EEM 424
MICROWAVE ENGINEERING

INTRODUCTION

2014 – 2015 SPRING SEMESTER

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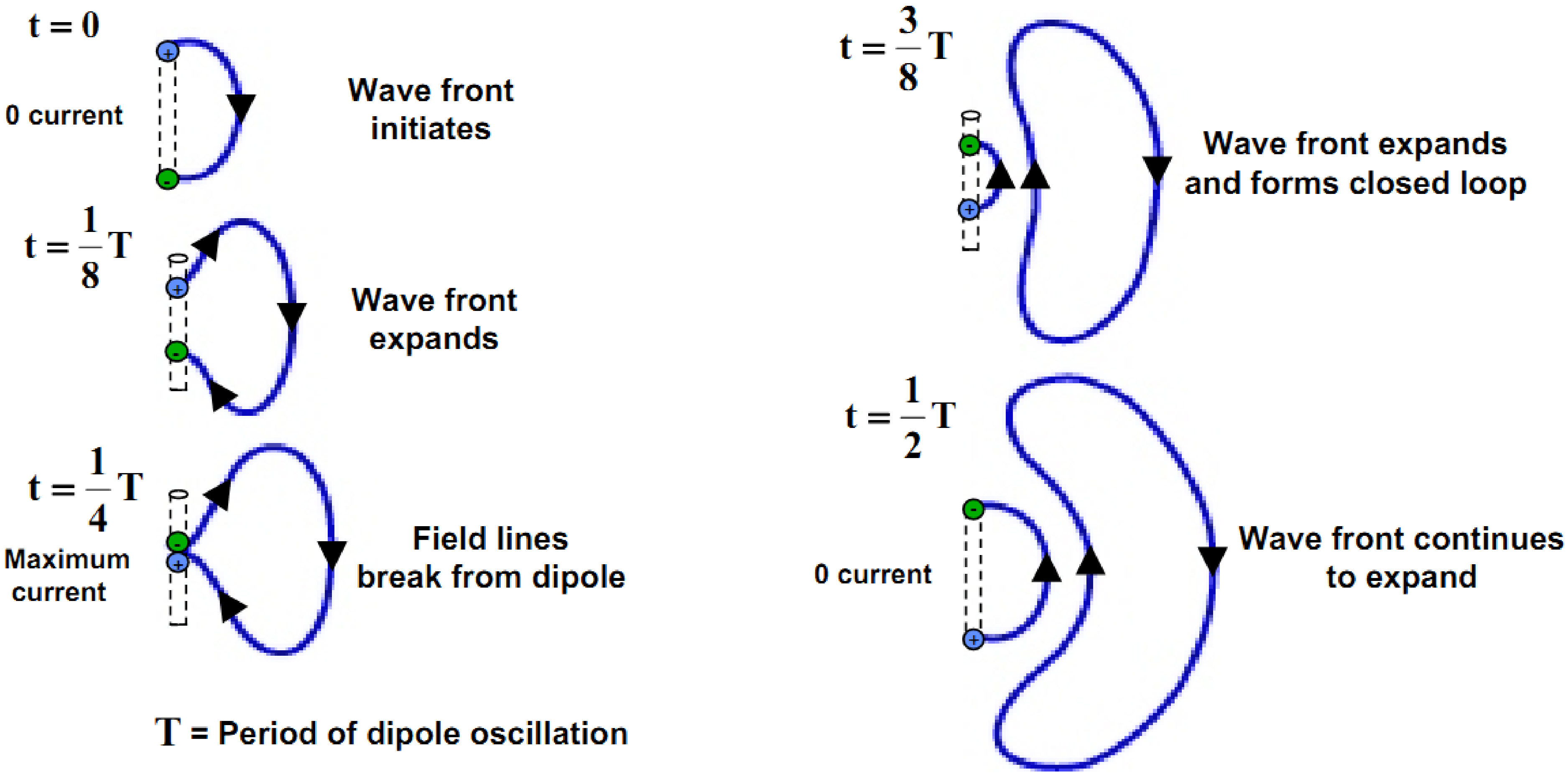
REVIEW – EMT 1 & 2

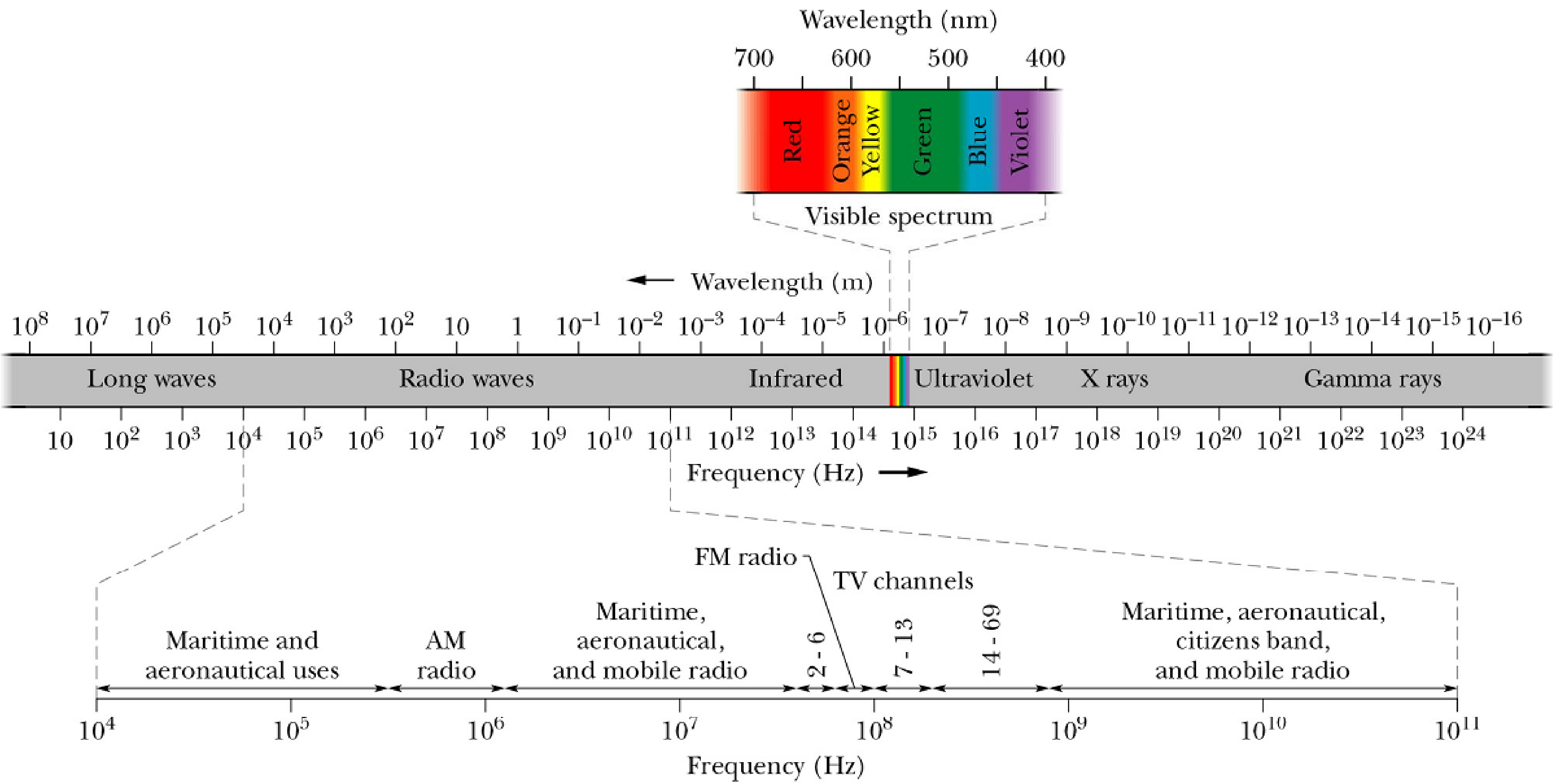


T = Period of dipole oscillation

Illustration of propagation and detachment of electric field lines from the dipole
Two charges in simple harmonic motion

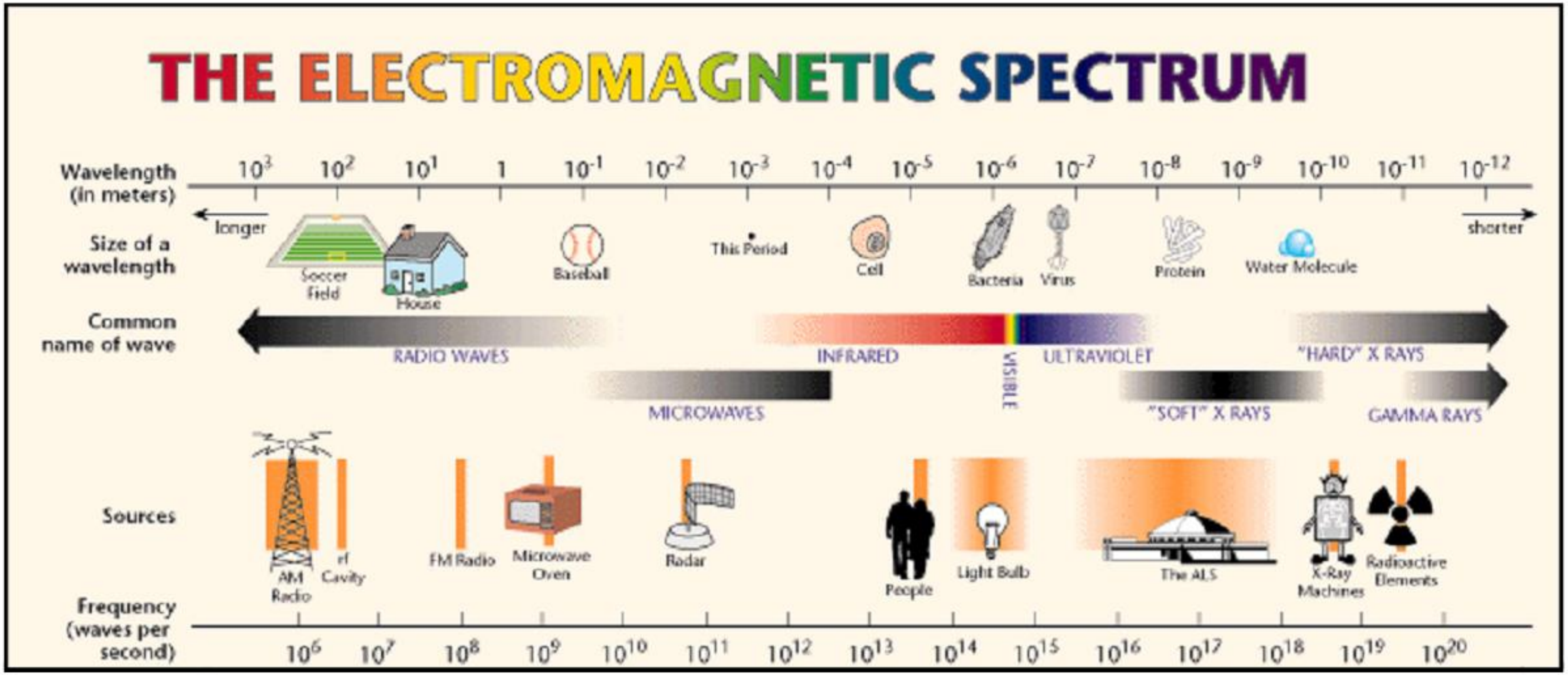
[R. M. O'Donnell]

THE ELECTROMAGNETIC SPECTRUM



[S-O. PARK]

THE ELECTROMAGNETIC SPECTRUM

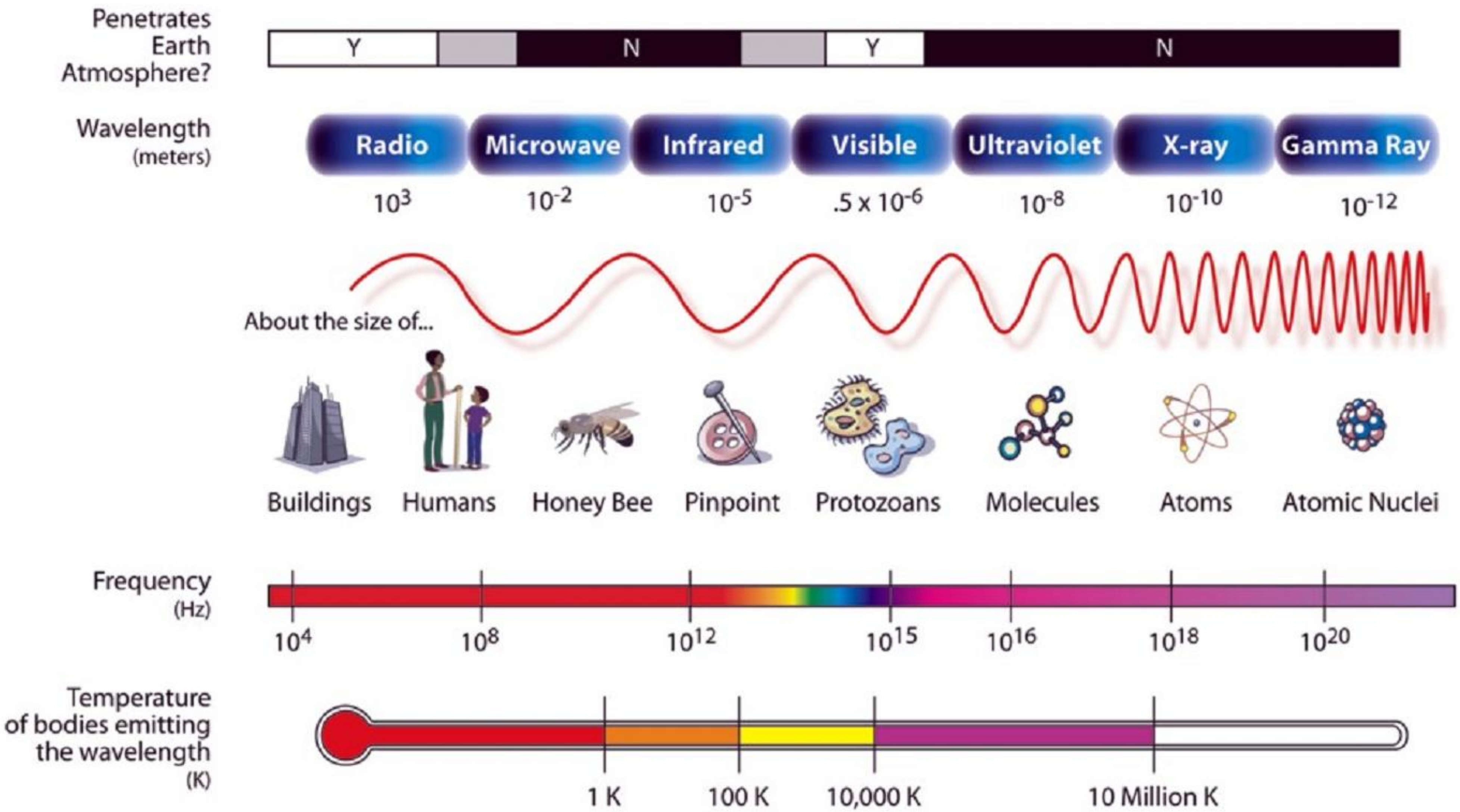


Courtesy Berkeley National Laboratory

Radar Frequencies

[R. M. O'DONNELL]

THE ELECTROMAGNETIC SPECTRUM



[KEVIN CHEN]

Microwaves as part of the electro magnetic spectrum

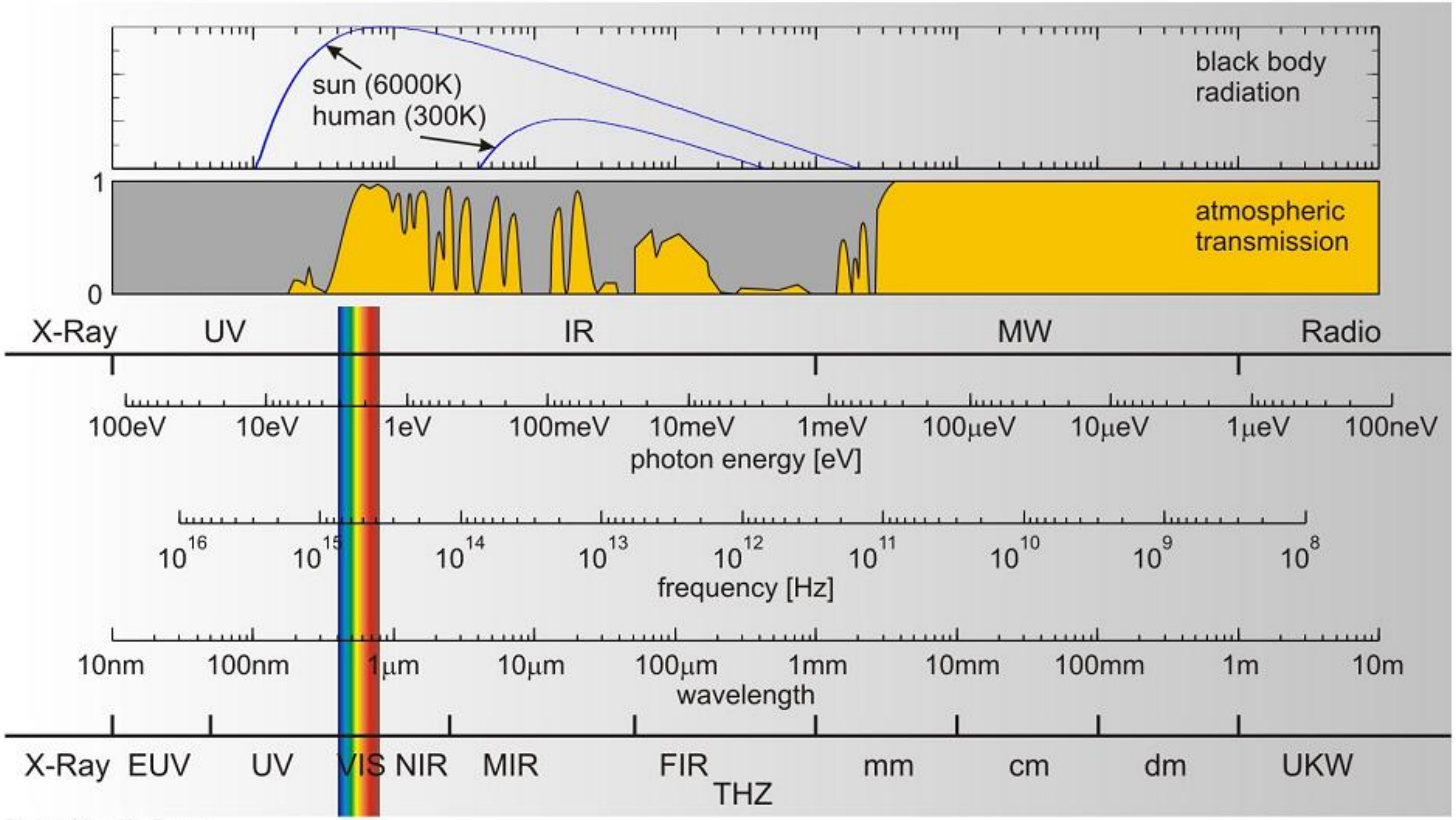
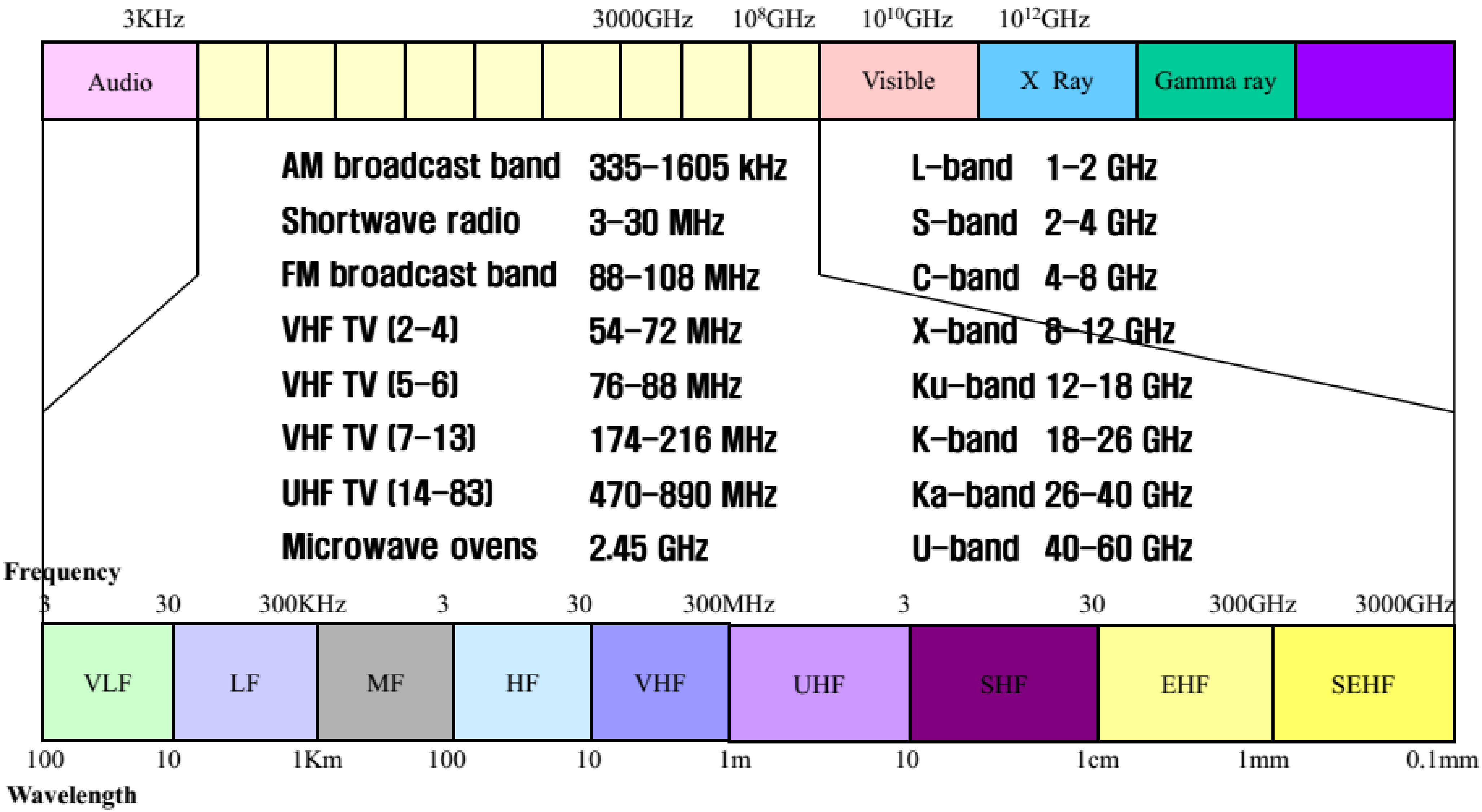


Figure from Th.Feurer

$$\lambda[\mathrm{mm}] = \frac{300}{\nu[\mathrm{GHz}]}$$

[KAMPFER, MURK]

THE ELECTROMAGNETIC SPECTRUM



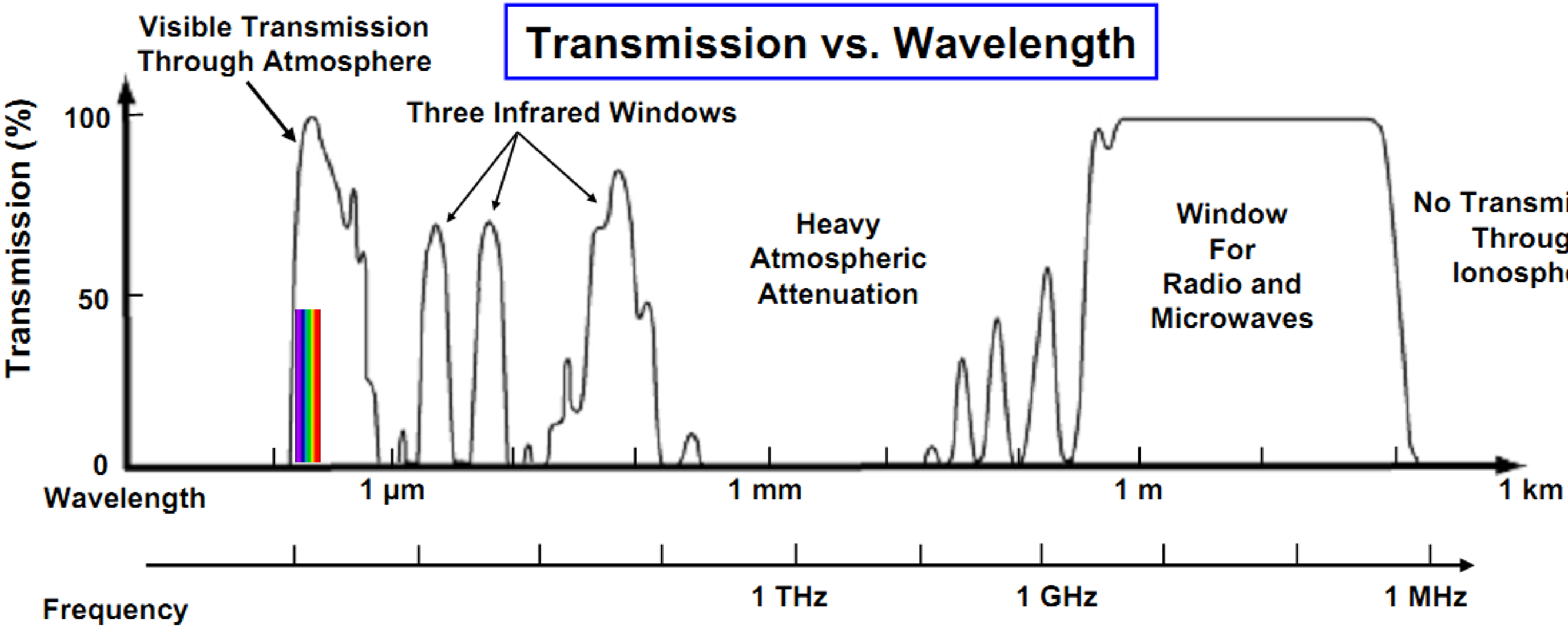
[S-O. PARK]

Frequency Spectrum Designations

Frequency band	Wavelength	Designation	Services
3 to 30 kHz	100 to 10 km	Very Low Frequency (VLF)	Navigation, sonar, submarine
30 to 300 kHz	10 to 1 km	Low Frequency (LF)	Radio beacons, navigation
300 to 3000 kHz	1000 to 100 m	Medium Frequency (MF)	AM broadcast, maritime/coast-guard radio
3 to 30 MHz	100-10 m	High Frequency (HF)	Telephone, telegraph, fax; amateur radio, ship-to-coast and ship-to-aircraft communication
30 to 300 MHz	10-1 m	Very High Frequency (VHF)	TV, FM broadcast, air traffic control, police, taxicab mobile radio
300 to 3000 MHz	100-10 cm	Ultrahigh Frequency (UHF)	TV, satellite, radiosonde, radar, bluetooth, PCS, wireless LAN
3 to 30 GHz	10-1 cm	Super High Frequency (SHF)	Airborne & automotive radar, microwave relay, satellite, mobile communication, local wireless ntw
30 to 300 GHz	10-1 mm	Extremely High Frequency (EHF)	Radar, experimental, security systems

[NIKOLOVA]

WHY MICROWAVES ?



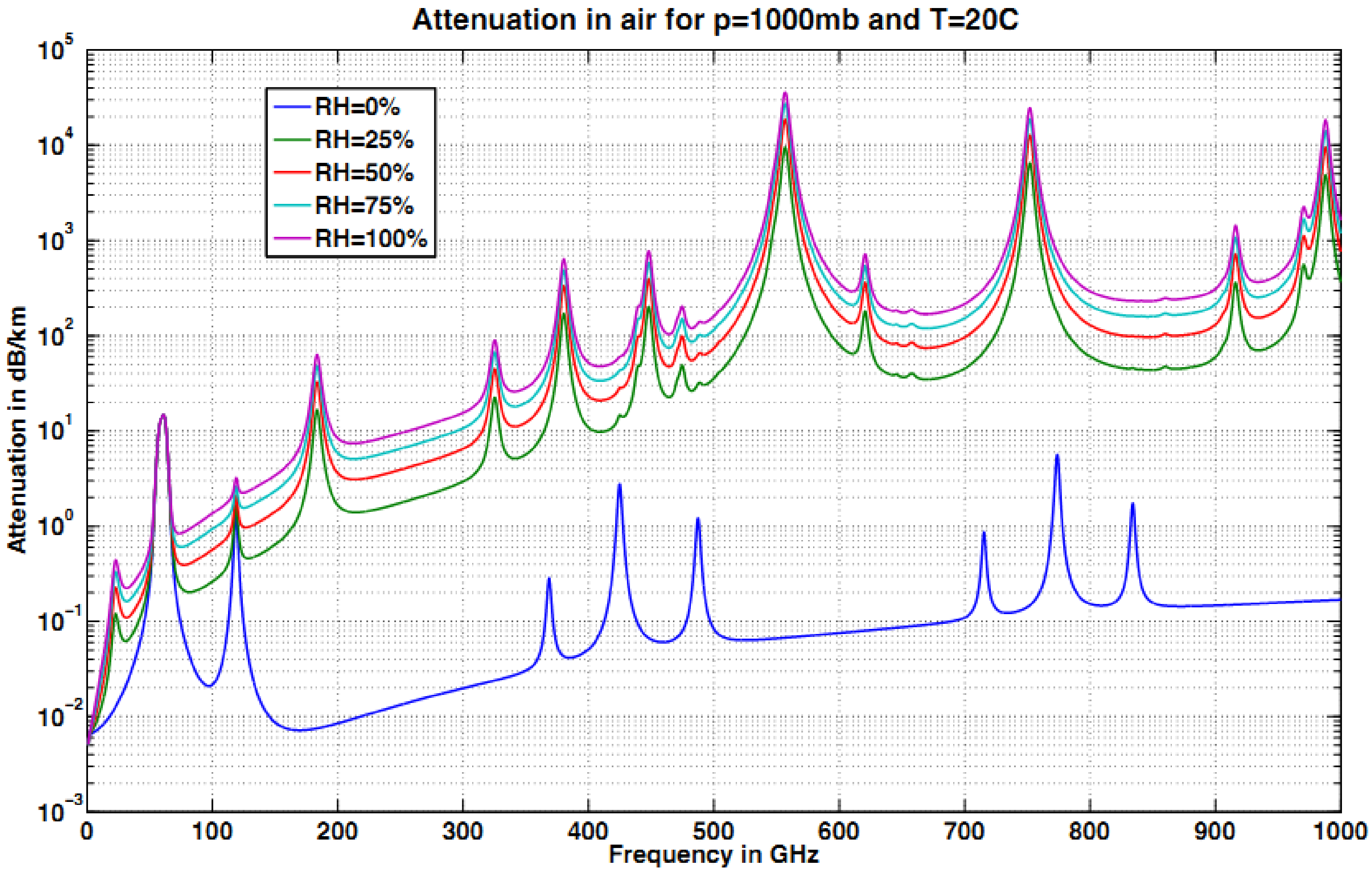
The microwave region of the electromagnetic spectrum (~3 MHZ to ~ 10 GHZ) is bounded by:

- **One region (> 10 GHz) with very heavy attenuation by the gaseous components of the atmosphere (except for windows at 35 & 95 GHz)**
- **The other region (< 3 MHz), whose frequency implies antennas too large for most practical applications**

[R. M. O'DONNELL]

Attenuation of a microwave signal in air

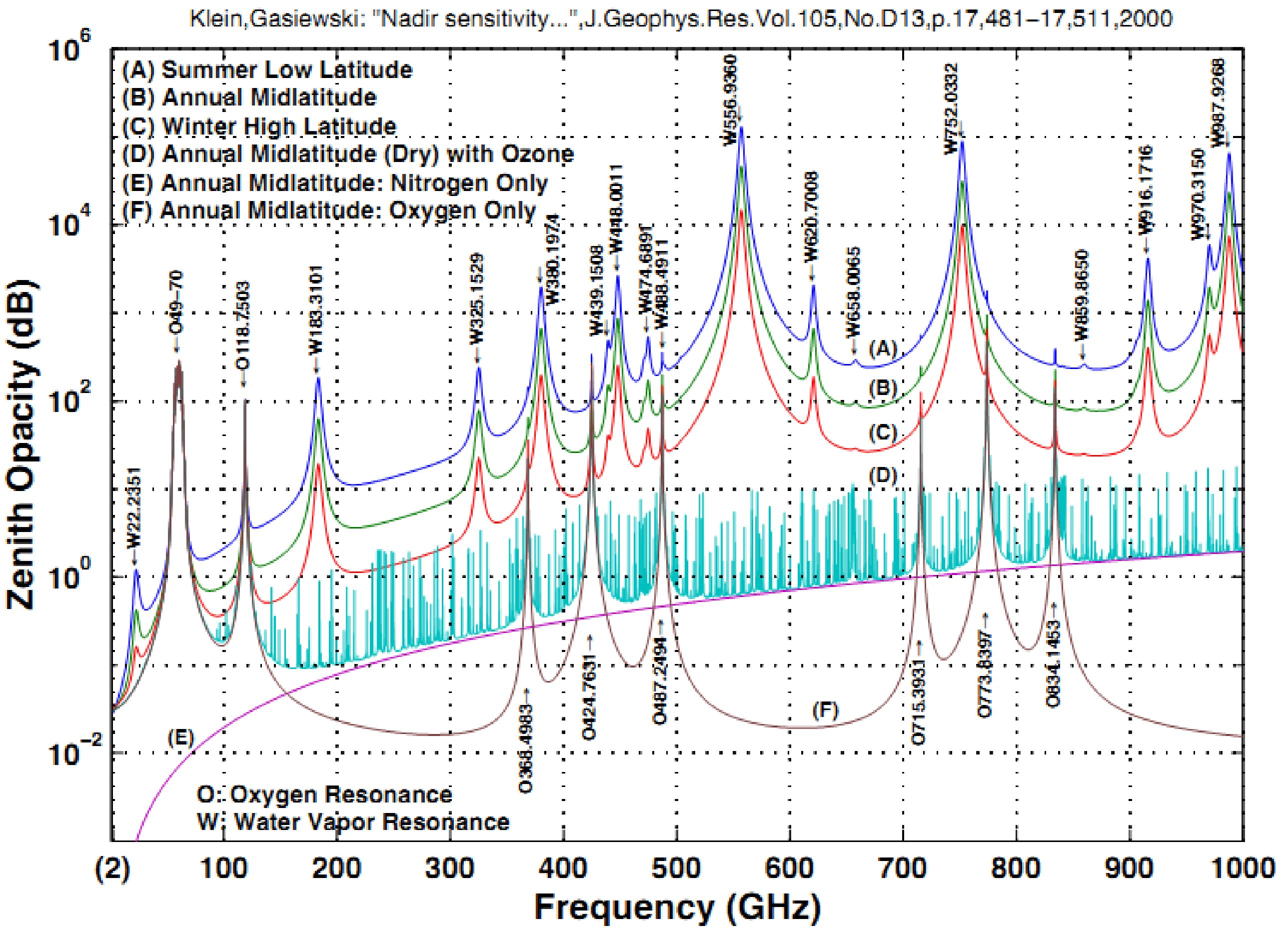
Attenuation in a horizontal propagation path in the atmosphere according Model MPM



[KAMPFER, MURK]

Zenith attenuation (loss) expressed in dB from 1 to 1000 GHz

Calculations with model MPM by H.Liebe

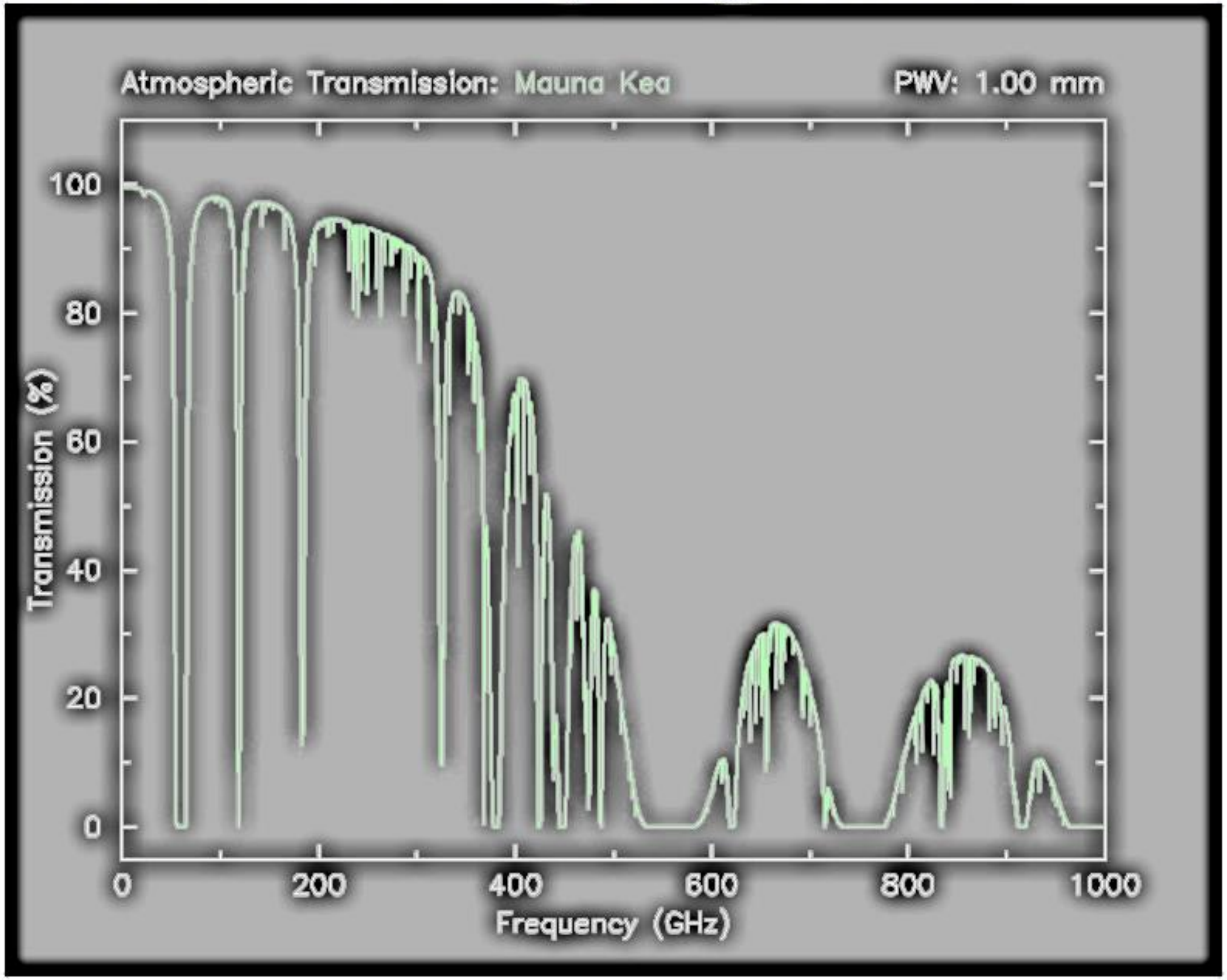


☞ link between transmissivity t, loss L and opacity τ is: $t = \frac{1}{L} = e^{-\tau}$

τ =opacity in dB/4.343

[KAMPFER, MURK]

Microwave zenith transmissivity at high altitude ▸ submm Caltech



Why all these lines? ☞ microwave spectroscopy

[KAMPFER, MURK]

IEEE Microwave Band Designations IEEE

Frequency	Old	New
500-1000 MHz	VHF	C
1-2 GHz	L	D
2-3 GHz	S	E
3-4 GHz	S	F
4-6 GHz	C	G
6-8 GHz	C	H
8-10 GHz	X	I
10-12.4 GHz	X	J
12.4-18 GHz	Ku	J
18-20 GHz	K	J
20-26.5 GHz	K	K
26.5-40 GHz	Ka	K

[NIKOLOVA]

Some Frequency Band Allocations: North America

international and national regulatory bodies allocate frequency bands for commercial, government and personal use

FCC (USA): Federal Communications Commission

Industry Canada: Radiocommunications and Broadcasting Regulatory Branch

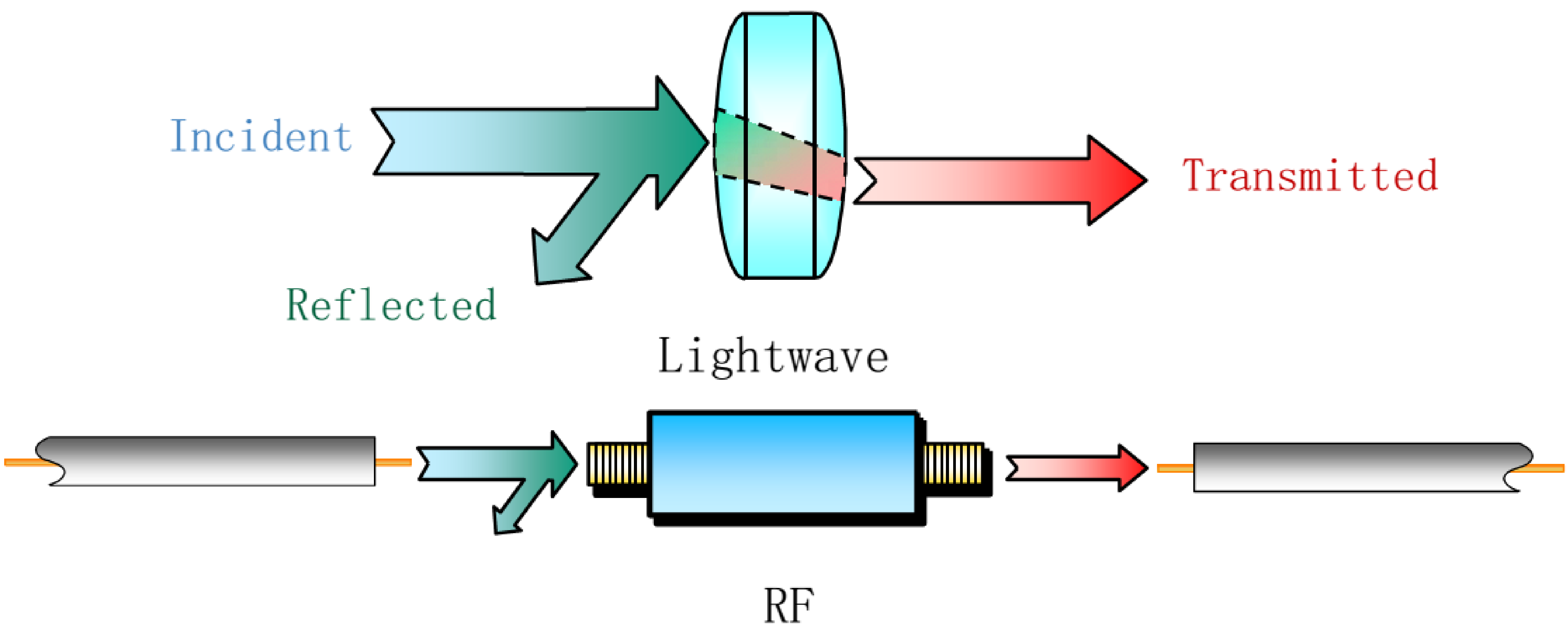
AM broadcast	535 kHz to 1605 kHz
FM broadcast	88 MHz to 108 MHz
VHF TV (ch. 2 to 4)	54 MHz to 72 MHz
VHF TV (ch. 5 to 6)	76 MHz to 88 MHz
UHF TV (ch. 7 to 13)	174 MHz to 216 MHz
UHF TV (ch. 14 to 83)	470 MHz to 890 MHz
US cellular telephones	824 MHz to 849 MHz 869 MHz to 894 MHz
Europe GSM	880 MHz to 915 MHz 925 MHz to 960 MHz
GPS	1575.42 MHz / 1227.60 MHz

[NIKOLOVA]

HOMEWORK – 1: Find similar allocations for Turkey.

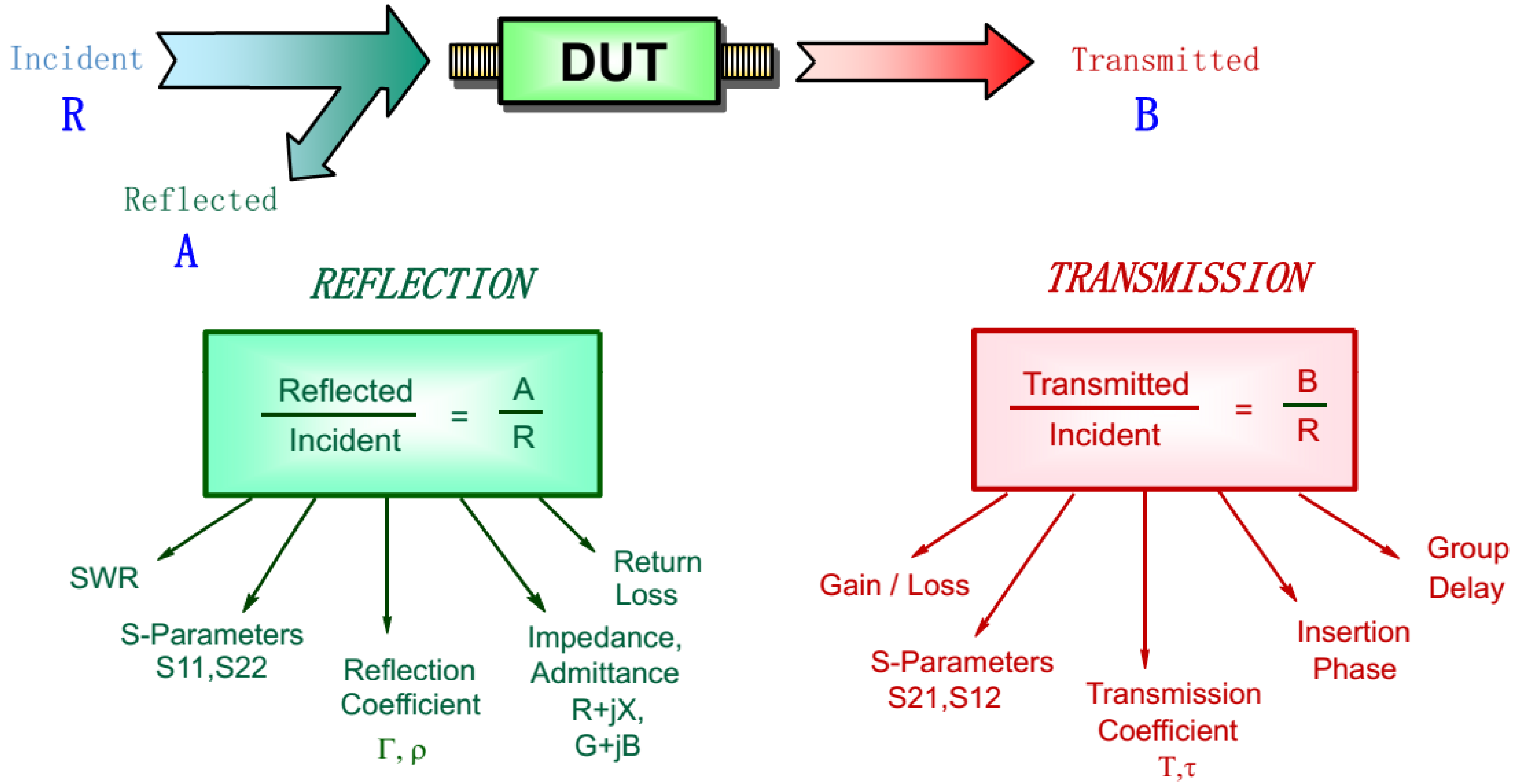
ANALOGY: RF AND OPTICS

Lightwave Analogy to RF Energy



[S-O. PARK]

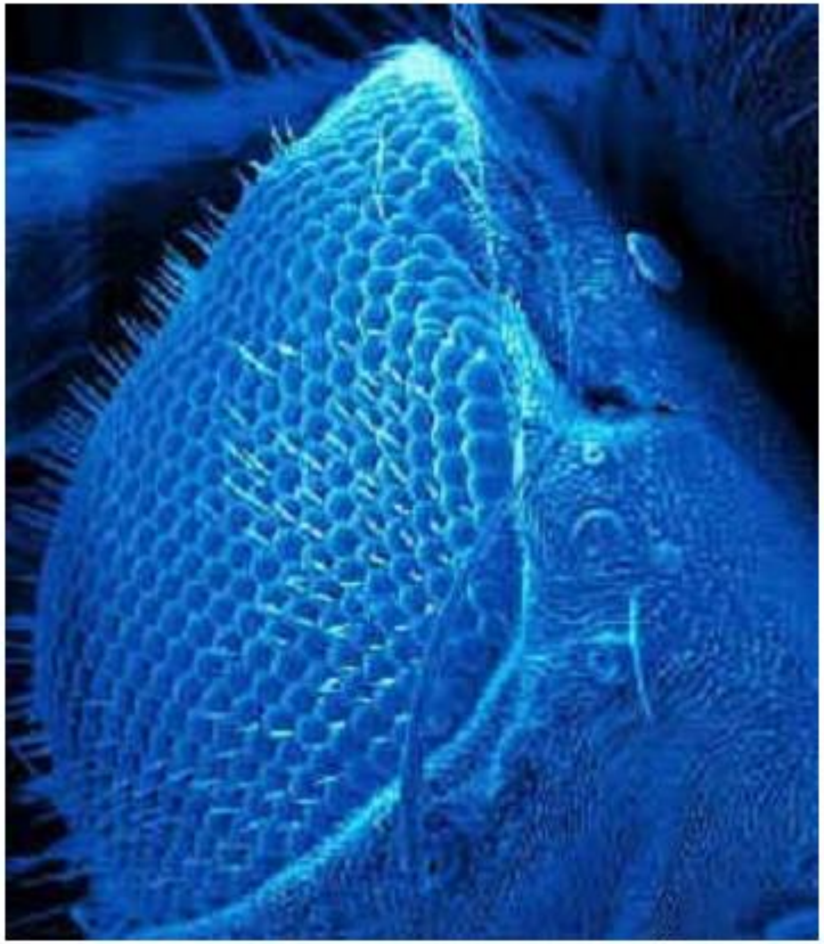
High-Frequency Device Characterization

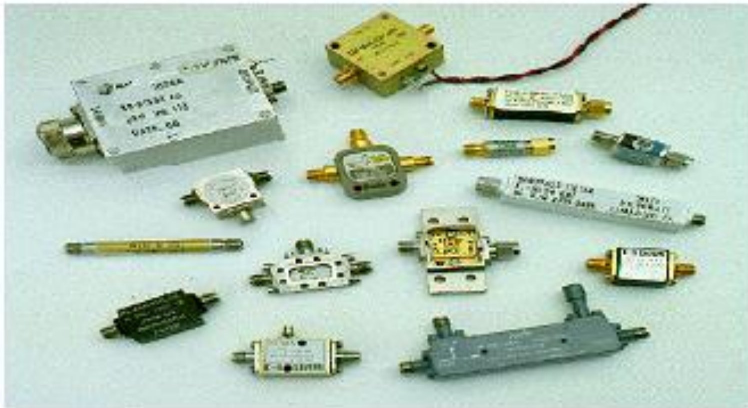


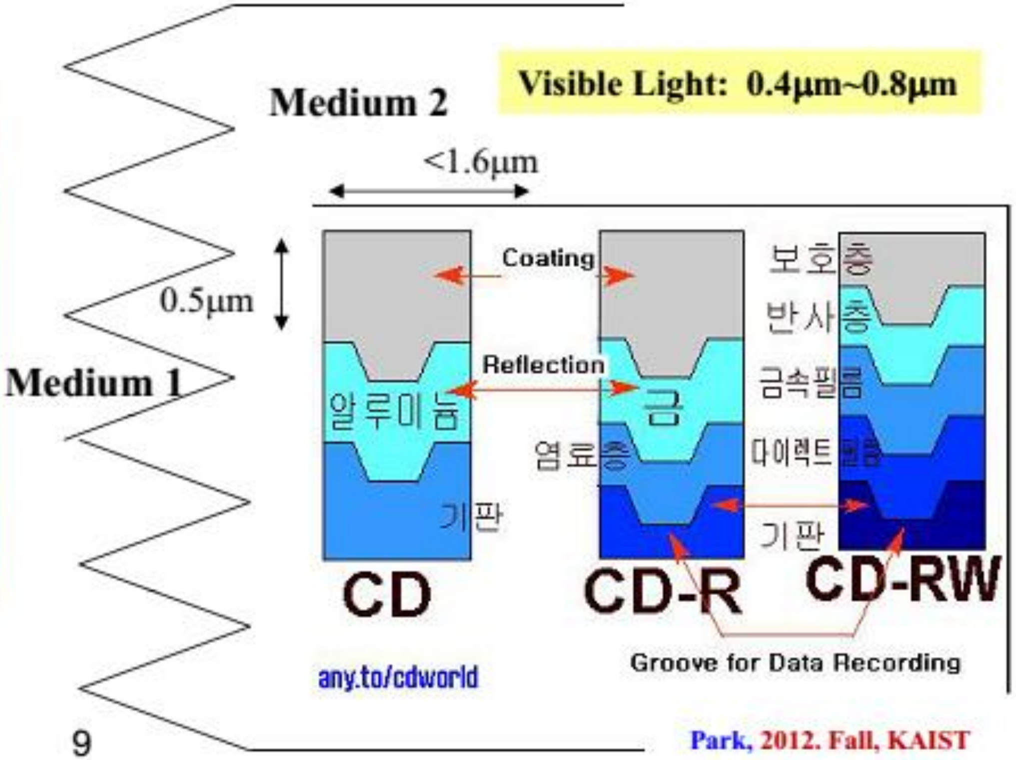
[S-O. PARK]

ANALOGY: BIOLOGICAL AND RF SOLUTIONS

Fly's-eye view. (Adult eye shown here.)



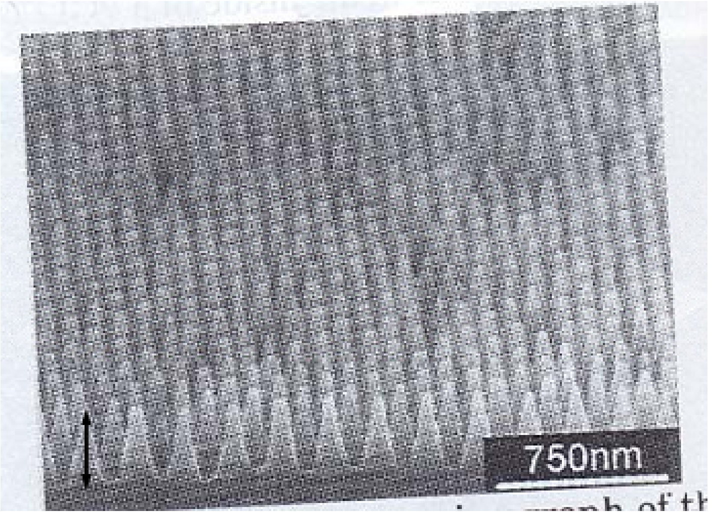




EE542 Microwave Engineering, 9 Park, 2012. Fall, KAIST

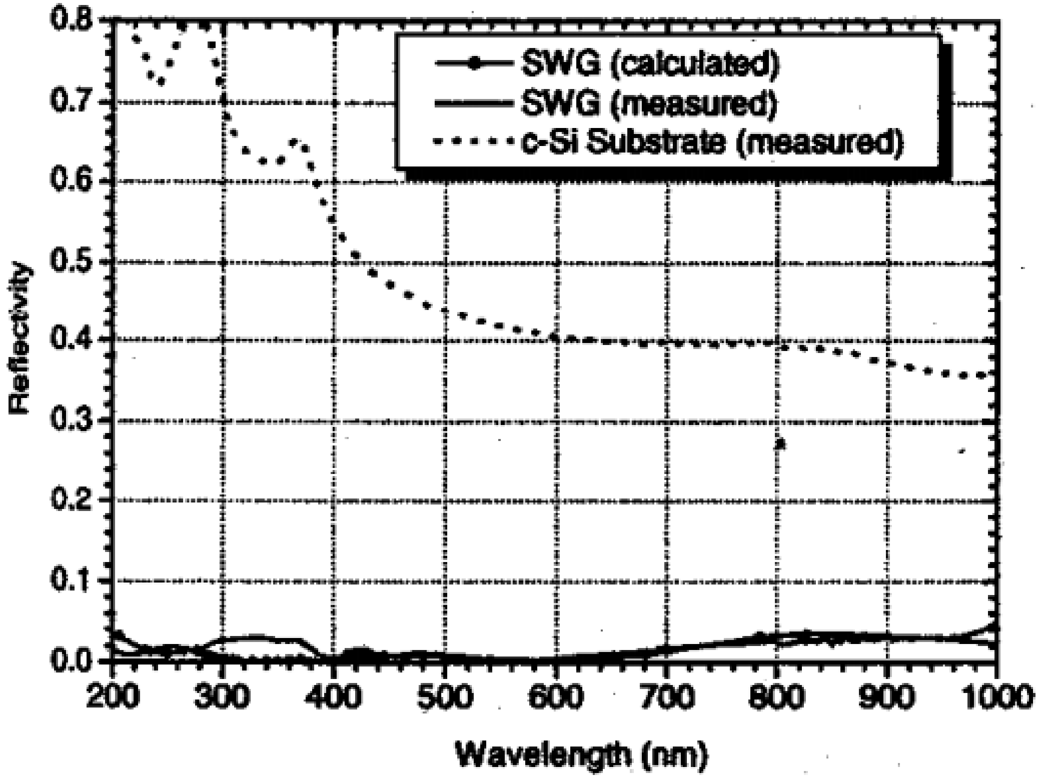
Sub-wavelength Device in Optics and Microwave

Sub-wavelength Structured Surface (SWS) on crystal silicon



350*nm*

150*nm*



The grating period is 150*nm* and the groove is 350*nm* deep.

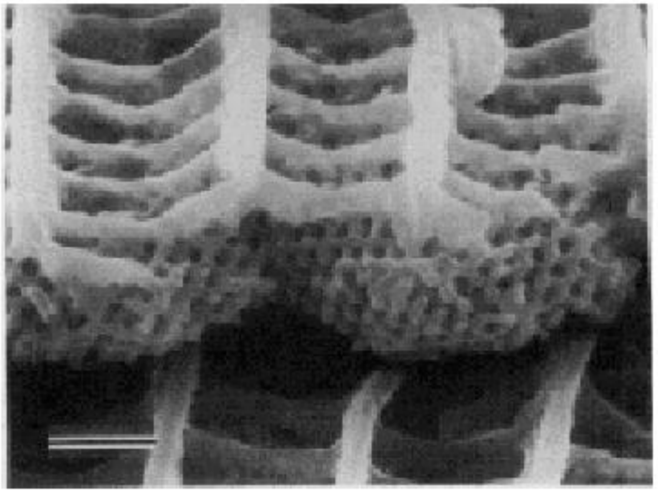
Visible Light: 400*nm* ~ 800*nm*

The reflectivity of the SWS surface is less than 3% at the wavelength from 200*nm* to 800*nm*.

At 400nm, Ref. decrease from 54.7% to 0.5%.

Manufacturing Photonic Materials: The Biological Option

As yet, technology has not caught up with our desire to create fully three dimensional, micron scale, periodic structures. Drawing patterns on a surface presents few problems to the integrated circuit industry, but that third dimension defeats us for the time being; though not, we suspect, for long.



On the other hand nearly all of biology is `engineered' on the micron scale and with the help of DNA very complex structures are manufactured. Not surprisingly the optical properties are frequently exploited, nowhere with more spectacular effect than in the butterfly. Many species show irridescent green or blue patches and these owe their colouring to diffraction from periodic material in the scales of the wing. On the left is an electron micrograph of a broken scale taken from mitoura grynea revealing a periodic array of holes responsible for the colour.

Right we see a specimen of the Adonis Blue butterfly. Note the blue patches to the rear of the wing.

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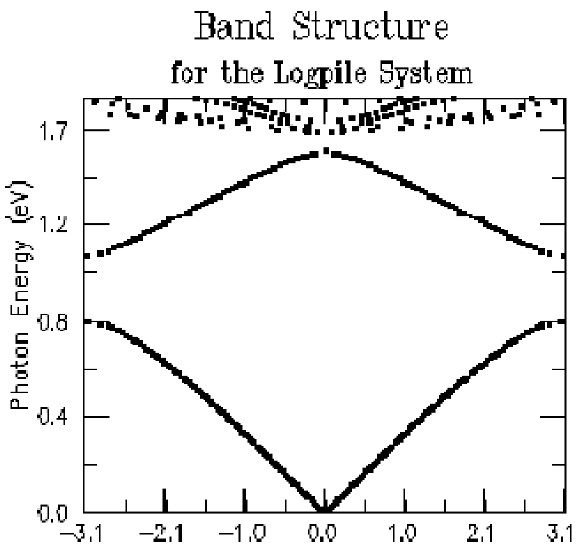
[S-O. PARK]

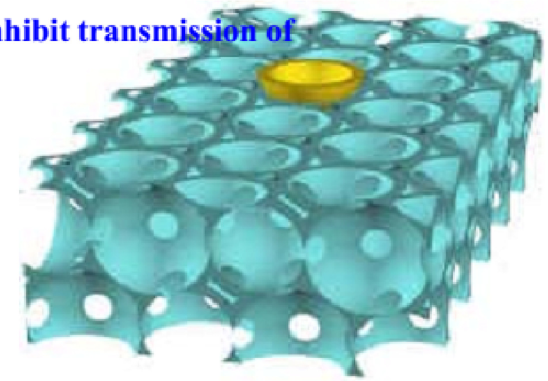
Band Structures, Transmission and Reflection Coefficients

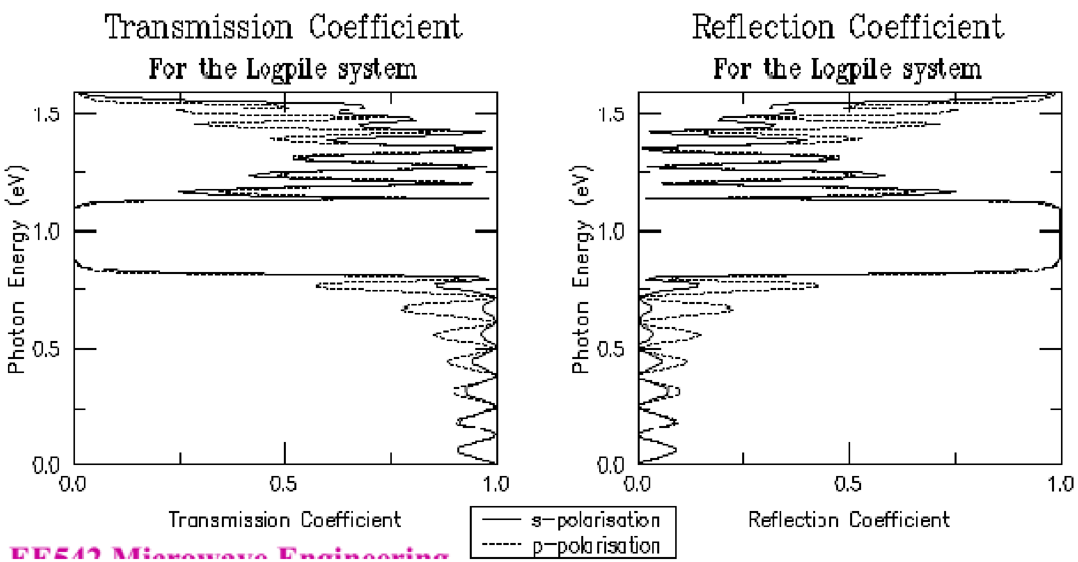


The figures show the band structure, transmission and reflection coefficients for the logpile structure which we have calculated using the OPAL codes. Compare the band structure and transmission coefficient. Within the band gap, where there are no extended states, transmission falls dramatically whereas the

corresponding reflectivity reaches a peak.

Inverse opal structure can inhibit transmission of specific wavelength of light





Compare also the band structure shown here to the dispersion surface on the opposite page. Whereas the band structure is an w, k plot, the dispersion surface is a surface of allowed states in k space at a fixed w. The band structure is built by slicing through through dispersion surfaces at different w.

[S-O. PARK]

Applications of Microwaves

Features of microwave

- Higher bandwidth
- Antenna directivity:highly directive communication
- Reasonable antenna size for practical implementation
- unique interaction with materials: remote sensing, medical diagnostics, heating

Applications:

- Wireless communications: cellular phones dominate

  DBS, PCS, WLAN, GPS, UWB, RFID, WiFi, Wimax, LTE…..
- High speed interconnects: on-chip or in-system
- Remote sensing, medical diagnostics, heating…

ELEC344, Kevin Chen, HKUST 13

OTHER APPLICATIONS IN MICROWAVES

El reflector mas grande del mundo

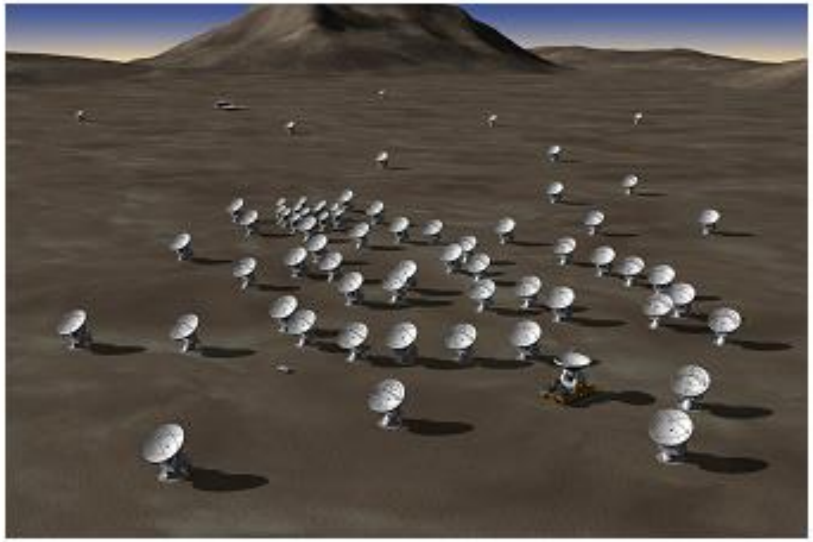
Arecibo Observatory in Puerto Rico (300m diameter)

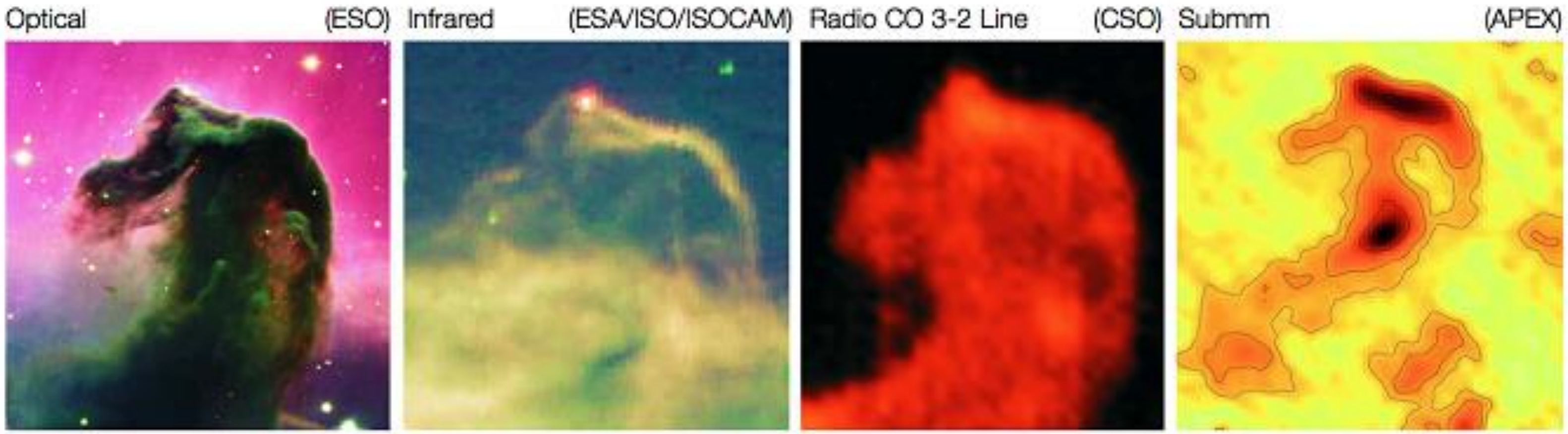
[KAMPFER, MURK]

Arecibo radio telescope in Puerto Rico

[KAMPFER, MURK]

Atacama Large Millimeter Array ALMA

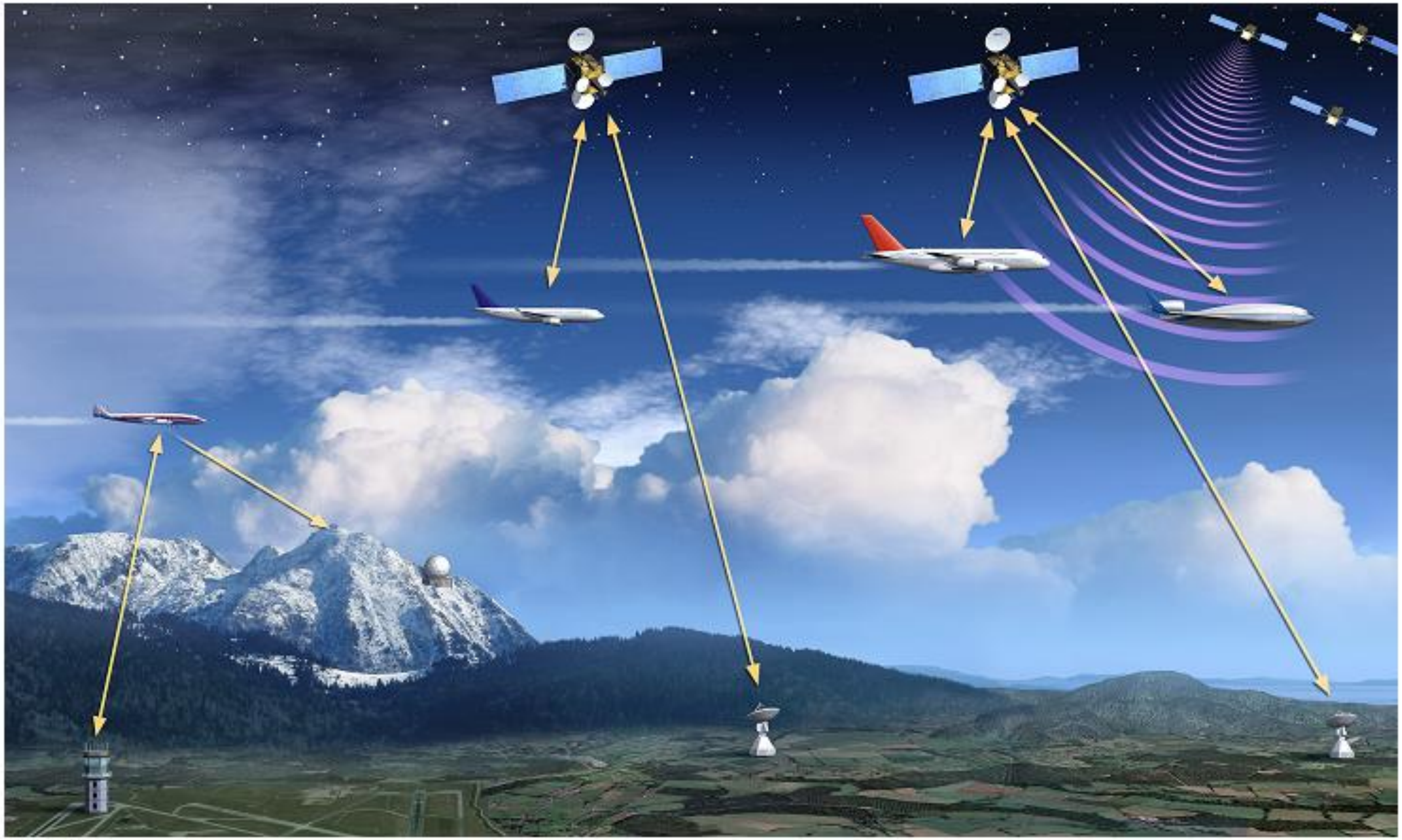




In the optical, dust obscures star-forming activity in the Horsehead Nebula. In the infrared, the hot, thin layer of dust around the cloud glows. At radio wavelengths, both dust and molecules glow, providing a wealth of information on the internal structure, density and kinematics of optically invisible regions. ALMA will map the glowing emission (the two rightmost panels) at the resolution of the optical image

[KAMPFER, MURK]

Worldwide telecommunication



from ESA

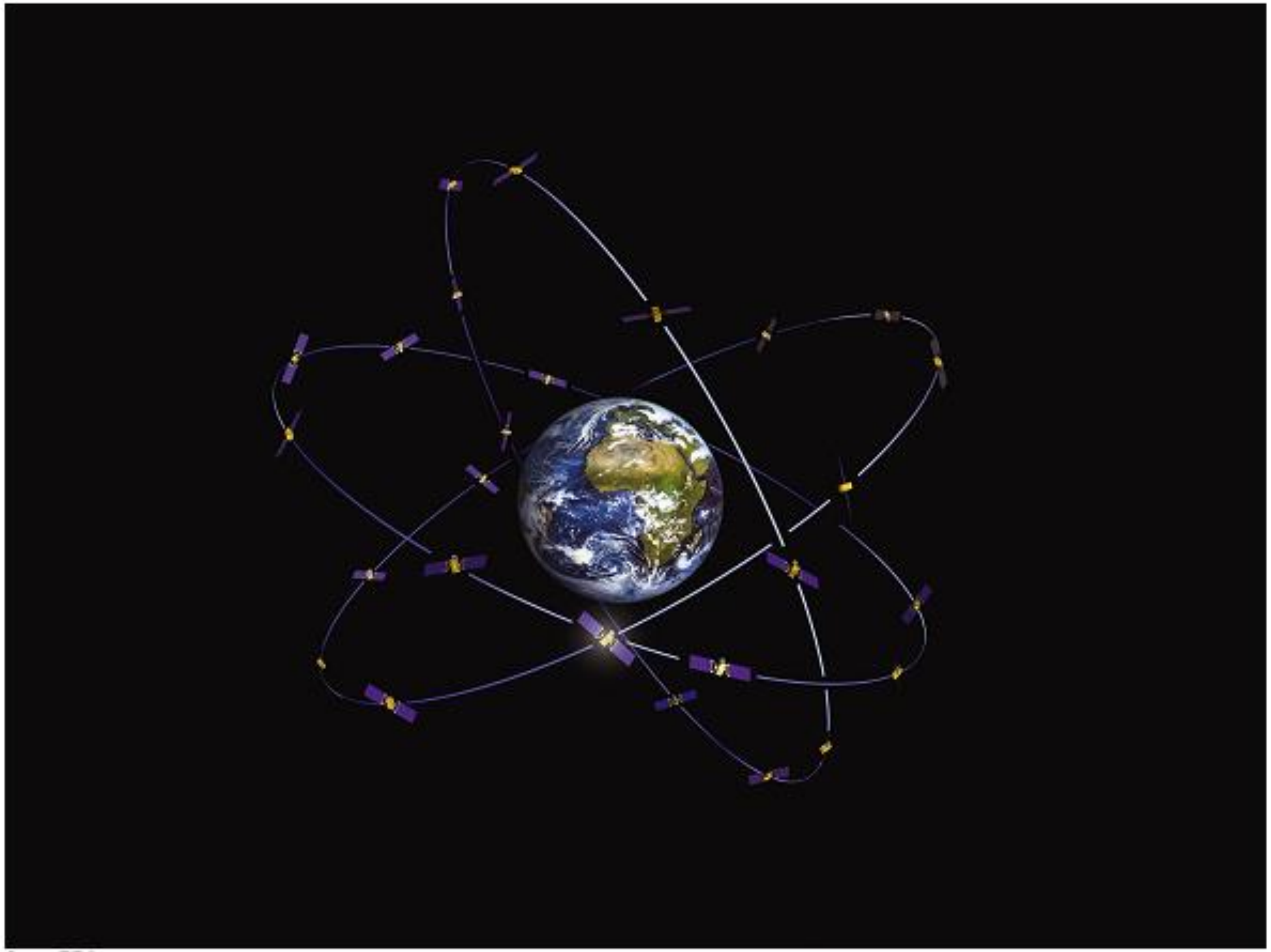
Telecom links at microwave frequencies

[KAMPFER, MURK]

Ground station for ENVISAT in Lapland

[KAMPFER, MURK]

Navigation system Galileo satellites



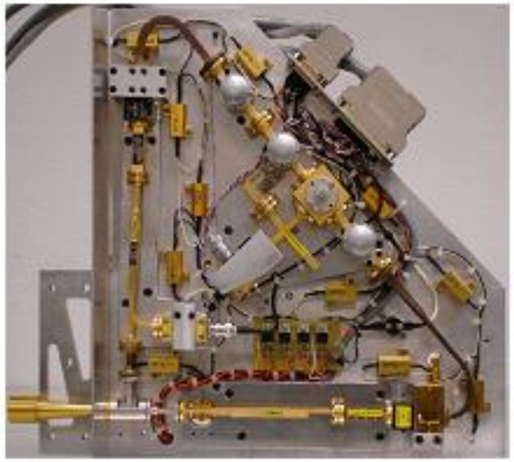
from ESA

GPS signal work in the microwave range

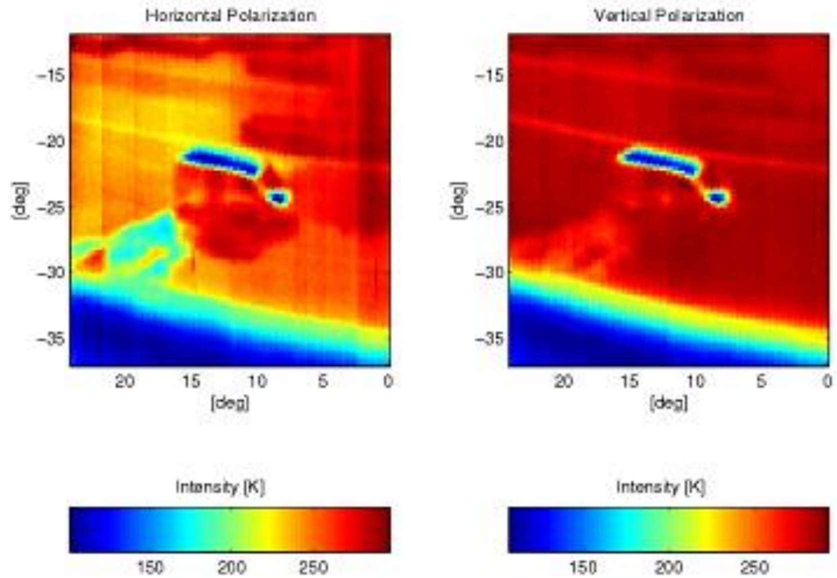
[KAMPFER, MURK]

SPIRA: Scanning Polarimetric Imaging Radiometer

SPIRA on roof ExWi



Microwave receiver



[KAMPFER, MURK]

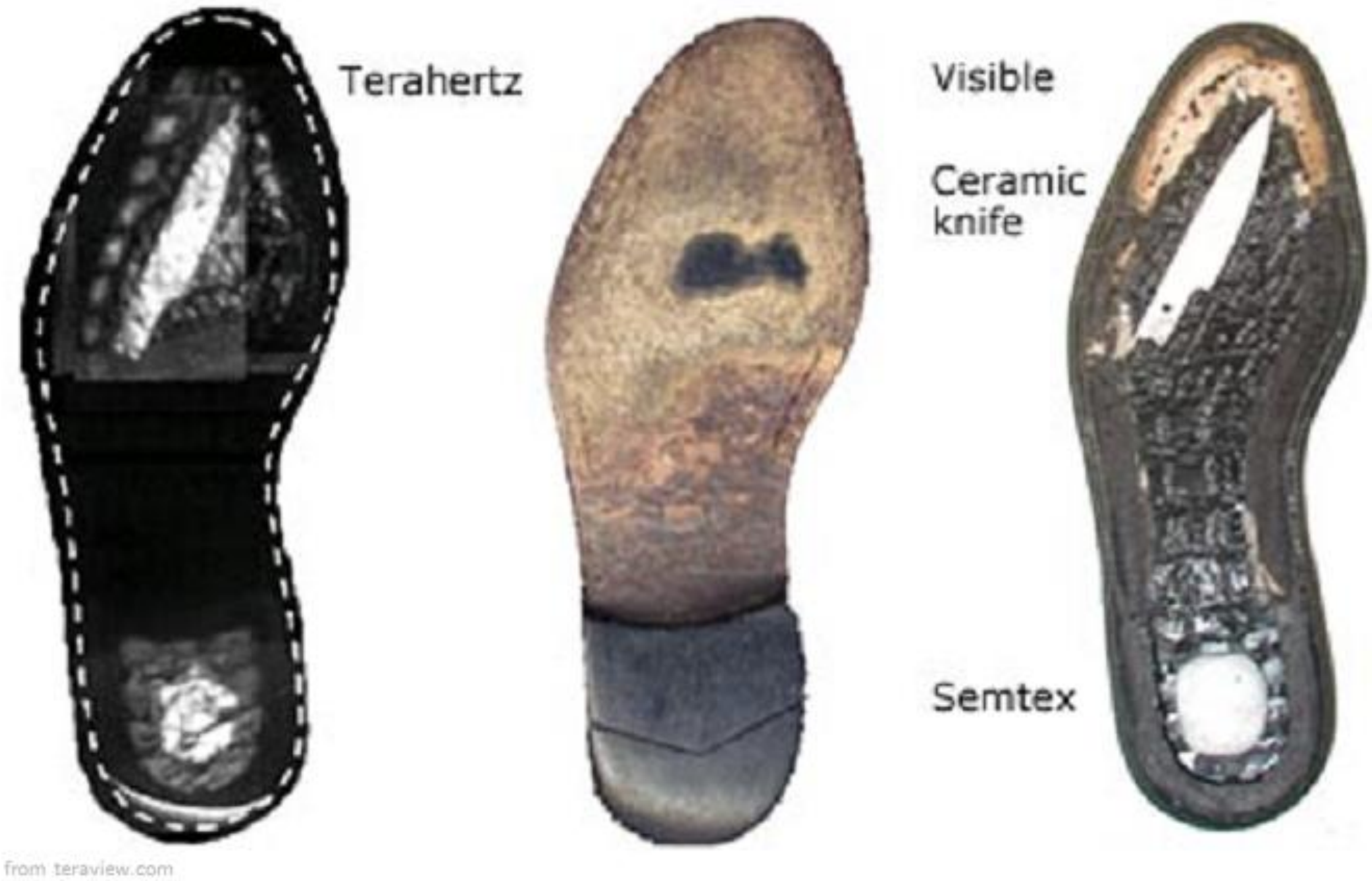
Hidden objects made visible at THz frequencies

Bodyscanner at airport

image obtained from bodyscanner

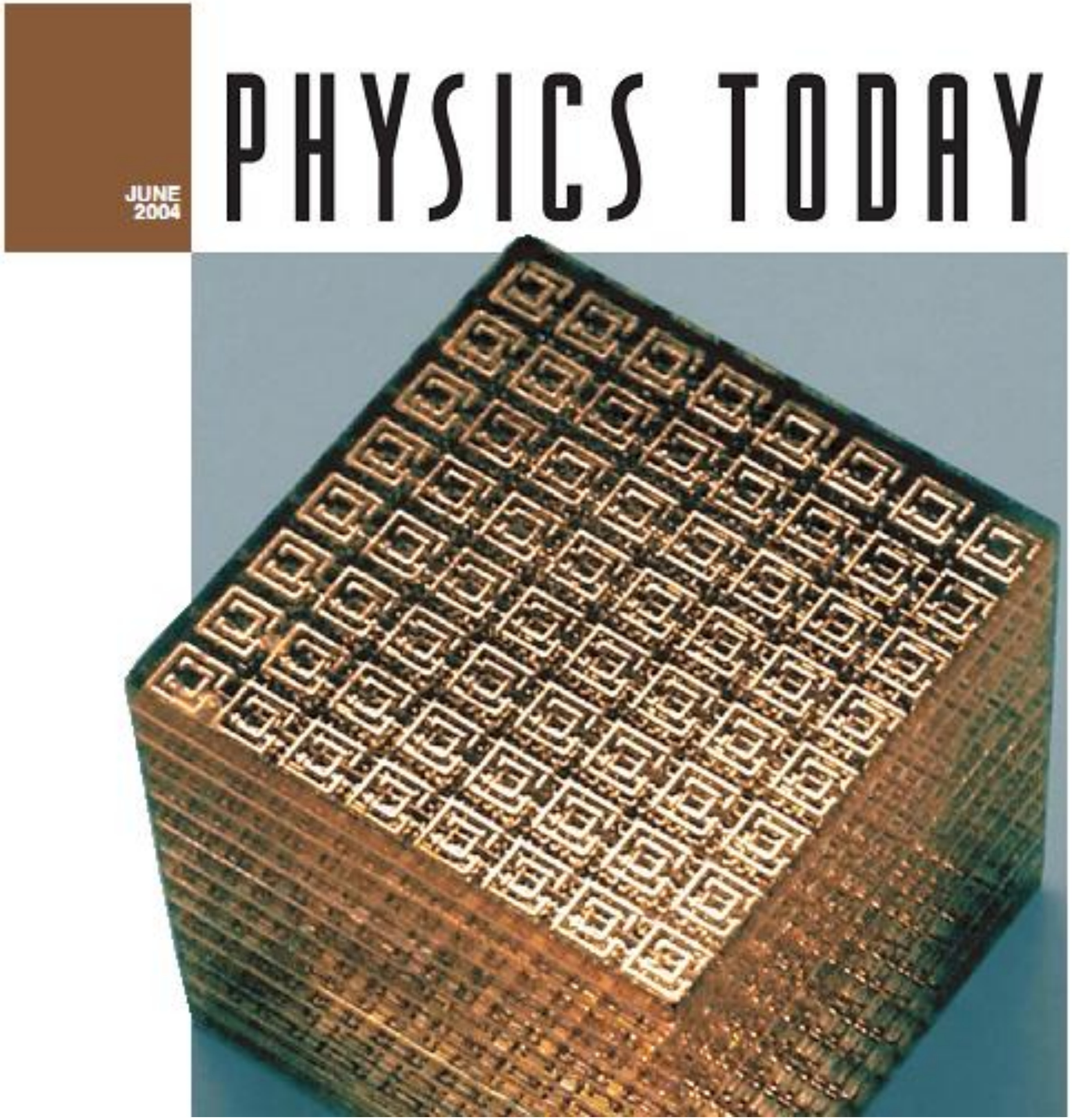
[KAMPFER, MURK]

Hidden objects made visible at THz frequencies



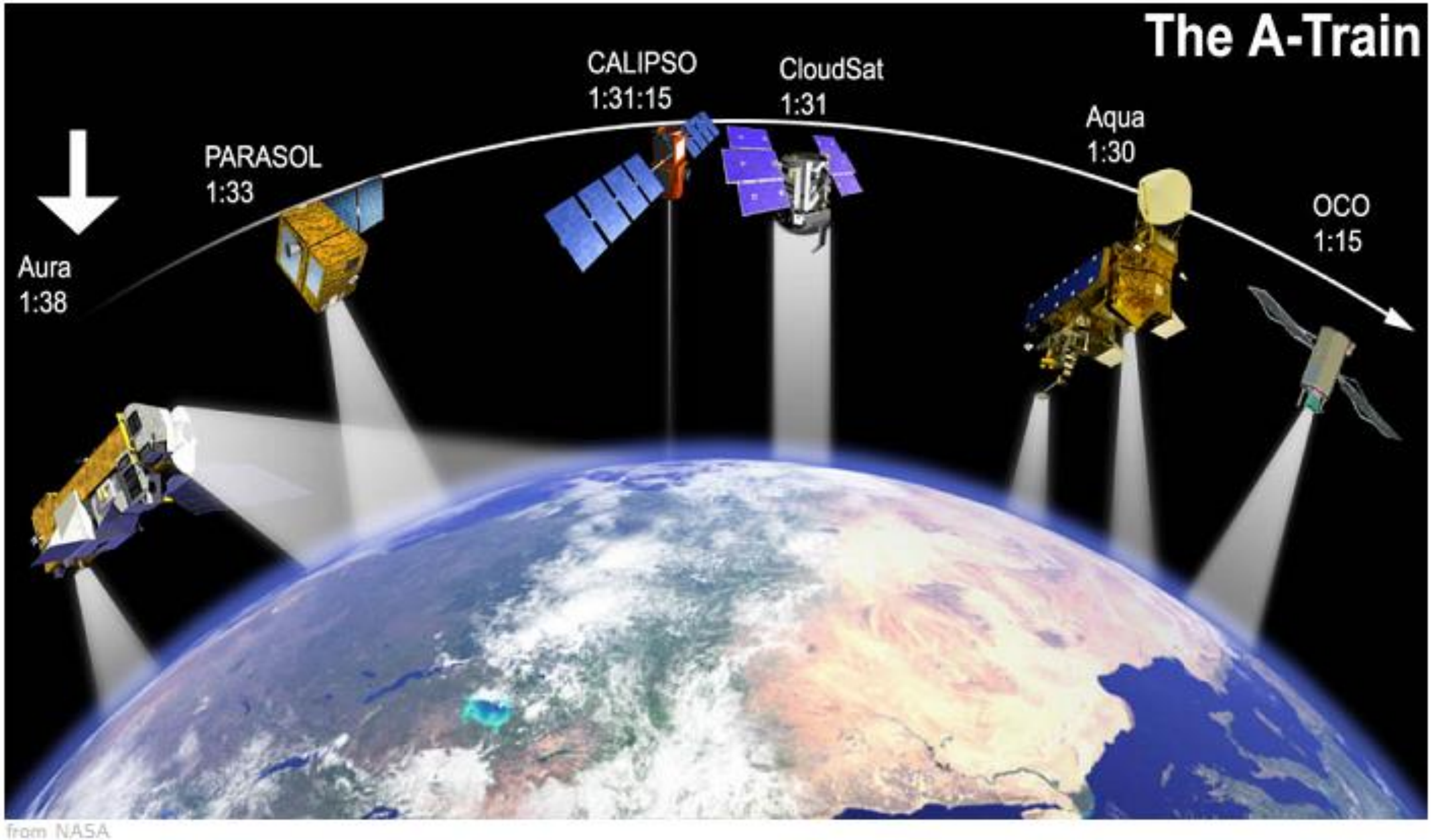
[KAMPFER, MURK]

Metamaterials



[KAMPFER, MURK]

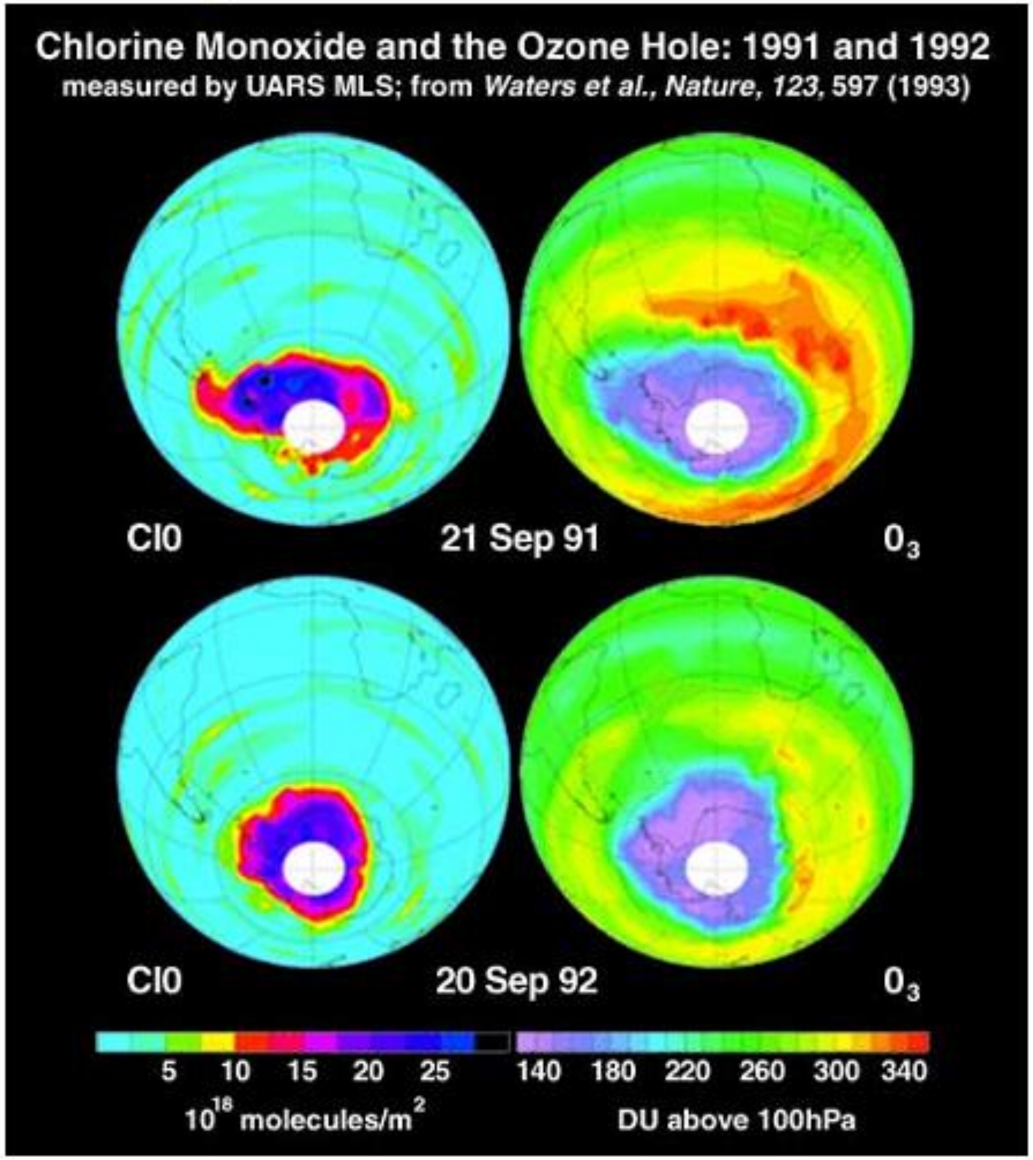
Whole trains of satellites survey the Earth



The so called A-train

[KAMPFER, MURK]

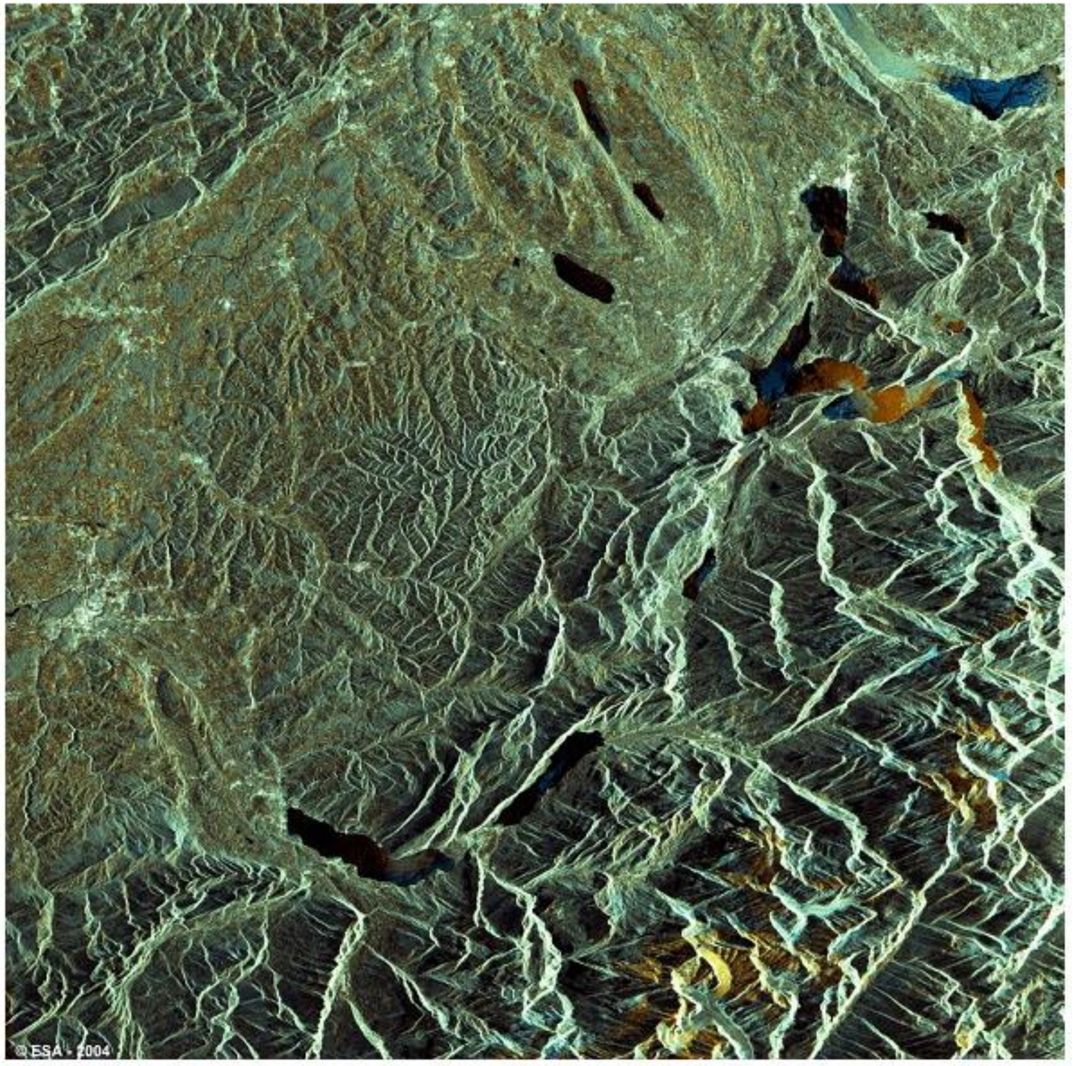
Ozone-hole as seen by microwave limb sounder



NOTE: + Ionospeheric sonde using radiometers, [KAMPFER, MURK]

ASAR on ENVISAT

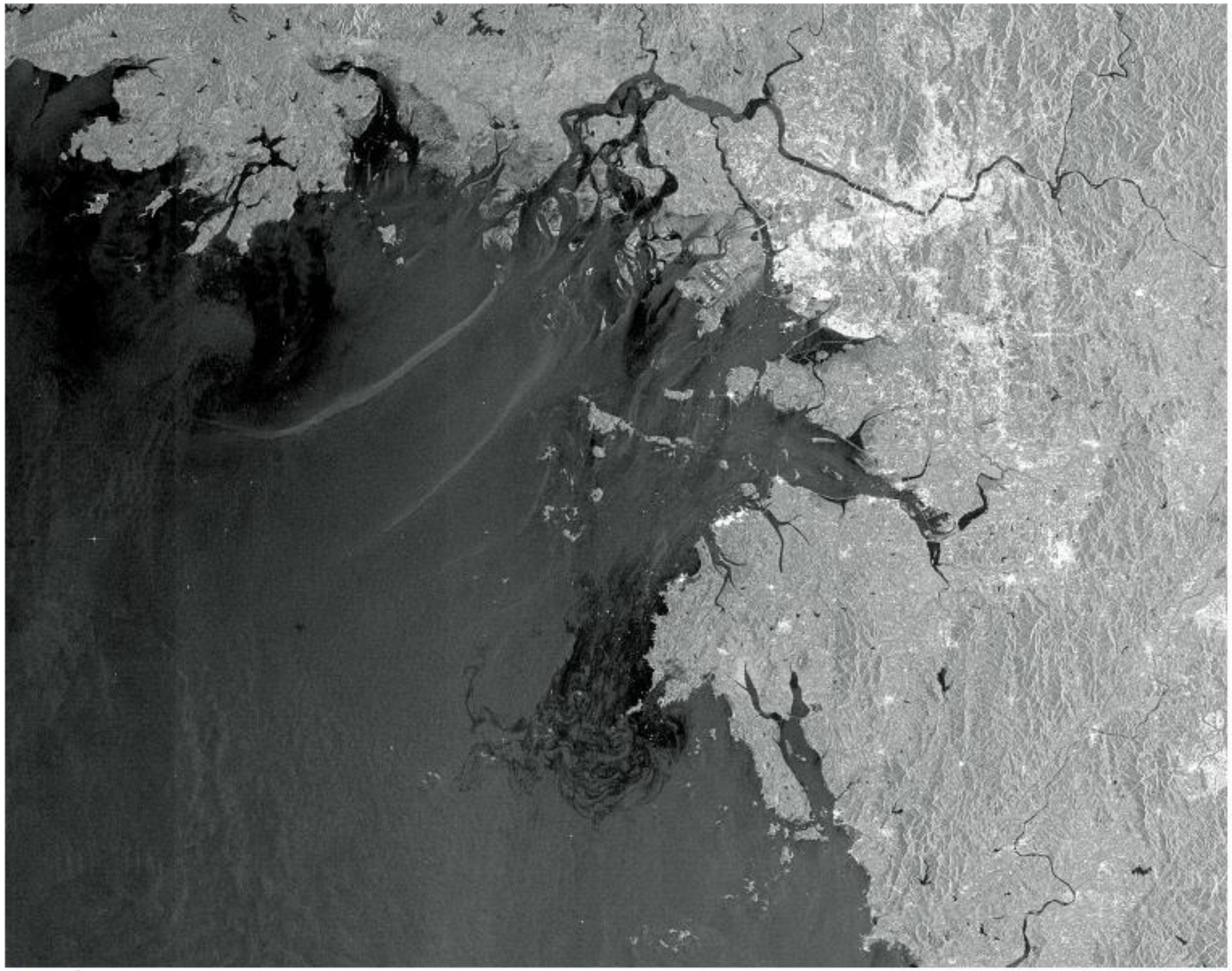
Synthetic Aperture Radar image of central Switzerland



Distorted mountains due to sideways looking instrument

NOTE: We are examining SAR in EEM 538. **[KAMPFER, MURK]**

Detection of environmental pollution by ASAR



from ESA

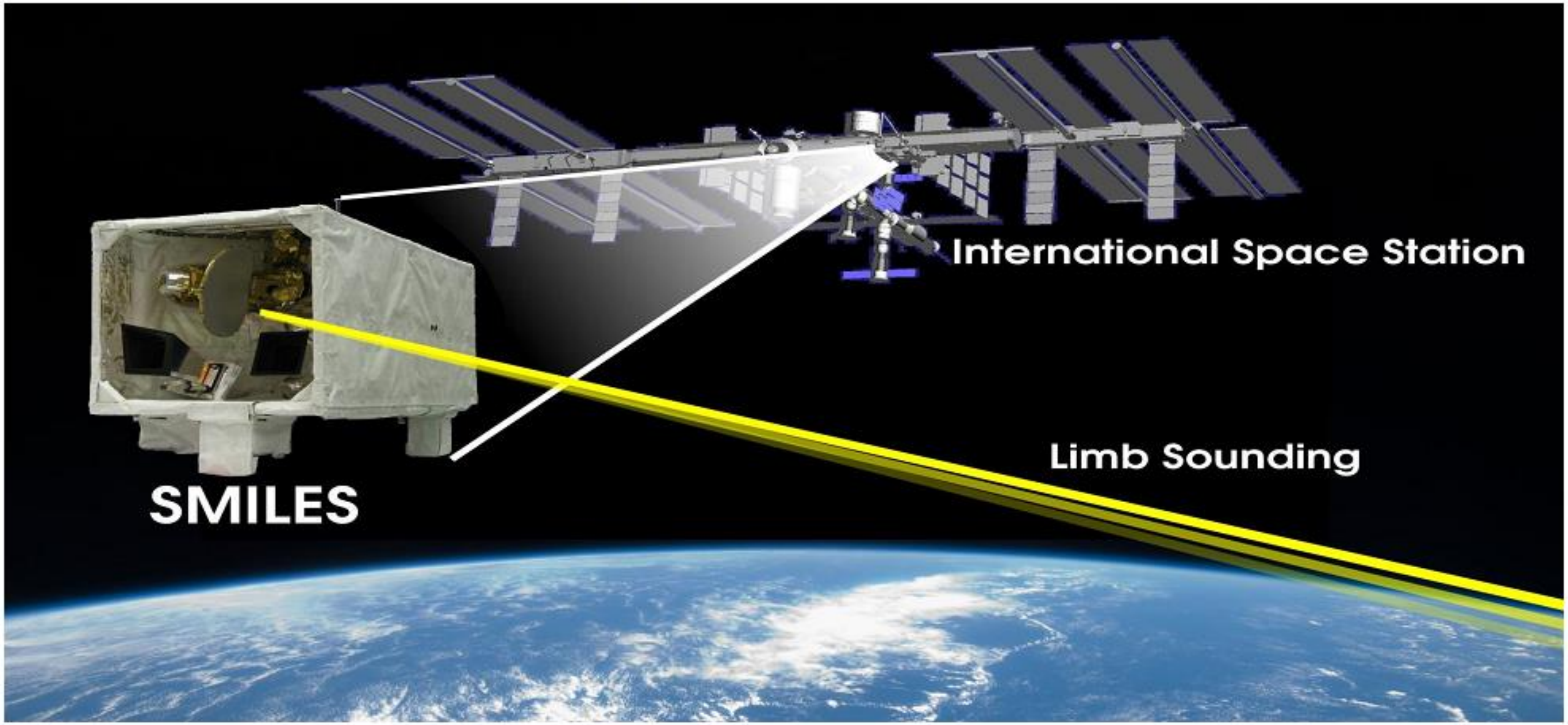
Oil spill on coast of South Korea

HW (Internet Search): Find documents on this problem, about ASAR and explain what you understood.

[KAMPFER, MURK]

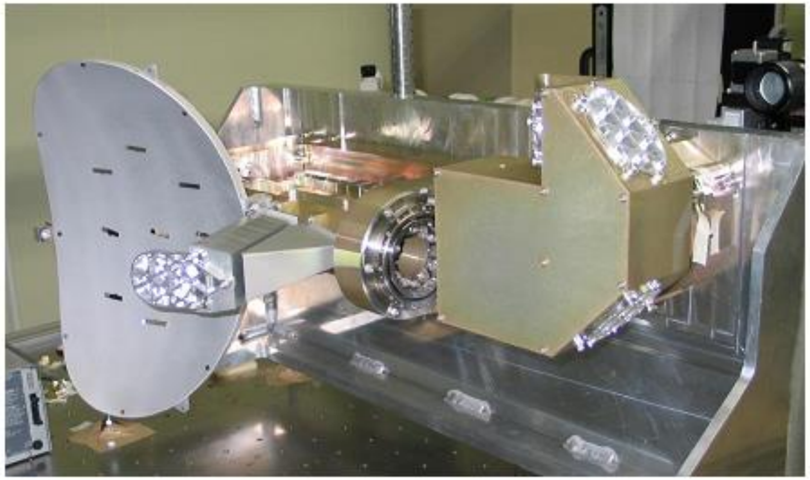
Submillimeter Wave Limbsounder SMILES

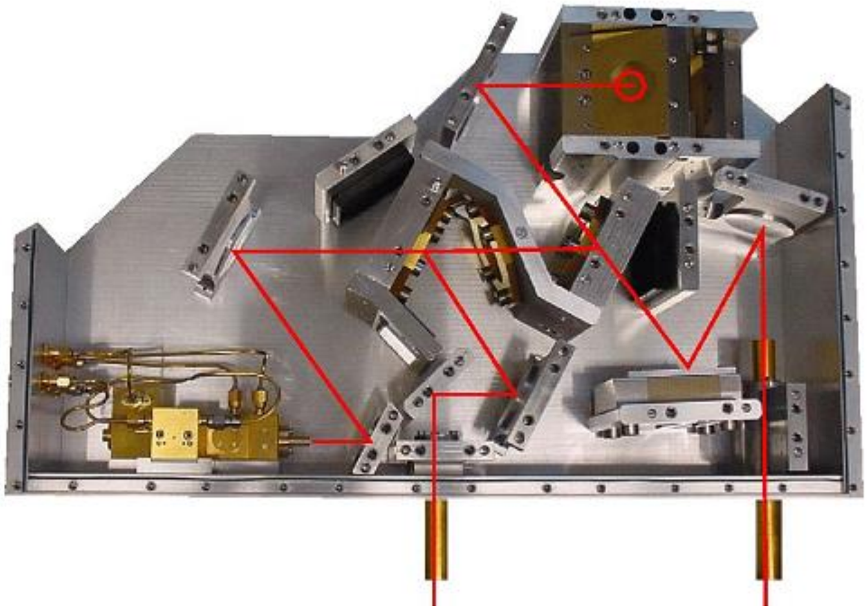
- Japanese instrument for remote sensing of stratospheric O_3, HCl, ClO, BrO
- Two SIS receivers at 625 and 650 GHz, cooled by the first 4K closed cycle refrigerator in space
- Launched to International Space Station 11.9.2009.



[KAMPFER, MURK]

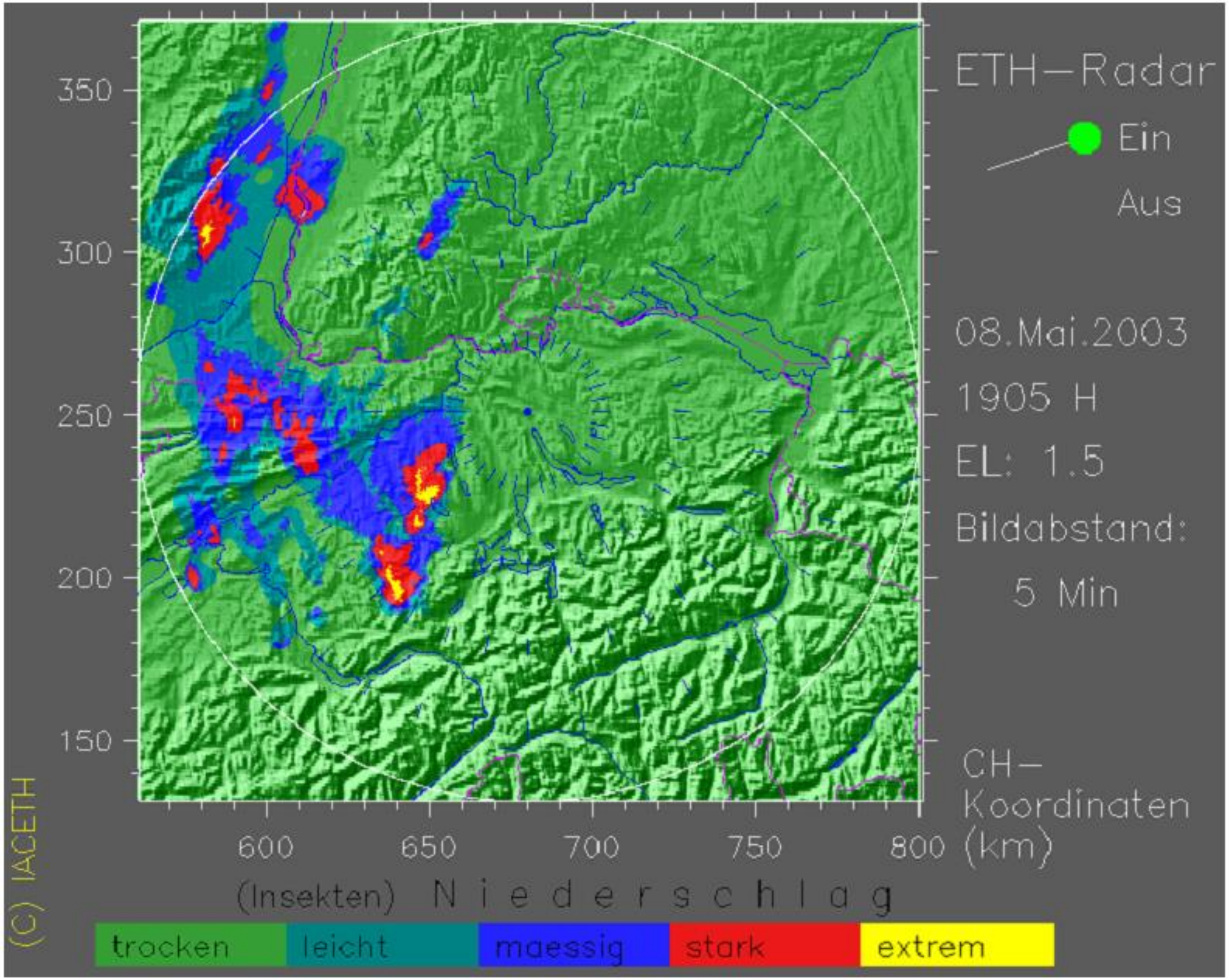
SMILES Antenna and Optics as tested at IAP





[KAMPFER, MURK]

Weather radar



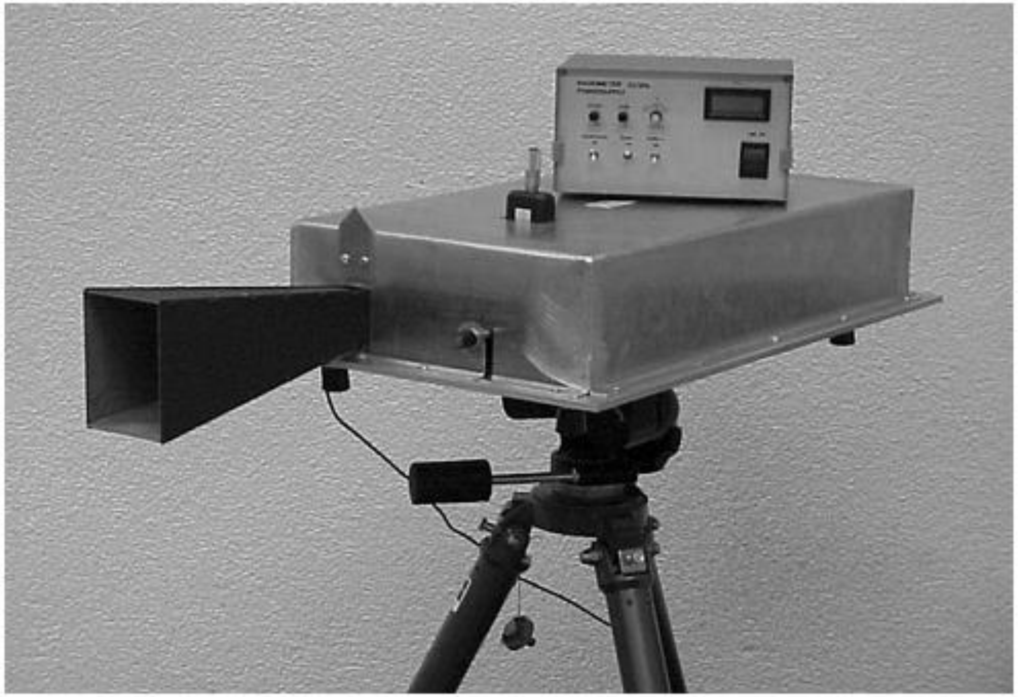
[KAMPFER, MURK]

We are surrounded by microwaves

Two experiments with respect to microwave radiation:

radiation from a microwave oven

radiation from our environment



[KAMPFER, MURK]