GEFÖRDERT VOM
Bundesministerium
für Bildung
und Forschung

Body scanning for security: A sub-mm video camera using cryogenic detectors

- Security body scanning: demand and actuality
- Chance for cryogenic systems
- Realization of our camera
- Conclusion

T. May, E. Heinz, S. Anders, D. Born, G. Thorwirth,
V. Zakosarenko, T. Krause, A. Krüger, K. Peiselt,
M. Schulz, G. Zieger, and H.-G. Meyer

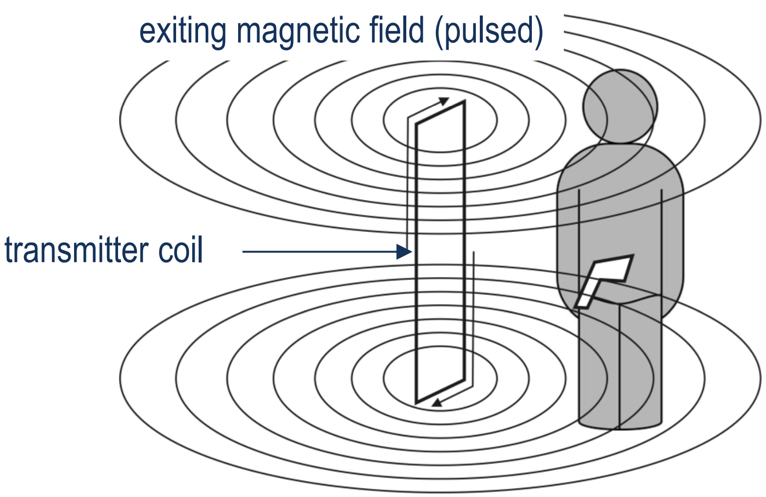
Institute of Photonic Technology, Jena, Germany

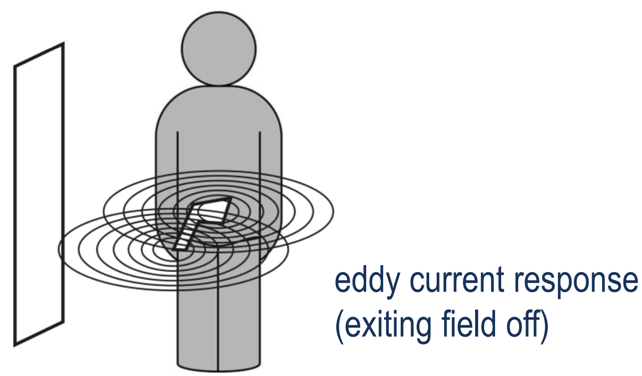
M. Starkloff, M. Schubert

Supracon AG, Jena, Germany

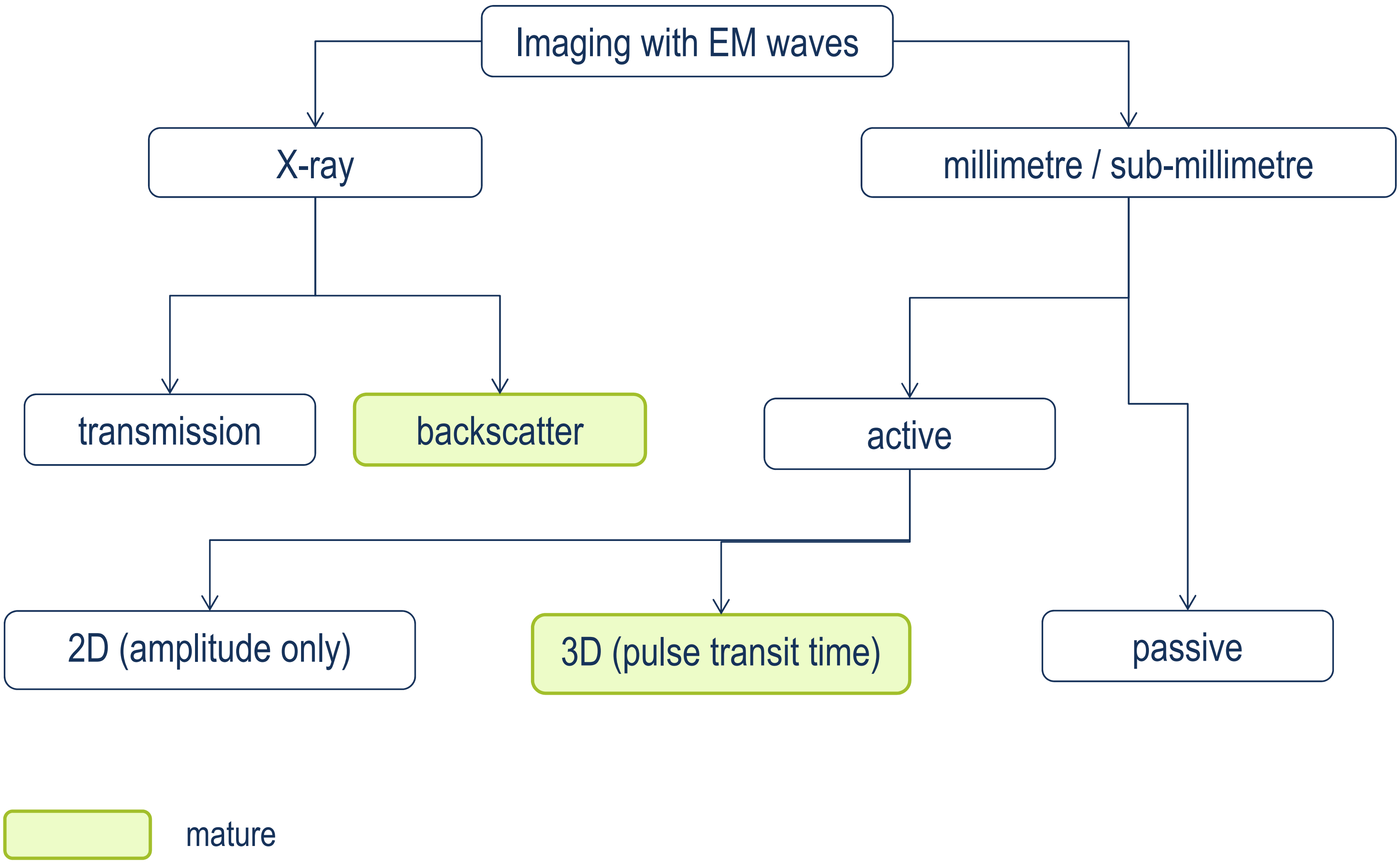
Demand for body scanning

- standard procedure walk-through metal detector: pulsed induction (coil transmits EM pulse $\rightarrow$ eddy currents created in conducting objects cause response)
- detection zones (first localization)
- statistically generated false alarm to trigger manual recheck





Variety of body scanning concepts



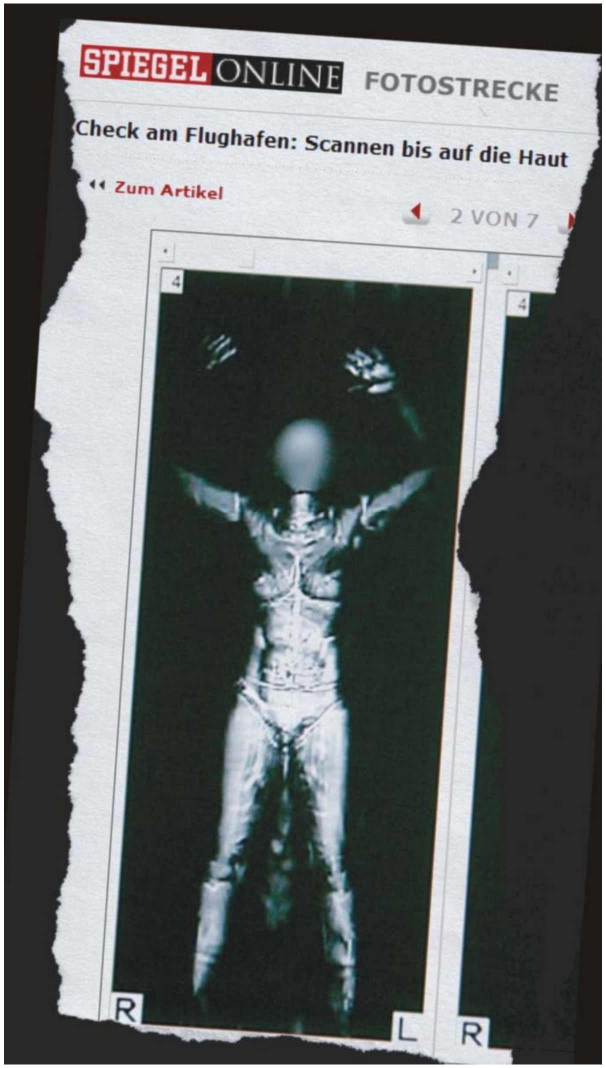
Prospects and limits of established solutions

What they have achieved

- full 3D image reconstruction with high spatial resolution
- high maturity level including automated object detection

What is difficult or (almost) impossible to reach:

- abandonment of artificial illumination
- operation from a distance (stand-off = optical imaging from a few meters) because of:
    - low spatial resolution
    - required high transmission power for real time



What is ‘*stand-off*’ good for?

- ‘*stand-off*’ is synonymic to ‘flexible’:
  - → camera for quasi-mobile deployment in different configurations,
- Perspective: reconsidering traditional security measures
  - detection of hazard prior to potential threat
  - surveillance of public events (e.g. sports)
  - check ‘en passant’ (German ‘*Wandelgang*’)
  - temporary protection of public buildings (embassies, election office etc.)

vision of the International Air Transport Association (IATA)

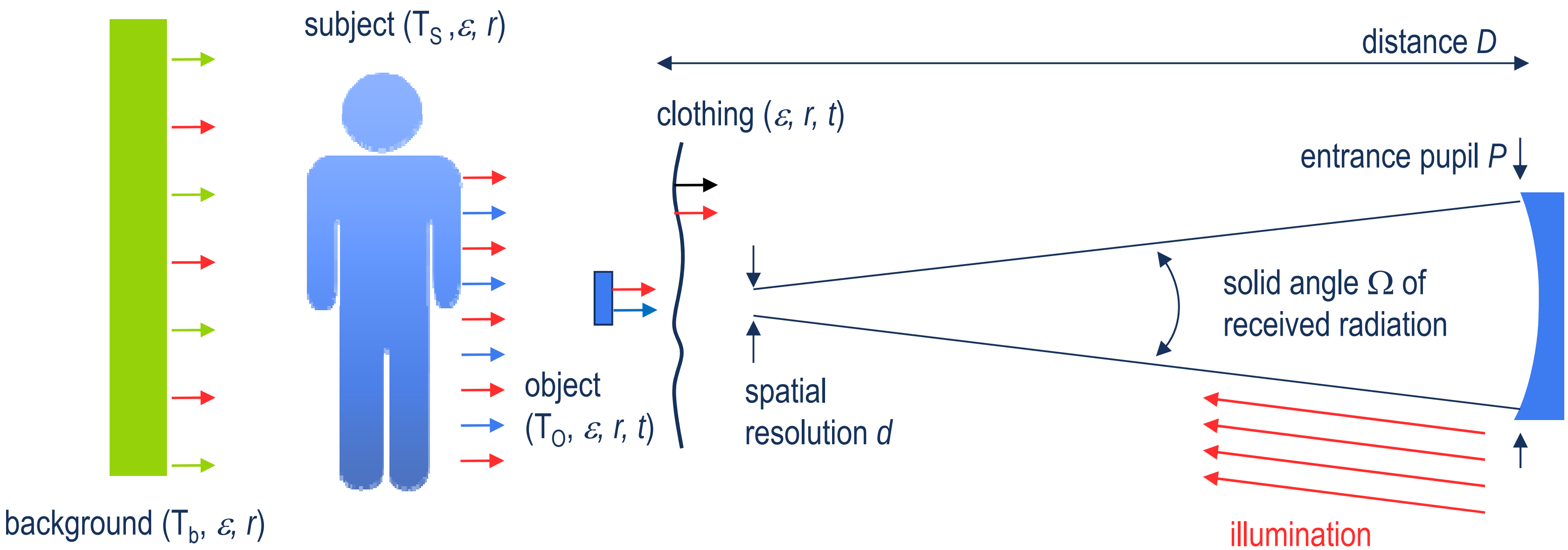
Optical (radiometric) imaging

$$d = \frac{\lambda}{2n \sin\alpha}$$

Ernst Abbe, 1870

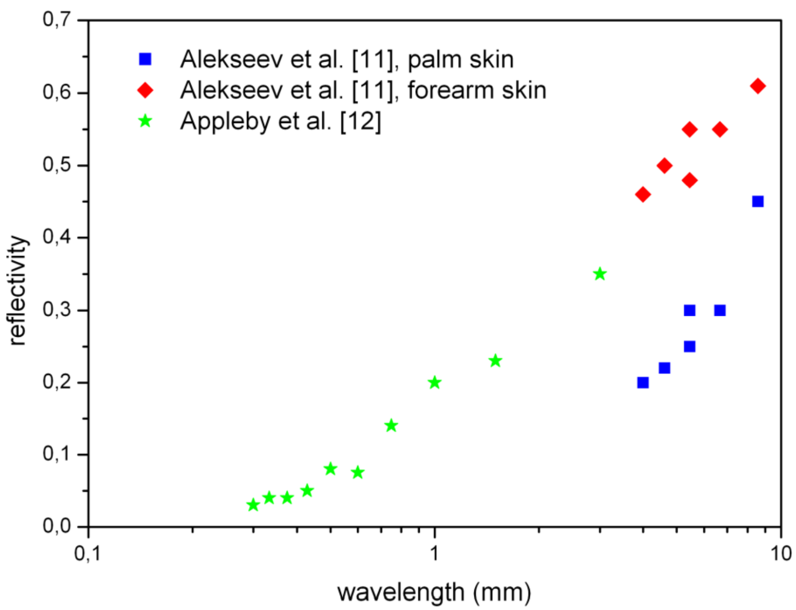
spatial resolution $d \simeq D \cdot \frac{\lambda}{P}$

transmitted AND received signal $\sim \frac{1}{D^2} \cdot P$

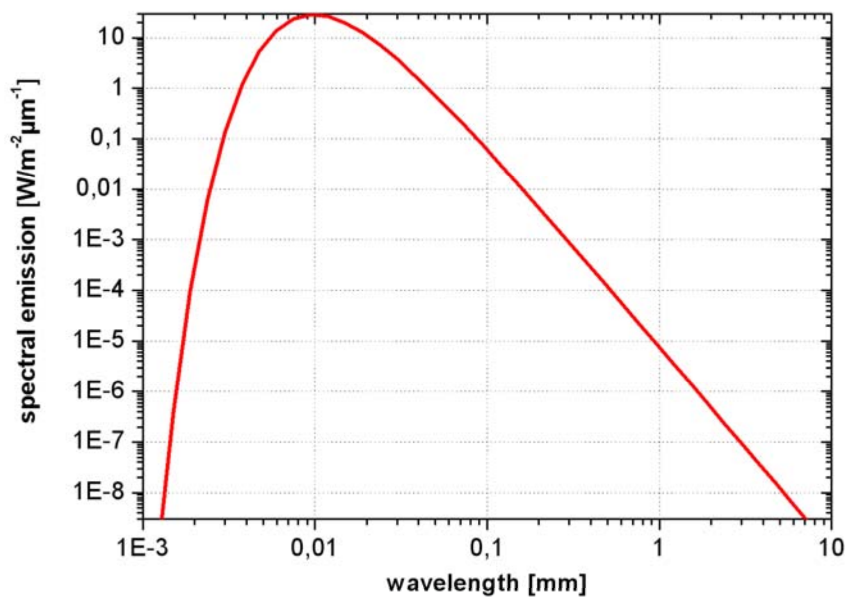


Physical (and other) limitations

reflectivity of human skin



black body emission at 310K



[11] S.I. Alekseev et al., Human Skin Permittivity Determined by Millimeter Wave Reflection Measurements, Bioelectromagnetics 28, 331-339 (2007)

[12] R. Appleby et al., Standoff Detection of Weapons and Contraband in the 100 GHz to 1 THz Region, IEEE Transactions on antennas and propagation, 55 (11), 2944 – 2956 (2007)

Note:
active illumination of persons with EM waves beyond 300GHz (λ<1mm) is not yet permitted by law!

Passive sub-mm imaging

Planck's equation for spectral emission of a black body with a radiating area of $1m^2$

38µW/GHz @ 310K

35µW/GHz @ 295K

in atmospheric window (355±20)GHz

→ ΔP = 120µW, background power 1.4mW

chosen optical configuration:

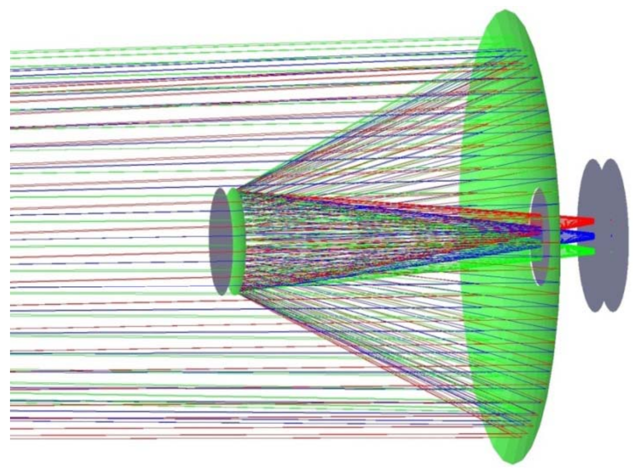
airy disk ≡ radiating area $1.8cm^2$

aperture ≡ receiving area ∅0.5m @ 10m distance (Ω = 0.008sr)

received background power: 250pW

Thermal resolution 0.1K@ΔT=15K: 150fW

simple on-axis telescope as example



Ø primary mirror: 0.5 m

spatial resolution (approx): 1.5 cm

That is the chance for cryogenic detectors!

Detector requirements

figure of merit: NEP, defined as resolvable power per square root of integration bandwidth

NEP = 150fW/√Hz ≡ resolving 150fW in 1 second integration time

At the example of a 100 x 100 pixel THz image :

→ resolving 150fW in 100 millisecond integration time (10Hz frame rate):
NEP = 50fW/√Hz

Implication: the need for a full detector array (10000 pixels)

→ resolving 156fW in a 10Hz frame, scanned with N pixels

integration time shortened by N/10000:
NEP = √N · 0,5fW/√Hz

reasonable concept using approved radioastronomy technology:
N = 20

→ required NEP 2.2fW/√Hz

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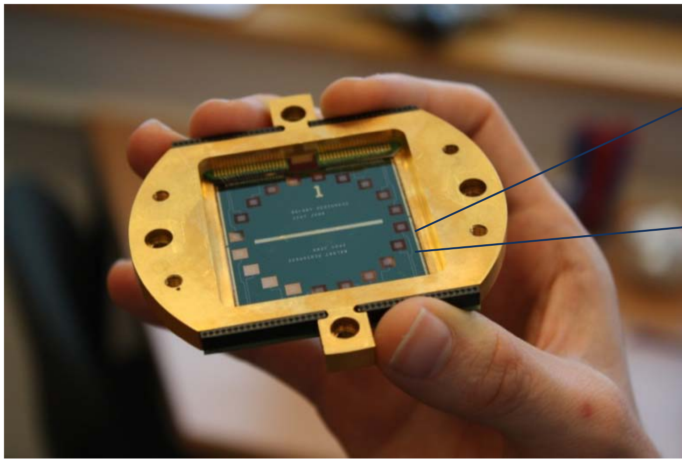
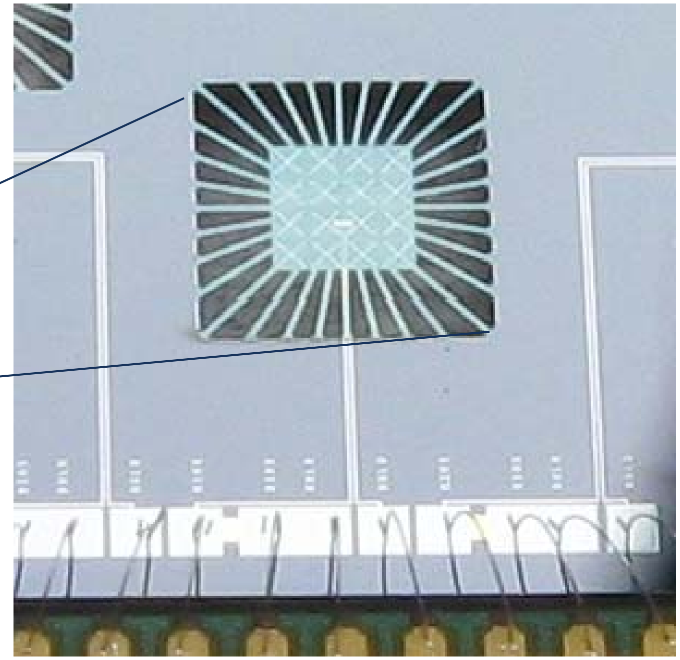
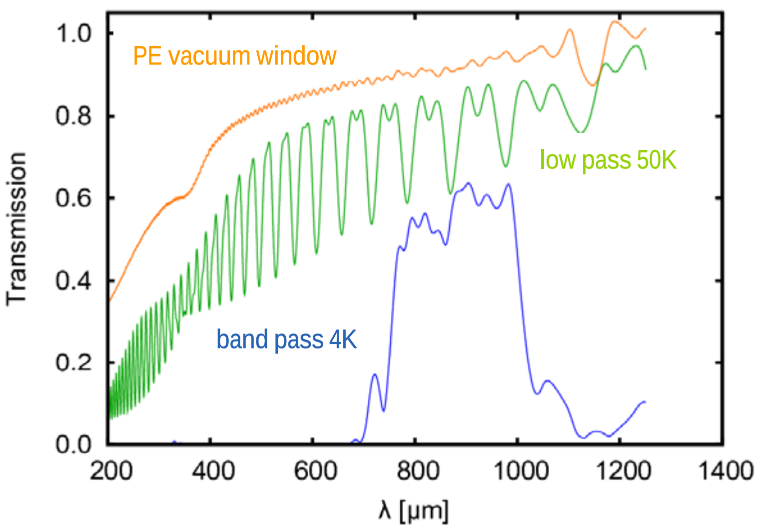
Receiver



20 TES bolometers in a circular array

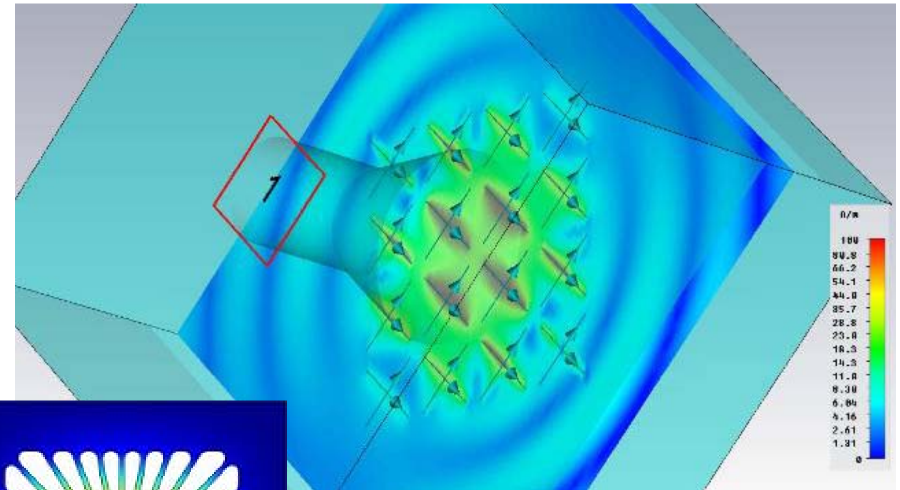


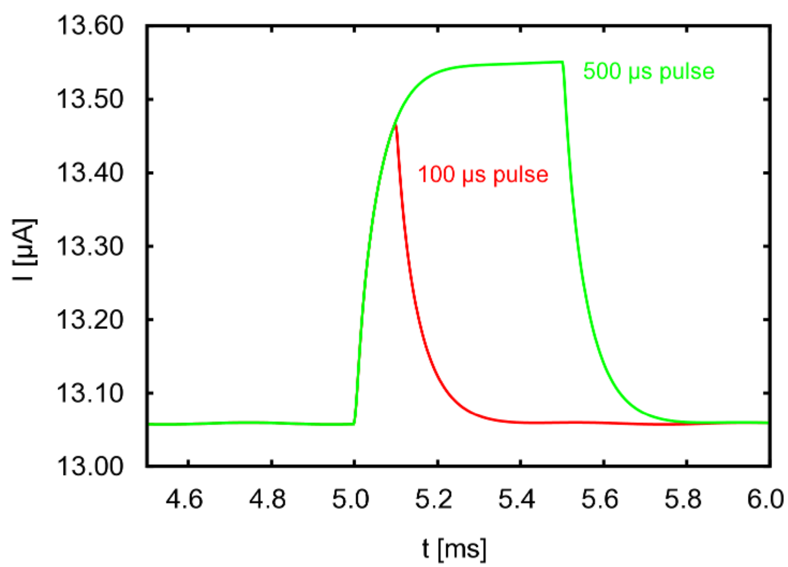


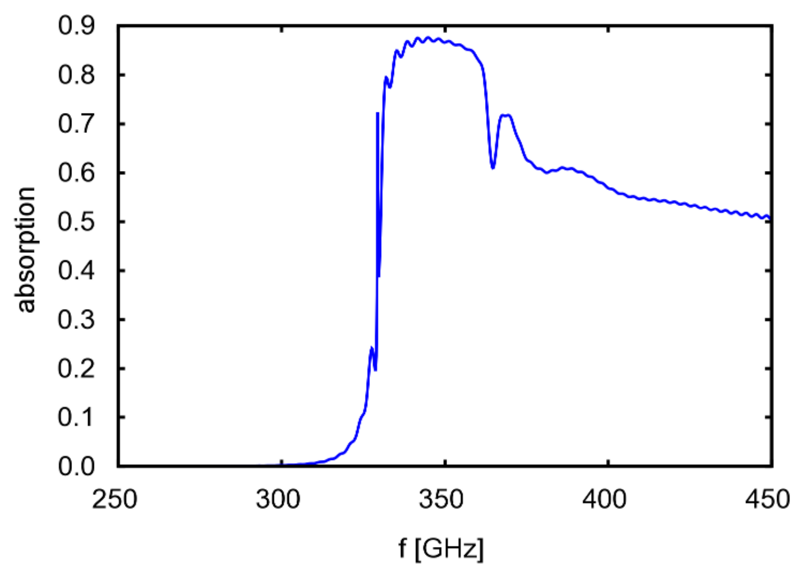
- 1µm thick silicon nitride membrane with low thermal conductivity (1nW/K)
- absorption in an array of dipole antennas (λ/2)
- band definition by set of cryogenic filters (see poster Anika Brömel for details)

Detector optimization

- FEM simulations (COMSOL® Multiphysics®)
- radiation, thermal properties, electrical behavior
- optimized: design, G, C
- $\tau \approx 50$ µs, efficiency ≈ 70 %

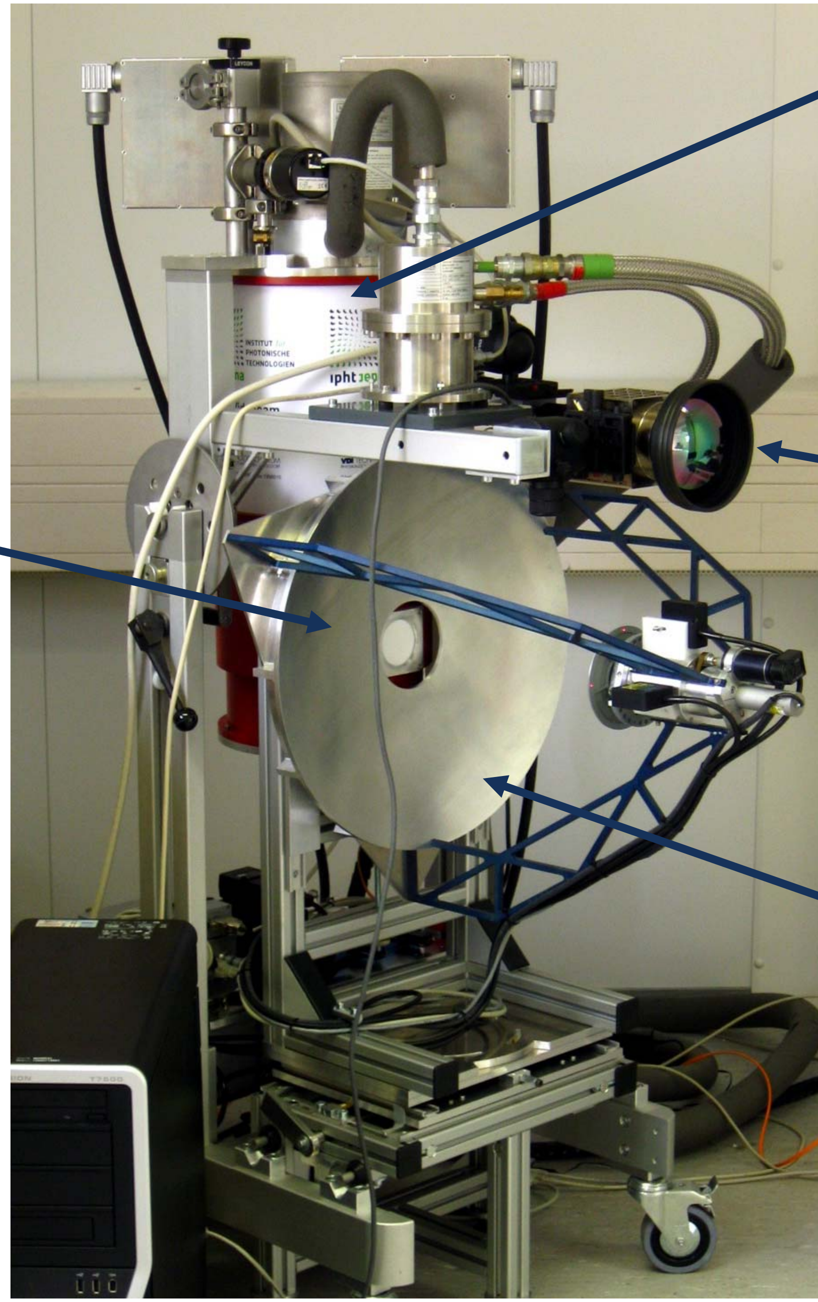






System

cryogenic receiver with temperature resolution about 0.5K at 10Hz video frame rate



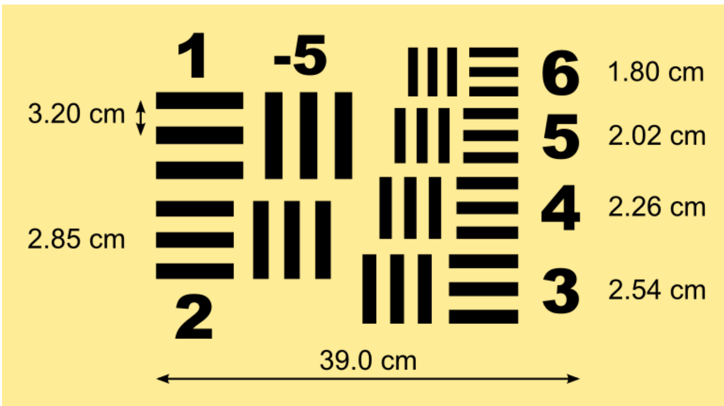
cryogen free cooling system

commercial module for simultaneous recording of visible and IR-video

reflecting optics for 7 to 10 meter distance (adjustable), spatial resolution 1.5cm

For details see E. Heinz et al., Journal of Infrared, Millimetre, and Terahertz Waves 2010

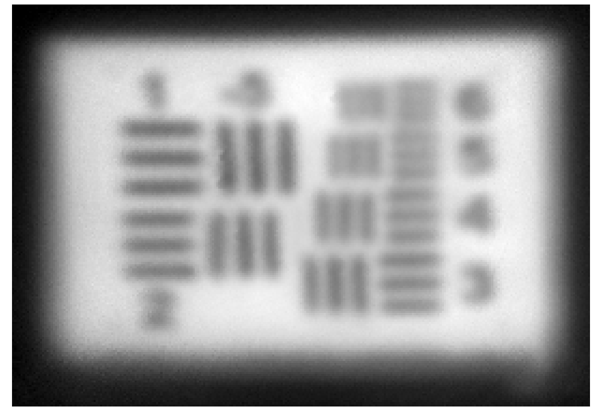
Achieved spatial resolution



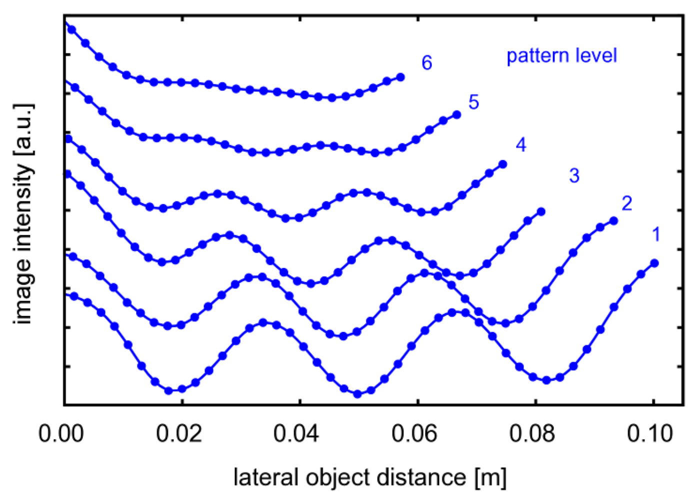
spatial cut-off frequency

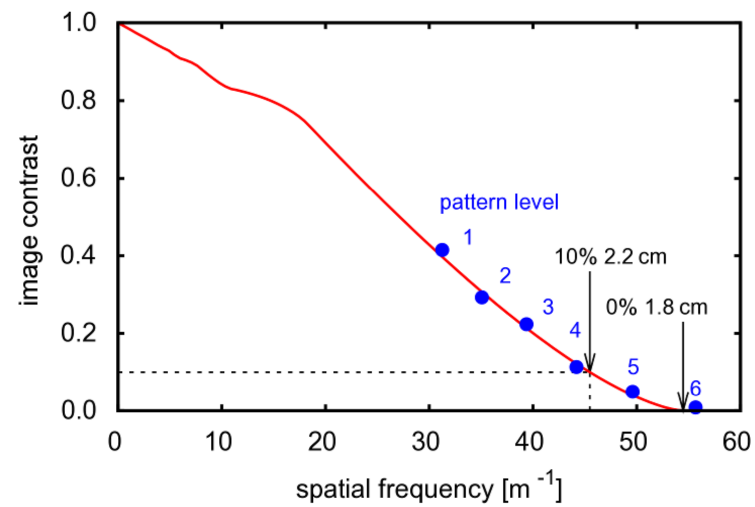
s = D / λ d

Kottler/Perrin, J.Opt.Soc.Am 56, 377 (1966)



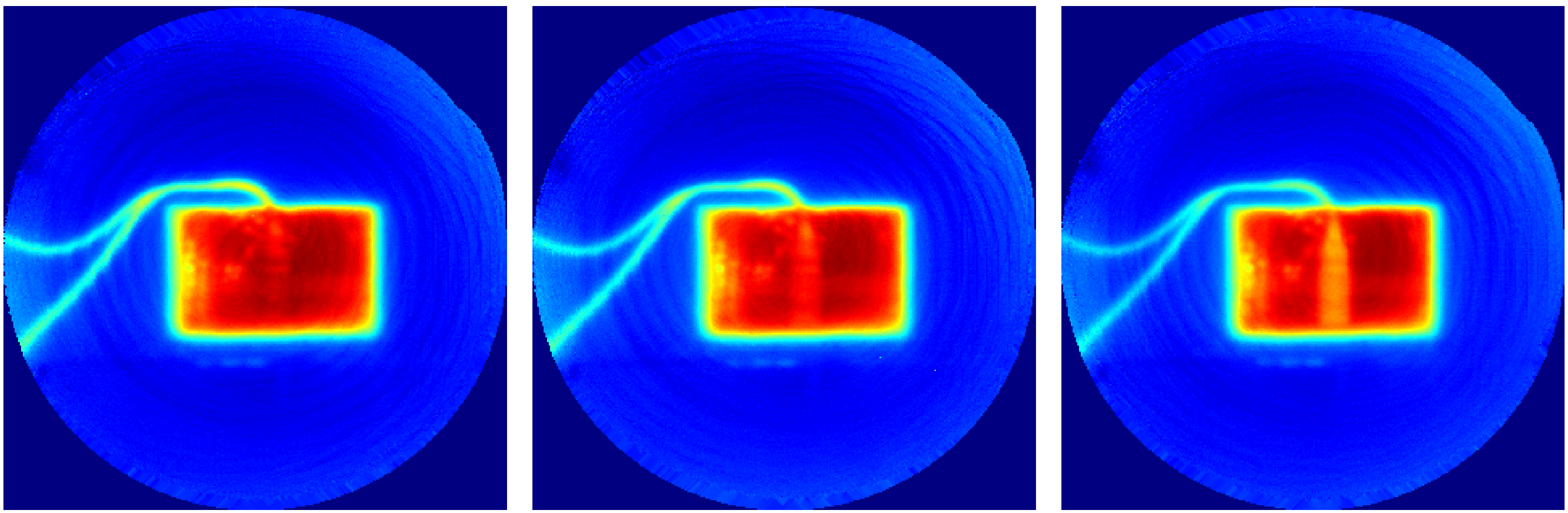
9 m distance, 20 s integration





Achieved thermal resolution

temperature resolution – experiment
background ≈ 24 °C, panel 35.1 °C,
temperature resolution is “confusion limited” (limited by spatial noise)



ΔT = 0.1 K ΔT = 1 K ΔT = 3 K

Conclusion

1. The concept of near-field mm-wave imaging is mature. Cryogenic detectors can hardly compete in that field.
2. A passive sub-mm wave camera is the most effective solution for stand-off application scenarios. Cryogenic detectors are able to meet the demands of such a system
3. Such systems can answer a variaty of application scenarios – so future systems should be as flexible as possible

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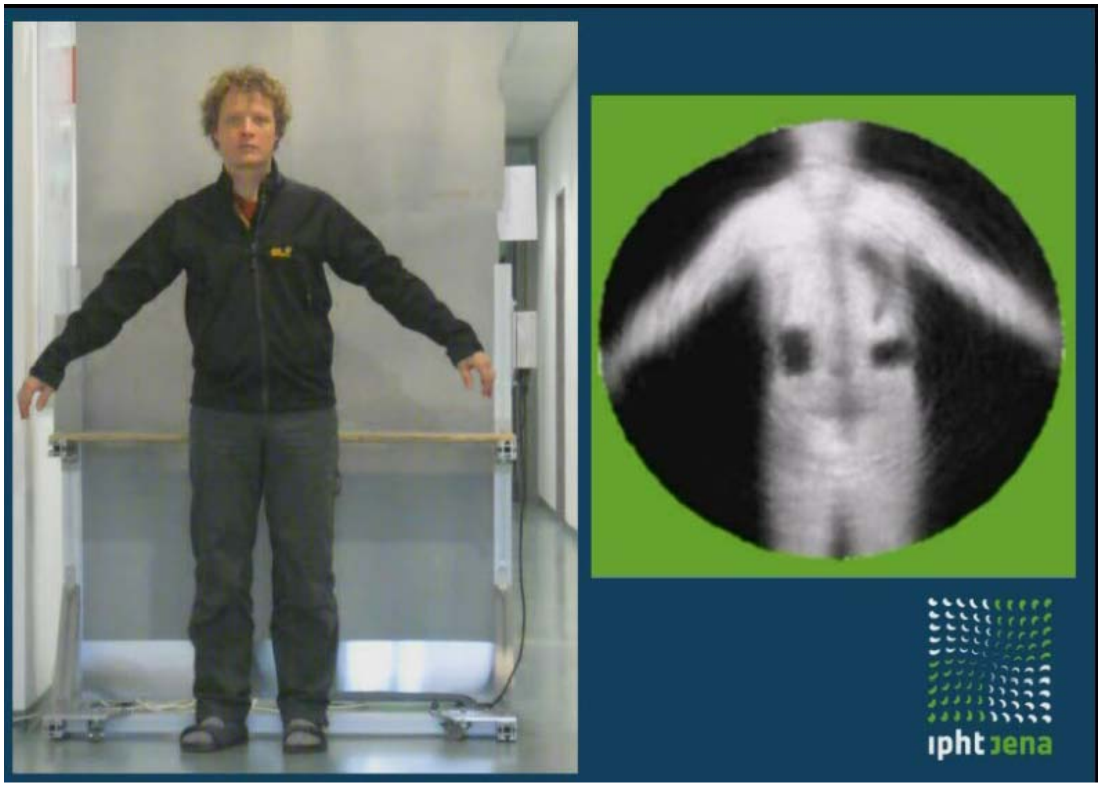
Thanks for the attention and to the team



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in alphabetic order:

Solveig Anders
Harijanto Bone
Detlef Born
Bernhard Borns
Anika Brömel
Erik Heinz
Torsten Krause
Andre Krüger
Torsten May
Katja Peiselt
Marco Schubert
Marco Schulz
Michael Starkloff
Günter Thorwirth
Slava Zakosarenko
Gabriel Zieger

and last but not least

Hans-Georg Meyer