Natural electromagnetic fields and their interactions with living organisms

Lluis M. MIR

DRCE CNRS emeritus – D. Sc., Dr h. c. (Lima, Buenos Aires, Ljubljana)
METSY UMR 9018 CNRS, Université Paris-Saclay, Institut Gustave Roussy
Villejuif, France

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Natural electromagnetic fields and their interactions with living organisms

Foreword n°1

This topic was not covered by my activities at CNRS for 42+ years of career

(the biological and **medical applications of the pulsed electrical** and electromagnetic **fields**)

Thus …

I will not be exhaustive (by lack of knowledge and lack of time – about 30 minutes…)

MY APOLOGIES

Natural electromagnetic fields and their interactions with living organisms

Foreword n°2

As stated in the title, this presentation «abandons»

the whole issue of the electromagnetic fields of anthropogenic origin

A reminder of the URSI-France JS2020,
on 5G…

Natural electromagnetic fields and their interactions with living organisms

Foreword n°3

As IS NOT stated in the title, this presentation will “also leave out”

all that concerns the endogenous electric fields of biological objects

All the biological objects are electrical objects

Any of our cells: an electrochemical gradient across the membrane of our cells is always present and may vary in excitable cells (muscle=>contraction, nerves=> nerf influx)
Our body: an electrochemical gradient across our skin transforms skin in a battery that is short-circuited in the case of a wound (wound=>electrical leaks=>currents=> skin repair)
Interactions between living beings (example between bees and flowers, explaining the pollinisation efficacy of the flowers by the bees)

Natural electromagnetic fields

- TERRESTRIAL:
  Earth magnetic field with its two components, vertical and horizontal
- ATMOSPHERIC (presentation of the GEC):
  Lightning and other electric flashes
  Static electric field, with its circadian and local variations,
  Schumann resonance at 7.8 Hz, and its harmonics
- MINERALS:
  At the interface between the atmosphere and the lithosphere,
  in particular the pyroelectric materials
- TELLURICS (LITHOSPHERICS):
  Consequences of the movements of the Earth's crust

PARADIGM

The most important interaction is a non-interaction:

The Earth's magnetic field protects all biological objects from cosmic rays; without this magnetic field there would have been no life, even if our planet is in the habitable zone of the Solar System (temperatures allowing the existence of «liquid» water)

NORTHERN LIGHTS:
Without a magnetic field, we would not beable to see them,

- not just because they could not be
- but also because we wouldn't be there to admire them…

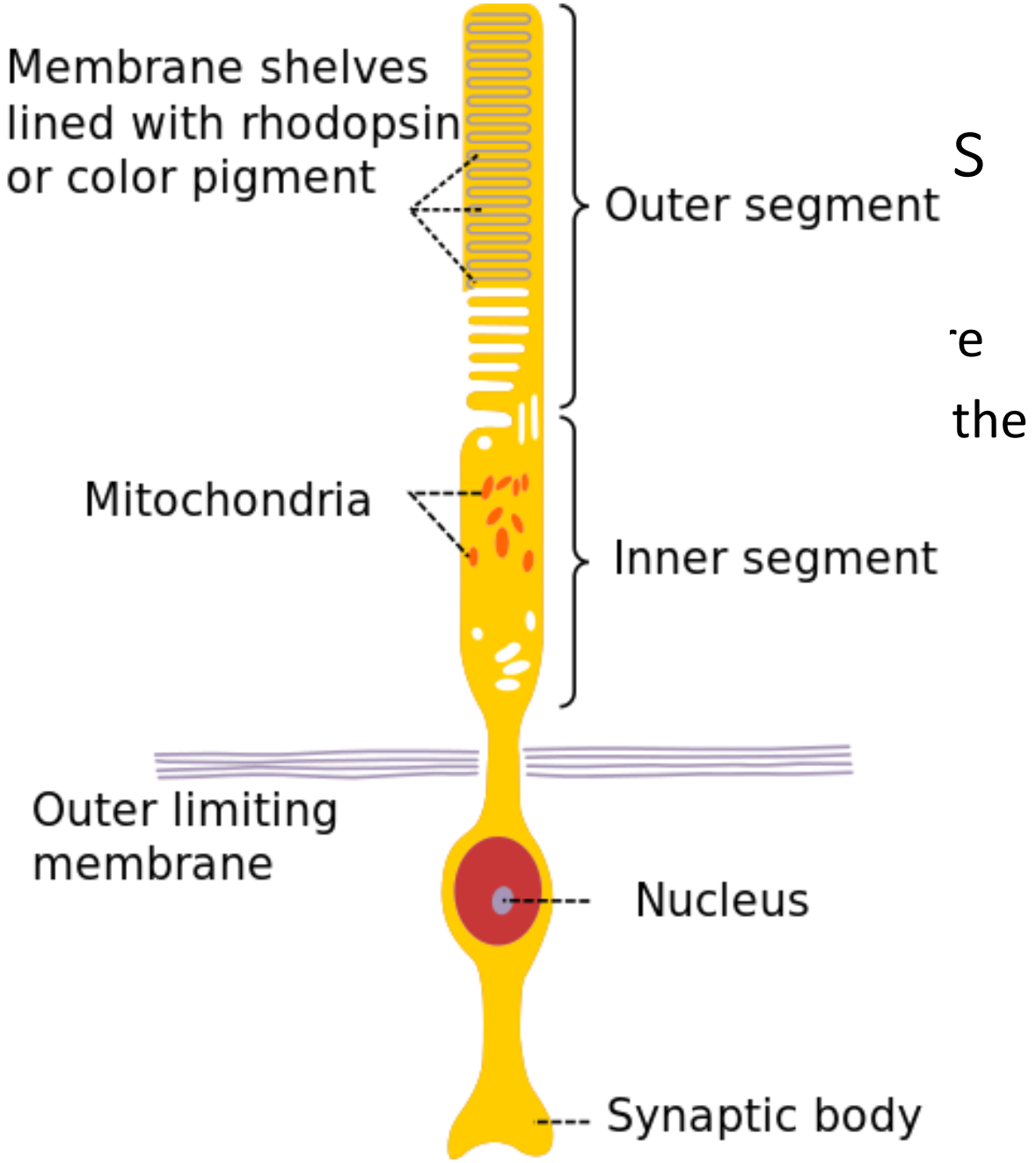
Detection of the Earth's magnetic field
The case of solitary nocturnal migratory birds

Molecular basis: a specific protein, cryptochrome, which is an enzyme whose function involves a **pair of radicals** (the alignment (or not) of the reactive centre with the direction of the magnetic field modulates the spin of the radicals and the product of the reaction catalyzed by this enzyme - proven).

Detection
The case of sc

Molecular basis: a specific p
function involves a **pair of r**
with the direction of the ma
product of the reaction cata

Cell basis: specific cells, the
rods, that are specialized
cells of the retina with a
very special shape



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Cell basis: specific cells, the **rods**, that are specialized cells of the retina with a very special shape

Organ basis: the rods are in the eye, precisely located in the retina, that covers the inner surface of the eye and which allows the precise orientation of the rods in all the directions; therefore cryptochromes are arranged over the 360° orientation.

Detection of the Earth's magnetic field
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Physiological basis: night perception of the Earth's magnetic field; it is considered that, in darkness, these birds «see» the direction of the field in their eye and use it as a compass.

A solitary nocturnal migratory bird

This mechanism was explored by Henrik Mouritsen (University of Oldenburg (Gemany) and colleagues in the Grey-cheeked Thrush (grives à joues grises américaines), in the laboratory and in the Great Plains of North-America

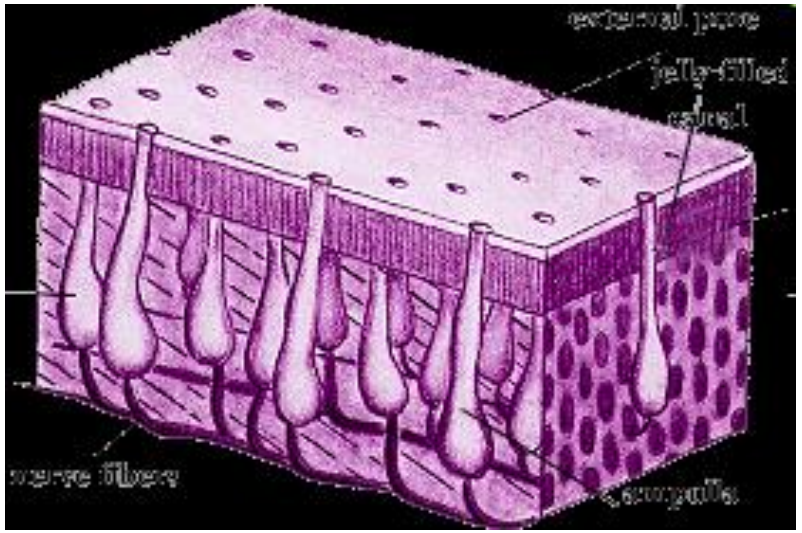
Direct detection of the Earth's magnetic field Presence of cryptochromes does not directly mean "magnetic field detection"

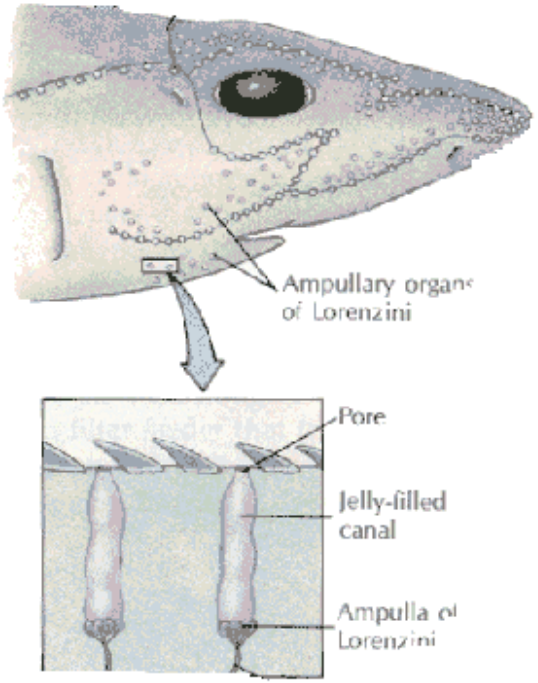
- **The cryptochromes** are photoreceptors of the blue light.
- **The Cryptochromes** can be found in many other living organisms, where they may have other functions: for example, in plants, role in phototropism, circadian rythms regulation, etc.
- **Does humans express the genes coding for the cryptochromes? Yes.**
- **Human** cultured cells expressing this cryptochrome can "**react**" to the application of electromagnetic pulses while almost identical cells without cryptochrome "**will not react**" but this does not mean that we can detect/feel magnetic fields…

Indirect detection of the Earth's magnetic field
The case of sharcks, rays and chimeras

- **Physiological basis:** very sensitive perception of electric fields (5 nanovolts per cm, or 500 nV/m)

- **Organ basis:** a specialized organ, the ampullae of Lorenzini, present in cartilaginous fish (sharks, rays, etc.)





Indirect detection of the Earth's magnetic field
The case of sharcks, rays and chimeras

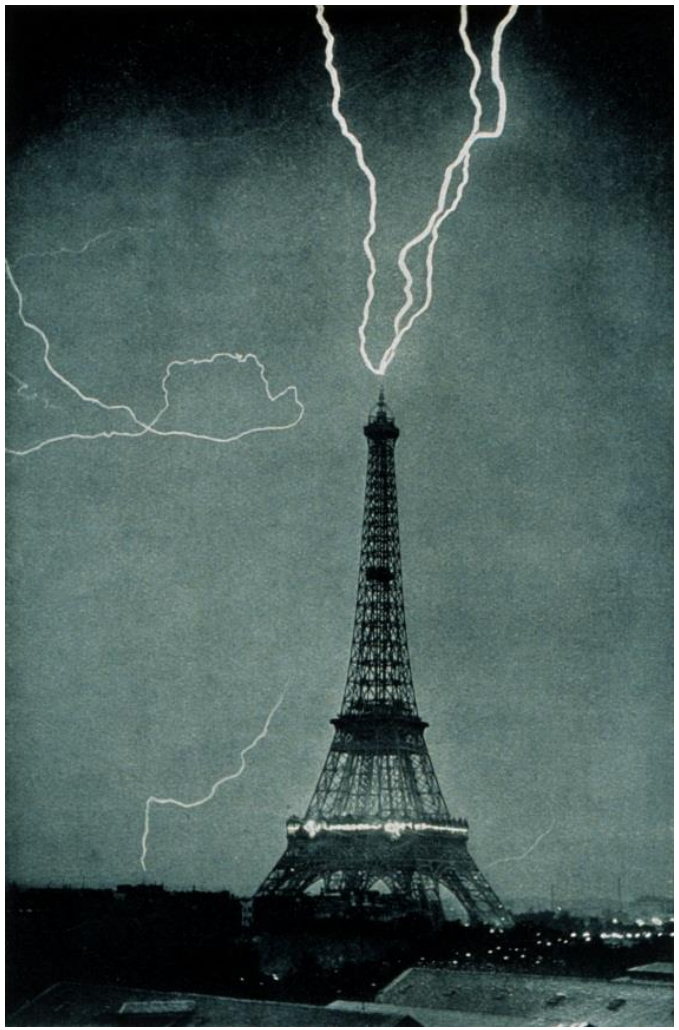
- **Physiological basis:** very sensitive perception of electric fields (5 nanovolts per cm, or 500 nV/m)

- **Swimming in the Earth's magnetic field** is sufficient to generate an electric field that these fishes can detect, which gives the Earth's magnetic field direction

- Note that the Ampullae of Lorenzini:
  - it is probably an organ not selected /conserved in the evolution to detect the Earth's magnetic field but for other reasons, for example to detect the prays (cf. charges at the surface of the skin, currents in case of wounds, …).
  - Still, they provided a real advantage to these fishes, particularly about 400 Millions years ago, to conquer the whole ocean, which might explain why these "old" animals survive until the present.

Natural electromagnetic fields and their interactions with living organisms

From « detection »
to « effects » of the
electromagnetic fields
on biological objects



Most impacting:

Lightning

(EMF + UV,
acoustic waves,
heat, …)

Even before biological objects exist, at the origin of life …

Experiments, in 1953, by Stanley Miller, in the laboratory of Professor Harold Urey (Nobel Prize in Chemistry in 1934) at the University of Chicago

Stanley Miller mixed several gases, including methane (CH4), gaseous ammonia (NH3), hydrogen (H2) in a water-filled (H2O) and boiling tank. The vapours then pass into another balloon where they were subjected continuously to electric arcs, supposed to reproduce lightning.
After one week complex organic compounds appeared, including amino acids (2%).

Controversial – however, would there have been life on Earth without lightning (without electromagnetic energy?) (cf. the alternative hypothesis, that all the bricks of the life would have been brought to Earth by asteroids…)

Progression of the lightning

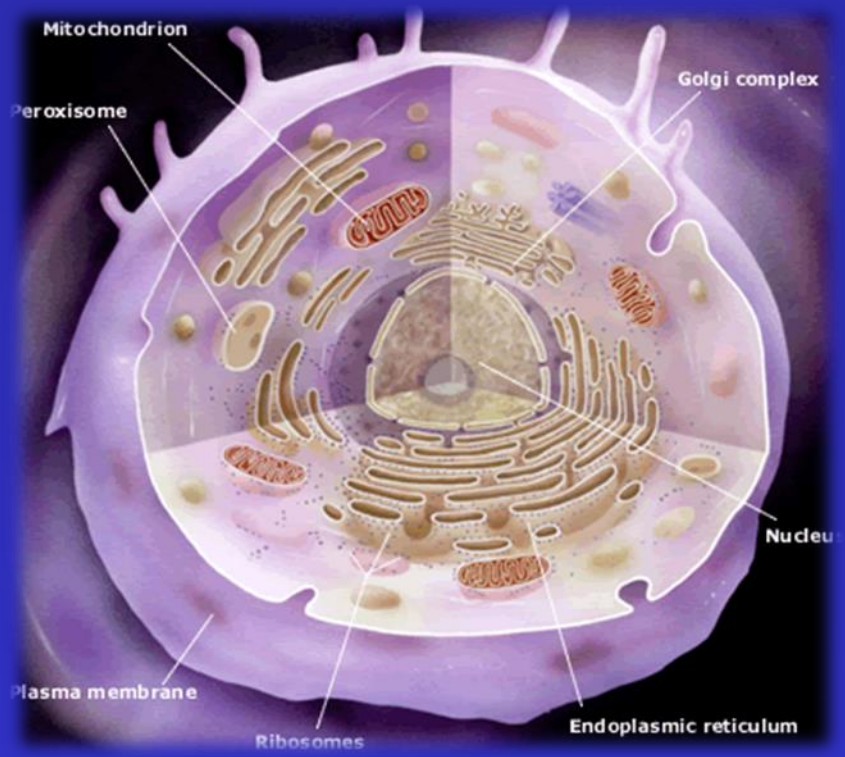
Streamer generation + charge progression in the ionized air:

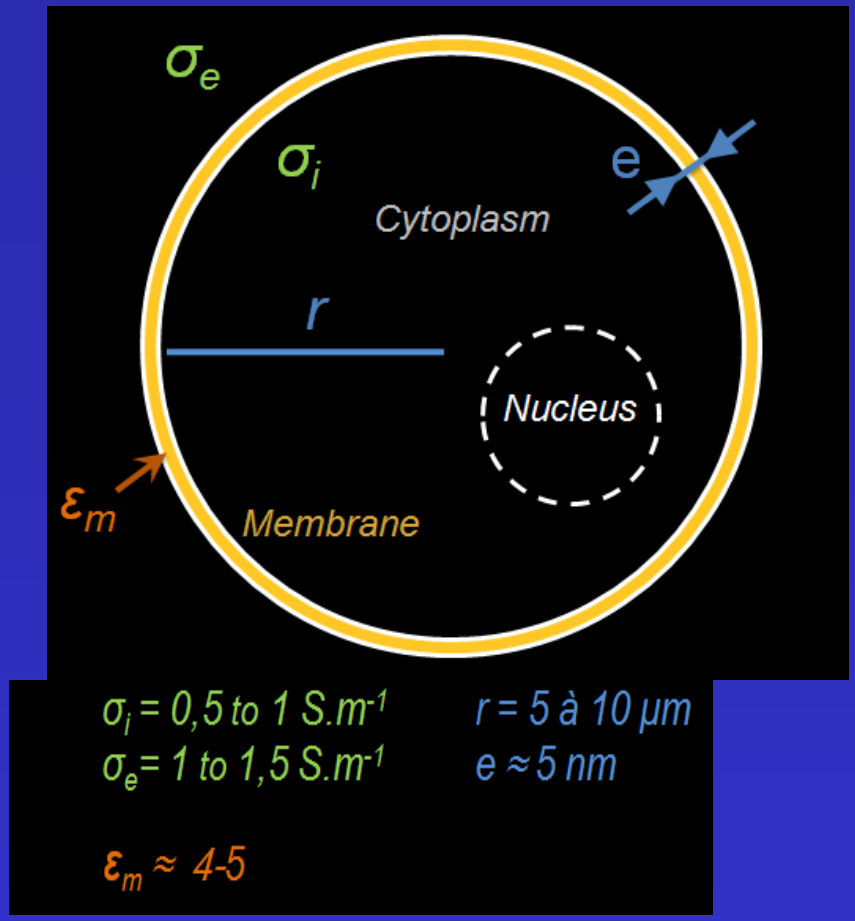
steps of about 10 nanoseconds

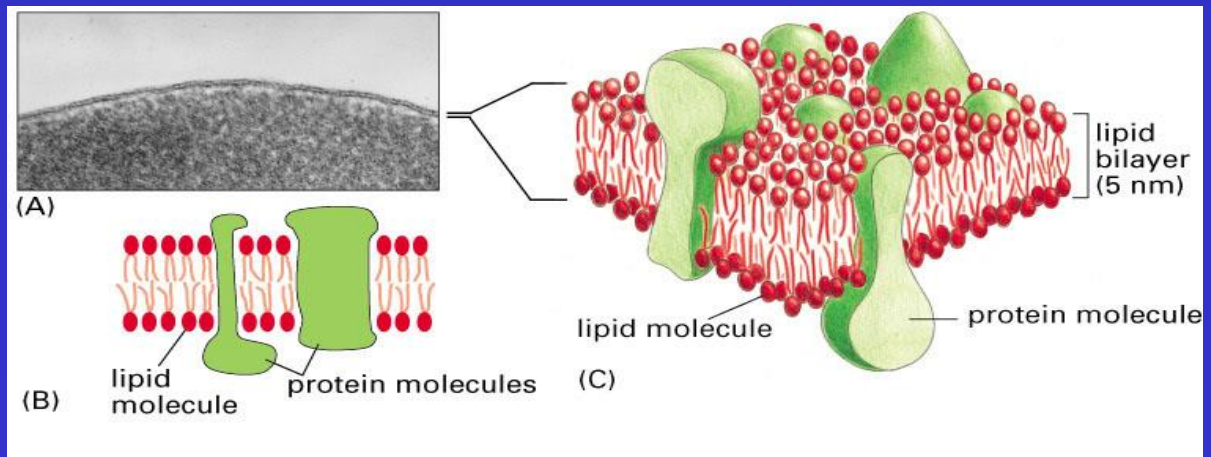
In the laboratory, we have demonstrated that these electric pulses can make the cells permeable to otherwise non-permeant molecules using field amplitudes in the order of tens of kV/cm (a few millions of V/m):

the « cell electroporation » (or cell electropermeabilization)

Electrical modeling of a single cell





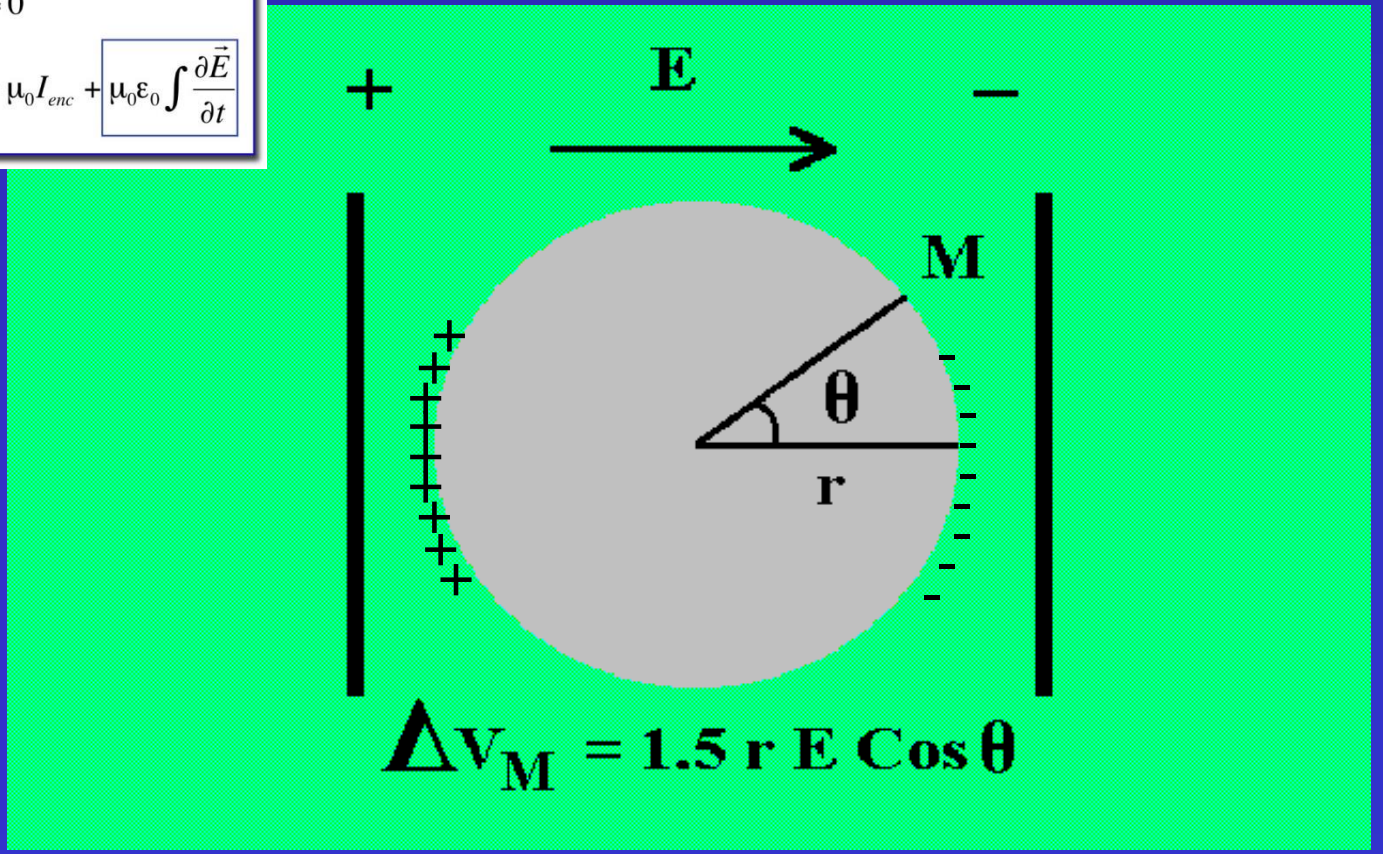


N.B.: Cells naturally display a resting TransMembrane Difference of Potential of -20 to -70 mV
Because this TransMembrane Voltage is established across 5 nm, the field associated to a 30 mV TMV is 3.10^{-3}V/5.10^{-9}m = 6.10^{5} V/m **that is 0,6 MV/m**

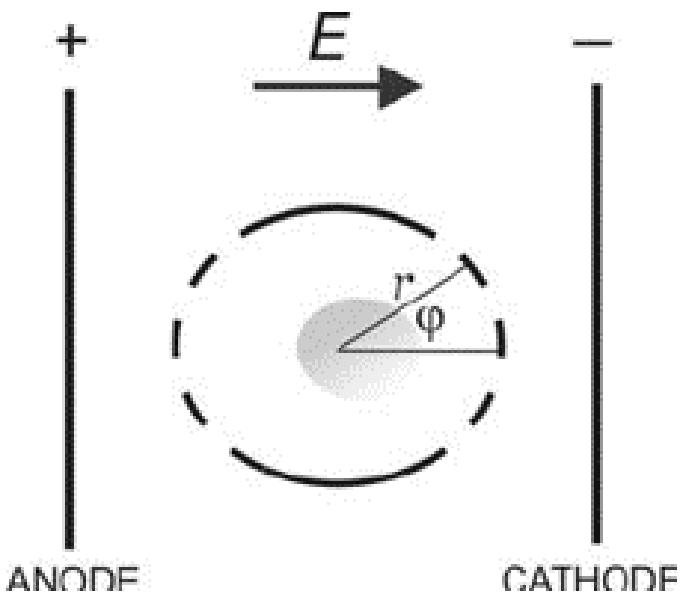
CELL ELECTROPULSATION

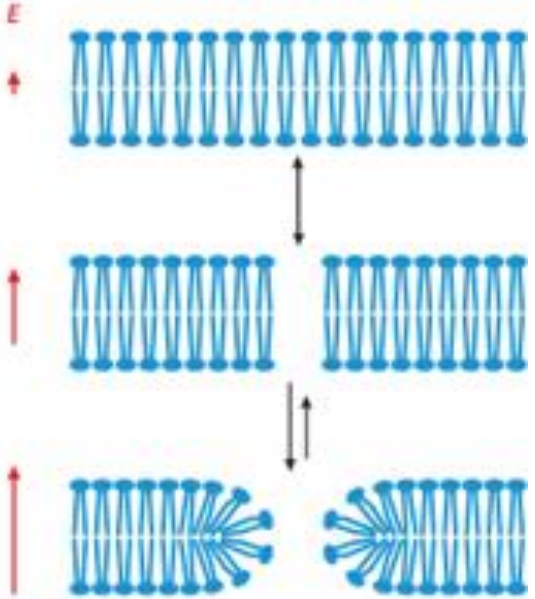
Maxwell's Equations Differential form	Maxwell's Equations Integral form
$\nabla \cdot \vec{E} = \frac{\rho}{\varepsilon_0}$	$\oint \vec{E} \cdot d\vec{a} = \frac{Q_{enc}}{\varepsilon_0}$
$\nabla \times \vec{E} = -\frac{\partial \vec{B}}{\partial t}$	$\oint \vec{E} \cdot d\vec{l} = -\int \frac{\partial \vec{B}}{\partial t} \cdot d\vec{a}$
$\nabla \cdot \vec{B} = 0$	$\oint \vec{B} \cdot d\vec{a} = 0$
$\nabla \times \vec{B} = \mu_0 \vec{J} + \mu_0 \varepsilon_0 \frac{\partial \vec{E}}{\partial t}$	$\oint \vec{B} \cdot d\vec{l} = \mu_0 I_{enc} + \mu_0 \varepsilon_0 \int \frac{\partial \vec{E}}{\partial t}$

The exposure of living cells to short and intense electric pulses induces position-dependent changes in the transmembrane potential difference ΔTMP



More simply (*takehome message*)





Membrane electroporation can be achieved using one or a few pulses of:

Duration in the millisecond range and hundreds of V/cm (tens of kV/m)
Duration in the microsecond range and thousands of V/cm (hundreds of kV/m)
Duration in the nanosecond range and tens of thousands of V/cm (thousands of kV/m)
Duration of hundreds of picoseconds and ??? of V/cm (??? of kV/m) – Ph D work of L. Vallet

Speculations

For the life to develop:

- Need of the bricks of the biological macromolecules (DNA, RNA, proteins): the Stanley Miller experiments…
- Need of boundaries (no chemical reactions in the whole volume of the oceans…): impermeant lipid vesicles (limiting small hydrophilic compartments)
- Boundaries => transport across the boundaries
  - Today (all the cells): transport is perfectly regulated (membrane proteins, like channels, pumps, …) even for ions like Calcium (allowing for the metabolically-generated electrochemical gradient across the cell membrane and thus the transmembrane voltage
  - At the origin of life (before LUCA), unregulated transport mediated by lightning-mediated transient proto-cells electroporation?

Pyroelectricity (mineral electricity)

Definition

Pyroelectricity is a property of certain crystals that generate a temporary voltage when they are heated or cooled. The change in temperature modifies the positions of the atoms slightly within the crystal structure, such that the polarization of the material changes and gives rise to a voltage across the crystal.

Facts

Recently, my group showed* that the exposure of cells in culture to tourmaline crystals previously heated/cooled/frozen results in the transient permeabilization of the cells (to classical permeabilization markers). (NB: distance between crystals and cells matters, as we showed using another type of nanoparticles, conductive gold nanoparticles).

Speculation

At the beginning of life, « soils » were reduced, thus minerals (including pyroelectric crystals) could be exposed at the surface and daily heated/cooled (sun, weather, …) thus affecting the proto-cells membrane permeability…

*: T. García-Sánchez, A. Muscat, I. Leray and L. M. Mir
Pyroelectricity as a possible mechanism for cell membrane permeabilization
Bioelectrochemistry 119 (2018) 227–233; doi:10.1016/j.bioelechem.2017.10.007

Back to lightning and cells evolution…

Evolution

One of the ways is through horizontal genes tranfer (particularly in bacteria) thus through the transfer of pieces of DNA. Horizontal gene transfer (HGT) is one of the main mechanisms that contribute to microbial evolution and adaptation based on the analysis and comparison of numerous complete prokaryotic genome sequences

Facts

Is a role of lightning possible ?

Yes: DNA are molecules that resist to degradation in clays

Yes: experimentally proved by H. Ceremonie and colleagues (ENS Lyon) years ago.*

Using a laboratory-scale lightning system provides an estimate of the volume of soil affected by natural electrotransformation (responsible for the horizontal gene transfer).

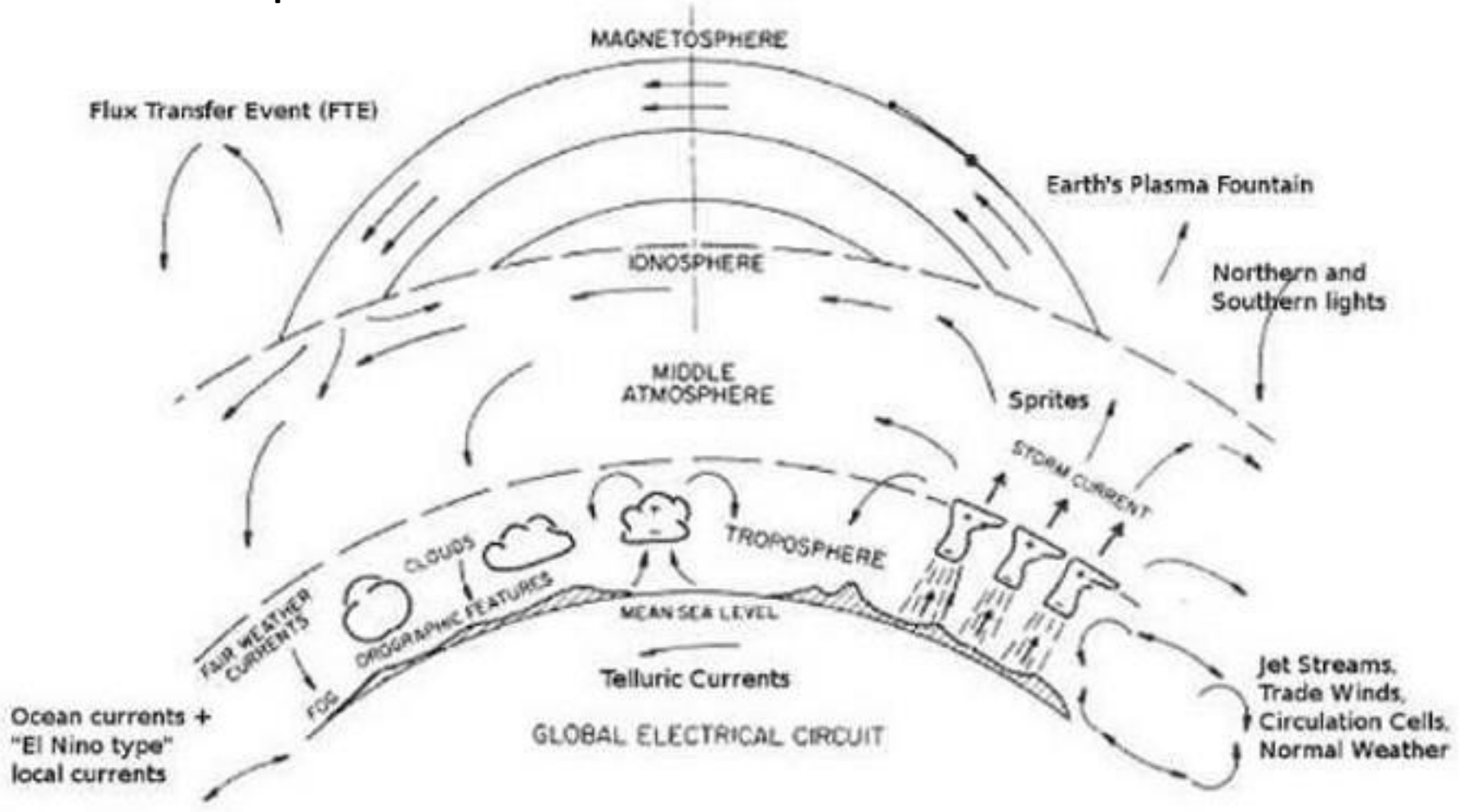
Speculation

Only on the importance of the processus, not on its existence…

*: Ceremonie H, Buret F, Simonet P, Vogel TM (2006)
Natural electrotransformation of lightning-competent Pseudomonas sp.strain N3 in artificial soil microcosms.
Appl Environ Microbiol72:2385–2389. https://doi.org/10.1128/AEM.72.4.2385-2389.2006

Last but not least: the influence of the GEC

GEC: global atmospheric electric circuit



Two consequences:

An electrostatic permanent electric field + an electromagnetic field at ≈7.6 Hz (and harmonics)

The electrostatic permanent electric field

What has been measured?

- Average amplitude: about 100 V/m in fair weather
- Much larger amplitudes under thunderstorm clouds (responsible for St Elmo's fires)
- Circadian variation (the Carnegie curve)

What can be its influence on the living organisms?

- I dont'know
- Not on aquatic species. For humans, we are grounded…
- For other species?

An electromagnetic field at 7.6 Hz (and harmonics): the Schumann resonance

Origin:
The atmosphere is a resonant cavity between the ground and tje ionosphere, fuelled by continuous lightning (1000+ per second all over the world)

Facts:
Cardiomyocytes (the muscle cells of the heart) contract spontaneously in culture responding to oscillations of the Calcium concentration inside the cell
Colin Price and colleagues (Israël) have shown that, when cardiomyocytes in culture are exposed to a 7,8 Hz EMF (20 pT – 100 nT), the calcium oscillations amplitude decrease and after 30 minutes the cells stop their mechanical spontaneous contractions.

Role and influence in the construction of the living organisms:
Only speculations… I don’t know

*: Elhalel G, Price C, Fixler D, Shainberg A (2019)
Cardioprotection fromstress conditions by weak magnetic fields in the Schumann resonance band.
Sci Rep 9:1–10. https://doi.org/10.1038/s41598-018-36341-z

Natural electromagnetic fields

- TERRESTRIAL: √

  Earth magnetic field with its two components, vertical and horizontal

- ATMOSPHERIC (presentation of the GEC): √

  Lightning and other electric flashes
  Static electric field, with its circadian and local variations
  Schumann resonance at 7.8 Hz, and its harmonics

- MINERALS: √

  At the interface between the atmosphere and the lithosphere,
  in particular the pyroelectric materials

- TELLURICS (LITHOSPHERICS):

  Consequences of earthquakes and volcanic eruptions

d

Thank you very much for your attention

Recent references:

M. Cifra, F. Apollonio, M. Liberti, T. García-Sánchez, L. M. Mir

Possible molecular and cellular mechanisms at the basis of atmospheric electromagnetic field bioeffects

Int. J of Biometereology, 65:59-67, JAN 2021

e-pub 2020 doi.org/10.1007/s00484-020-01885-1

S. Savoska, P. Fernández-Arróyabe Hernáez, M. Cifra, K. Kourtidis, E. Rozanov, K. Nicoll, S. Dragovic & L. M. Mir

Toward the creation of an Ontology for the coupling of atmospheric electricity with biological systems

Int. J of Biometereology 65: 31-44, JAN 2021

E-pub 2020 doi.org/10.1007/s00484-020-01885-1