2022 Italian URSI Annual Meeting
September 20-21, 2022, Catania, Italy

Bioelectromagnetic research based on lessons learned, reliable techniques and microscopic models: the challenge of new emerging technologies

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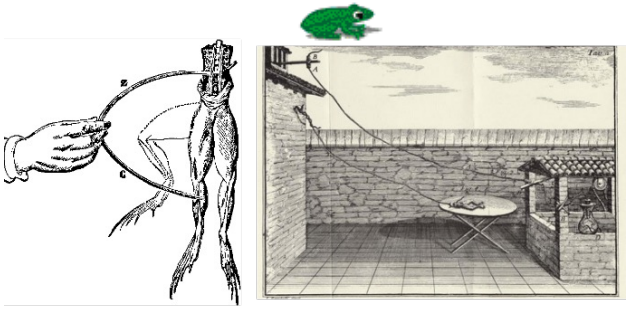
BioEMLab Group, Sapienza University of Rome

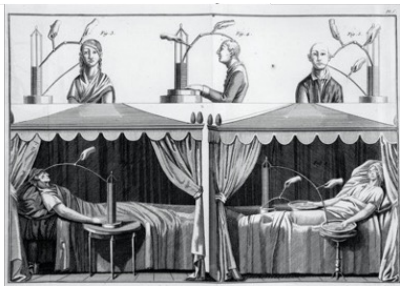
An ambitious title? We come from afar..

Electromagnetics: bio since the origins....

Galvani, 1791: De Viribus Electricitatis…



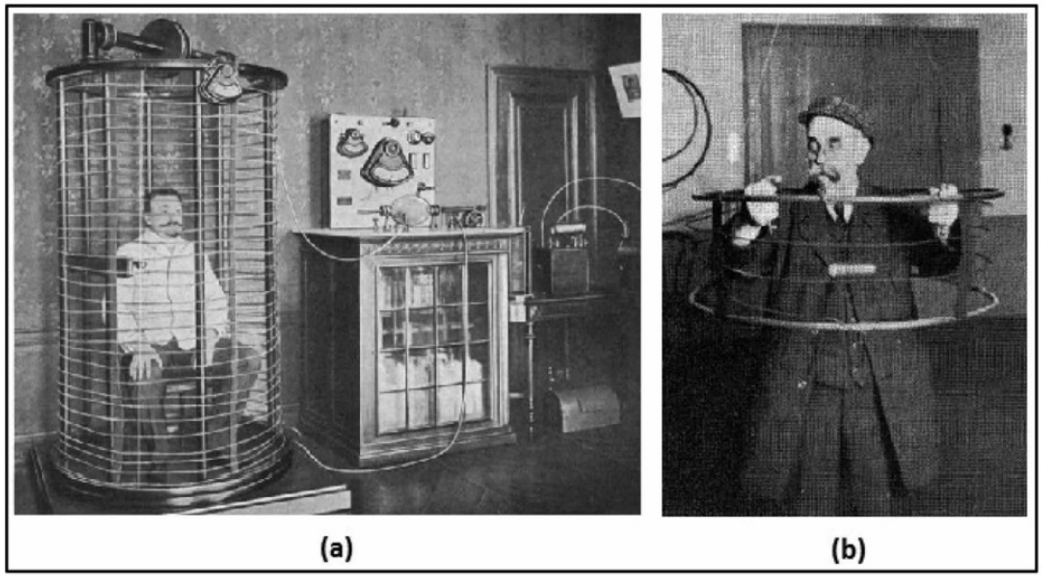
intrinsic source? outside source?



J. Aldini, Essai sur Le Galvanisme, 1804

Alessandro Volta, 1832, Proc. R. Soc. Lond

⇒ d'Arsonval (1896), applied a coil surrounding the head, and induced phosphenes, vertigo, and syncope

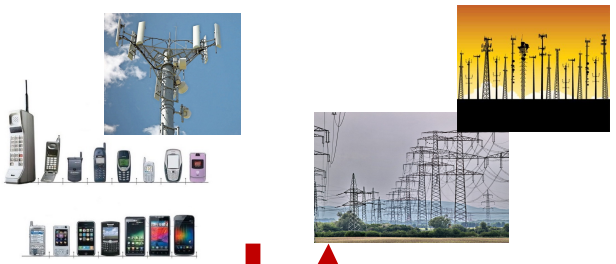


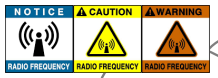
Simon Reif-Acherman, Proceedings of The IEEE , Vol. 105, No. 2, February 2017

Bioelectromagnetics Nowadays

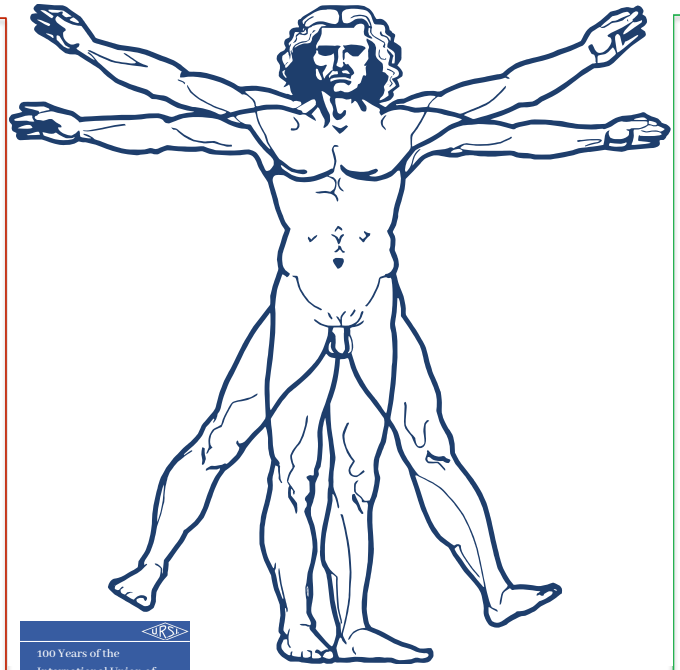
Human safety

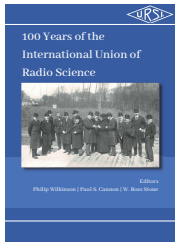
High frequency: e.g. mobile, wi-fi
Low frequency: e.g. power lines





Regulatory issues and policies

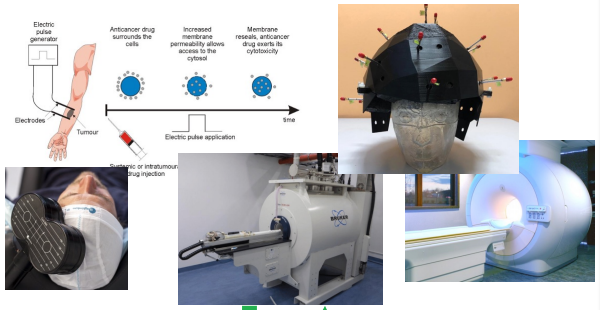




100 Years of the International Union of Radio Science, 2021

Biomedical Applications

Devices and applicators



Diagnosis and Treatment

Regulatory issues and policies

Guidelines for limiting exposure based on the *critical* adverse health effect (**1 °C heating**)

⇒ The basic restrictions are based on established health effects and are INSIDE of the exposed body

$$i.e.: SAR = \frac{d}{dt}\left(\frac{dW}{dm}\right) = \frac{\sigma_{eq}}{2\rho}|E_{in}|^2 \ \left[\mathrm{W/kg}\right],$$

$$SA = \frac{dW}{dm} = \sigma_{eq}\,|E_{in}|^2 \ \left[\mathrm{W/m^2}\right]$$

⇒ Reference levels are provided for practical exposure assessment purposes to determine whether the basic restrictions are likely to be exceeded and are OUTside the exposed body.

i.e.: Incident E-field [V/m],
Incident H-field [A/m],
Incident Power density [W/m²],

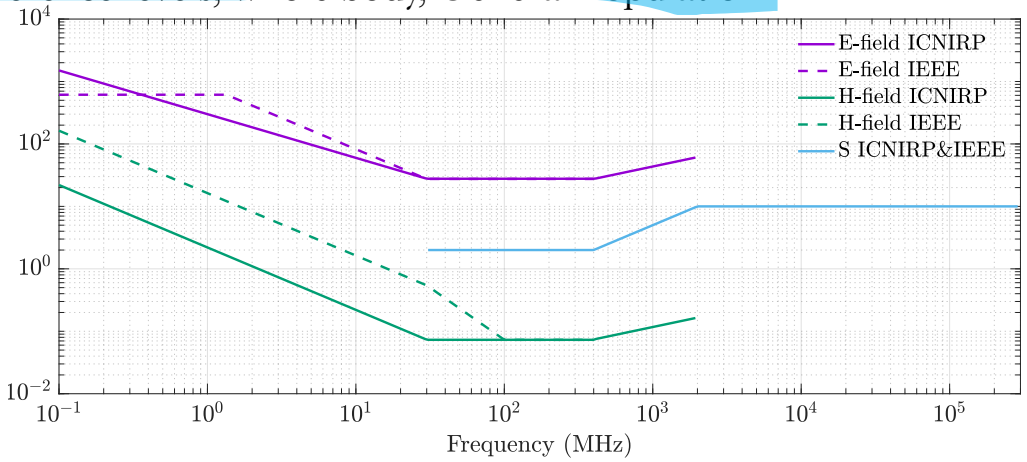
IEEE ICES, IEEE Std C95.1TM-2019,
ICNIRP, HEALTH PHYS 118(5): 483–524; 2020

ICNIRP and IEEE Guidelines

Table 2. Basic restrictions for electromagnetic field exposure from 100 kHz to 300 GHz, for averaging intervals ≥6 min.[a]

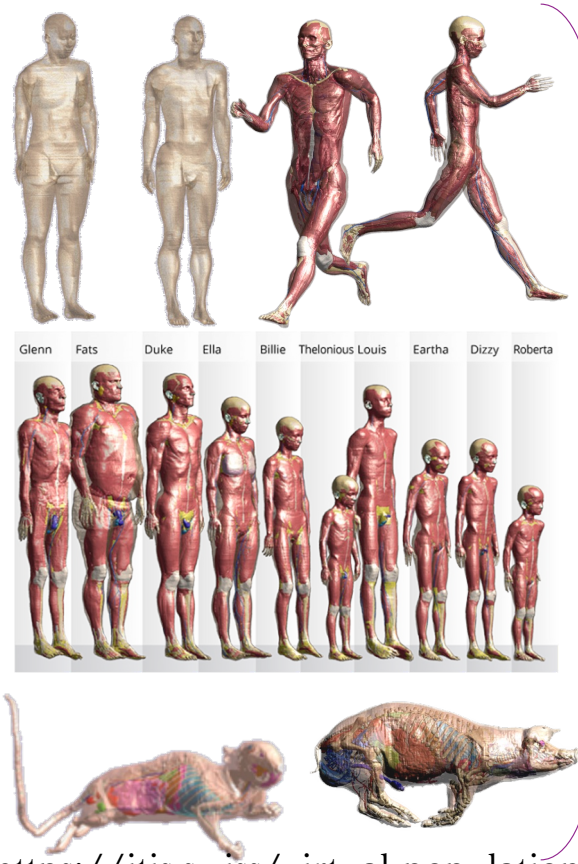
Exposure scenario	Frequency range	Whole-body average SAR (W kg^{-1})	Local Head/Torso SAR (W kg^{-1})	Local Limb SAR (W kg^{-1})	Local S_{ab} (W m^{-2})
Occupational	100 kHz to 6 GHz	0.4	10	20	NA
	>6 to 300 GHz	0.4	NA	NA	100
General public	100 kHz to 6 GHz	0.08	2	4	NA
	>6 to 300 GHz	0.08	NA	NA	20

Reference levels, whole body, General Population



INSIDE OUT: Contemporary dosimetry techniques

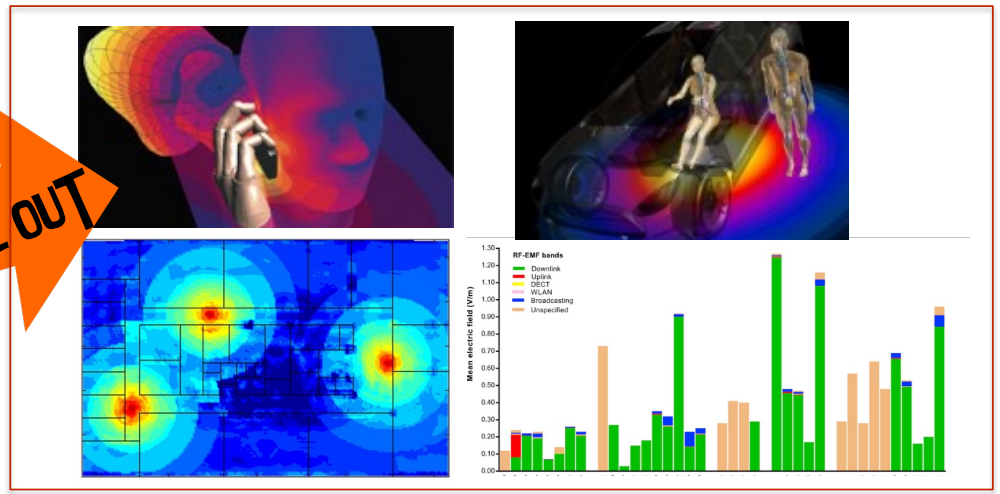
Human and animal anatomical models are crucial components for dosimetric assessment



https://itis.swiss/virtual-population/

INSIDE OUT

Exposure assessment: values of incident fields



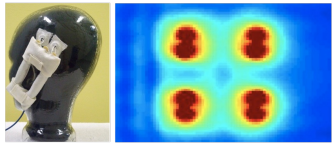
Tognola et al., Bioelectromagnetics 42:550--561 (2021)

Jalilian et al., Env Res, 2019

- Specific, complex and detailed, MRI based including different tissues types
- Each tissue is specified with its **electromagnetic characteristics**, to the limits of present knowledge.
- VVQA (Verification, **Validation**, and **Quality Assesment**) procedure

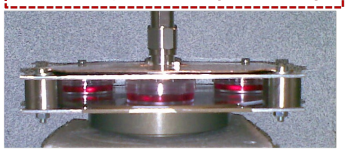
Scientific validation: a multilevel approach

Human exposure/microenvironment

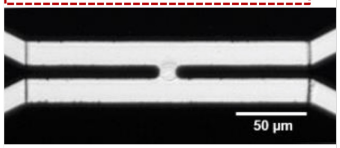


Animal exposure (in vivo)

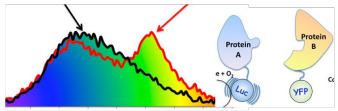
Cell exposure (in vitro)

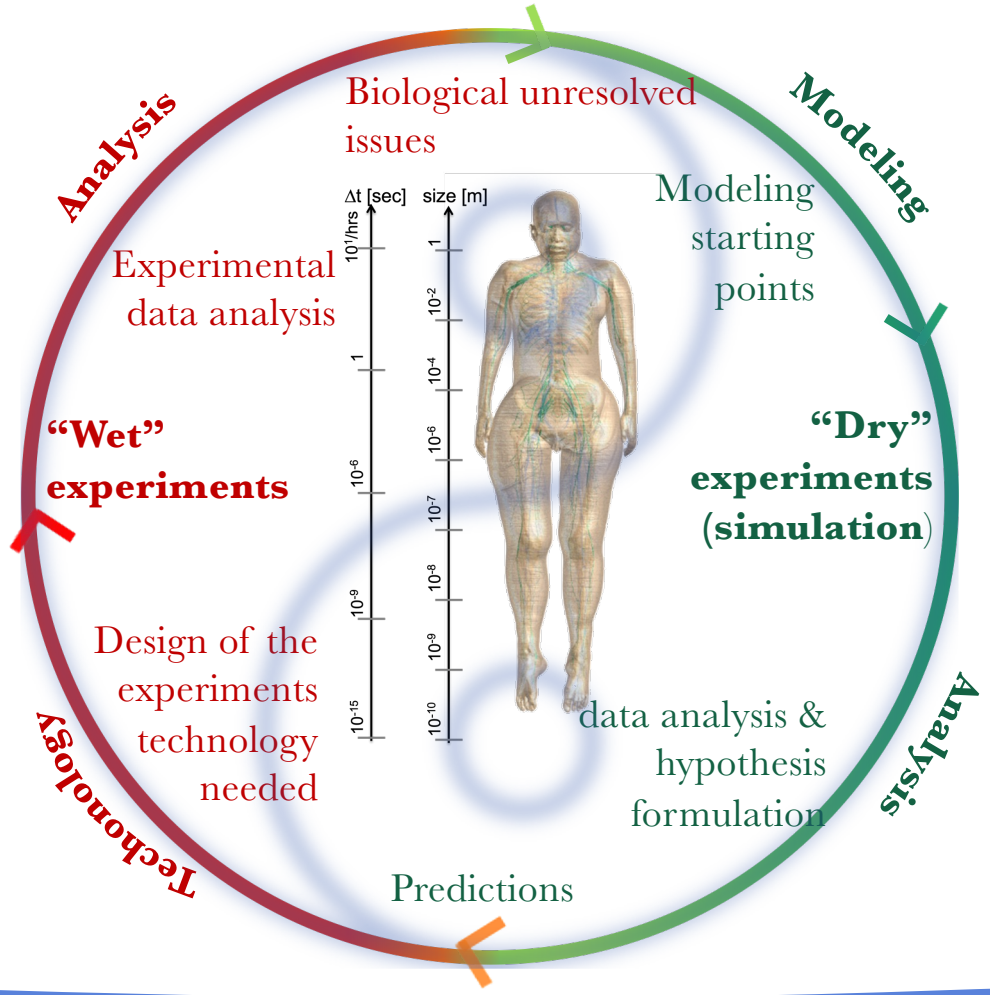


Single-cell exposure

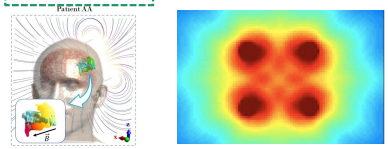


Protein/molecules exposure

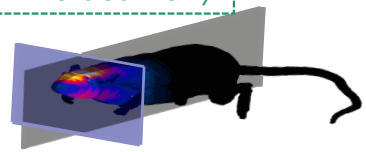




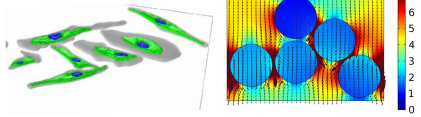
Dosimetry



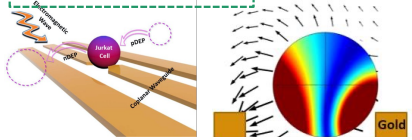
In vivo dosimetry



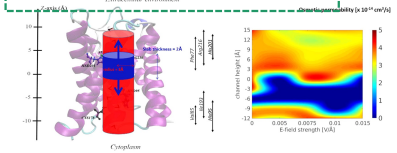
Mesodosimetry



Microdosimetry



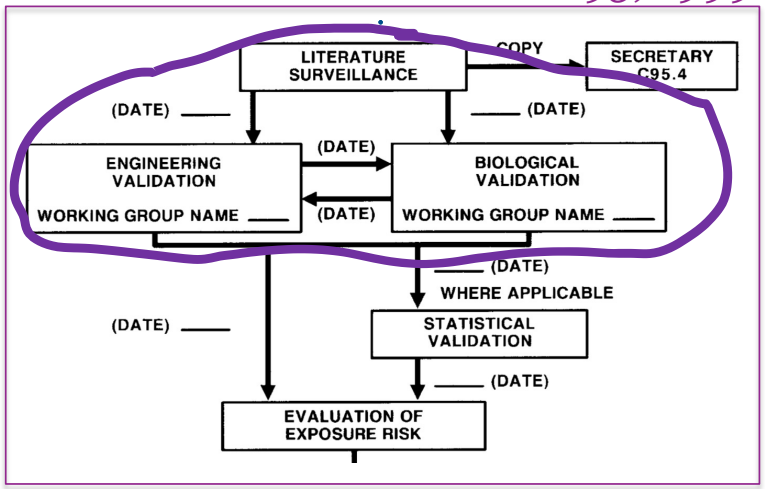
Molecular simulations



Requirements for reliable lab experiments

- Good practice in biological protocols
- Good practice in design, and characterization of devices
- Numerical and experimental dosimetry provided
- Accuracy in the integration with lab equipments
- Need to have a good statistical power
- Control and monitor of temperature
- Need to arrange sham and blind
- Care in EM compatibility

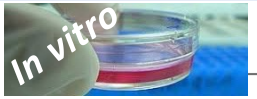
IEEE Standards Committee 95, 1999



FAIR data and robust evidence

Findability, Accessibility, Interoperability, and Reusability

Systematization and guidelines

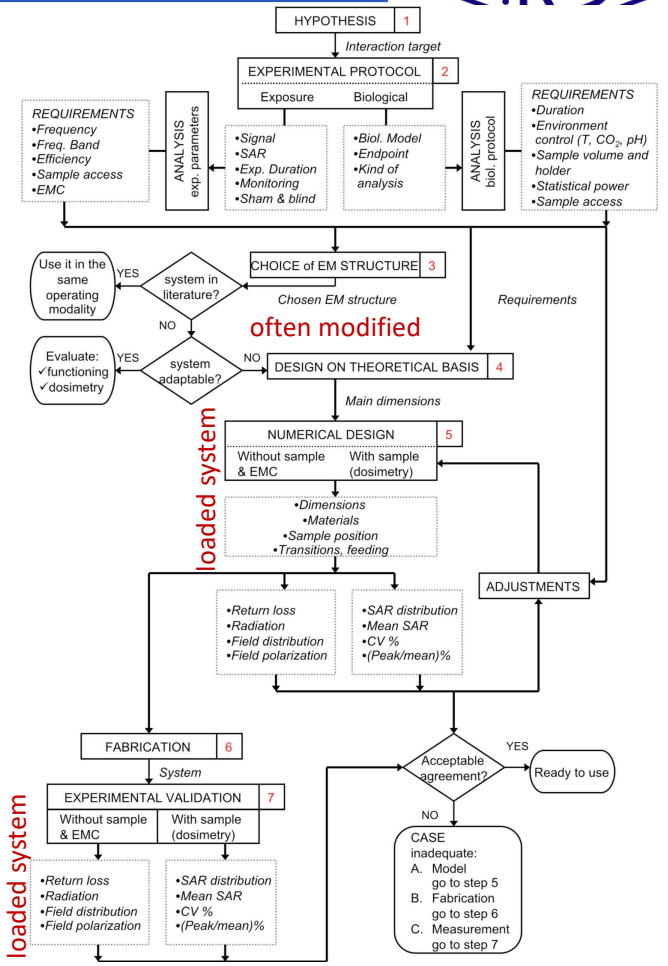


	Off-line	Real-time
PROPAGATING	Versatility; high field uniformity; broadband.	Reduced EM interference; Open or modified for sample accessibility.
RESONANT	Compact; high efficiency; Narrow band; critical sample positioning; localized uniformity regions.	Reduced EM interference; Critical sample accessibility.
RADIATING	High statistical power; high frequency; Low uniformity; low efficiency; uncontrolled environment.	Easy sample accessibility; EM interference.

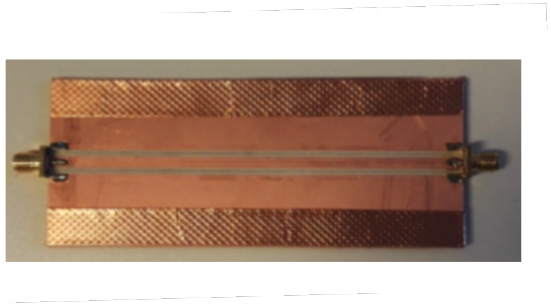
Paffi et al., IEEE Trans. Microw. Theory Tech., vol. 58, n. 10, 2010.

	LOCAL	WHOLE BODY	
	restrained	**restrained**	**freely moving**
PROPAGATING	–	Large scale experiments; Low efficiency.	
RESONANT	–	Large scale, long-term experiments; quite good efficiency; high frequencies.	
RADIATING	High efficiency (animals in the near-field region); Always restrained animals (short-term experiments).	Large-scale experiments; frequencies above 2 GHz; Low efficiency (animals in the far field region); anechoic conditions are necessary.	

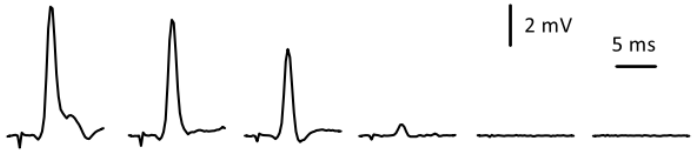
Paffi et al., IEEE Trans. Microw. Theory Tech., vol. 61, n. 5, 2013.



One example: a real-time system for nerve stimulation

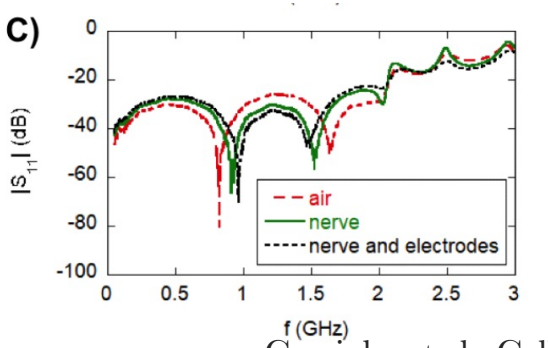


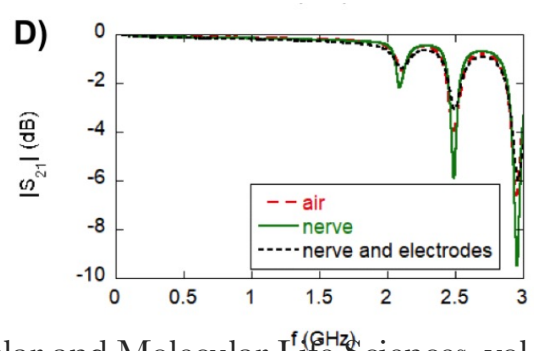
RESPONSE: **Elicited APs** in the nerve

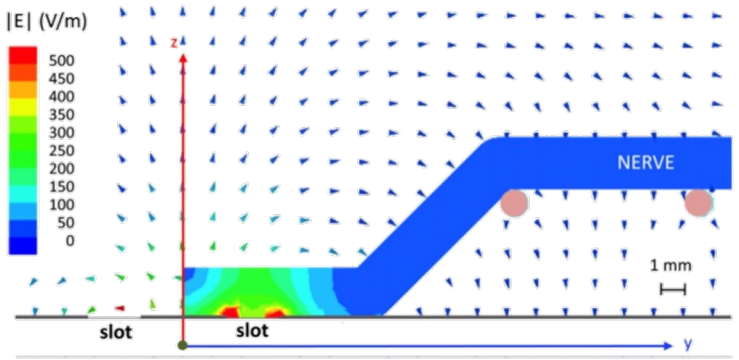


Exposure system: Grounded CPW

Observable: electrophysiological recordings; **Sample:** frog nerve; **Usability:** easy accessibility to the sample; **Operating frequencies:** up to 2 GHz; **Signal integrity:** down to a few ns long (R=0.92); **Efficiency:** ≈ 500 (V/m)/V; **EMI:** minimal coupling with the recording electrodes.

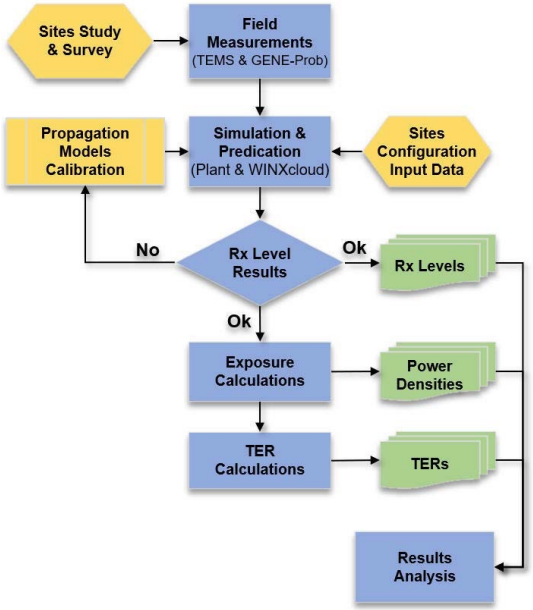


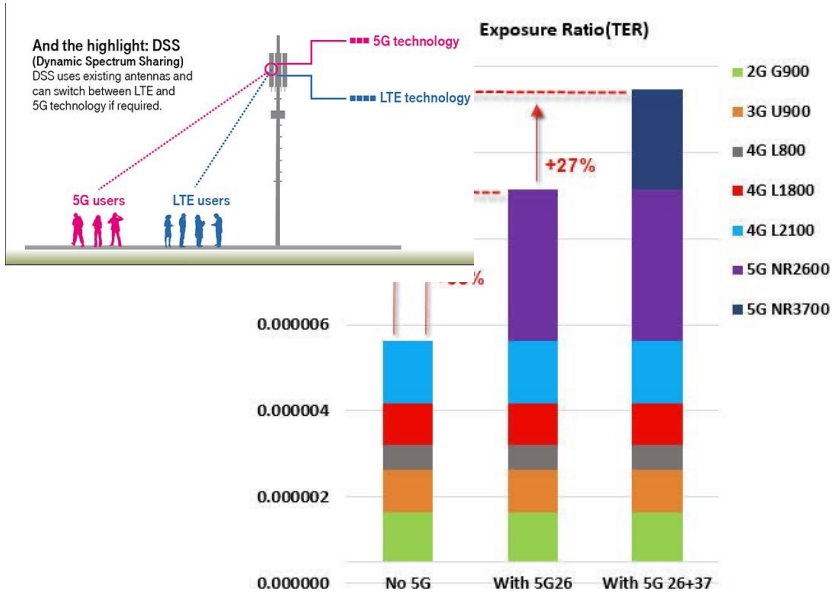




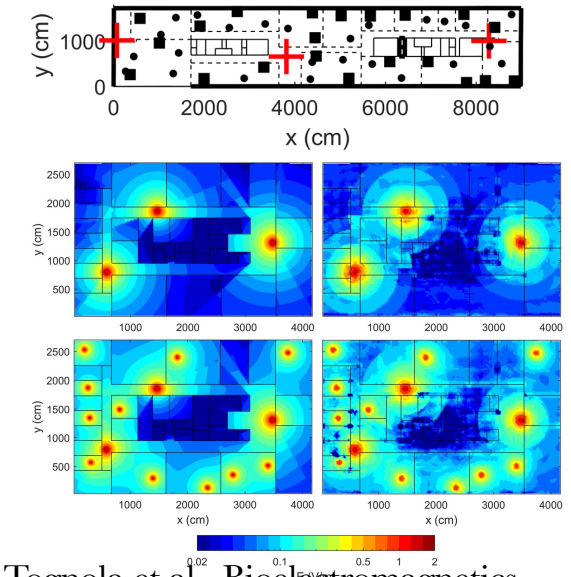
Casciola, et al., Cellular and Molecular Life Sciences, vol. 76, 2019.

Need of new dose models for microenvironments





Elbasheir et al., IEEE ACCESS, 2022



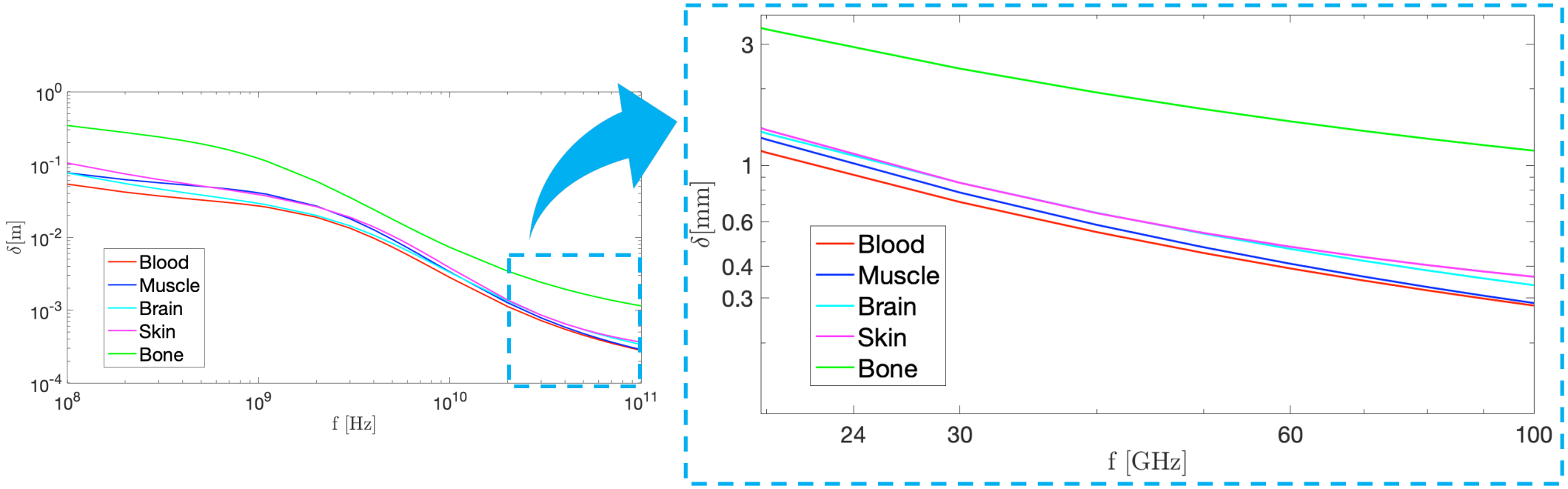
Tognola et al., Bioelectromagnetics 42:550--561 (2021)

⇒ Sites cohabitation and consequent population co and multiple exposure

⇒ New models capable of addressing the complexity and variability of real-life exposure setups, including the effects of not only down-link transmission but also up-link transmission by different sources (e.g. laptop, printers, tablets, and smartphones)

⇒ Methods relaying on machine learning, genetic algorithms, neural networks

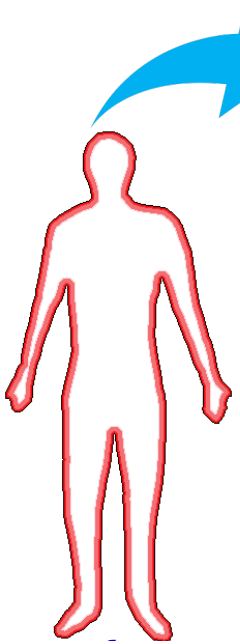
The new frequency band [24–100] GHz: what do we know about absorption?



Penetration depth δ decreases to mm–range in the frequency band of interest

⇒ Absorption becomes mainly superficial involving mostly the outer organs (i.e. skin and eyes)

What do we need: mesoscopic models of the skin



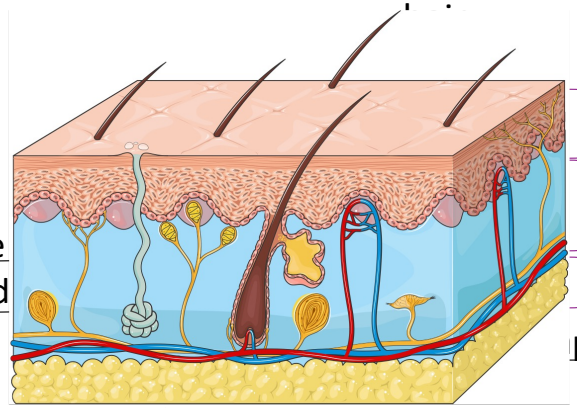
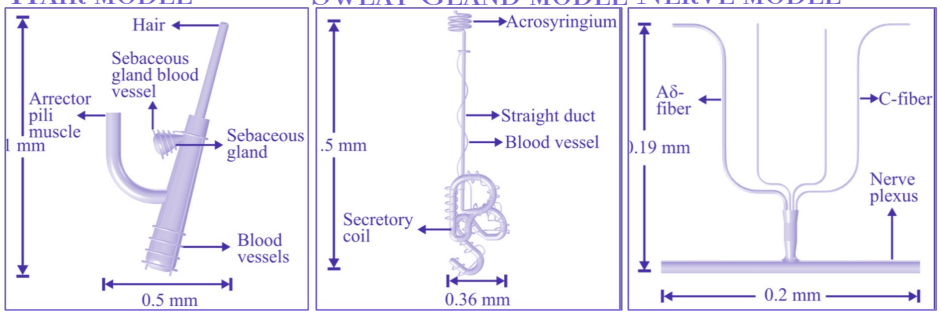


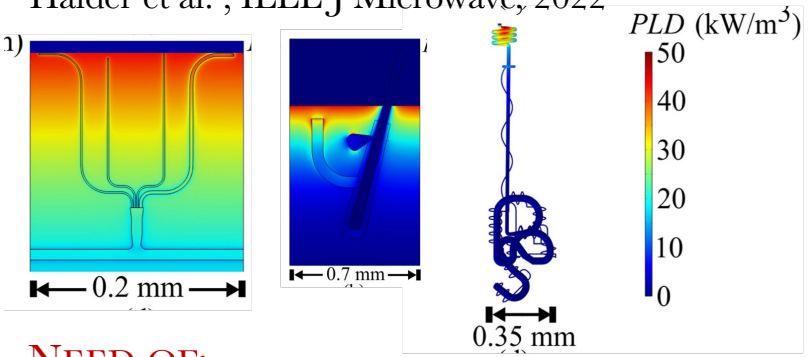
figure from www.servier.com.



Haider et al. , IEEE J Microwave, 2022

Dosimetric results

Haider et al. , IEEE J Microwave, 2022



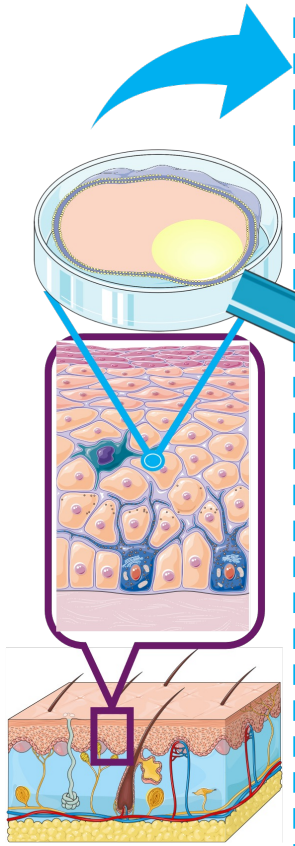
NEED OF:

⇒ Reliable EM properties of skin component in the range

⇒ Flexible/Stochastic modelling to take into account intra-subject variability (i.e. body regions) and inter-subject (e.g. age)

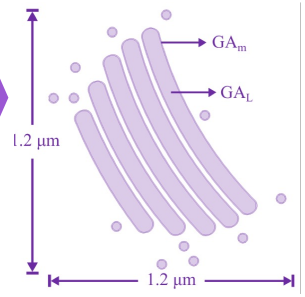
⇒ Setup of experimental validation procedures

We need to go even smaller: microdosimetry models

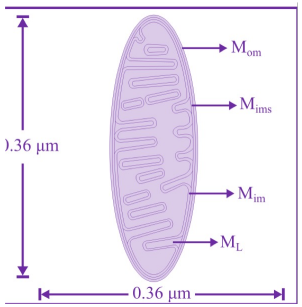


figures produced www.servier.com.

GA MODEL

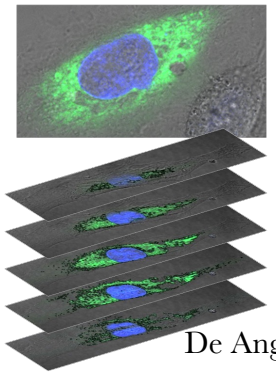


MITOCONDRIA MODEL

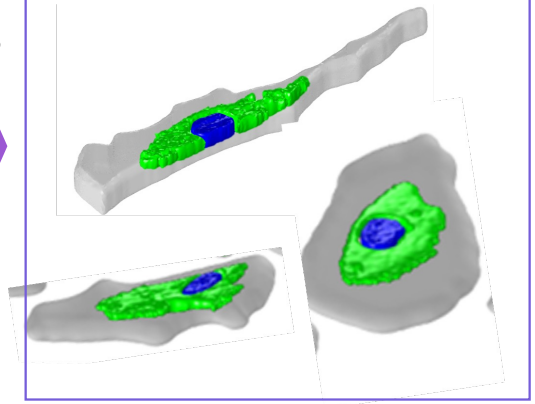


Haider et al. , IEEE J Microwave, 2021

Confocal images of Mesenchemial stem cells

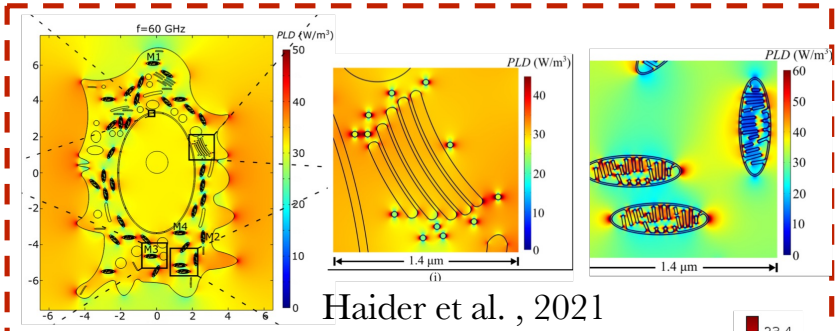


3D STEM CELL MODEL



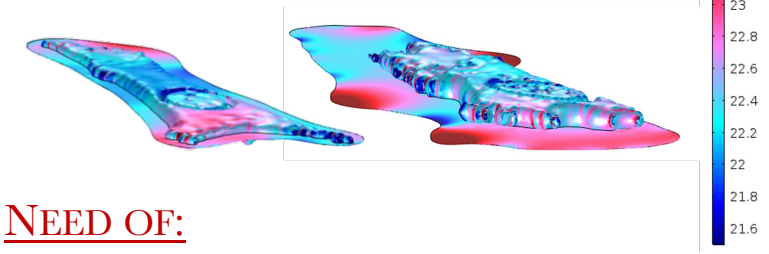
De Angelis et al., Frontiers in Bioeng. and Biotech., 2020

Dosimetric results



Haider et al. , 2021

VLD [W/m^3]



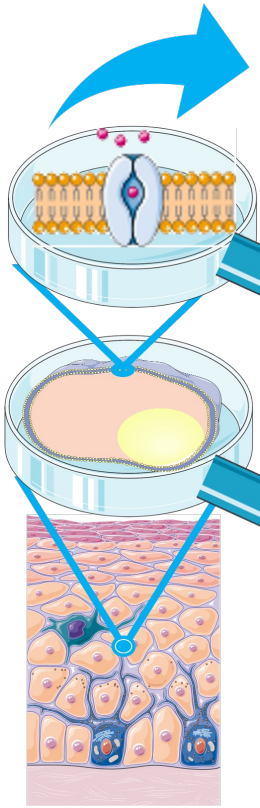
NEED OF:

⇒ Reliable EM properties of subcellular component in the frequency range

⇒ Flexible/Stochastic modelling to take into account shape variability

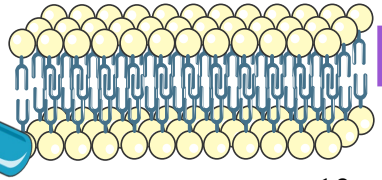
⇒ Experimental validation methods

Which the putative targets?: molecular models

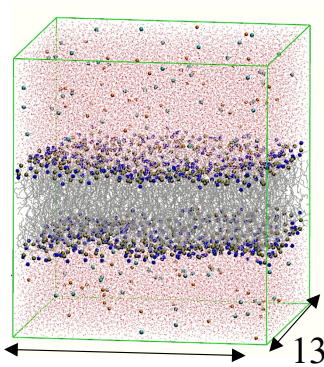


figures produced www.servier.com.

Lipid bilayer



13 nm

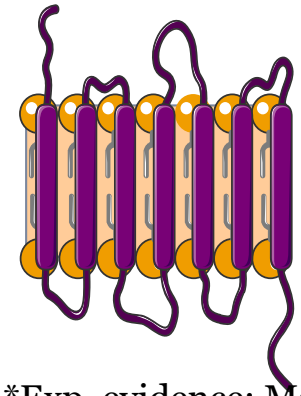


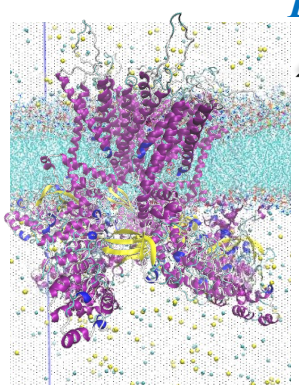
13 nm

13 nm

E Field

Receptors (e.g. TRPM8*)



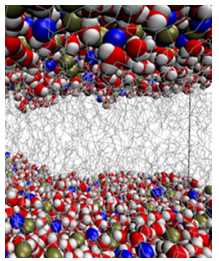


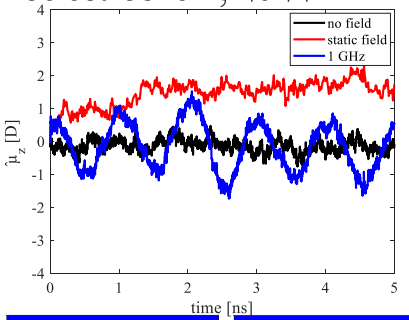
E Field

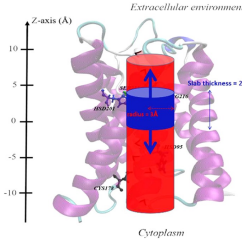
*Exp. evidence: Mai et al., Scientific Reports, 2020

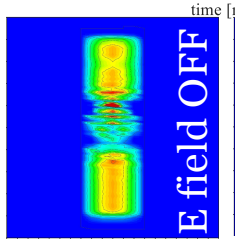
Molecular results

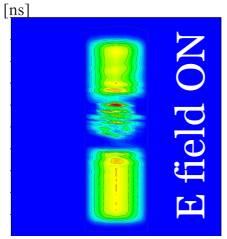
Marracino et al., Bioelectrochem, 2022











Marracino et al., J. Chem. Phys. 2018

NEED OF:

⇒ Proper and reliable molecular models of targets with exp evidence

⇒ New techniques for analysis of massive data (all atoms upto 250 GB)

⇒ Experimental validation methods

How to get ready in the next 3–5 years!

European Commission
Horizon 2020
European Union funding
for Research & Innovation

"Exposure to EMF and health" (HORIZON-HLTH-2021-ENVHLTH-02-01)
Funds: more than 30 MEuros

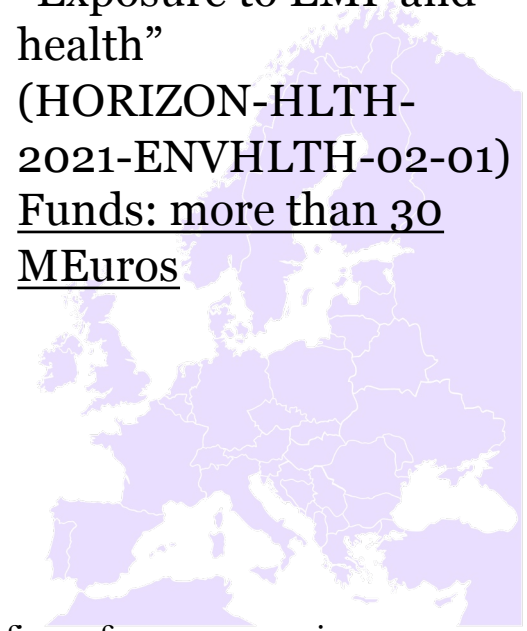


figure from www.servier.com.

NextGEM

Next Generation Integrated Sensing and Analytical System for Monitoring and Assessing Radiofrequency Electromagnetic Field Exposure and Health
Kick-off Meeting: Heraklion, 19–21 July 2022
Consortium: 20 partners, 10 different countries

GOLiAT

5G expOsure, causaL effects, and rIsk perception through citizen engagement
Kick-off Meeting: Barcelona, 6-7 July 2022
Consortium: 22 partners, 12 different countries

ETAIN

Exposure To electromAgnetic fIelds and plaNetary health
Kick-off Meeting: 4-5 July 2022
Consortium: 12 partners, 6 different countries

SEAWave

Scientific-based Exposure and risk Assessment of radiofrequency and mm-Wave systems from children to elderly (5G and Beyond)
Kick-off Meeting: 12 July 2022
Consortium: 15 partners, 6 different countries

ALL CONSORTIUMS

Cluster on EMF and Health (CLUE-H)

Kick-off meeting
Thessaloniki,
22 September 2022

Wikipedia

Concluding Remarks

- ✓ Protection Guidelines (ICNIRP and IEEE) are based on critical adverse health effects and run on continuous literature surveillance
- ✓ Bioelectromagnetics evolved as multidisciplinary and multilevel research and relies on a virtuous wheel of "dry" and "wet" experiments
- ✓ NEXT 5G/6G technologies will reopen the issue of biological effects
  - ⇒ Further efforts will be needed to study exposure in the new band [24–100] GHz
  - ⇒ Power absorption mainly limited to the skin
  - ⇒ Need of specific cell types microdosimetry models
  - ⇒ Need of specific targets to identify and study
- ✓ Large collaborative **Cluster on EMF and Health** is going to start originating from important EU fundings that called the scientific community to be prepared for answers

Bioelectromagnetics 2.0 is on the way

Mind the Gap: *Generation Bioelectromagnetics 2.0*

…La passione permette di sopportare amarezze e rinunce che l'ambizione non giustificherebbe in alcun modo…..

Enzo Ferrari