorphic photonics can offer sub-nanosecond latencies, high-bandwidth & low energies

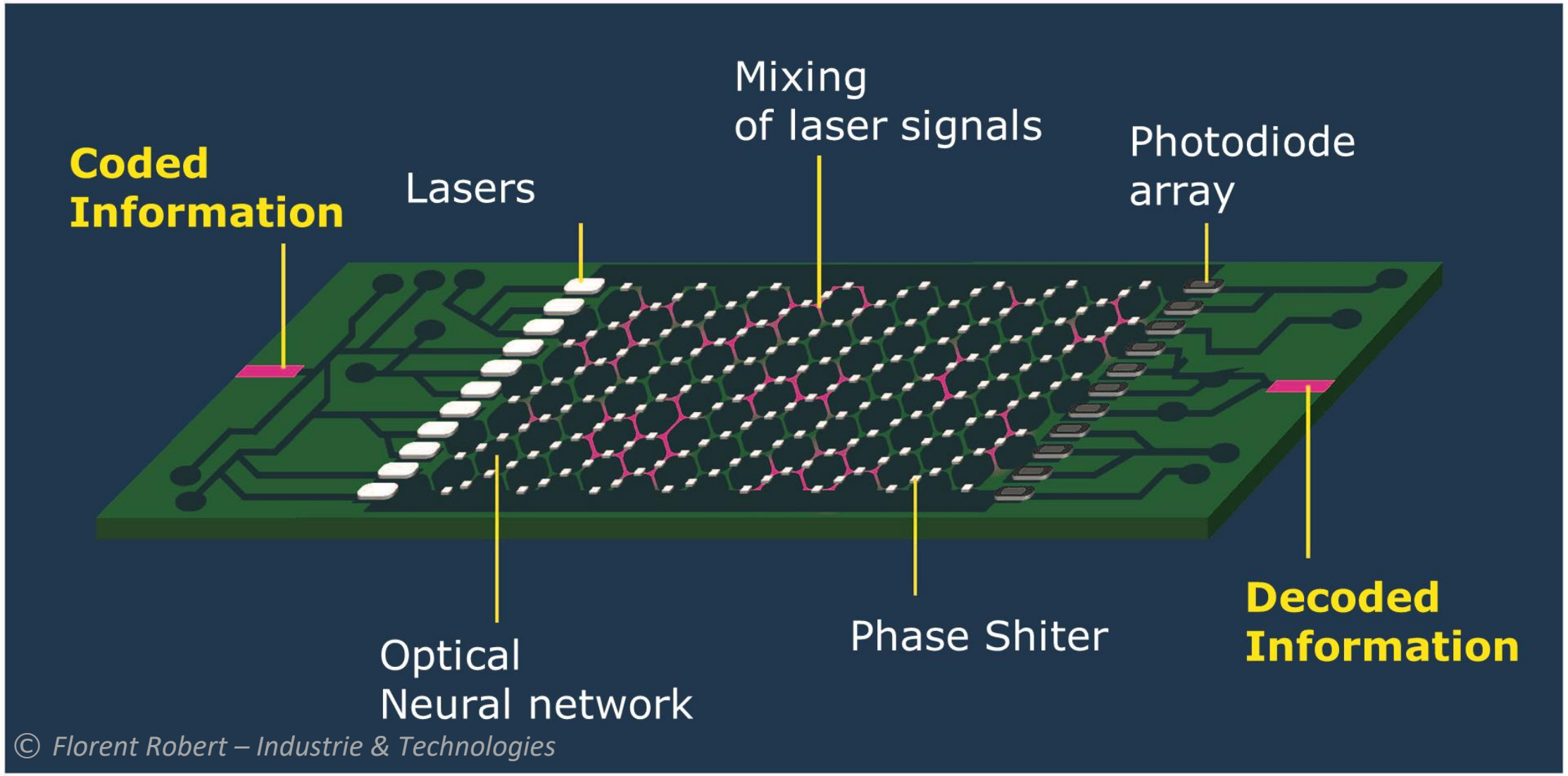
- CMOS-compatible platform
- 12” wafer process

SPIE. PHOTONICS WEST — **Multi-purpose 300mm silicon photonics platform for R&D and product prototyping, B. Szelag et al**

SPIE. PHOTONICS WEST — **Performant on-chip photonic detectors with lateral p-i-n silicon-germanium heterojunctions, L. Virot**

AI HARDWARE THAT REQUIRES LESS ENERGY

› Silicon photonics



PHOTONICS IN AI AND ML

Some examples

LightMatter Envise Processor

7 times the inferences/second/Watt on BERT-Base than the Nvidia DGX-A100

06/05/2021 : raises $113M funding

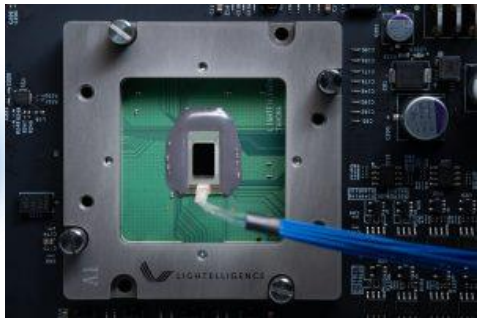
LightOn Qore

x11 energy savings in a transfer learning experiment compared to digital processor with the same final accuracy

Optalysys

Convolutions being performed with x40 energy savings compared to an all-digital implementation

Lightelligence



PHOTONICS IN AI AND ML

Some examples

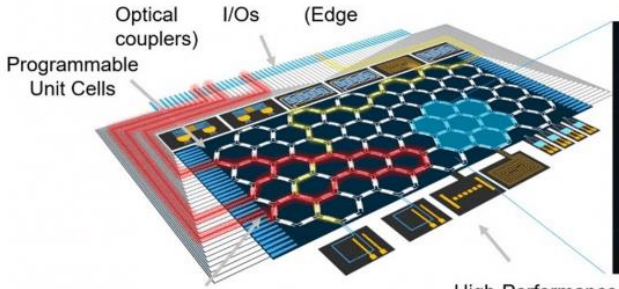
iPRONICS Programmable Photonics

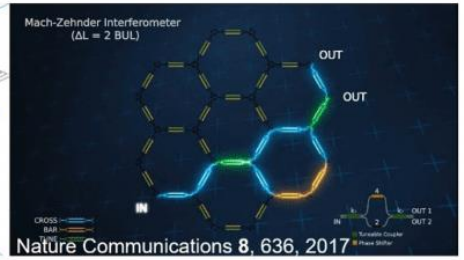
Programmable photonic circuits can be classified into:

iPRONICS Photonics Research Labs

Programmable Multifunctional PICs

General-purpose photonic processor





High-Performance Building Blocks

Tunable Coupler
Phase Shifter

D. Pérez-López, et al, Multipurpose self-configuration of programmable photonic circuits, ***Nat. Comms.***, *10.1038/s41467-020-19608-w, 2020*
D. Pérez, I. Gasulla, J. Capmany, Field-programmable photonic arrays, **Optics Express, 26, 21**, 2018.
D. Pérez, "Reconfigurable lattice mesh designs for programmable photonic processors," **Opt. Express, 24, 11**, 2016
L. Zhuang, "Programmable photonic signal processor chip for radiofrequency applications," **Optica, 2, 10**, 2015

CONFIDENTIAL ©Property of iPronics Programmable Photonics S.L.

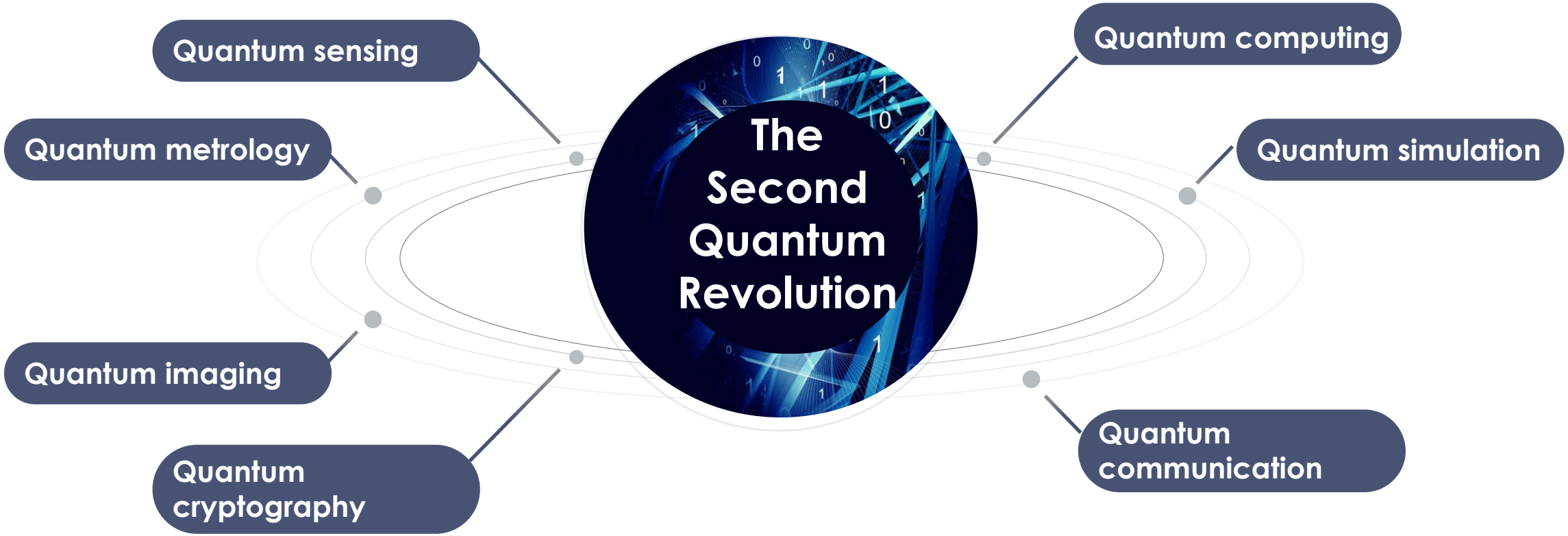
03/03/2022 : raises $105M funding

celestial AI

02/04/2022 : raises $56M funding

Quantum Photonics For communication & computing

QUANTUM TECHNOLOGIES



QUBITS TECHNOLOGIES

ATOMS | ELECTRONS (QuantumSilicon Grenoble) | PHOTONS

Trapped ions | Cold atoms | Topological nanowires | Superconductors | Si Spin | Defect-based | Photons

	Superconductors	Si Spin	Defect-based	Photons
SIZE	++	+++	+	++
OPERATION SPEED	+++	+++	+	+
MANUFACTURIABILITY	+	+++	+	+++
VARIABILITY	+	++	+++	++
OPERATING T°	+	++	++	++

COMPANIES & LABS*

Google, intel, IBM, OQC, rigetti, Raytheon, intel, QUANTUM MOTION, NTT, SILICON QUANTUM COMPUTING, QDTI, XANADU, PSIQUANTUM, TUNDRA SYSTEMS GLOBAL, qci, UCSB, QuTech, cea, ETH zürich, cnrs, cea, Yale University, UNSW, MIT, TU Delft, cea, Universität Stuttgart, cnrs, University of OXFORD, cea, University of BRISTOL, universität wien, UNIVERSITÀ DEGLI STUDI DI MILANO, SAPIENZA, QuiX

Photons

= best physical mean for Qbit transmission

Silicon photonics

= low-cost, compact, scalable

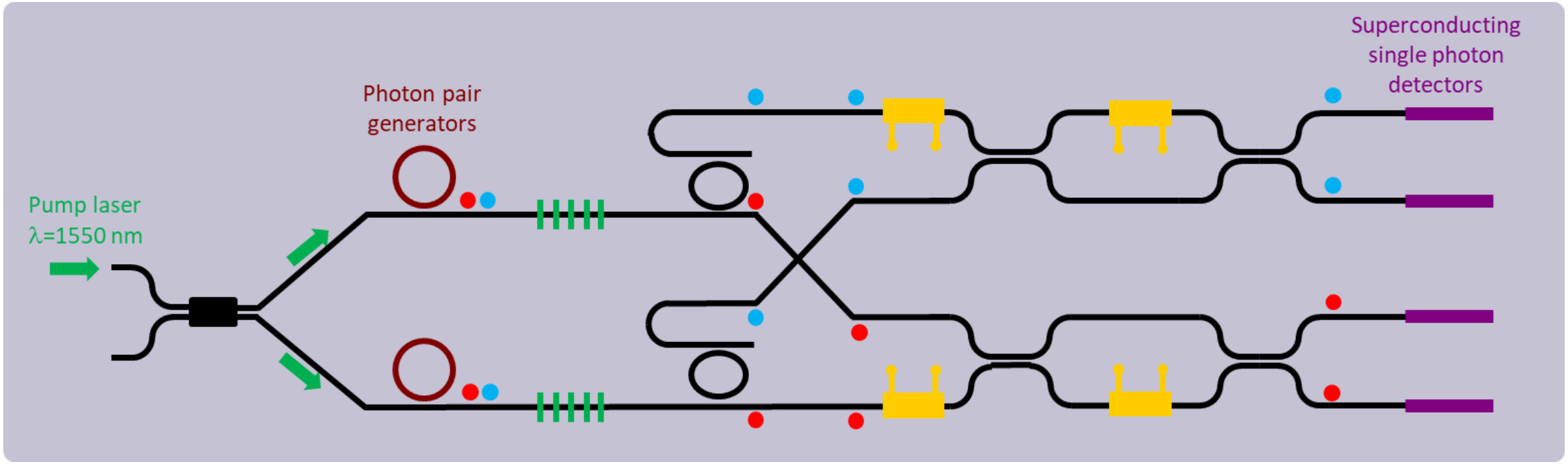
QUANTUM INTERNET

Quantum computing | Quantum communication

*source: www.oezratty.net

PERSPECTIVES

› Towards fully-integrated quantum photonic circuits on-chip



Single photon generation

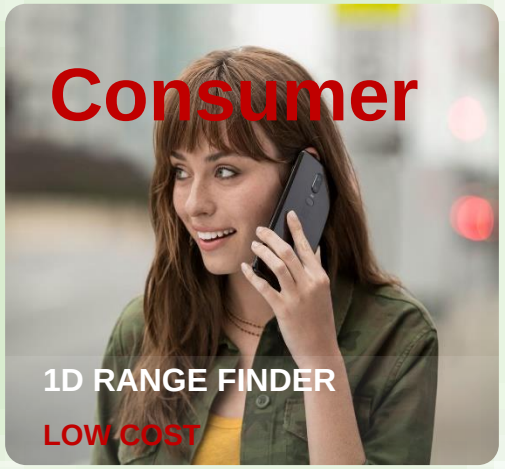
Photonic processing/encoding

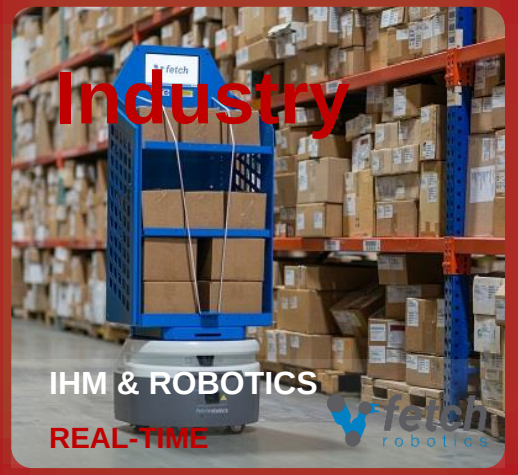
Single photon detection

Chip-scale LIDAR

TOWARDS SMART MINIATURIZED LIDAR – A PROMISING MARKET

LIght Detection And Ranging





SMART CHIP-SCALE LIDAR LETI PROGRAM

- **CEA-LETI HAS THE CAPABILITY TO MAP THIS STRATEGY**

TECHNOLOGIES

SYSTEM

CPS

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

Optical source

Beam steering

Optics (Tx, Rx)

3D Sensor

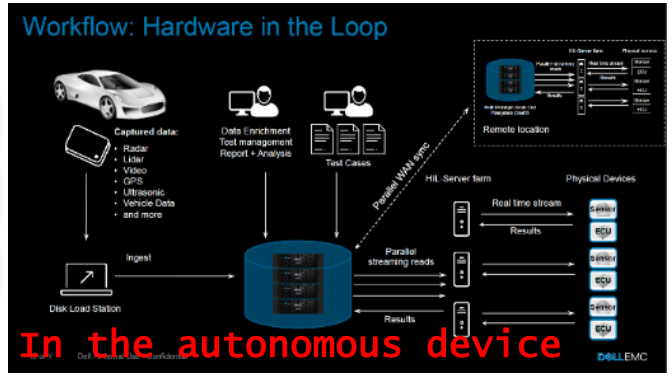
System integration

Data processing

AI

RF

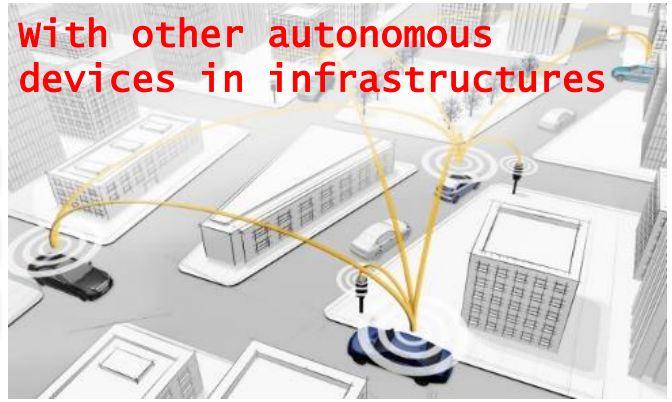
SLAM



V2I

V2V

...



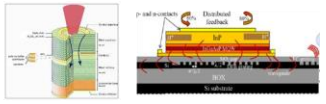
SMART CHIP-SCALE LIDAR LETI PROGRAM

- LETI HAS THE KEYS TO CRACK THE CODE OF A LOW COST CHIP-SCALE LIDAR

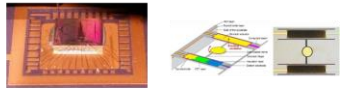
PHOTONICS

LOW COST TECHNOLOGIES & INTEGRATED ON CHIP

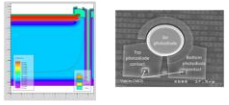
SOURCE LASERS



BEAM STEERING OPA / MEMS µMIRROR

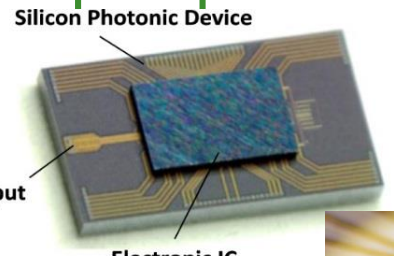


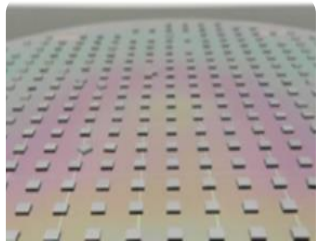
RECEIVER III-V, SI, GE PIN, APDS, SPADS

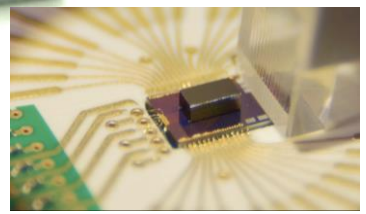


ELECTRONICS

HETEROGENEOUS INTEGRATION & 3D ASSEMBLY WITH ELECTRONICS

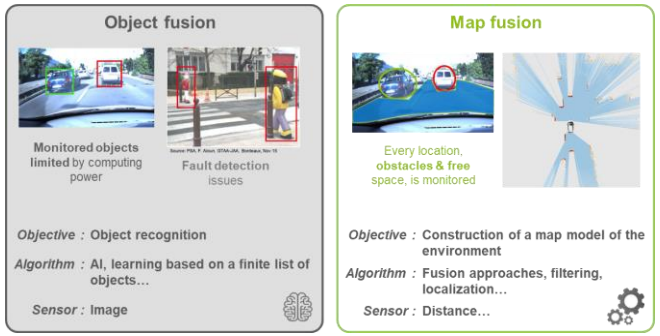






SOFTWARE

OPERATION DERIVED FROM DATA FUSION & AI



SteerLight

Chip-scale Si-photonics FMCW LiDAR

3D vision for safer & smarter mobility

High-volume scaling
Targeted cost 100's $

Manufacturing in std semiconductor fabs

Highly compact
Target volume < 100 cm^3

On-chip LiDAR system with Si Photonics

Highly robust

High immunity to sunlight & other LiDARs

Highly reliable
Targeted duration > 10 years

No moving part & on-chip calibration

High performance
Targeted range 200 m

Coherent detection in mid-infrared

On-chip optical sensing for particle matter detection

CONTEXT

› Air pollution: a silent killer

9 out of 10 people worldwide breathe polluted air.
#AirPollution

Air pollution is a major environmental risk to health.
By reducing air pollution levels, countries can reduce:

Every year, around
7 MILLION DEATHS
are due to exposure from both outdoor and household air pollution.

World Health Organization

© wanchanta – Fotolia/CEA3

SENSING CHALLENGES

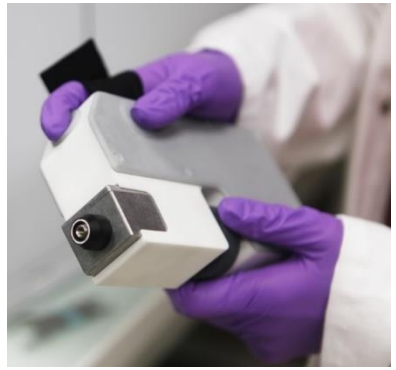
› Get laboratory closer to the user

Miniaturized sensors and systems

Portable

Low cost

High performances

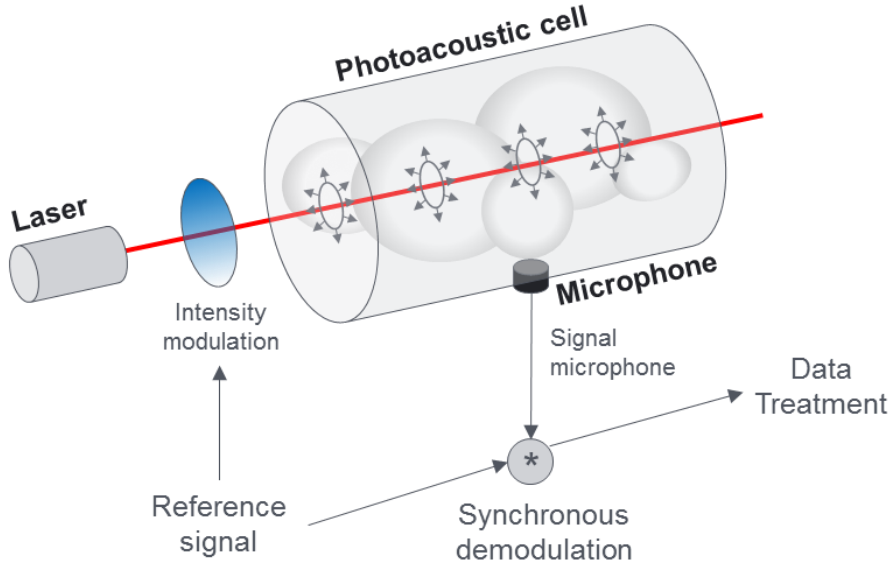


A. Enel *et al* “A microfluidic device for digital manipulation of gaseous samples”, *Lab on a Chip*, 20 (7), pp. 1290-1297 (2020)

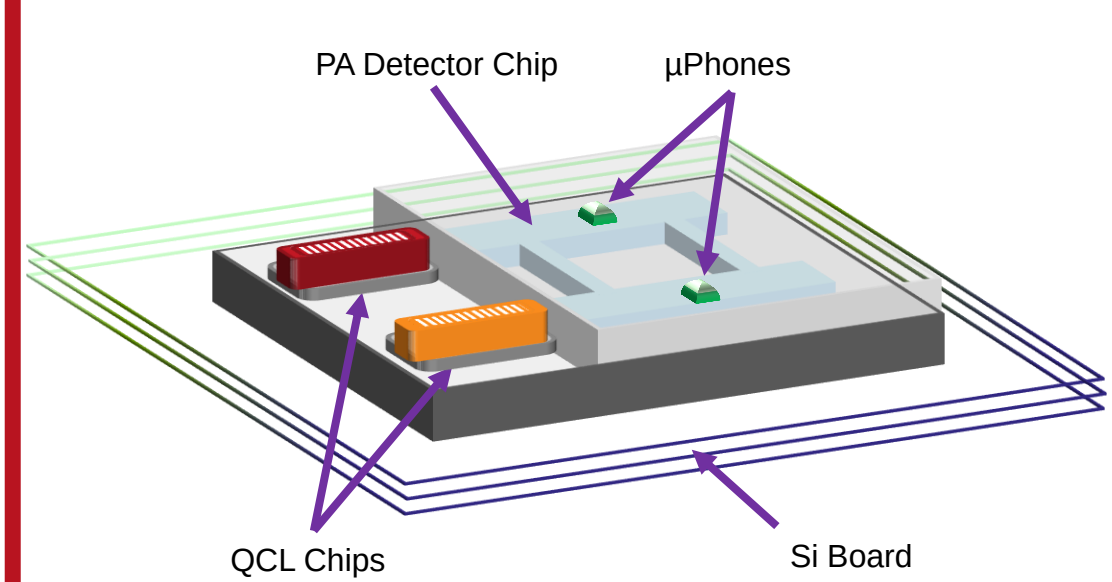
T. H. Chappuis *et al* “Miniaturization of breath sampling with silicon chip: application to volatile tobacco markers tracking”, *J. Breath Res.* **12** 046011 (2018)

FULLY INTEGRATED SI-PHOTOACOUSTIC SENSOR

› A game changer



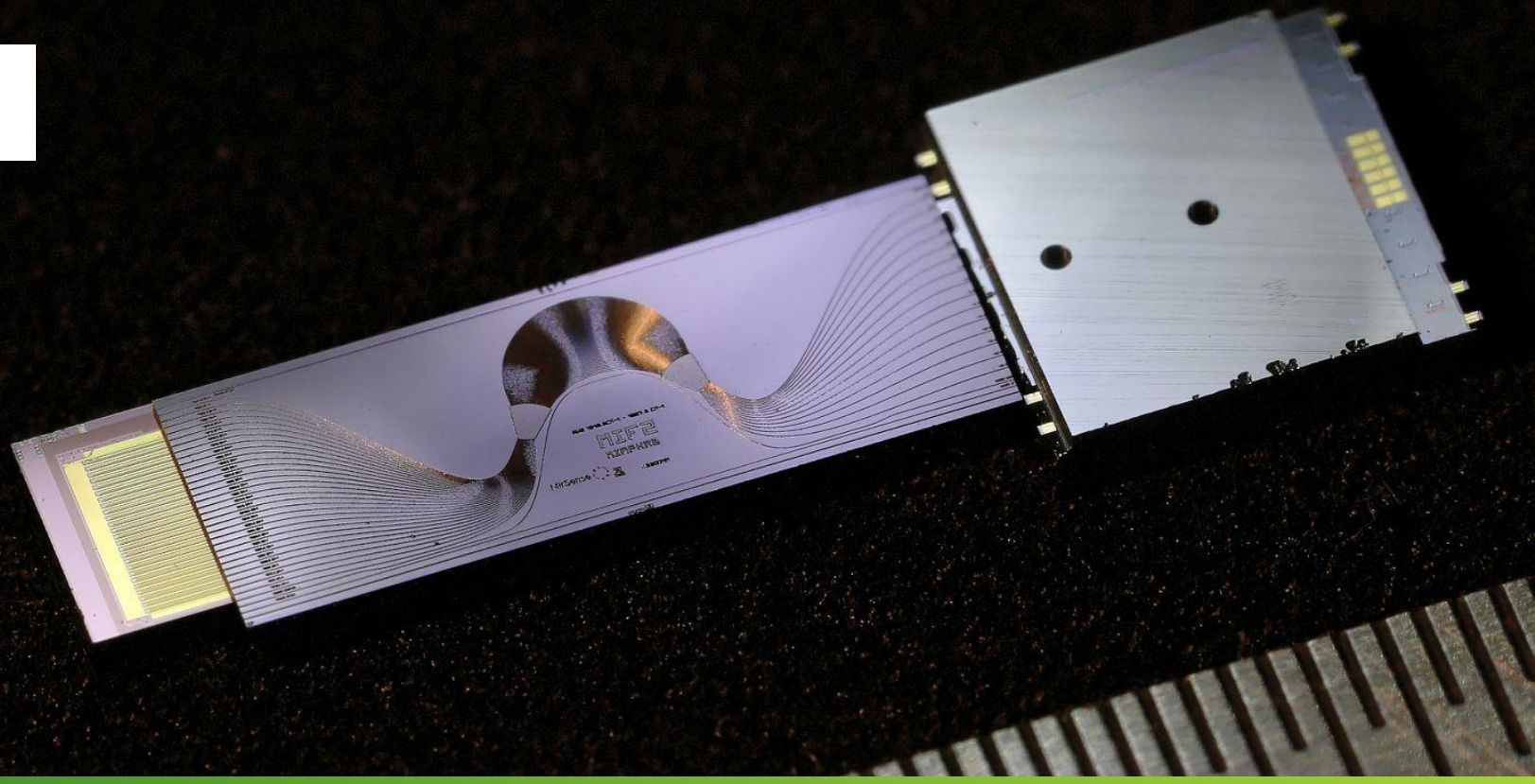
Photoacoustic detection technology



Fully integrated silicon photoacoustic sensor

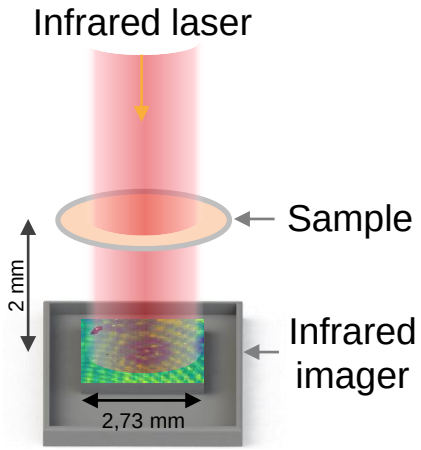
Optical integrated solutions for highly-accurate air-quality information

- Sub ppm detection limit
- Large dynamic range
  10 ppb – 10 ppm
- Identification / discrimination of chemicals
- Small-size analyzer

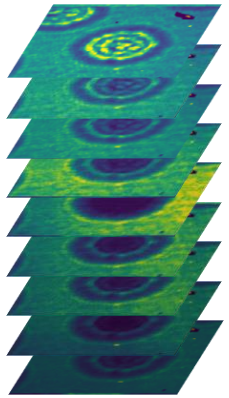


MEDICAL DIAGNOSIS

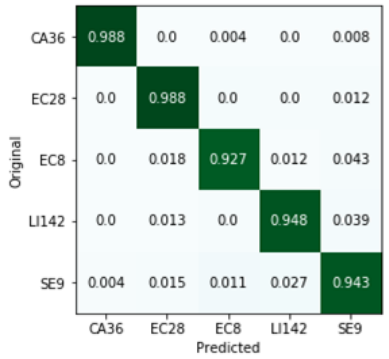
› Multispectral mid-infrared imaging



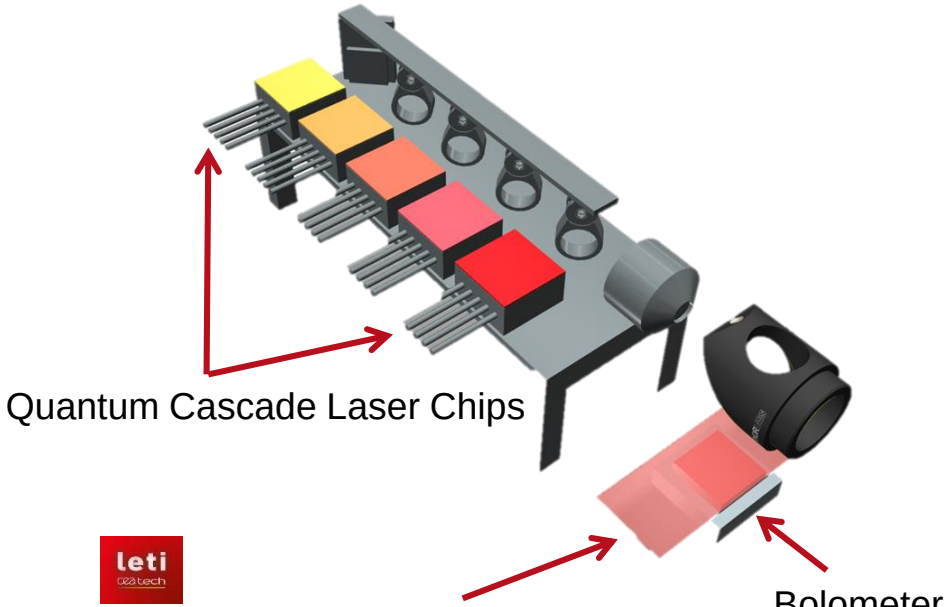
Acquisition



Multispectral stack

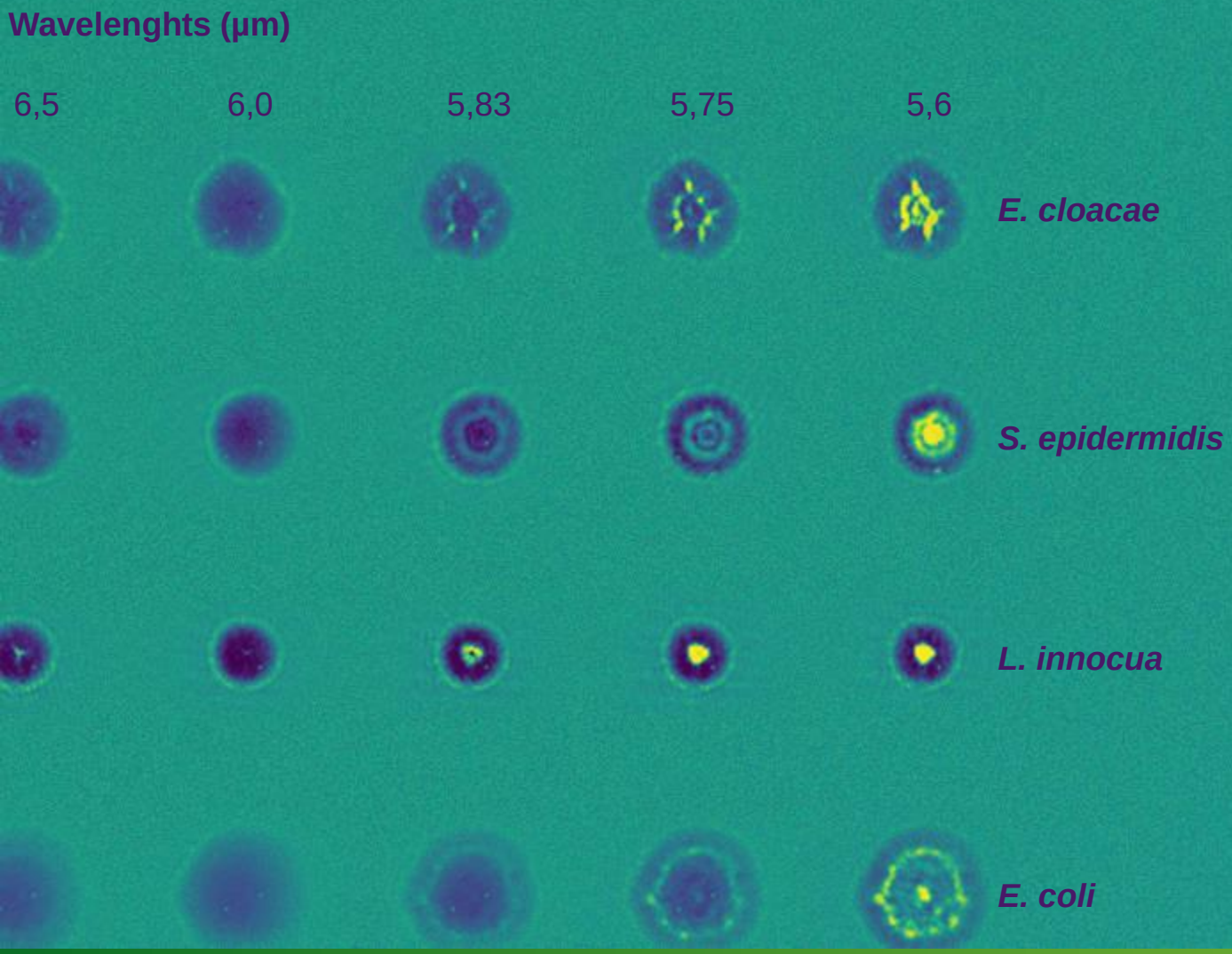


Species prediction
by machine learning



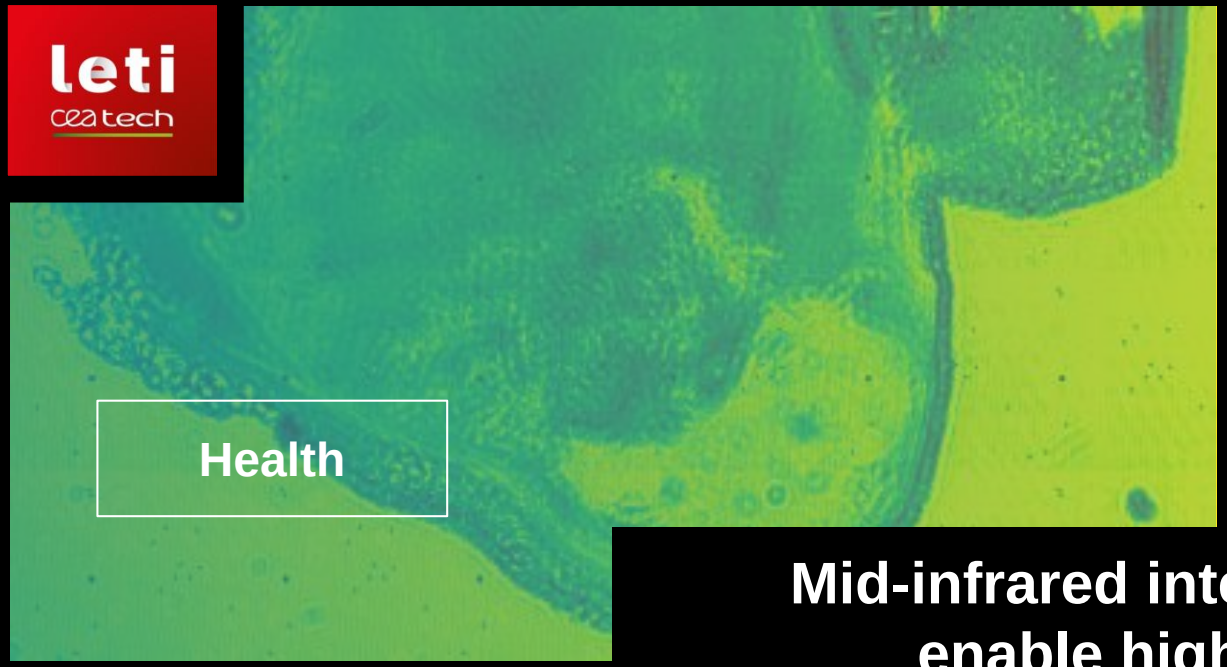
Miniaturized mid-infrared imaging system

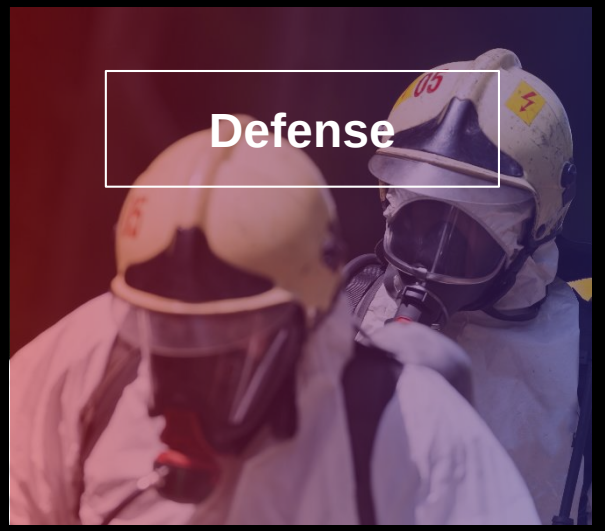
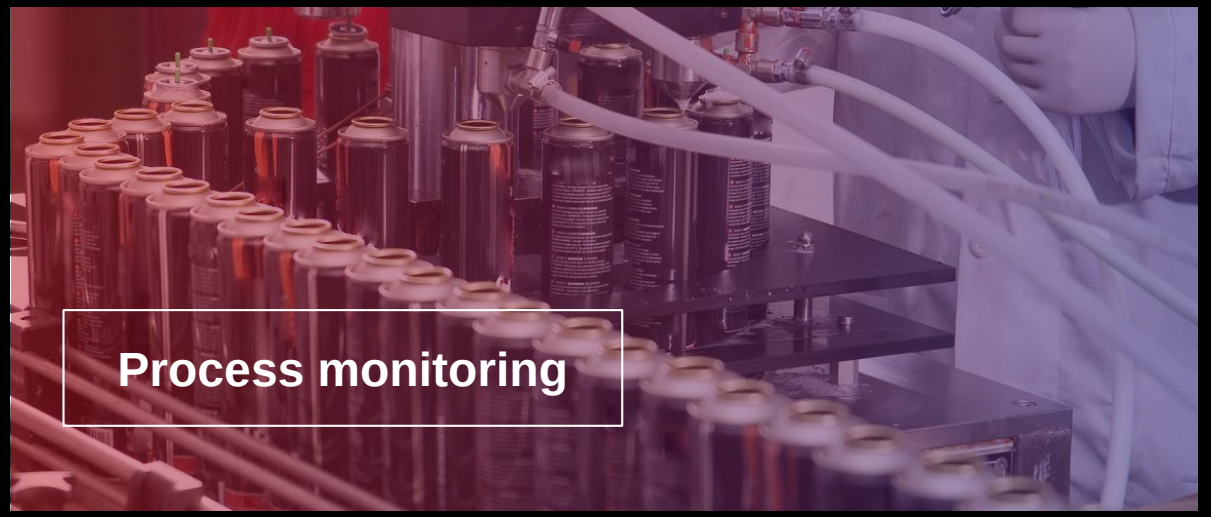
Le Galudec et al. "Mid-infrared multispectral lensless imaging for wide-field and label-free microbial identification", Proceedings of SPIE (2020)



Cross biochemical & morphological information with mid-infrared imaging

- Bacteria analysis (strain level)
- Cancerous tissue analysis
- No labeling
- Fast, lower cost, large field
- Miniaturized lab. system





Mid-infrared integrated Photonics
enable higher specificity
cost effective miniaturized sensors & systems
Various application fields