Terahertz Technology for Space and Earth Applications

P. de Maagt

Outline

- Introduction
- Space Applications (some examples):
  - Large Reflectors for Space Astronomy
  - Other Traditional Drivers
- Terrestrial Applications (some examples):
  - Concealed objects detection
  - Medical
  - Pharmaceutical/NDT
- Future Trends in Antenna Technology
- "Classical" and "Non-Classical" Feed Technology

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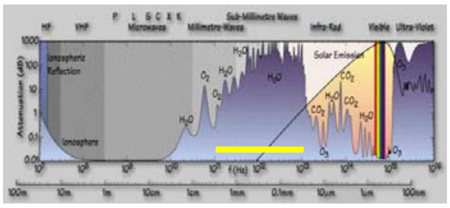
The THz Frequency Range

CLAIM: the most scientifically rich, yet most underutilized region of the electromagnetic spectrum



THz radiation is the electromagnetic radiation between infrared optics and microwaves, loosely defined between f = 0.1 - 10 THz (3 mm - 30 μm)

The THz "gap"

THz is at the transition from microwaves to optics

$$\nabla \times \vec{H} = \vec{j} + \frac{\partial \vec{D}}{\partial t}$$

current density $\vec{j}$ dominates at low "microwave" frequencies, using the motion of electronic charges to generate radiation.

At optical and infrared wavelengths, sources of radiation are associated with dipolar transitions, specifically electronic transitions, occurring within atoms or molecules and are related to the electric displacement $\partial \vec{D}$

in comparison to microwaves:

- higher bandwidth (data trans.)
- higher resolution (imaging)
- integration (small)

in comparison to optics:

- less scattering (dust)
- material selectivity (gases, semicond., biomolecules, …)
- transparency

"THz" photons

Optical photons are emitted when electrons change energy states during relaxation (e.g. from a conduction band to a valence band)

THz photons are emitted when a molecule changes its **thermal, rotational or bending state** ⇨ energies involved are much smaller

optical spectroscopy ⇨ information on atomic composition

THz spectroscopy ⇨ information regarding the **molecular concentration** as well as its **physical condition** (heat, pressure, speed etc.)

THz radiation emitted or absorbed by a gaseous region allows to investigate chemical and physical processes **in places where instrumentation cannot (easily) be sent**

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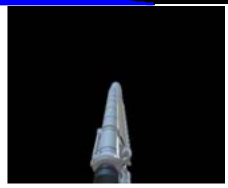
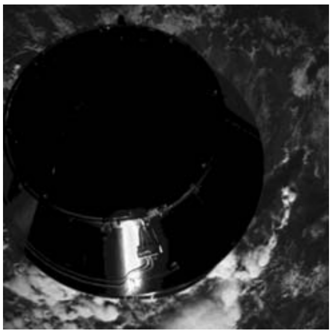
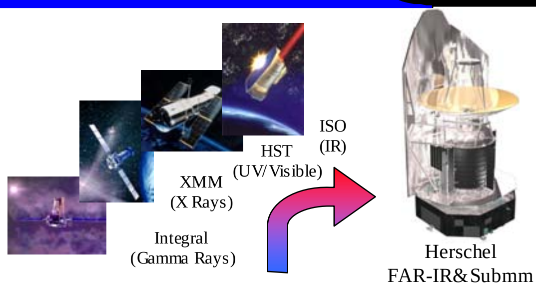
Herschel/Planck



Herschel/Planck



Spectral Coverage



COMPLETING THE SPECTRUM COVERAGE

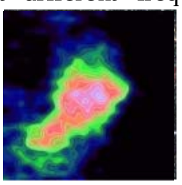
Herschel is the **only space facility** covering the far infrared to submillimetre range (no atmospheric absorption, no atmospheric emission)

"Discovery potential" is large

Sub-mm Wave Observation

- Things look "different" at "different" frequencies.

Millimetre and sub-millimetre wavelengths can penetrate dark clouds.



M16 – the 'Eagle Nebula'

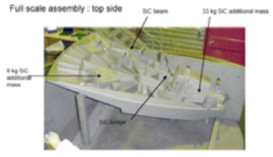
Orion nebula

Using 3 different parts of the electromagnetic spectrum allows us to peer through the obscuring matter to see objects hidden within.
1) visible light: Nebula is opaque
2) Near IR: will remove the reflected light, the Stars are revealed inside it.
3) THz: dust is revealed from which new stars and planets are born.

Herschel (FIRST) Antenna Configuration

HERSCHEL (previously named FIRST)
• Frequency coverage 450 GHz to above 4 THz
• Cassegrain Antenna (3.5 m)
• System focal length 28.5 m
• Wave Front Error < 10 µm (goal is 6 µm)
• High accuracy and in-orbit thermal stability required
• Passively cooled to below 80 K
•Total mass (reflectors, support, interfaces, Thermal hardware) 320 kg.

Herschel Reflectors




Assembly of petals


M1 after grinding


M1 on completion of polishing

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Herschel Antenna


M2 after polishing. Note scatter cone in the centre


M1 cleaned and prepared for coating

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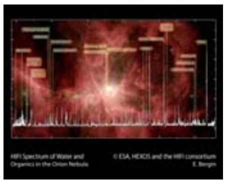
Herschel First Light

160 microns: Herschel vs Spitzer. At 100 and 70 microns Spitzer is blind

M51 shown as a composite of 160, 100, and 70 microns.



HIFI spectral scan of Orion. A HIFI spectrum displaying a plethora of lines from a number of molecules obtained in just a couple of hours, displaying the spectral richness so characteristic of Orion.

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Planck Antenna Configuration

Planck: Features a modified Gregorian Reflector design with
• An aplanatic main antenna (dimension 1.5 m)
• Extremely low sidelobes
• System focal length 1.8 m
• Main reflector surface accuracy is about 10 µm
• Very important to have strict control of stray light (micro-cracking, dust,etc.)
•Total mass (reflectors (30/14kg)+ support) 175 kg.

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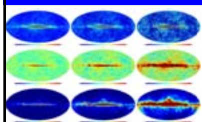
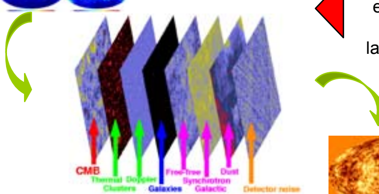
Distinctive features



Imaging the sky emission at many frequencies



In order to map the anisotropies in CMB, the observations must first be corrected for the effects of detector noise and many layers of intervening foregrounds
Peel off the different layers

Therefore, as a "by-product", Planck's observations will provide a wealth of information about our own Milky Way and other galaxies.

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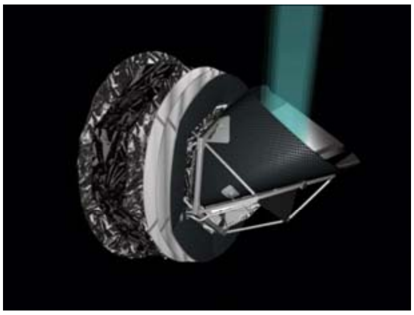
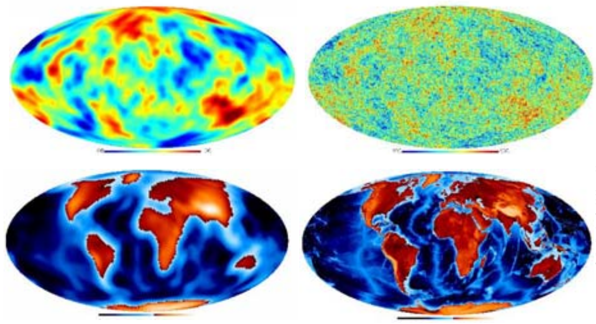
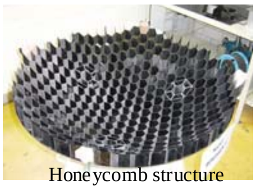
Planck Mapping of Sky

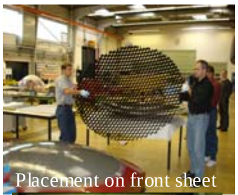


Cosmic Microwave Background

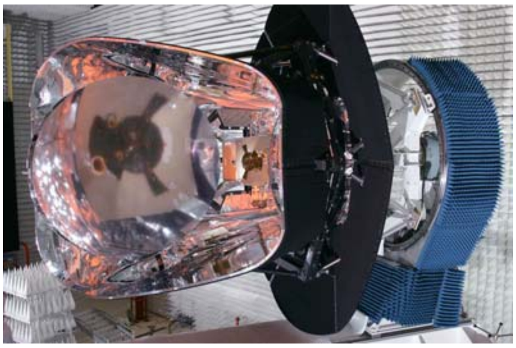


Planck reflectors

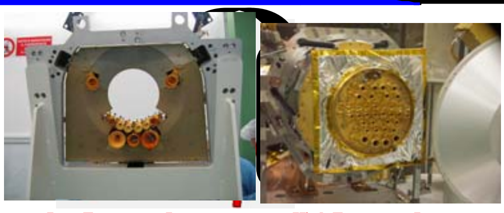




Planck Instrument

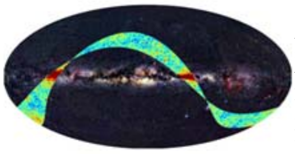


Planck Instruments

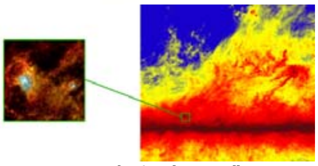


	Low Frequency Instrument	High Frequency Instrument
Freq.:	30, 44, 70 GHz	100, 143, 217, 353, 545, 857 GHz
Techn:	HEMT correlation receivers	Polarized sensitive and spider-web bolometers
Temp:	20K (Front end), 300K (back end)	0.1K
Ang. Res:	10' (100 GHz) to 33' (30 GHz)	10.7' (100 GHZ) to 5' (850 GHz)
Goal Temp. sens.:	12 μK (70Ghz)	4.5 μ K (100 GHz)

Planck First Light



A map of the sky at optical wavelengths shows a prominent horizontal band which is the light shining from our own Milky Way. The superimposed strip shows the area of the sky mapped by Planck during the First Light Survey.

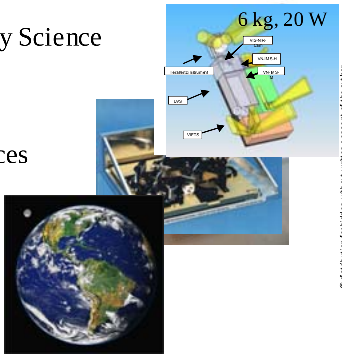


a region in the Aquila constellation covering a portion of the sky about 55°,

Filamentary structures are apparent on large scales (Planck, right) and small scales (Herschel, left) in the Milky Way. The Planck image, was obtained by the HFI @ 857 GHz. The dark horizontal band is our Galaxy. The colours represent the intensity of heat radiation by dust.

Other Traditional Drivers

- Planetary/ Cometary Science
- Atmospheric Sciences
- Meteorology



Outline

Space Applications

•Planetary/Cometary Science

•Astronomy Science

•Meteorology

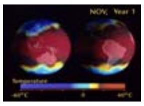
•Atmospheric Science

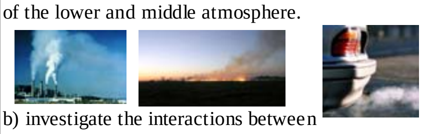
Terrestrial Applications

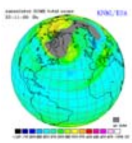
Atmospheric Science

Key topics

a) To measure and to understand the human impact on the chemistry and composition of the lower and middle atmosphere.







b) investigate the interactions between atmospheric chemistry, atmospheric composition and climate.

- limb-viewing observations at millimetre and submillimetre wavelengths in addressing the scientific objectives identified has a lot of potential.

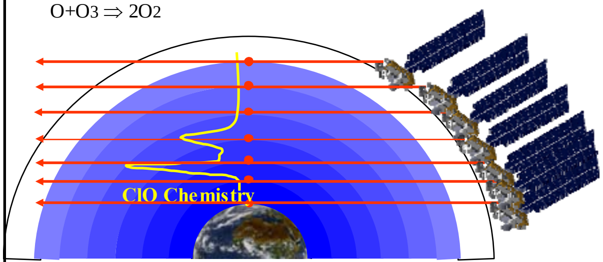
Limb sounding

$X+O_3 \Rightarrow XO + O_2$

$XO+O \Rightarrow X+O_2$

$O+O_3 \Rightarrow 2O_2$

Freq:100GHz to 3.5 THz



e.g.: O_3, N_2O, H_20, O_3, BrO, HCl, HBr, OH, NO, N_20, CO, ClO

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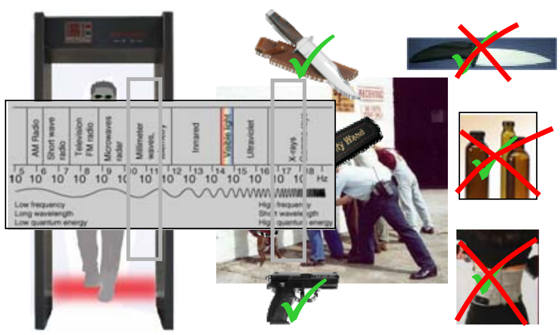
People screening



Security and Defence Applications

- Checkpoint people screening for hidden weapons & Explosives
- Stand-off detection of explosives-suicide bomber
- Baggage screening for explosives
- Postal screening for explosives, biological & chemical agents
- Chem/Bio detection
- Mine detection
- Communications
- Non-destructive evaluation

Melanoma Characteristic Spectra

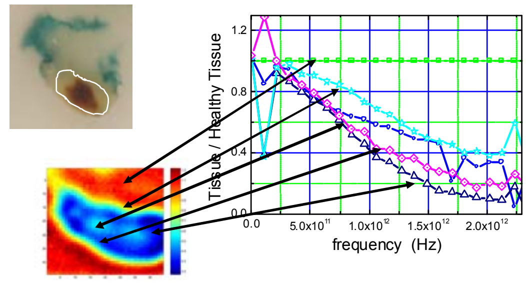
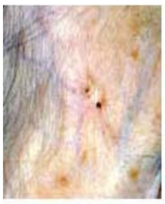
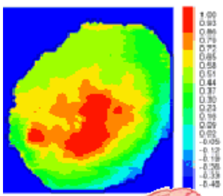
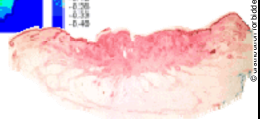


Image Analysis



THz image





Clinical photograph showing suspected basal cell carcinoma on patients forehead

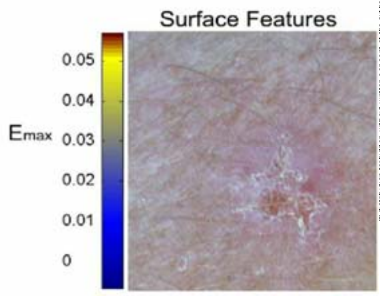
Histology confirms diagnosis

http://www.teraview.co.uk

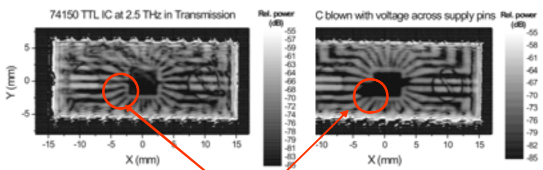
3-D-Imaging

visual and terahertz images of a patient with a basal cell carcinoma, one of the common forms of skin cancer.

- The visual image shows the skin surface.
- Terahertz image of the surface, which shows similar information.
- Terahertz image at a depth of a few hundred microns showing how the tumour (invisible from the surface) has spread underneath the top layer of the skin.



Imaging of semiconductors



2.5 THz Images of an Integrated Circuit before and after over voltage applied on supply terminals

THz image of an integrated circuit penetrates the plastic package to reveal circuit features, metal contacts, and connection integrity.

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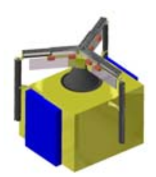
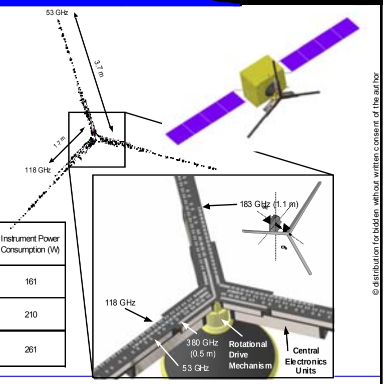
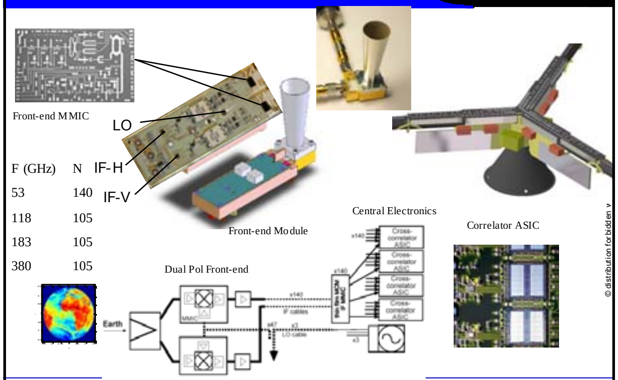
Terahertz Interferometry





	Instrument Mass (kg)	Instrument Power Consumption (W)
Basic nowcasting system 53, 183	214	161
Extended nowcasting system 53, 118, 183	235	210
Advanced nowcasting system 53, 118, 183, 380	253	261

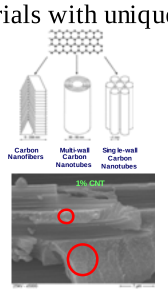
Terahertz Interferometry



CNF/CNT CFRP material

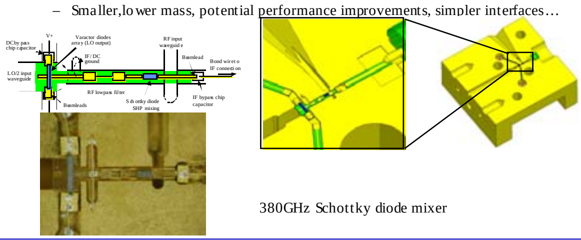
- The incorporation of nanotechnology in the field of composites has opened new horizons towards the development of advanced materials with unique functional properties.

•Carbon Nanofiber (CNF) and Carbon Nanotubes (CNT) are very promising filler materials due to high axial Young modulus and thermal and electrical properties. (Increased fracture resistance for 0.5% and 1% CNTs content)



CAD and Integration

- **Following advances in CAD, fixed tuned diode mixers and multipliers can now be accurately designed using commercial non-linear software and EM structure simulators which describe the circuit arrangement.**
- **Design and fabrication methodology is validated for frequencies up to 1THz**
- **There are potential advantages in integrating several functional components** (e.g., mixer LO, IF amplifier) **within a single waveguide cavity:**
  - Smaller, lower mass, potential performance improvements, simpler interfaces…



380GHz Schottky diode mixer

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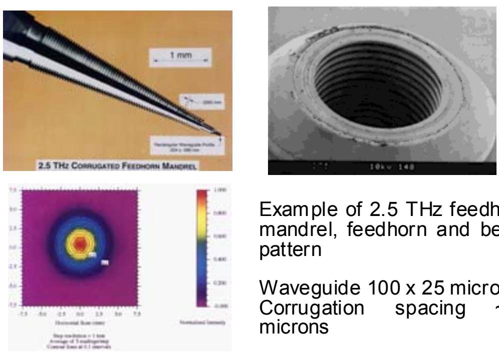
2.5 THz - Corrugated Feedhorn



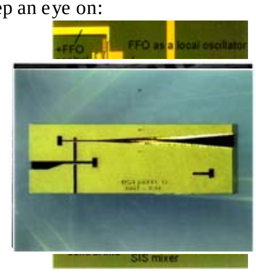
Example of 2.5 THz feedhorn mandrel, feedhorn and beam pattern

Waveguide 100 x 25 microns
Corrugation spacing ~26 microns

"Non-Classical" Technology

Conventional Technology exists, but keep an eye on:

- Integrated Antenna Technology
- Micromachined antenna Technology
- Metamaterial Technology



Objective:
to obtain equal or improved performance as compared to classical technologies with higher reliability.

Dipole measurements

Radiation patterns

Beamwidth E plane => **44 deg**
Beamwidth H plane => **64 deg**

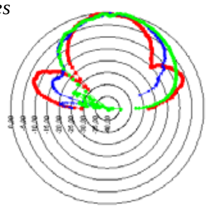
The high directivity values are due to an increase in the effective radiating area

Effective area dipole

$A_{em} = \frac{\lambda^2}{4\pi} D_0 \cong 0.13\lambda^2$

Dipole+woodpile

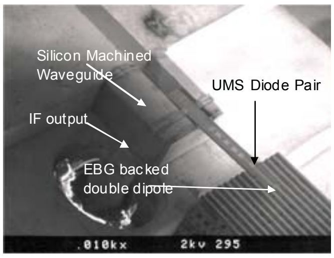
$A_e \cong 1.1\lambda^2$



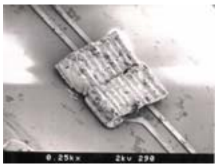
E-plane => 1-1.3λ
H-plane => 0.58-0.78 λ

Agrees well with predictions

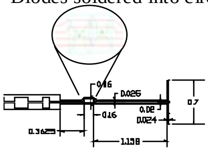
EBG Heterodyne Mixer



Complete EBG Mixer Circuit



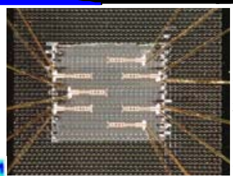
Diodes soldered into circuit

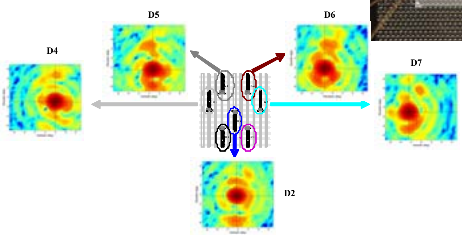


Noise Temperature at 250 GHz ≈3500K

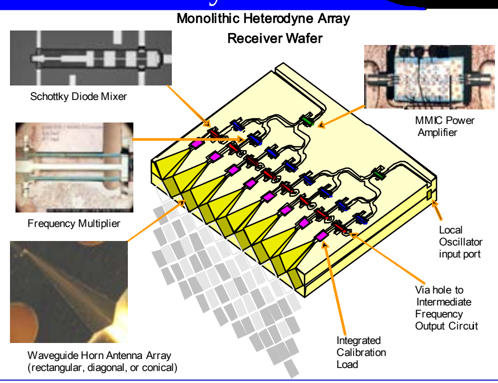
Imaging Array

Manufactured Heterodyne Imaging Array for 500 GHz

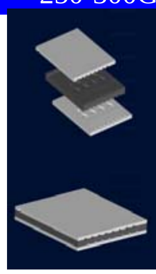


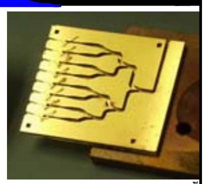


40.000 Pixel Array at 1 THz



250-300GHz Twin Array

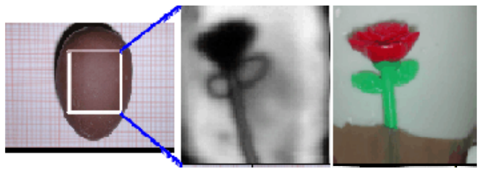




Conclusions

- Traditional heartland of THz technology (remote sensing and radio astronomy) continues to represent a strong technology push and pull.
- Key to success is top-perfomance combined with low-power and mass.
- Arguably this has paved the technological path towards broadly usable THz systems for everyday applications

The future?



Questions ??