DE LA RECHERCHE À L'INDUSTRIE

THz real-time cameras

Uncooled antenna-coupled bolometer array technology for real-life applications

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The CEA et a glance

energie atomique • energies alternatives

is one of the largest research organizations in Europe, focused on energy, health, information technologies, and national defense

>16,000 **People** (10% PhD and Post Doc)

10 **Research centers**

CEA DRT: Leti-List-Liten business units

leti

1800 personnes - 250 M€

Laboratory of Electronics and Information Technologies

Micro-nanotechnologies and their integration in systems

list

800 personnes - 90 M€

Laboratory of Integrated Systems and Technologies

Software-intensive systems

liten

1000 personnes - 160 M€

Laboratory of Innovation for new Technologies for Energy and Nanomaterials

New energy technologies and nanomaterials

t echnologies

l aboratories

Research Technology Organisations in EU

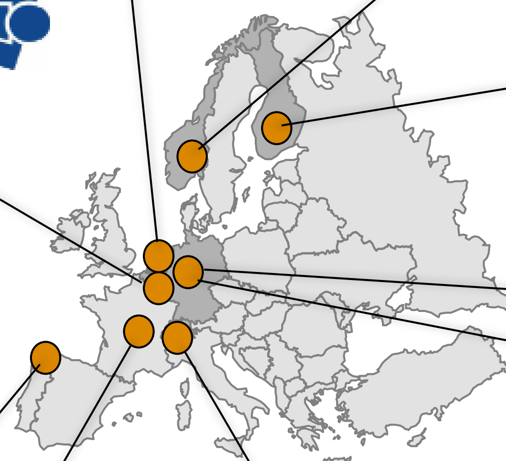
TNO
512 M€
3 833 pers.

SINTEF
315 M€
2 100 pers.

SINTEF

IMEC
270 M€
1 664 pers.

imec



VTT
247 M€
2 700 pers.

VTT

FZK
396 M€
3 580 pers.

KIT

Forschungszentrum
Karlsruhe

FhG
1 500 M€
17 000 pers.

Fraunhofer

tecnalia
Corporación Tecnológica

TECNALIA
140 M€
1 700 pers.

CSEM
45 M€
390 pers.

csem

DRT
500 M€
4 500 pers.

Leti-List-Liten in France

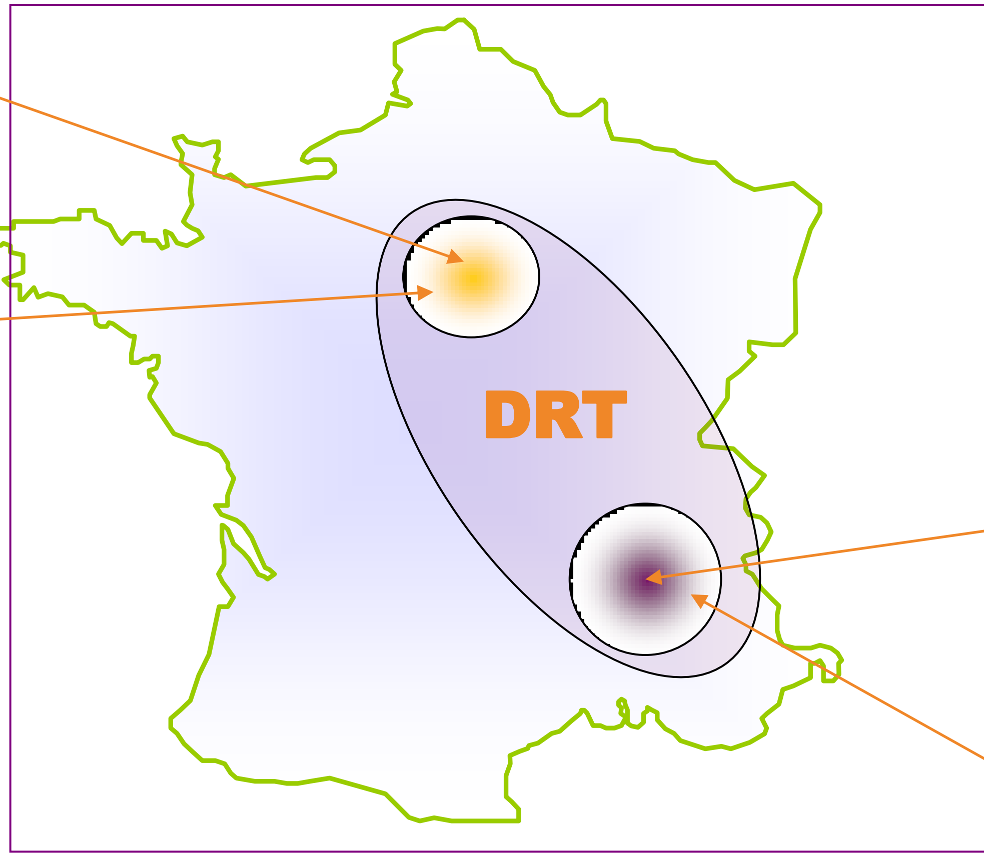
CEA-Saclay

digiteo labs

Recherche en sciences et technologies de l'information

CEA-Fontenay-aux-roses

list



CEA-Grenoble

leti

liten

MINATEC®

Chambéry

ines

INSTITUT NATIONAL DE L'ENERGIE SOLAIRE

DE LA RECHERCHE À L'INDUSTRIE

CEA-Leti at a glance

Founded in 1967 as part of CEA

1,700 researchers

210 PhD students + 30 post PhD
with 85 foreign students (35%)

CEO
Dr. Laurent Malier

Over 1,880 patents

273 generated in 2011
40% under license

250 M€ budget

~ 30M€ CapEx

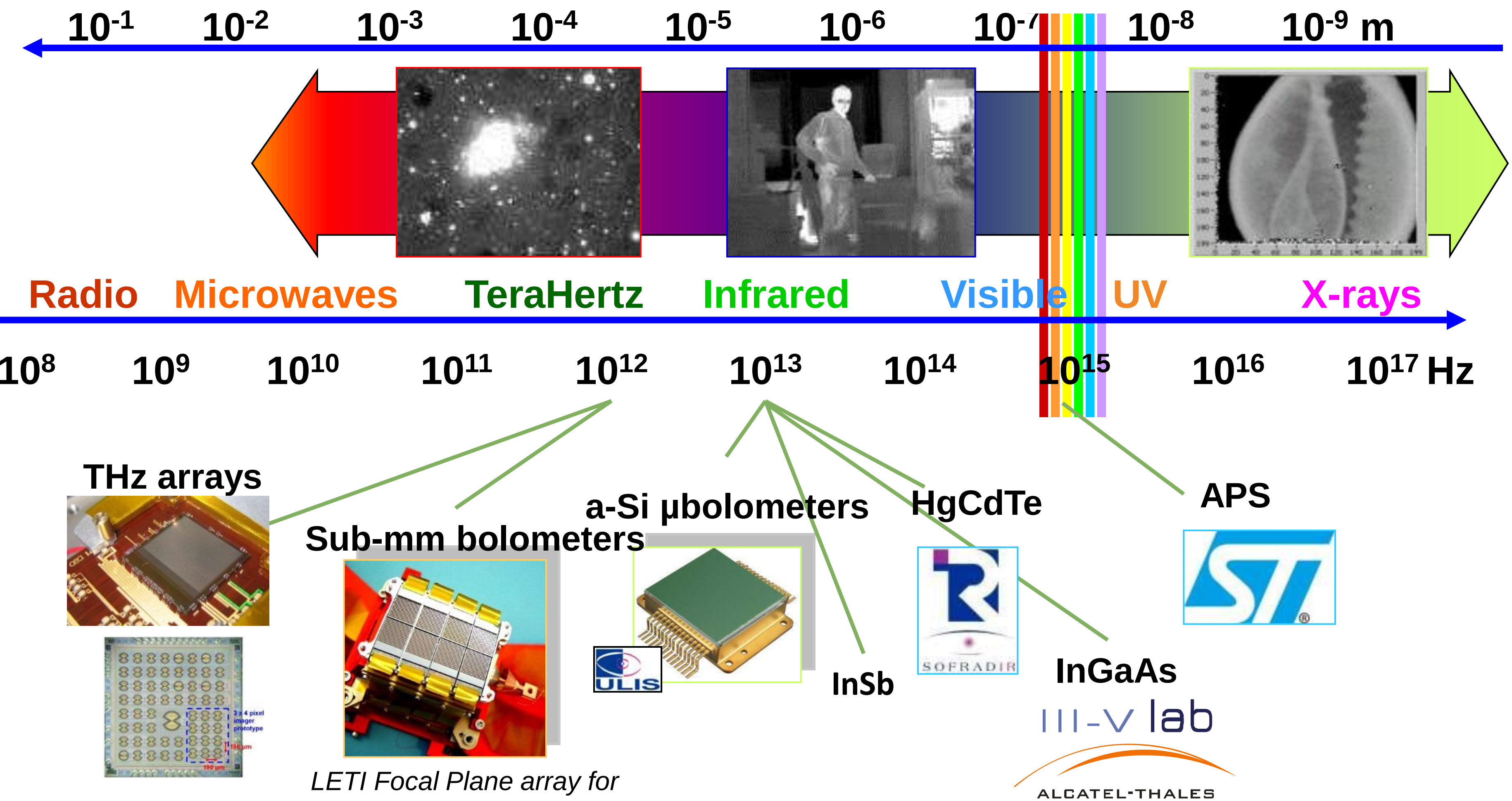
50 start-ups
& 365 industrial partners

cea

PHOTONICS DIV. : IMAGING DETECTORS

Covering a wide spectral range

280 people



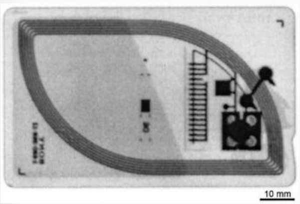
LETI Focal Plane array for ESA Herschel satellite

Terahertz imaging

- Market requirements for volume applications

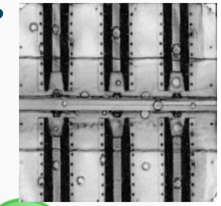
Industry

Plastic card NDT



A. Dobroiu et al., Applied Optics 43, 5637-5646 (2004).

NASA shuttle foam



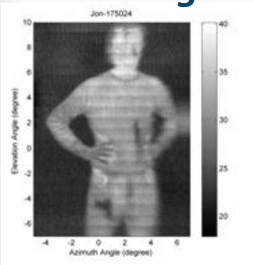
Karpowitz, APL, Vol. 86 (2005)

Antenna radome

W. Köhler, Proc. of European Conference of NDT, P181, (2006)

Security

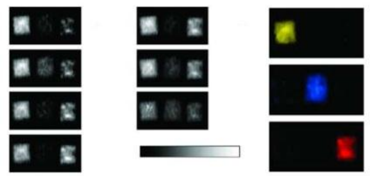
Body scanning



E.N. Grossman et al. ICEAA (2009)

Navigation assistance

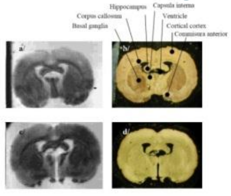
Mail screening



K. Kawase et al., Opt. Expr. 11 (2003)

Health

Cancer diagnosis

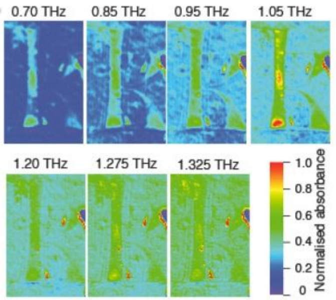


Darmo et al., Optics Express 12 (2004)

Pharmaceutical control

- Reduced acquisition time
- Simplified optics – Limited scanning
- Compactness
- Easy-to-use
- Reliable
- Low cost in fabrication & operation

Art



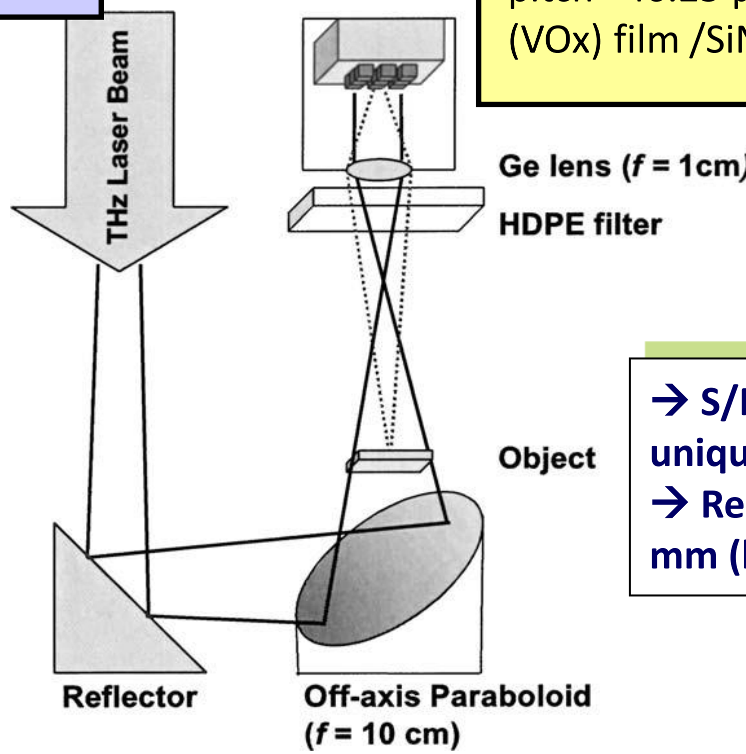
K. Fukunaga et al., IEICE Elec.Expr. 5, (2008)

THz 2D images with standard IR µbolometer FPA

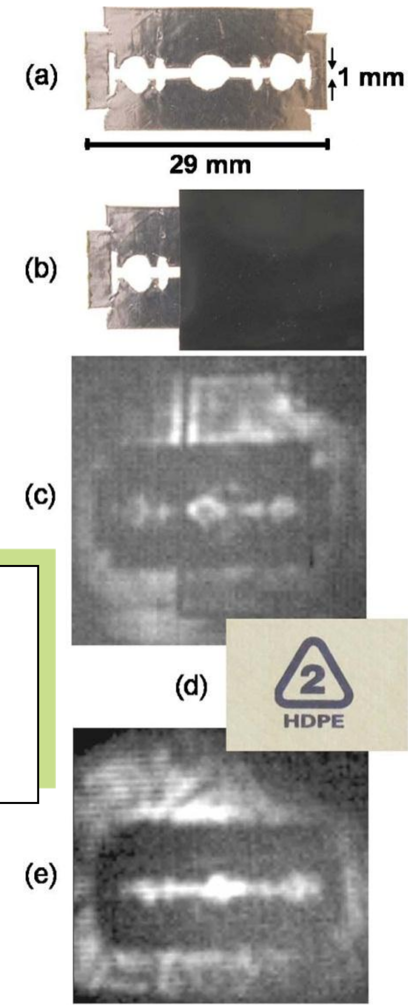
room-T 2.52 THz pumping CH_3OH vapor with a CO2 laser → Pout~10 mW

MIT, 2005

160x120 µbolometer FPA
(BAE)
pitch =46.25 µm
(VOx) film /SiN air bridge



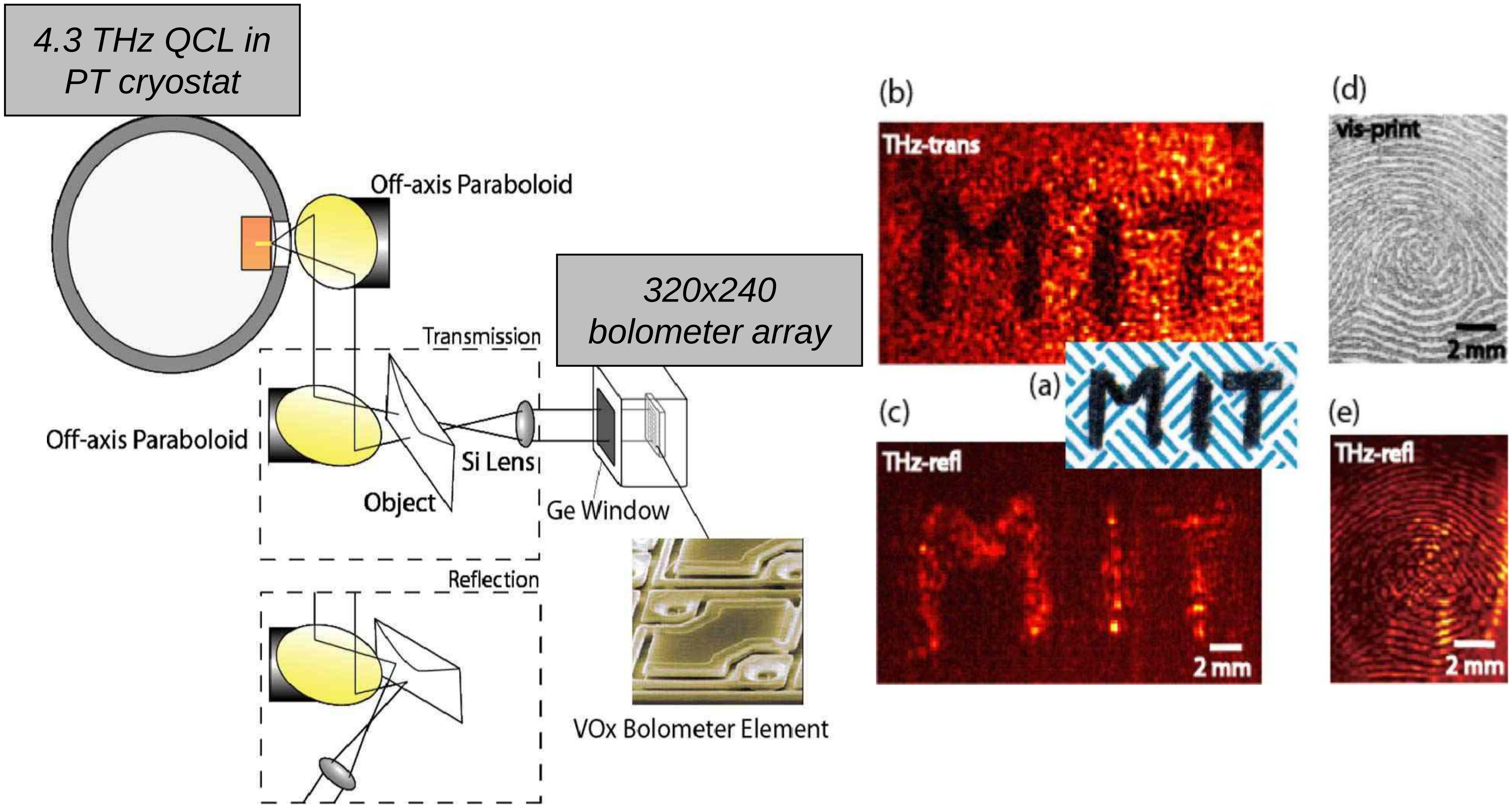
→ S/N ~ 13dB for unique frame
→ Resolution ~ 1,5 mm (limited by lens)



« Real-time, continuous-wave terahertz imaging by use of a microbolometer_FPA », Lee & Hu, October 1, 2005 / Vol. 30, No. 19, Optics Letters 2005

THz 2D images with standard IR µbolometer FPA

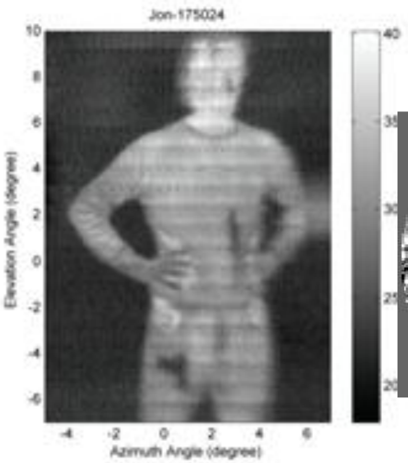
MIT, 2006

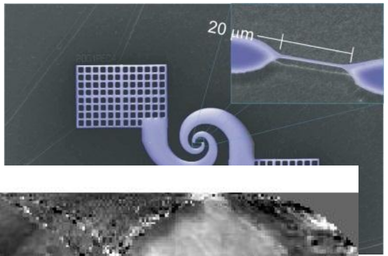


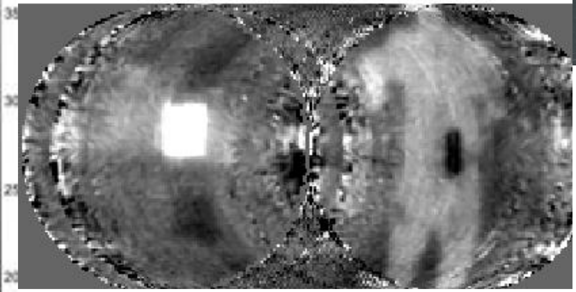
Lee, A. W. M., Williams, B. S., Kumar, S., Hu, Q. and Reno, J. L., "Real-Time Imaging Using a 4.3-THz Quantum Cascade Laser and a 320x240 Microbolometer Focal-Plane Array", IEEE Photonics Technology Letters, 18(13), 1415-1417 (2006).

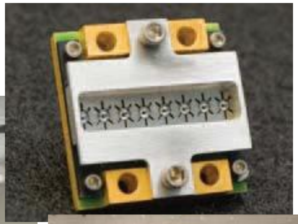
Ex. (very) cooled real-time THz cameras (1D array)

- **4K NbN bolometers at 0.6THz (VTT-NIST)**









4K cooled

- **4K NbN bolometers at 0.6THz (FhG Jena, Ge)**

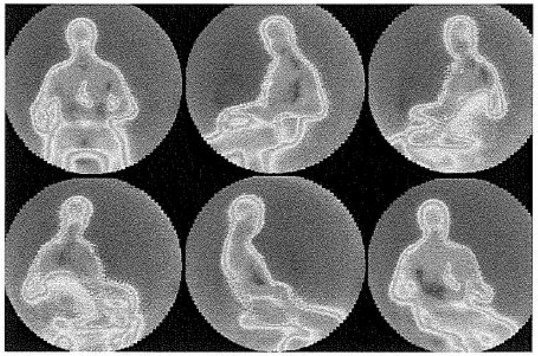


Fig. 5. Freeze images of a person sitting on a lab chair, with a handgun mock-up hidden underneath its clothing. The images have been taken from a movie with 4 Hz frame rate.

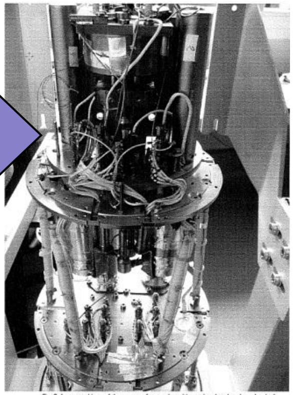
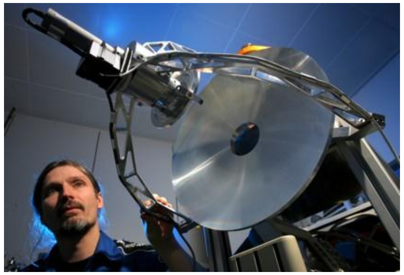
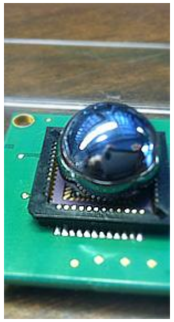


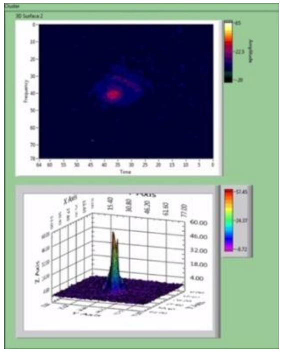
Fig. 3. Inner workings of the cryogen-free cooler with receiver head and mechanical stabilizers.



Ex. uncooled real-time THz cameras (2D arrays only)

- **Traycer (US)** 80x64 ou 100x100, 0.6 – 1.2 THz



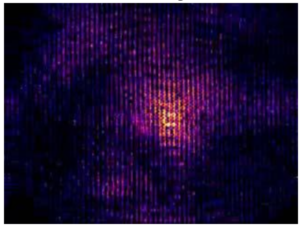


- **INO (Canada)**

160x120 pixels, NEP<70pW @3THz

- **Agiltron (US)** 130x190, 1-10THz

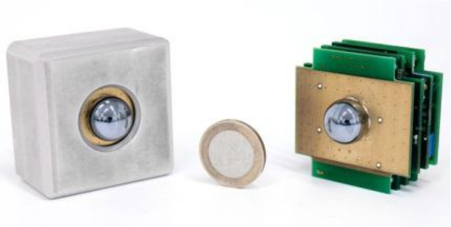
Heterostructure Backward Diodes hybridized on CMOS ROIC



- **NEC (JP)**

320x240, NEP<100pW @4THz

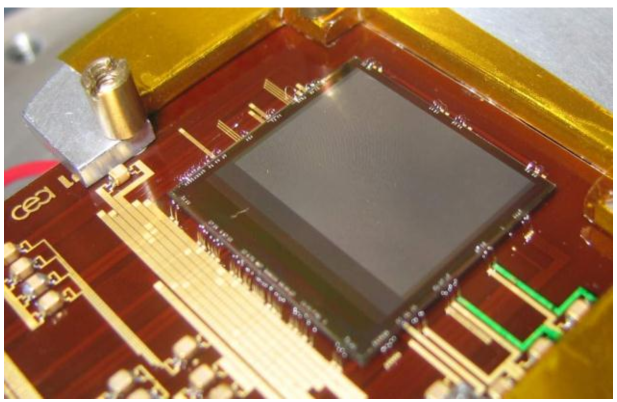
- **Univ Wuppertal-IEMN-STm (Ge-Fr)**
  FET CMOS 32x32, 7nW / pixel @0.9THz



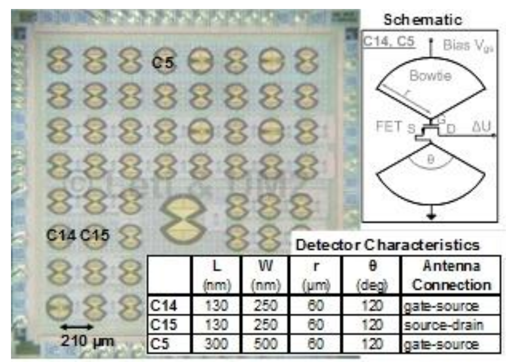
2 complementary technologies

Both operate at ambient temperature (no cooling system) and exhibit sensitivity in the order of few pW.

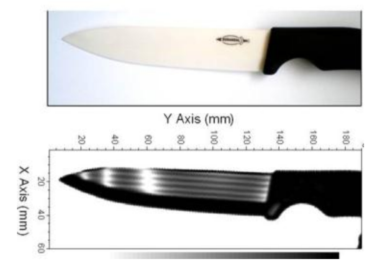
1.Bolometer large array real-time camera	2. CMOS antenna-coupled FET array direct direct detection camera
High level maturity on large focal plane array imaging with real-time imaging capabilities mainly in the high frequency range, i.e. the QCL operation spectrum.	FET CMOS detectors imaging demonstrated for smaller arrays size and with sensitivity lowered as frequency rises Advantage of very short relaxation time and suitability for heterodyne detection.



320x230 pixel real-time video sequence demonstrated in [1.5-3.5THz]



	L (nm)	W (nm)	r (µm)	θ (deg)	Antenna Connection
C14	130	250	60	120	gate-source
C15	130	250	60	120	source-drain
C5	300	500	60	120	gate-source



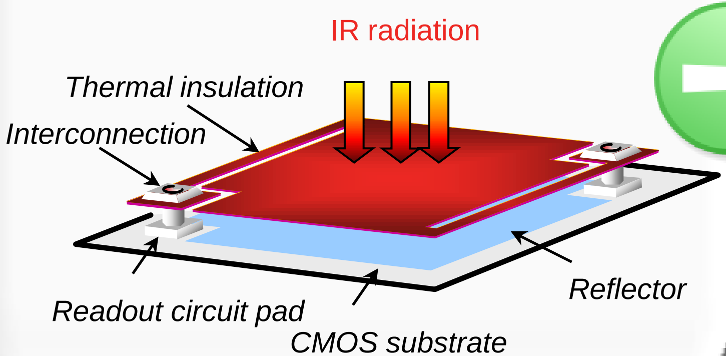
0.3THz

Imaging demonstrated between 0.3 THz & 1THz

Terahertz imaging

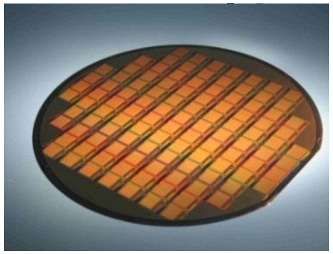
Bolometer array technology : relevent features

- Resistive amorphous silicon
- Std Si microelectronic flow chart
- Full CMOS compatible process
- Monolithic FPA: Retina+ROIC

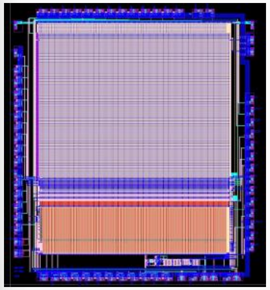


- Reduced acquisition time
- Simplified optics – Limited scanning
- Compactness
- Easy-to-use
- Reliable
- Low cost in fabrication and operation

- Room temperature operation
- Mature technology
- High yield in manufacturing



- 2D large arrays



- Real time FPA signal acquisition
- High performance CMOS ROIC(ASIC)

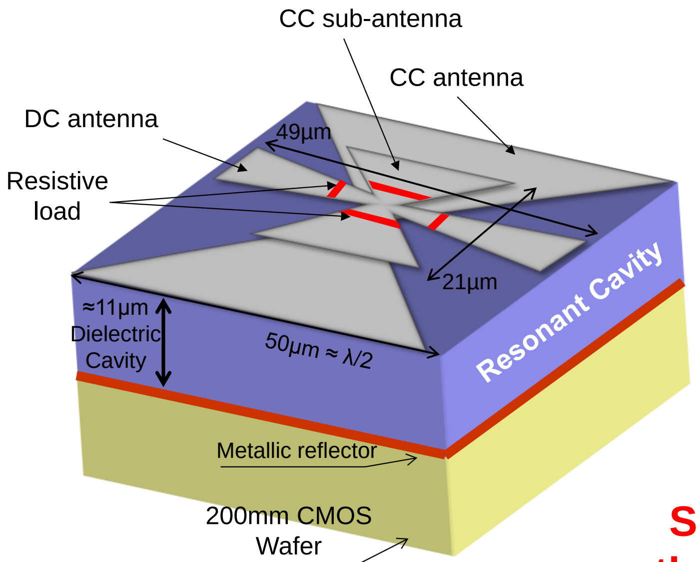
cea leti — Spin-off 2002 → ULIS

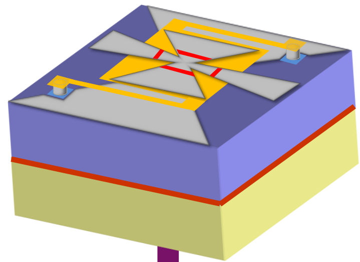
R&D in IRFPA since 90's

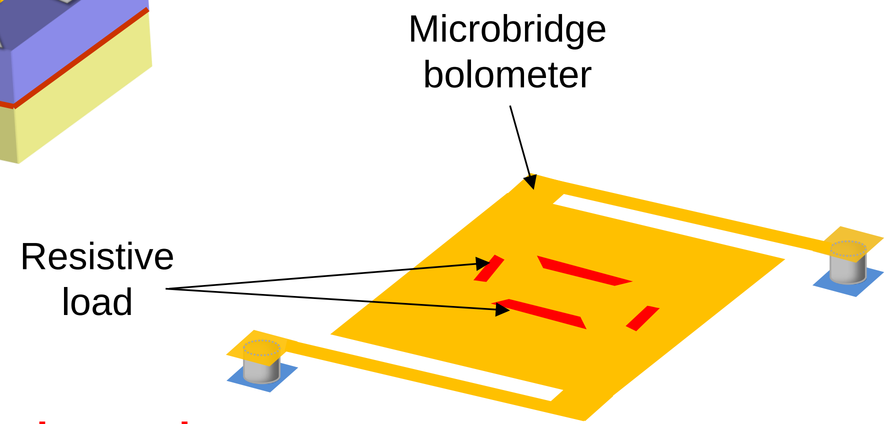
3rd leader in IR sensor market

LETI base technology patents

Innovative antenna-coupled µ-bolometer principle







Split of absorber and thermometer elements

- Cross-polarized bow-tie antennas
  - Direct coupling antenna
  - Stacked capacitive coupling antenna
- Quarter wavelength resonant cavity to enhance antenna gain
- Through–silicon Oxide Vias ensure CMOS connection
- Any frequency can be addressed by proper tailoring of antenna dimension and cavity

- IR bolometer based µ-bridge
- Size of bolometer independent of pixel pitch
  - Electro-thermal performances preserved
- Antenna current dissipated in resistive loads located within the membrane

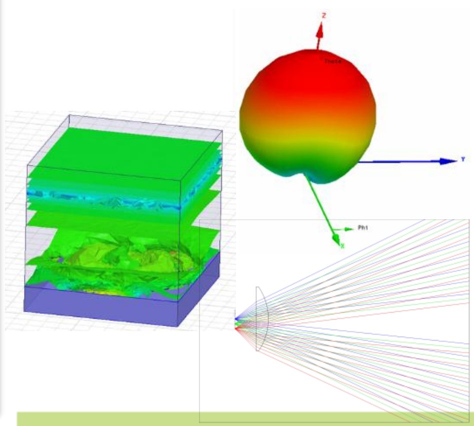
THZ BOLOMETER ARRAY AT CEA-LETI

LETI know-how: from modeling to image characterization

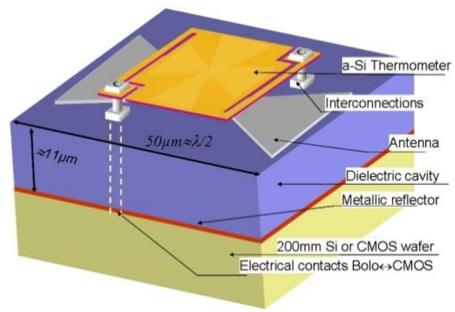
2D imaging sensor design at CEA-LETI

Sensor Pixel array

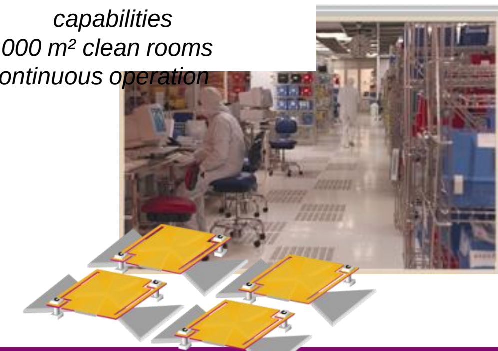
Modeling (EM, Optics, thermal)



Flow chart definition (+Technological R&D)

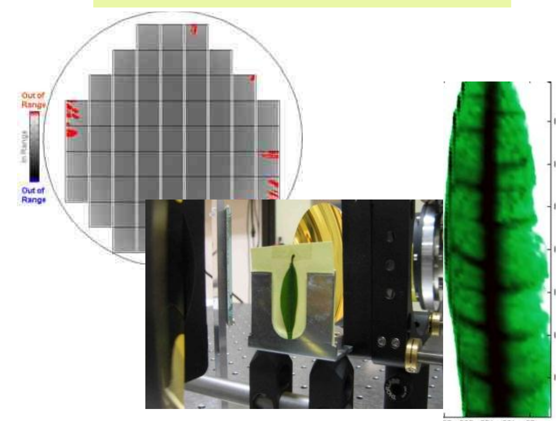


200 and 300mm Si capabilities
8,000 m² clean rooms
Continuous operation



Collective manufacturing above CMOS ASIC

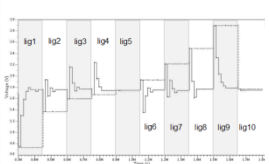
Characterizations



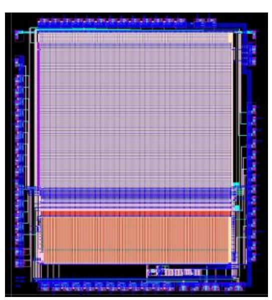
Read-Out-Circuit

Design & simulations of ASIC ROIC

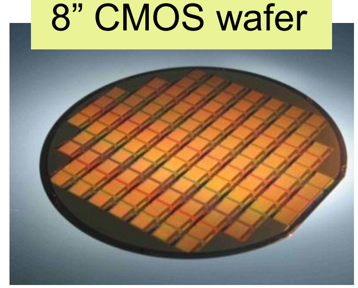
External fondry



ASIC layout

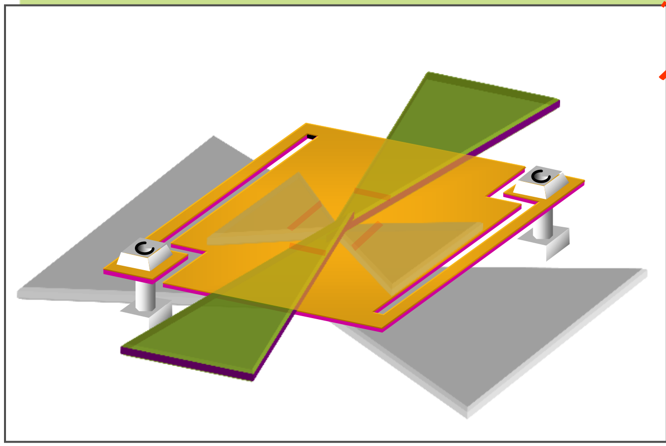


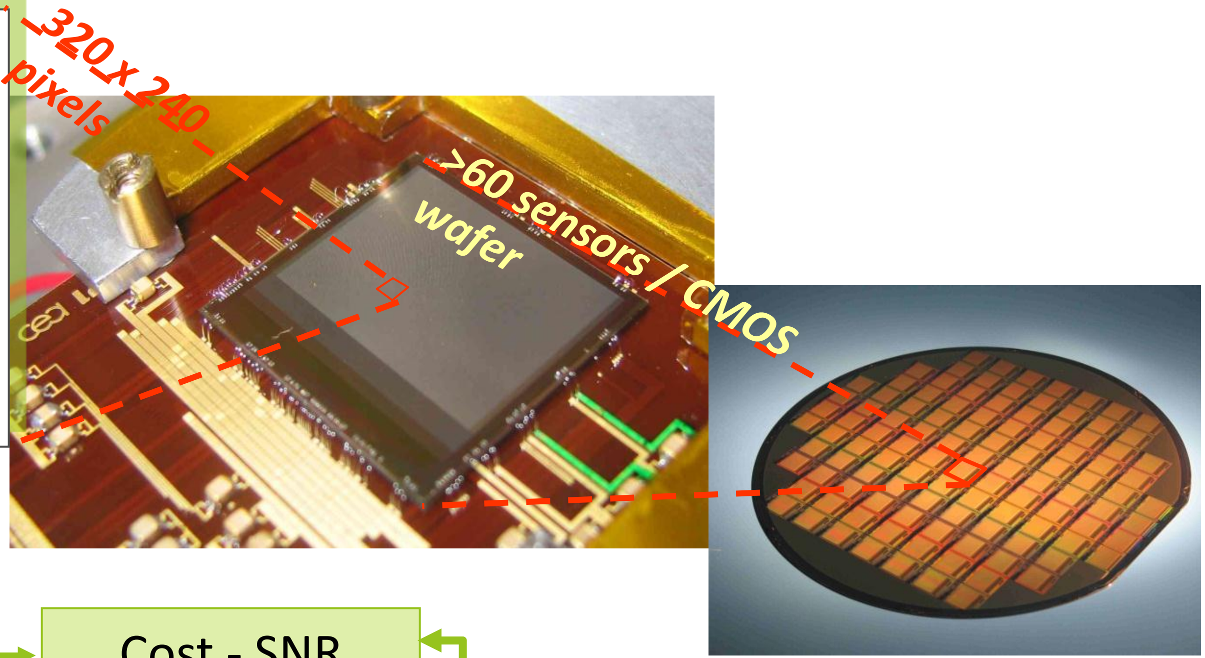
8” CMOS wafer



Uncooled THz imaging bolometer array

- Technological features





Innovative µbolometer pixel
(CEA-LETI patent)

Based on mature IR techno.

Operating at ambient temperature

Broadband spectral absorption

Cost - SNR compromise

Compact

2D FPA

Std Si microelectronic processes

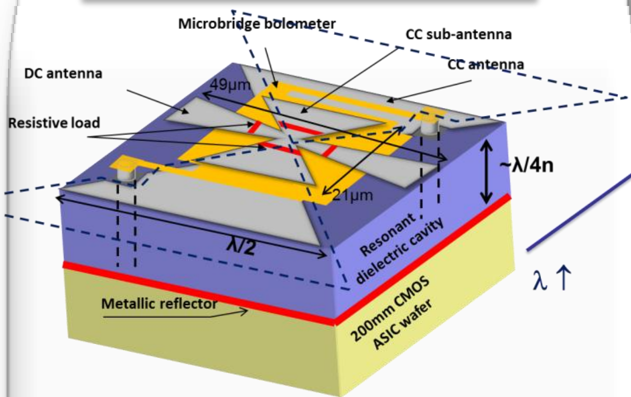
Monolithic 2D sensor

High speed processing (CMOS ASIC)

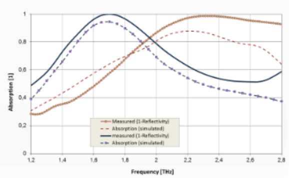
Uncooled THz imaging bolometer array

- Real-time imaging 2D arrays fabrication & tests

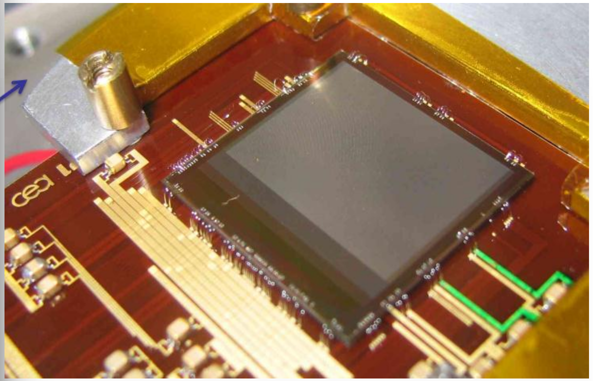
Innovative THz pixel



- Uncooled THz antenna-coupled microbolometers
- Standard µ-electronic processes
- Broadband spectral absorption



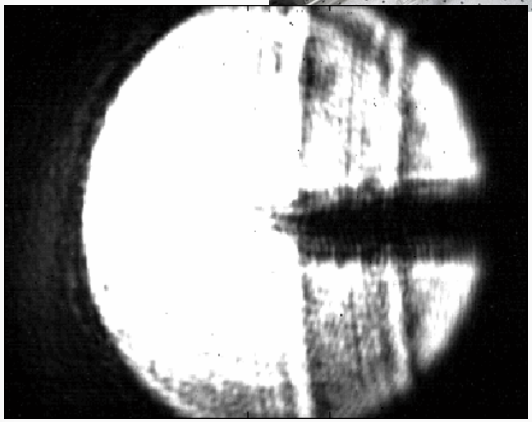
320x240 pixel FPA



- Process above IC
- Avanced image signal processing (CMOS ASIC)
- Monolithic 2D sensor
- 320 x 240 50µm pitch pixels : Sensitive surface =16x12mm²

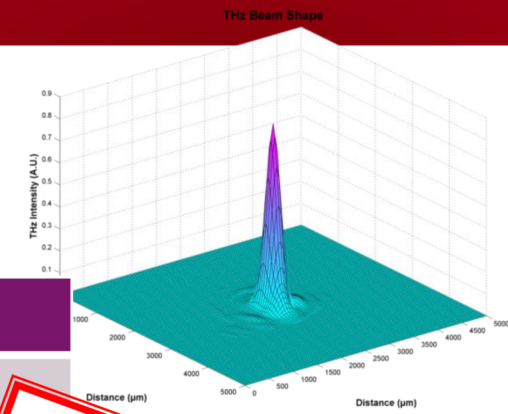
Imaging lab tests

- Transmission optical set-up



- Real-time video output
- Sensitivity in the pW range
- Room T Operation

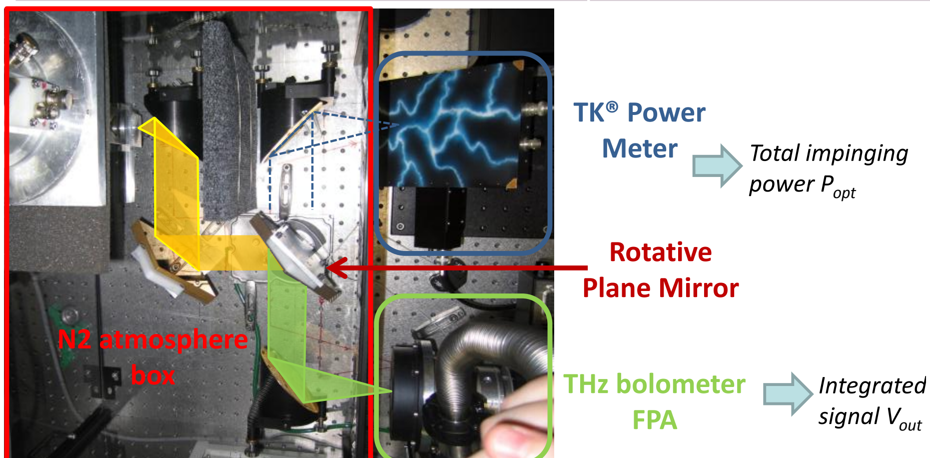
Uncooled THz bolometer array performance



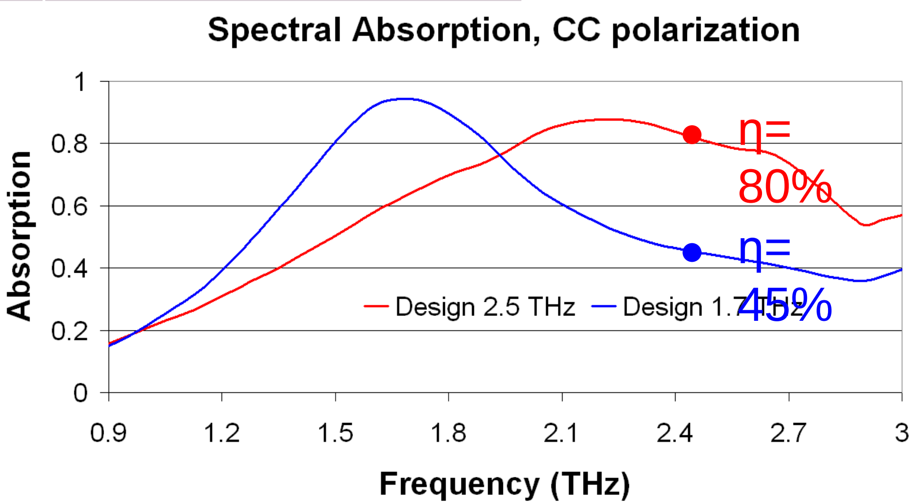
- Performances of 1.7 THz and 2.5 THz designs

	Design 1.7THz	Design 2.5THz
Responsivity	5.9 MV/W	12.6MV/W
FPA noise V_{noise}	400 µV (rms)	
Threshold detection power	68 pW	32 pW

Measured @ 2.5 THz

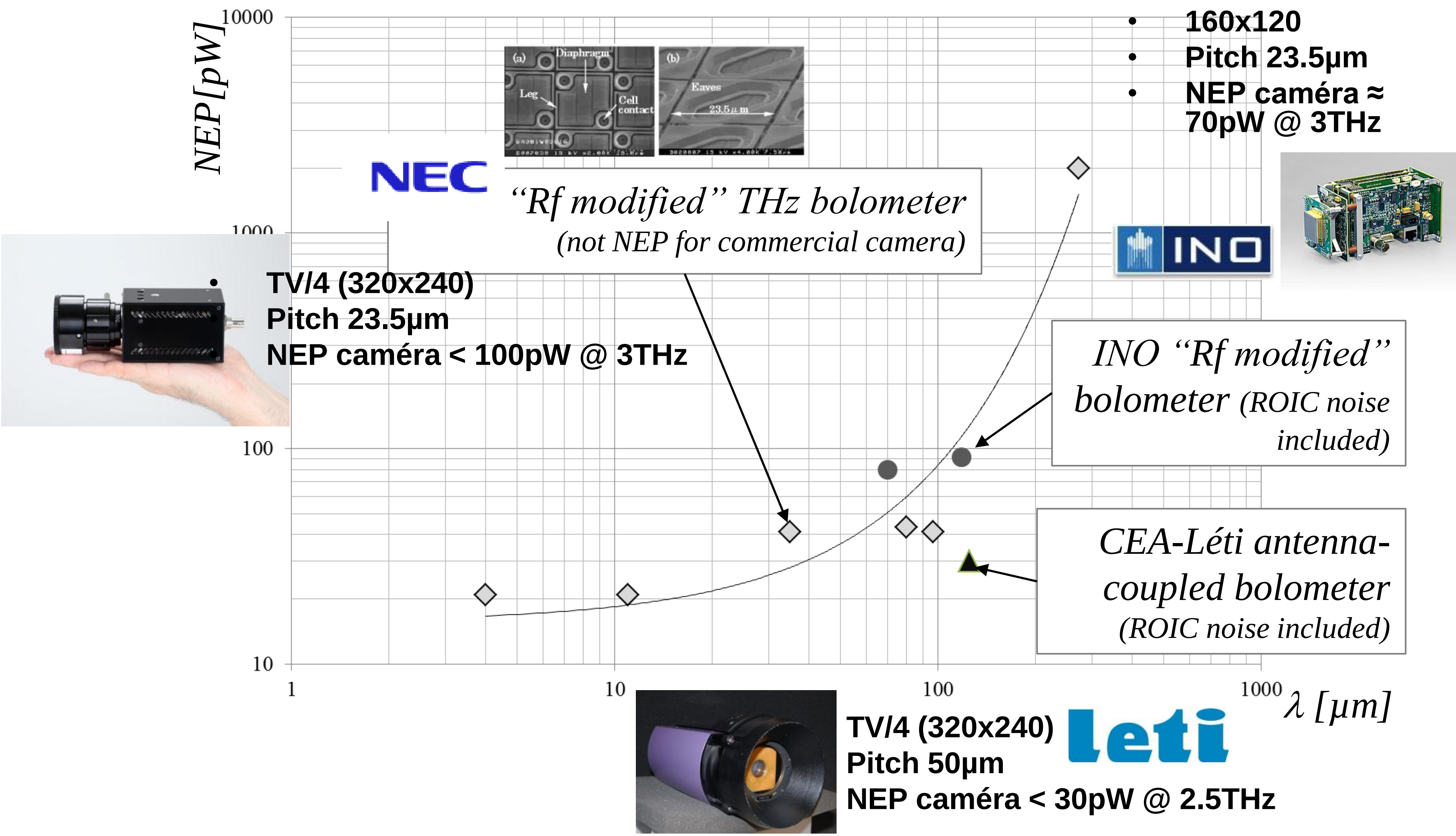


$$R_{THz}^{Popt} = V_{out} / P_{opt}$$



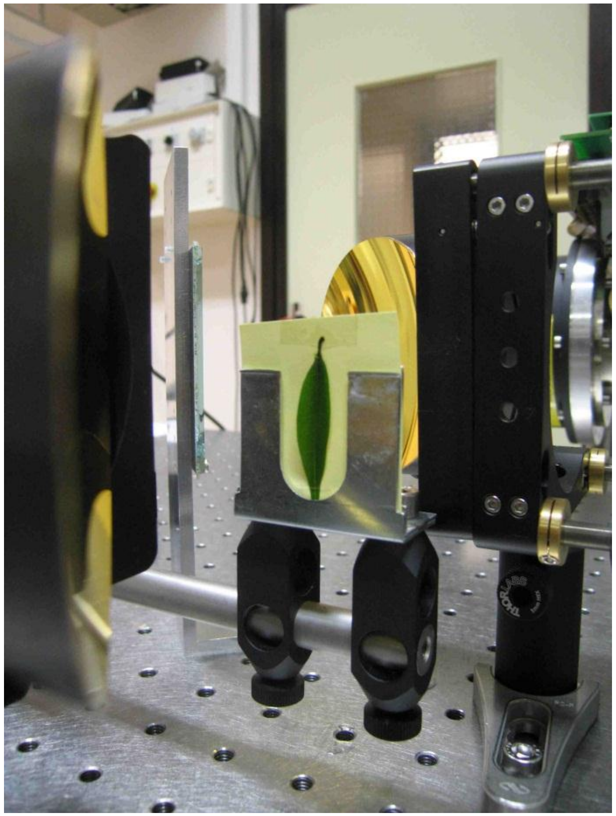
Leti – NEC – INO THz uncooled bolometer camera

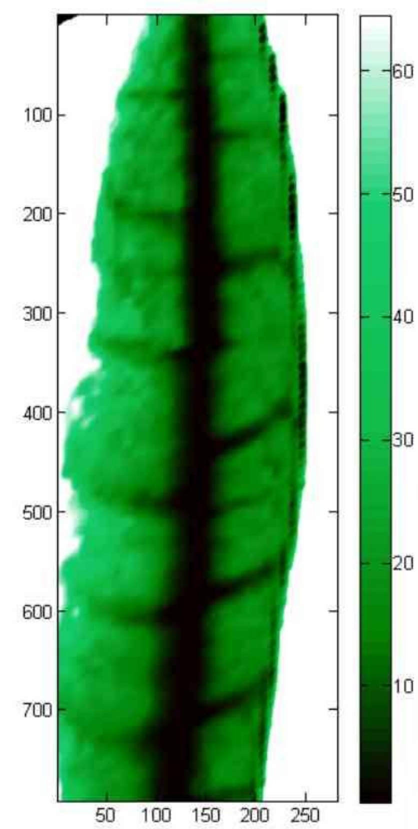
- Published NEPs



Imaging demonstrations

- Raster scanning image : tree leaf

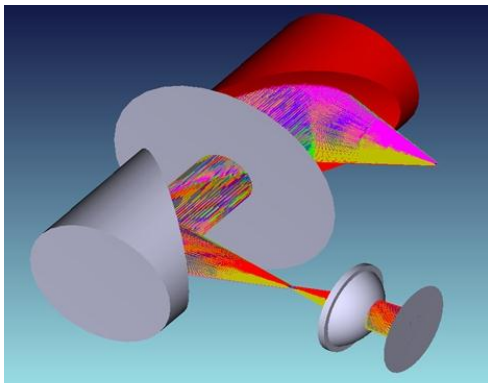


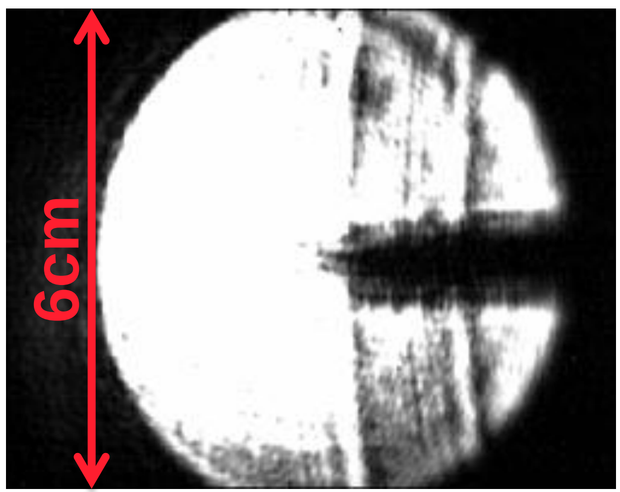


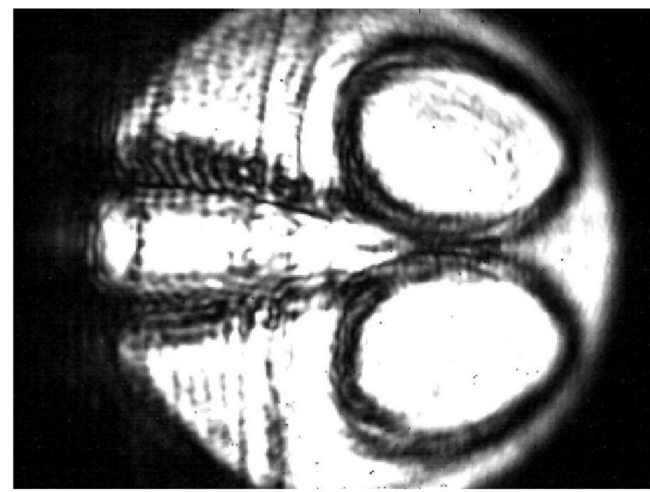
→ Humidity content imaging

Imaging demonstrations

- Real-time 2D imaging in transmission geometry: video of scissors concealed in an envelop

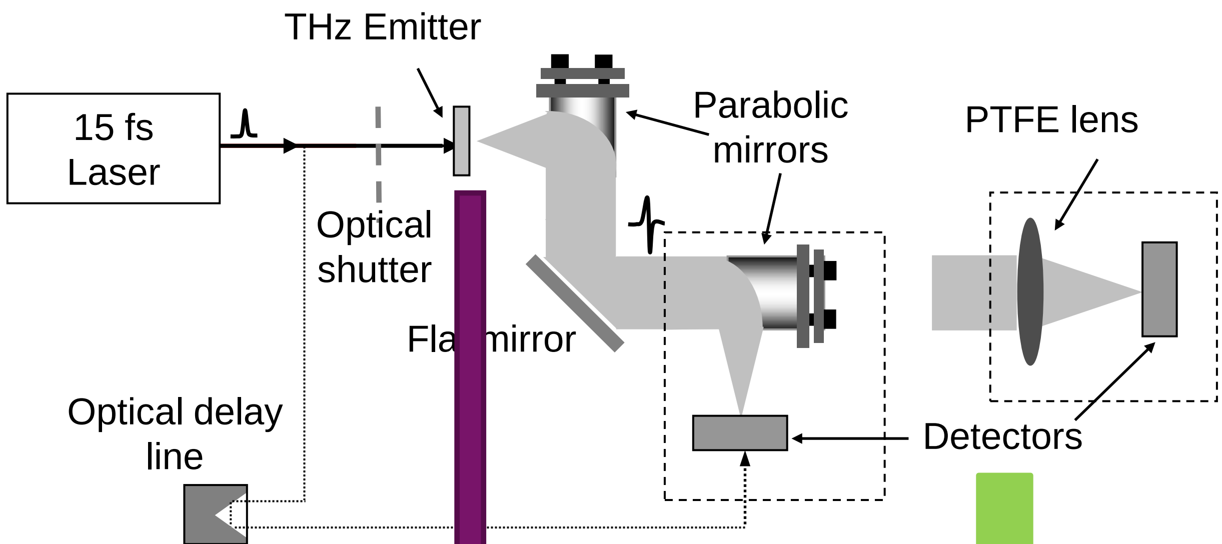






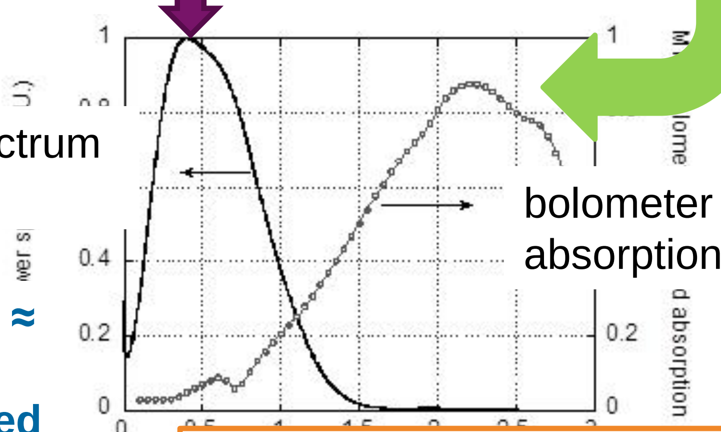
Imaging demonstrations

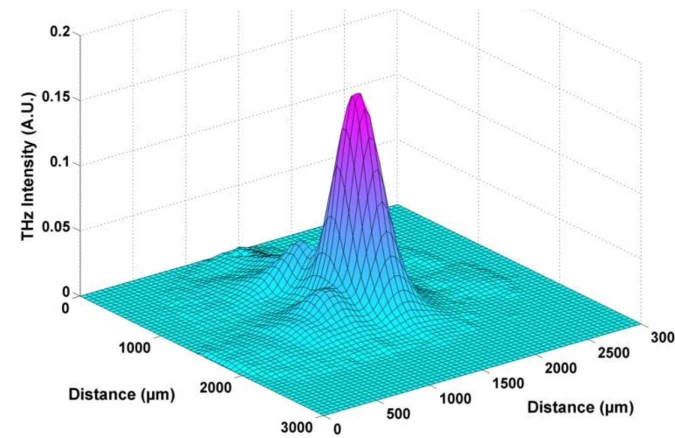
- Real-time imaging of THz TDS photoconductive emitter



Good SNR imaging is achieved

- Peak Voltage 332.5mV
- Background level noise 0.43mV
- SNR 29dB





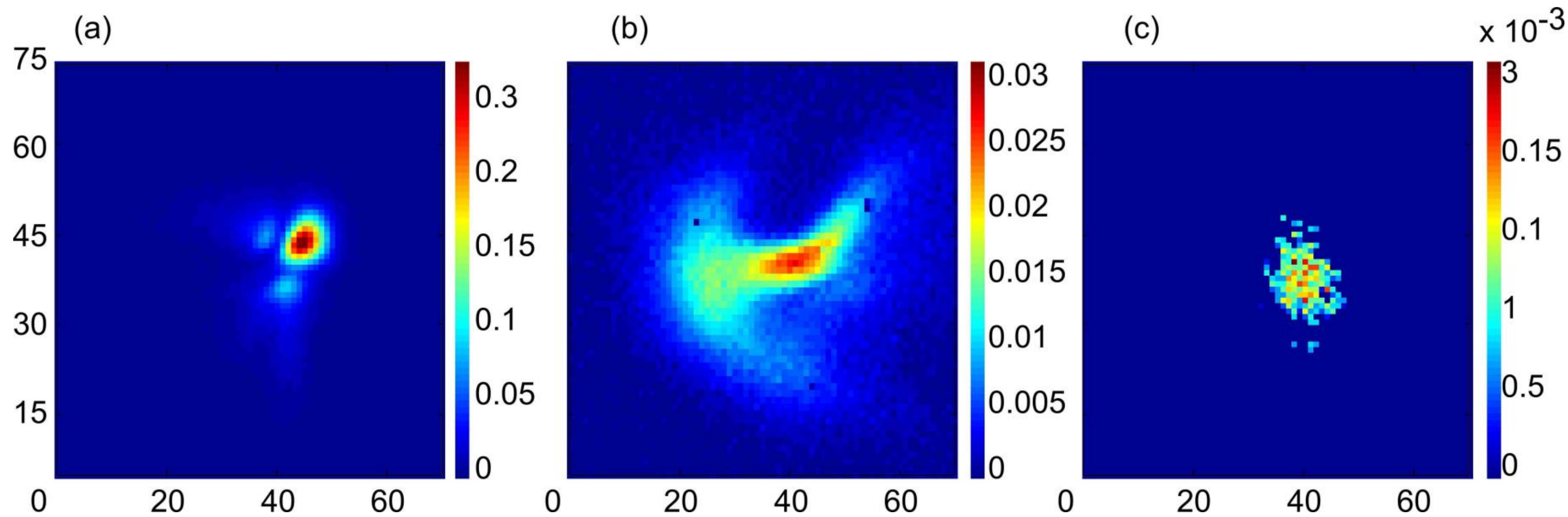
Spectral overlap ≈ 10% of overall signal is absorbed

Accepted for Optics Express + OTST2013 oral presentation

Imaging demonstrations

- Real-time imaging of THz TDS photoconductive emitter

2D images of a focused beam using a *f*=50 mm optics



Parabolic mirrors correctly adjusted | Misaligned parabolic mirrors | PTFE doublet (strong absorption)

Accepted for Optics Express + OTST2013 oral presentation

All images correspond to the same surface of 70 x 75 pixels.

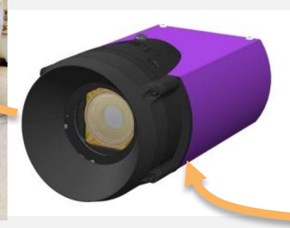
THz spectro-imaging demonstrator

- THz frequency-sensitive imaging: 2 combined functions

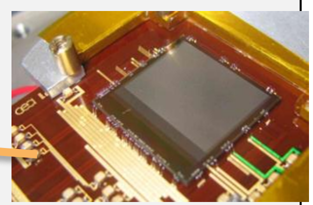
• THz 2D real time active imaging

QCL-based multicolor THz source → optical system → 2D bolometer imaging sensor

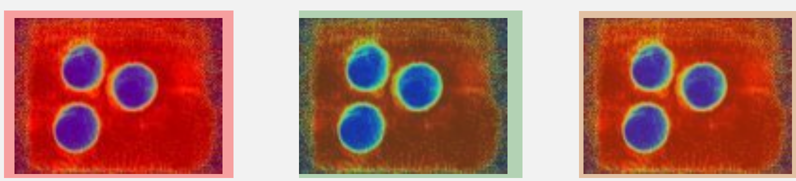
THz system demonstrator



THz camera



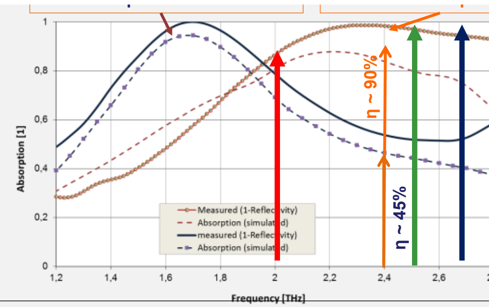
THz 2D sensor



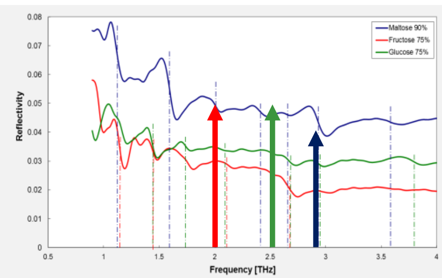
Multicolor 2D THz images

• THz spectroscopy

Broadband absorption 2D sensor



THz spectral fingerprints database

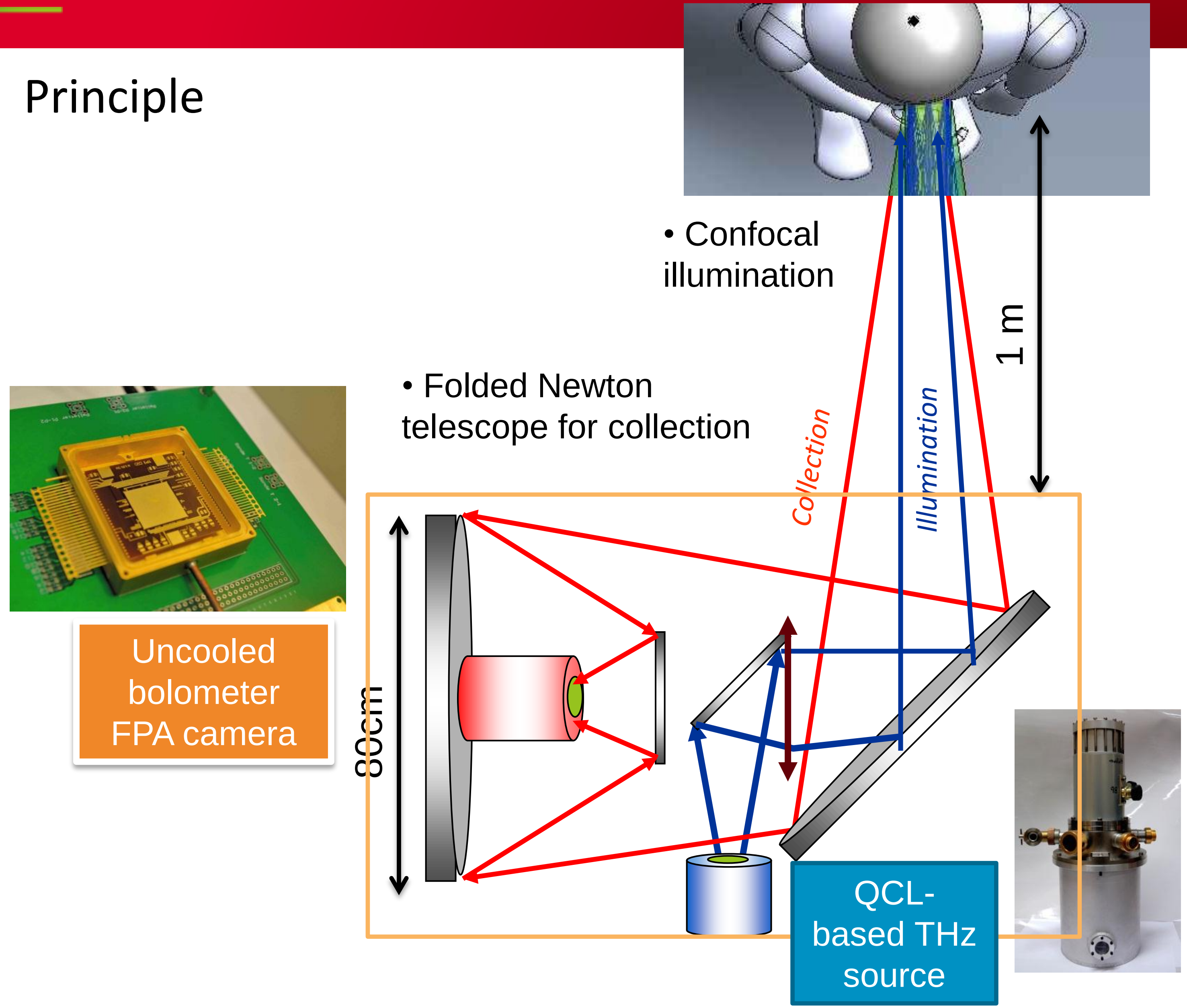


Location of hidden objects

Chemical nature identification

THz spectro-imaging demonstrator

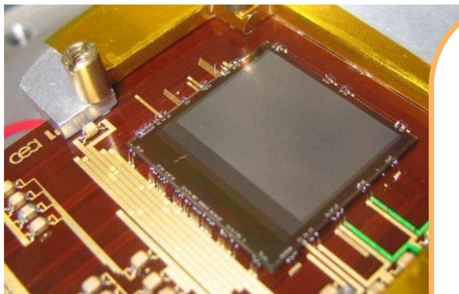
- Principle



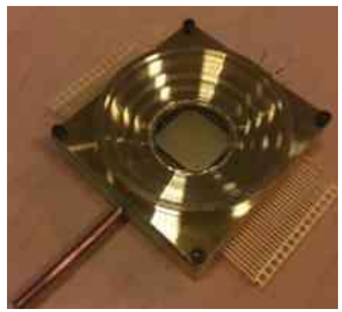
THz spectro-imaging demonstrator

Camera integration

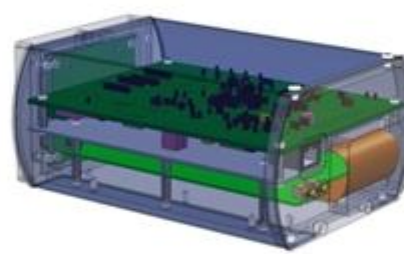
320x240 pixel FPA



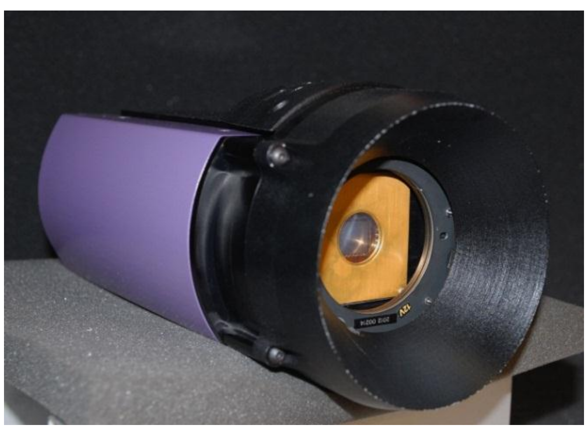
Specific vacuum packaging



FPGA front-end electronics

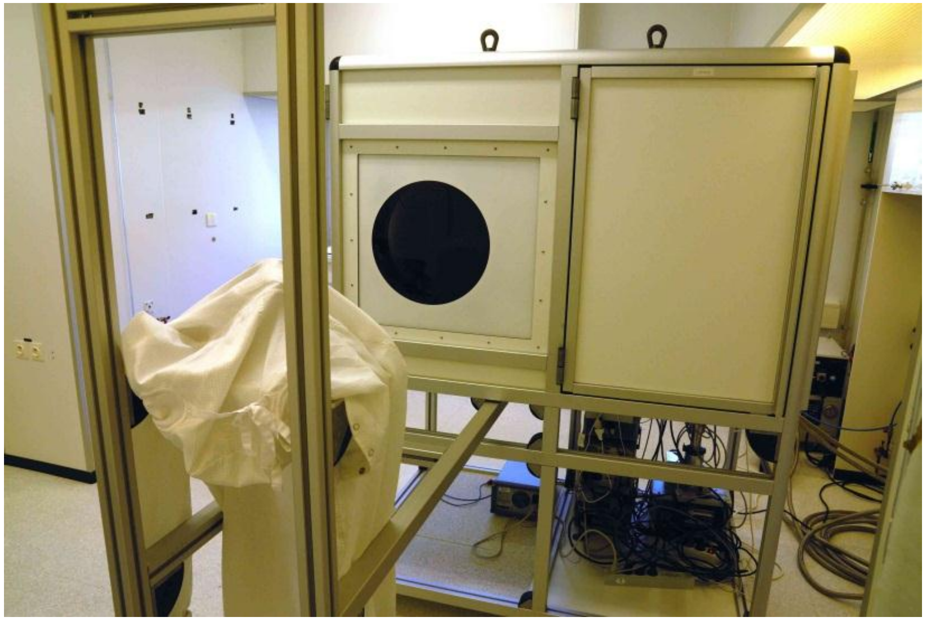


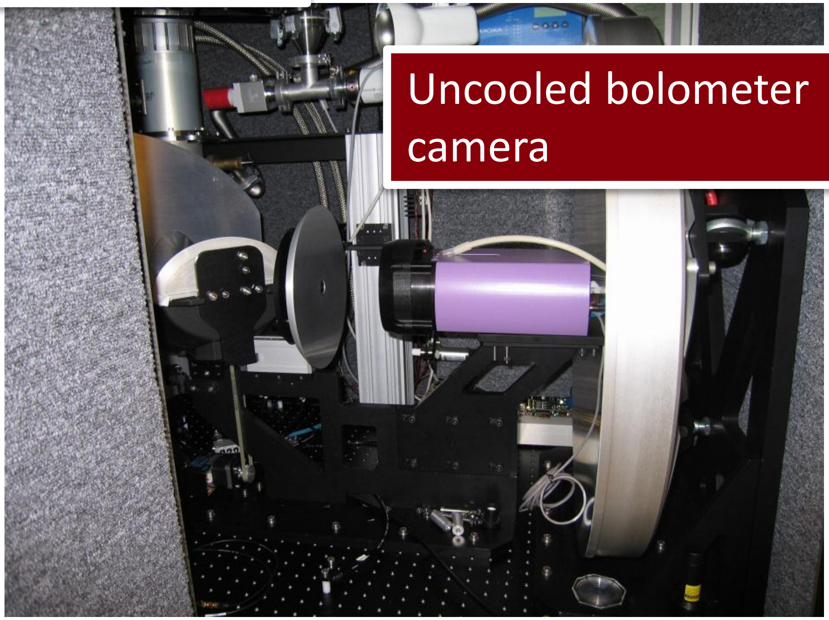
Camera housing



THz spectro-imaging demonstrator

- Complete system



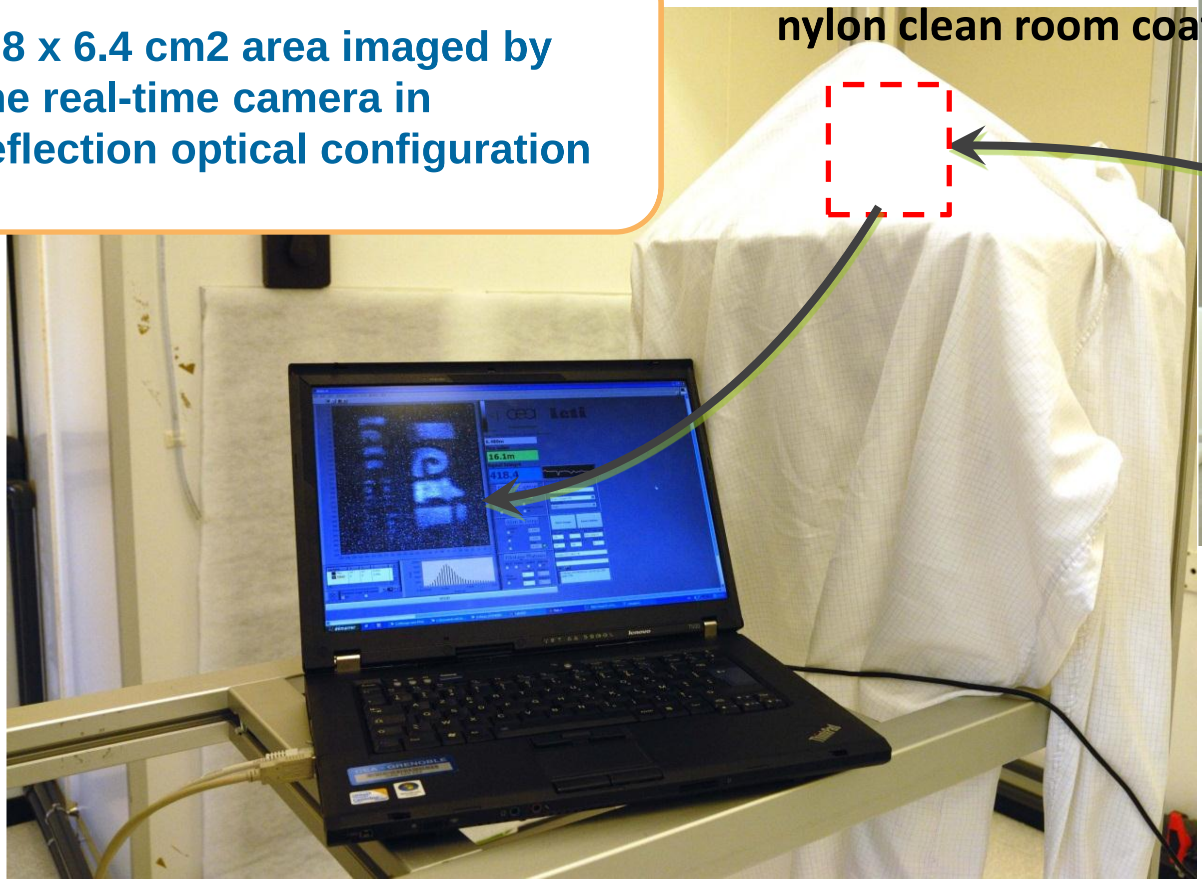


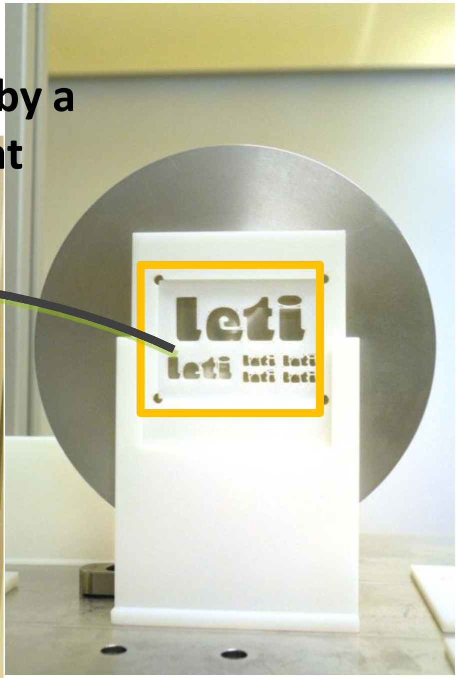
THz spectro-imaging demonstrator

Real-time imaging of a concealed object

- **4.8 x 6.4 cm2 area imaged by the real-time camera in reflection optical configuration**

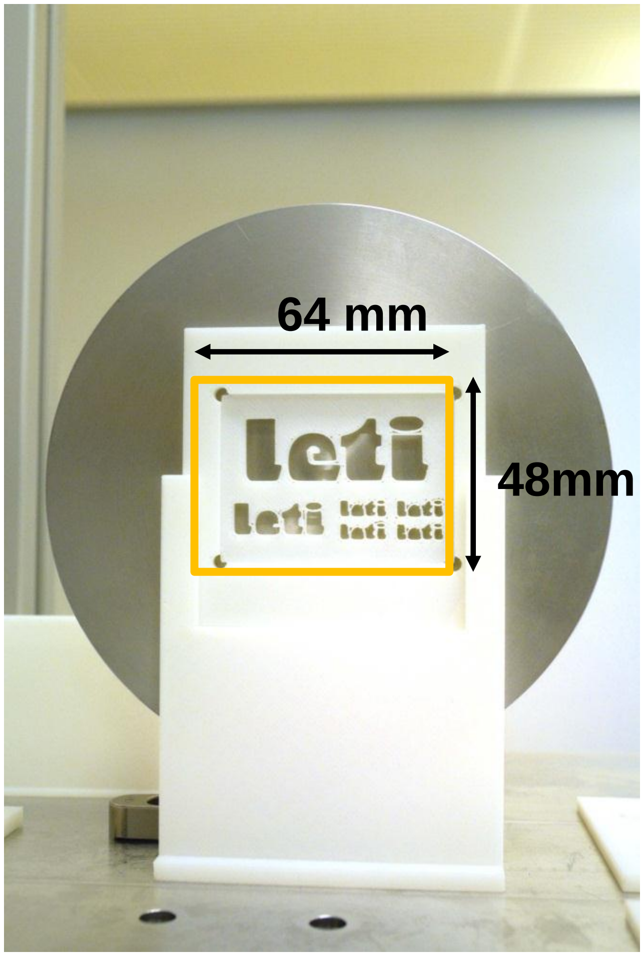
Leti pattern covered by a nylon clean room coat

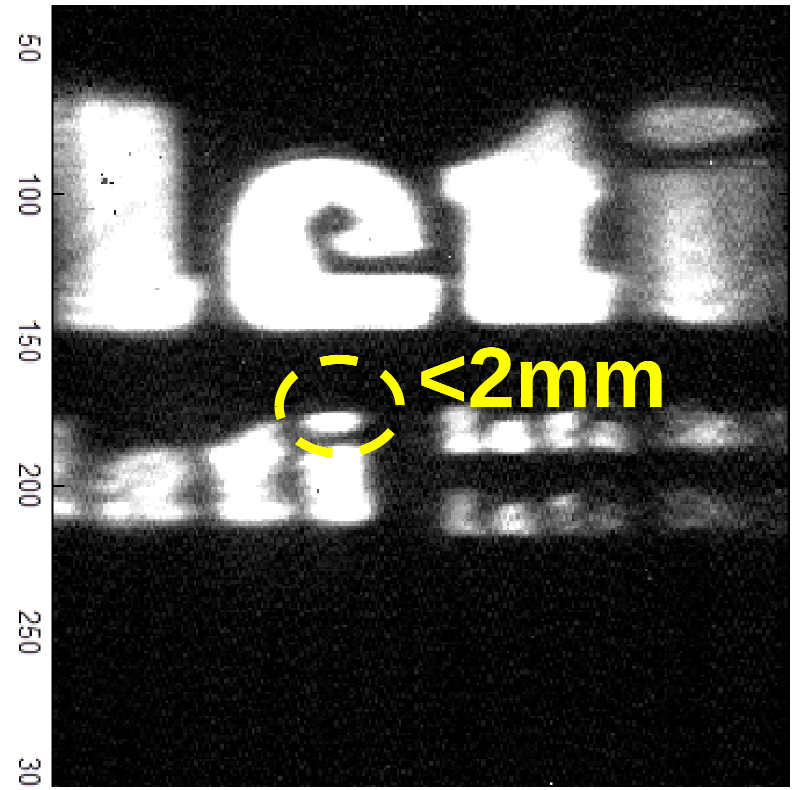




High spatial resolution reflectance imaging

- Real-time imaging of a concealed object





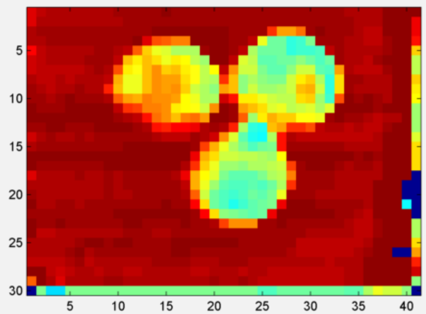
Resolution of the order of 2mm

THz spectro-imaging demonstrator

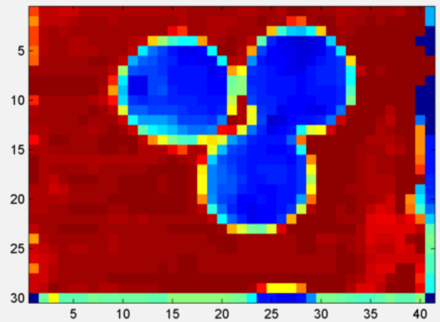
- Localization and identification of sugar pellets

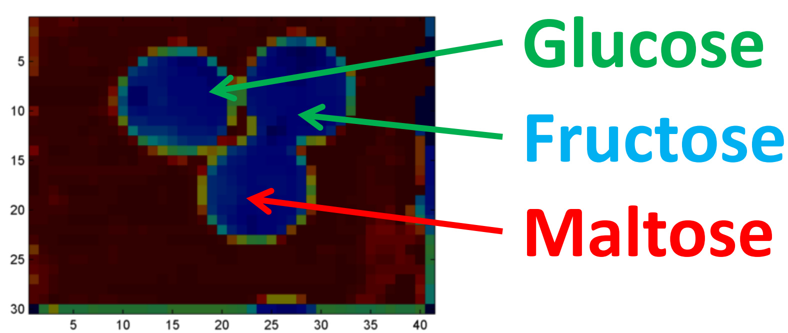
- THz 2D real time active imaging

f1 =2.5THz



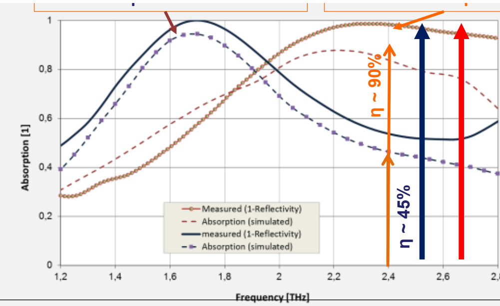
f2 =2.7THz



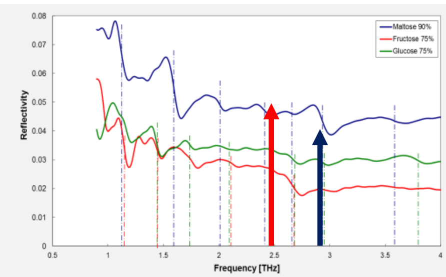


- THz spectroscopy

Broadband absorption 2D sensor

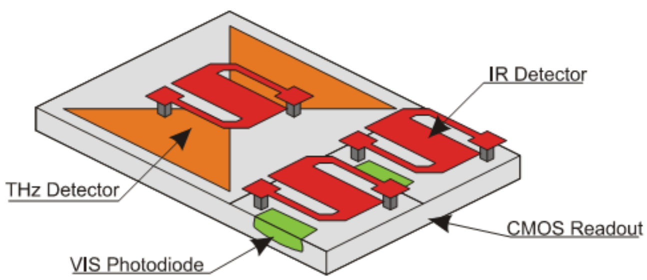


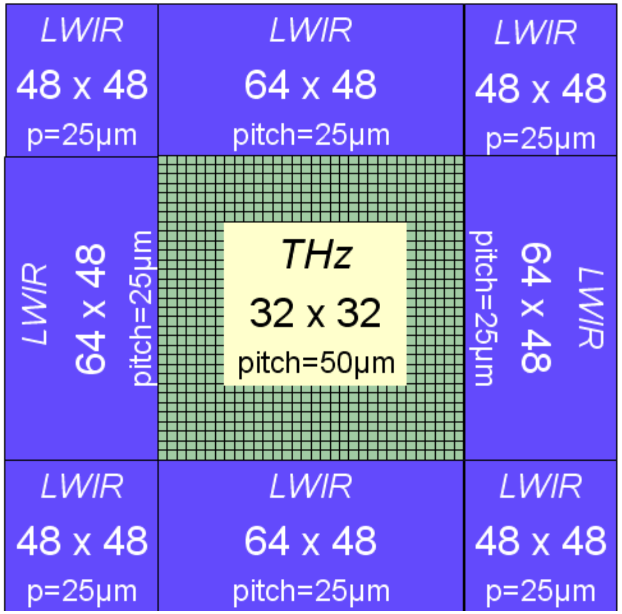
THz spectral fingerprints database

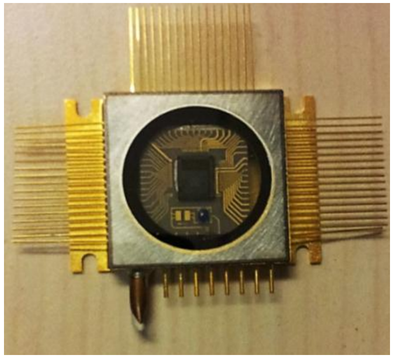


Integration agility : Multispectral FPA

- MUTIVIS FP7 → imaging in multiple spectral band for security applications
  - VIS, IR for surveillance
  - THz for spectroscopic analysis of threats
- Monolithic detector → FPA bolometers
  - Fully compatible with CMOS standard technology
  - Similar process flow for IR and THz antenna coupled bolometer
  - Low-cost both in fabrication and operation



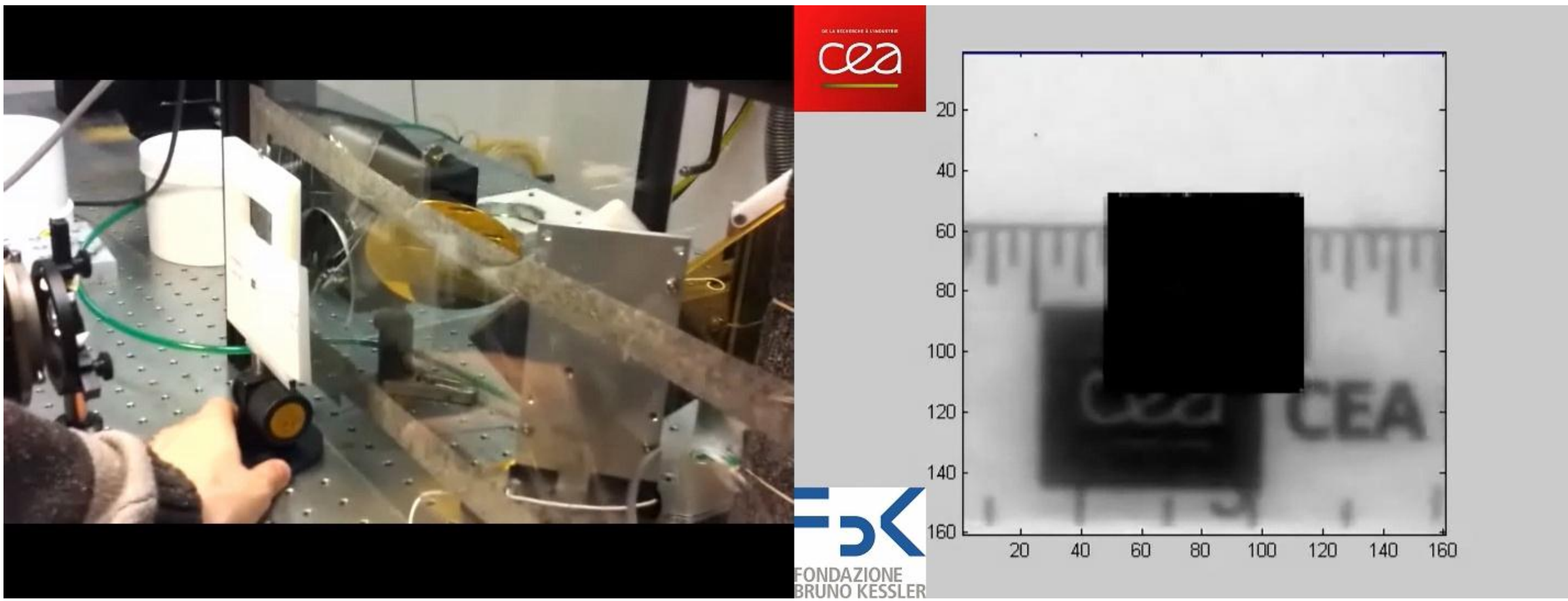




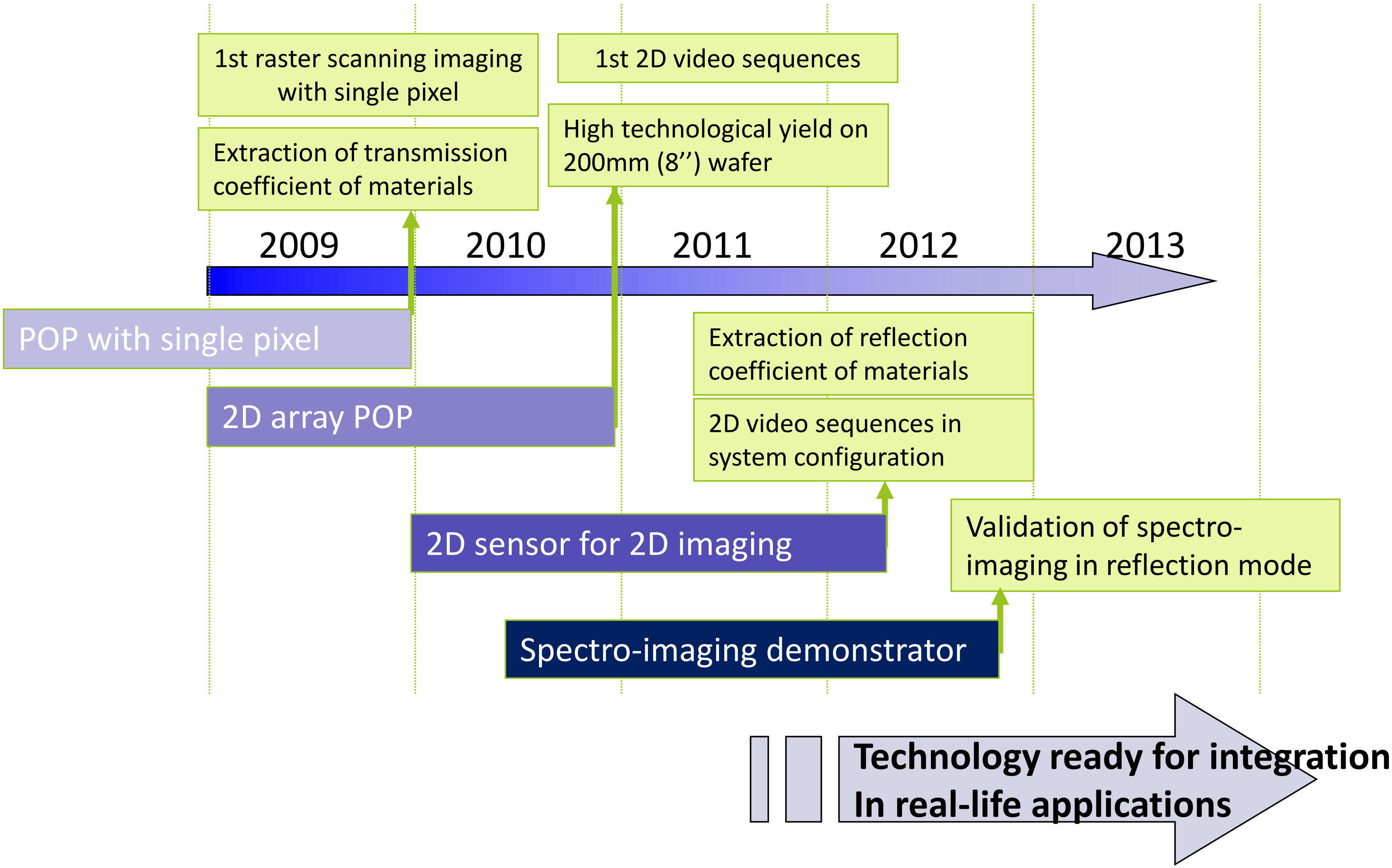
Integration agility : Multispectral FPA

Real-time VIS / THz simultaneous imaging

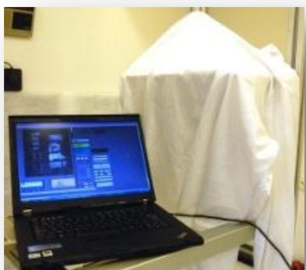
- Very simple optical system → Tsurupica lens doublet
- 2.5THz QCL modulated at 1.25Hz imaged through paper sheet
- « CEA » test pattern imaged with VIS photo-diode



Perspectives



Thanks for your attention



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