Earth's Electromagnetic Environment: Formation, Variability, Impact on the Biosphere

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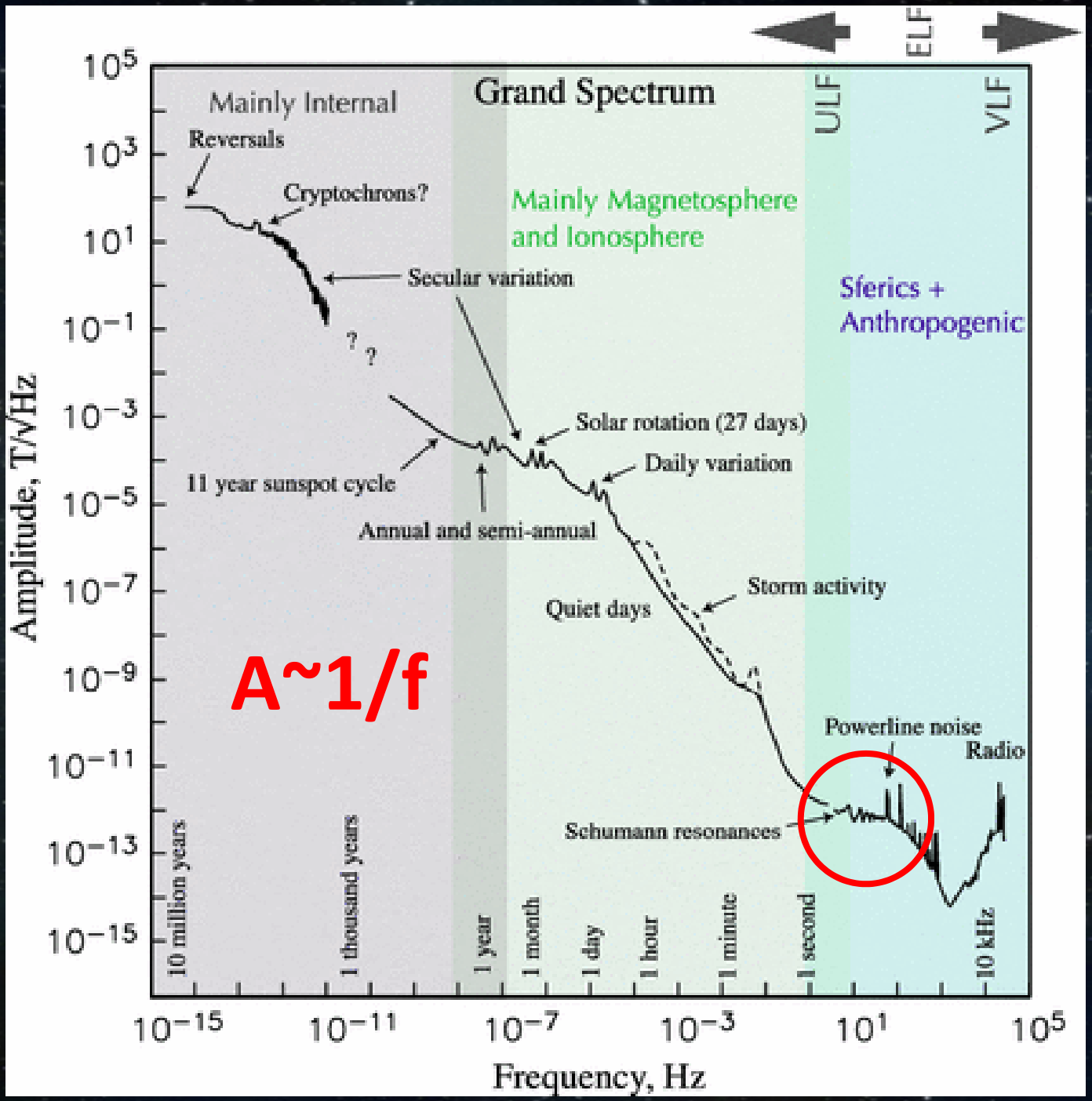
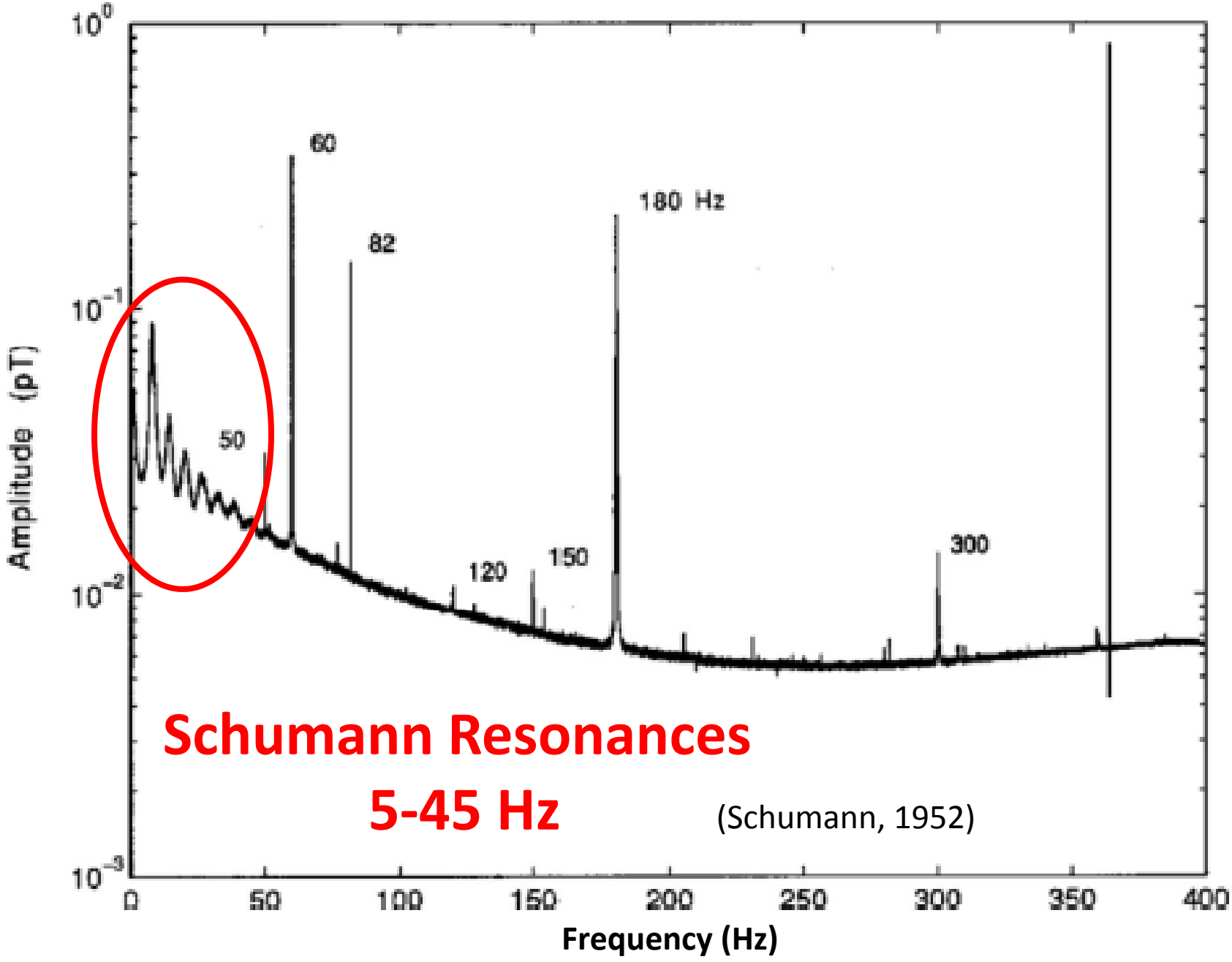
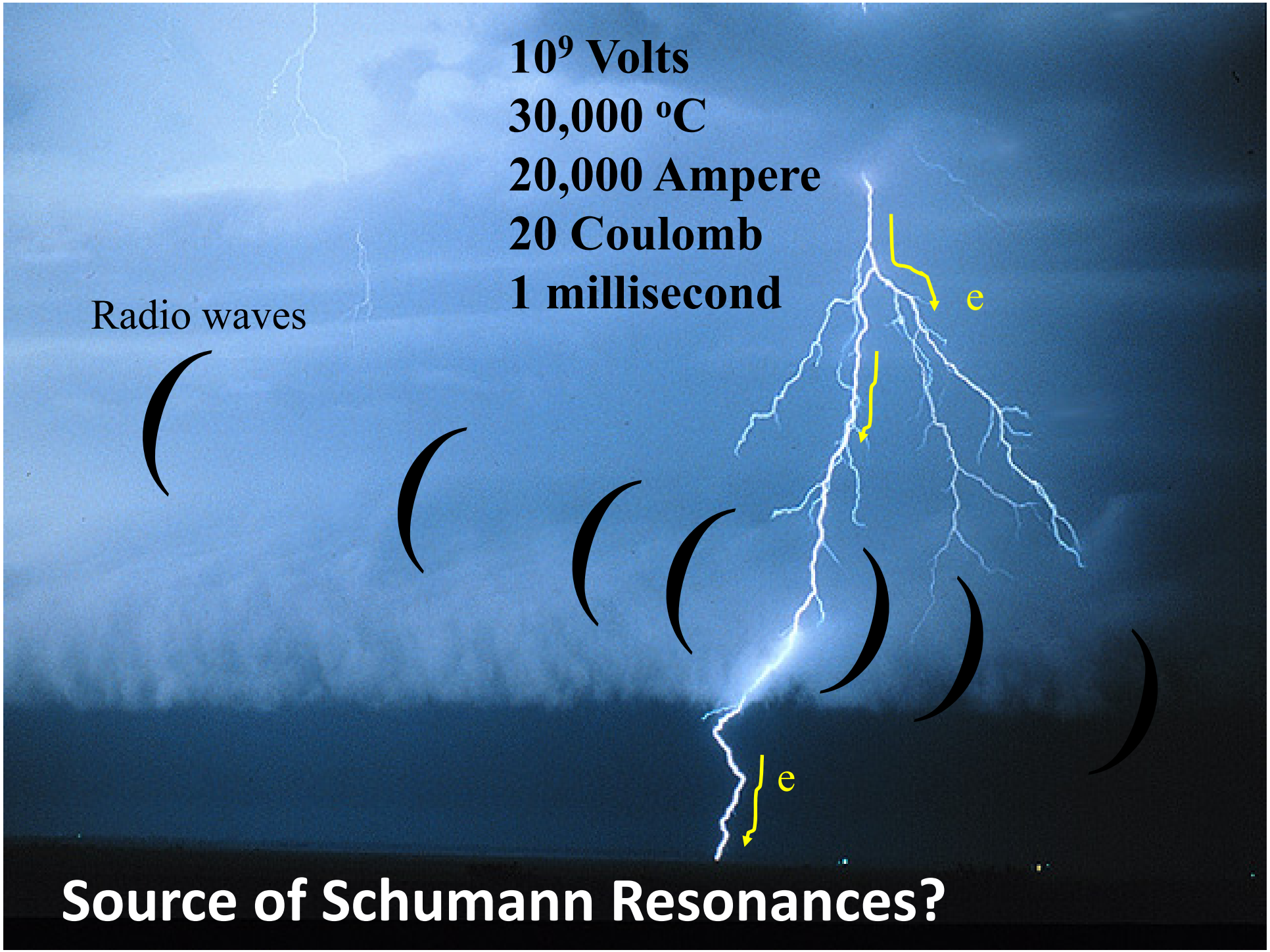

Grand Spectrum
Mainly Internal
Reversals
Cryptochrons?
Secular variation
? ?
Mainly Magnetosphere
and Ionosphere
Sferics +
Anthropogenic
Solar rotation (27 days)
Daily variation
11 year sunspot cycle
Annual and semi-annual
Storm activity
Quiet days
A~1/f
Powerline noise
Radio
Schumann resonances
ULF
ELF
VLF
Amplitude, T/√Hz
Frequency, Hz
10 million years
1 thousand years
1 year
1 month
1 day
1 hour
1 minute
1 second
10 kHz



Schumann Resonances

5-45 Hz (Schumann, 1952)



Source of Schumann Resonances?

Lightning Waveform

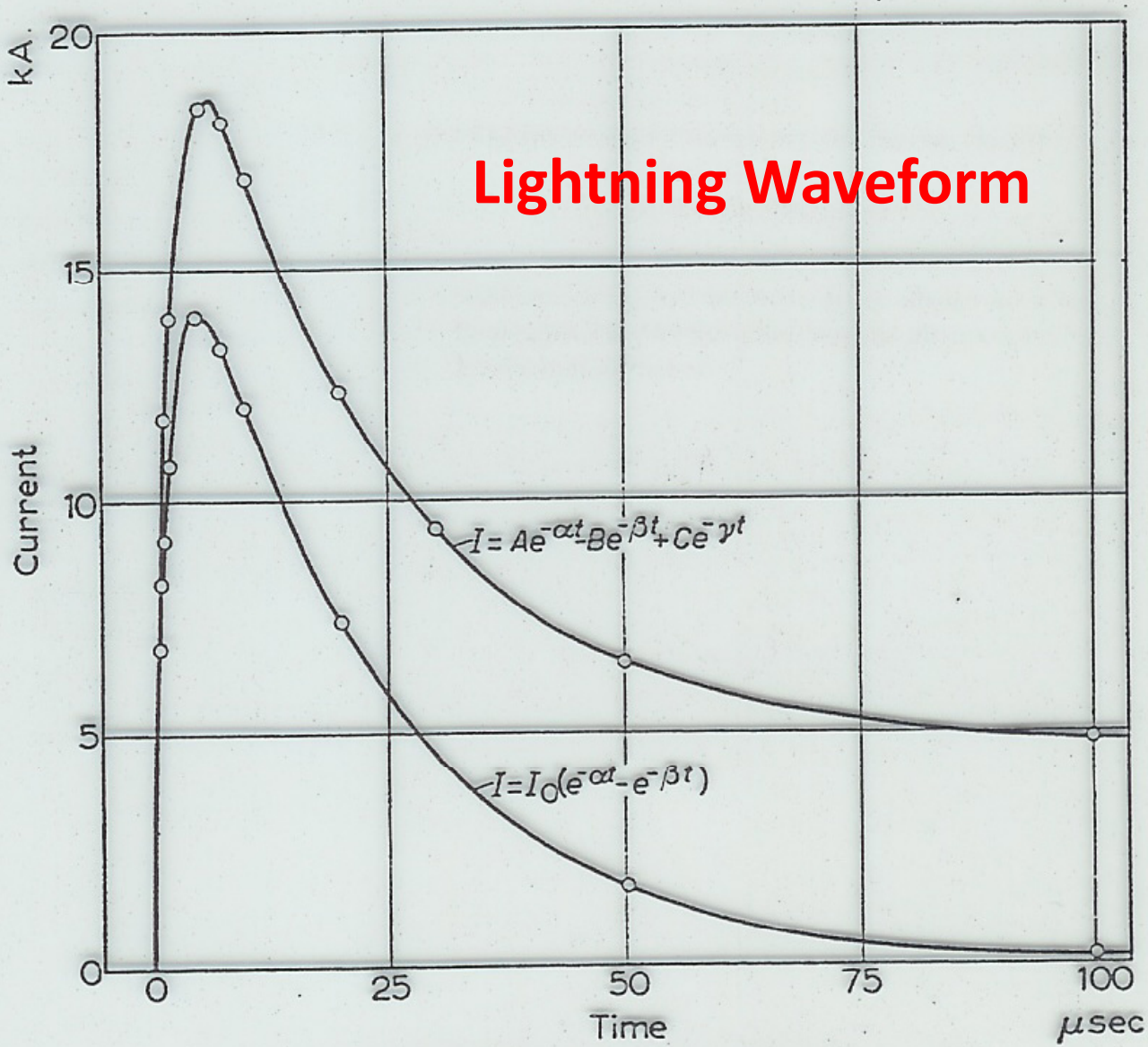
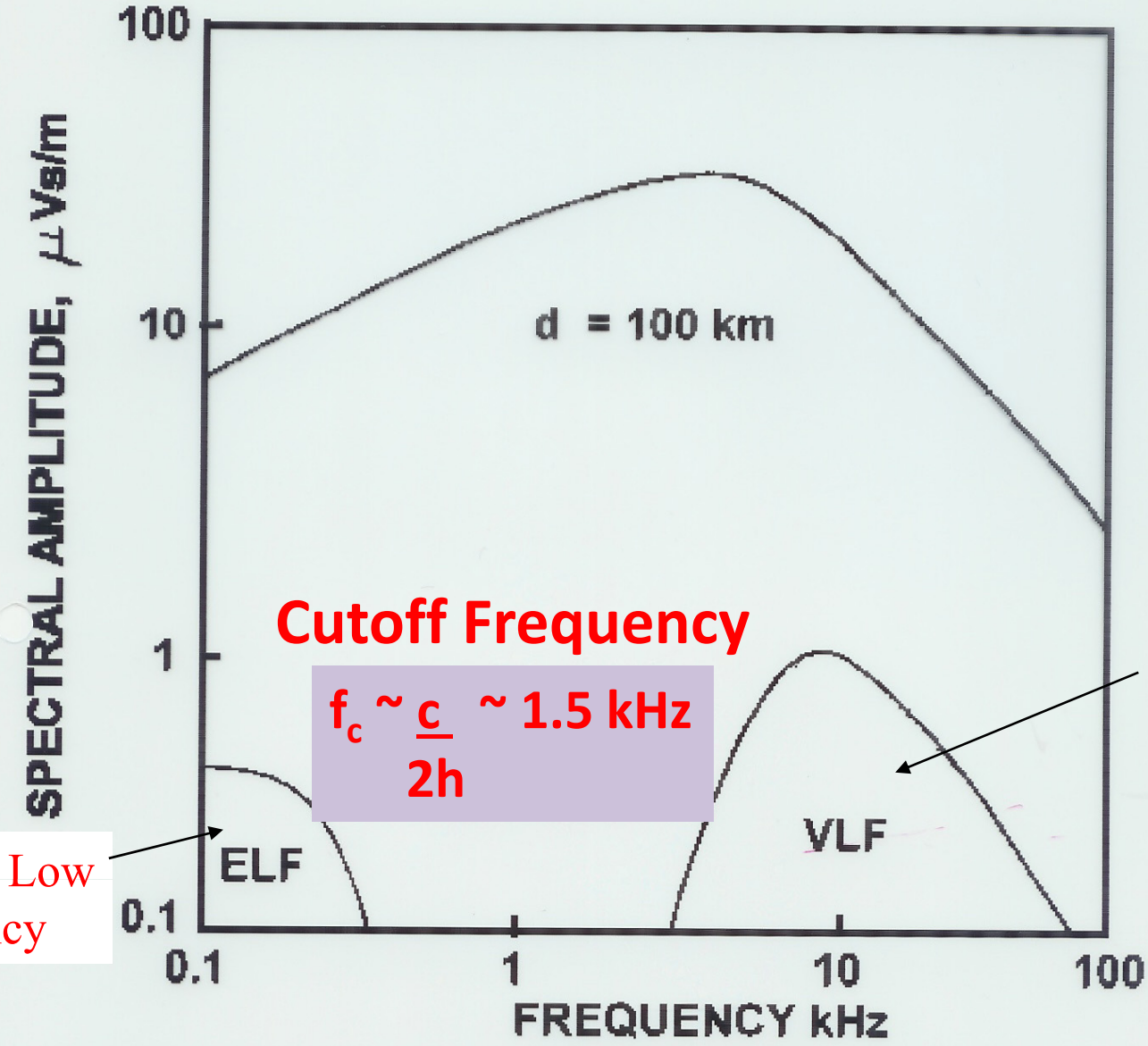


Fig. 2.—Discharge current variations.

$\alpha = 5 \cdot 10^4\ s^{-1}$
$\beta = 5 \cdot 10^5\ s^{-1}$
$\gamma = 7 \cdot 10^2\ s^{-1}$

$I_0 = 20$ kA
$A = 20$ kA
$B = 25$ kA
$C = 5$ kA



Cutoff Frequency

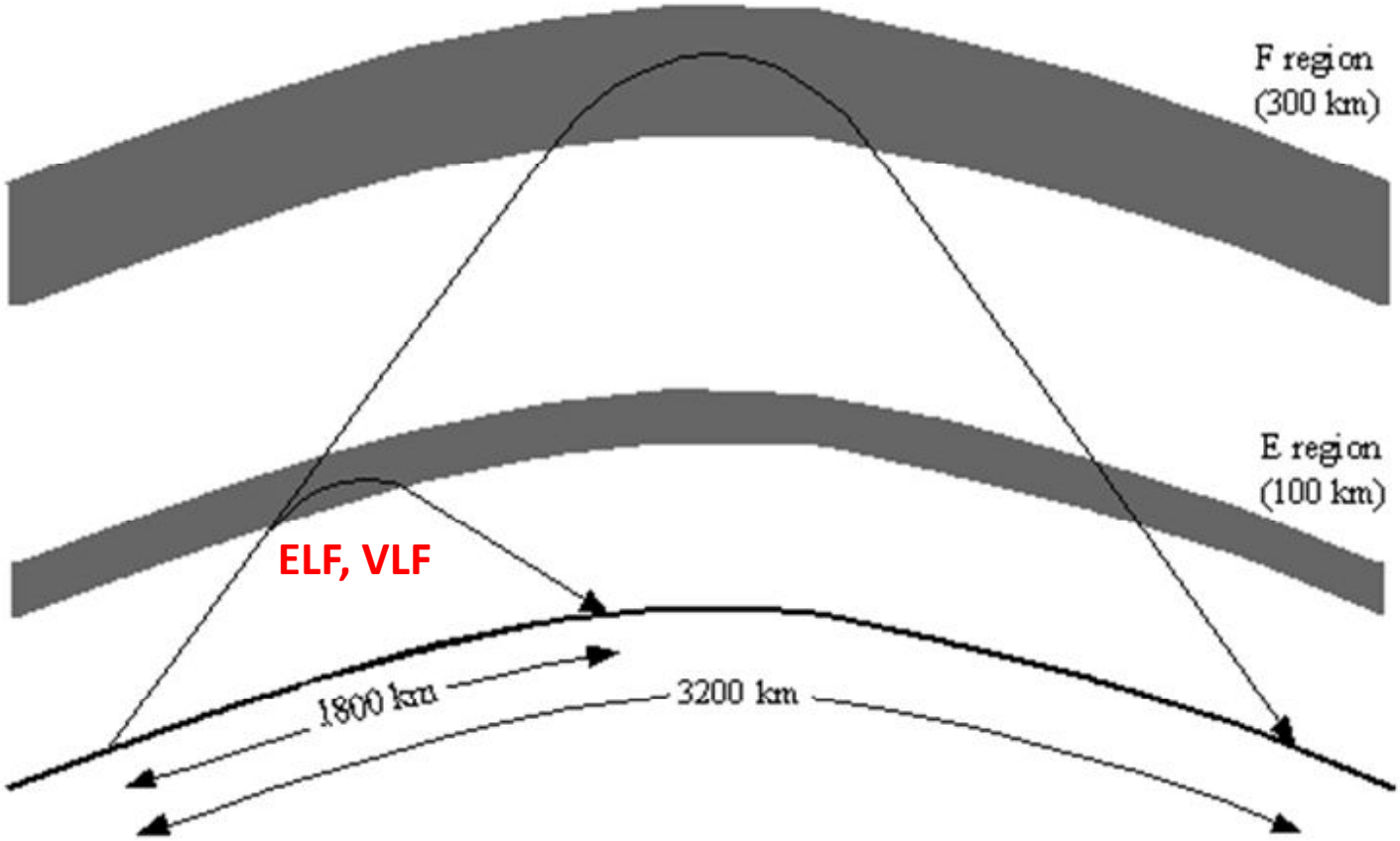
$$f_c \sim \frac{c}{2h} \sim 1.5 \text{ kHz}$$

Extremely Low Frequency

Very Low Frequency

Power spectrum of electromagnetic energy lightning discharges at a range of 100 km and at 3000 km. From Pierce (1977)

Reflection of Radio Waves by the Ionosphere



Reflection starts at the "Critical Frequency", which is when the radio frequency equals the plasma frequency.

$$f_0 = 9\sqrt{10^{-6} n_e}$$

(f_0 in megahertz, n_e in cm^{-3})

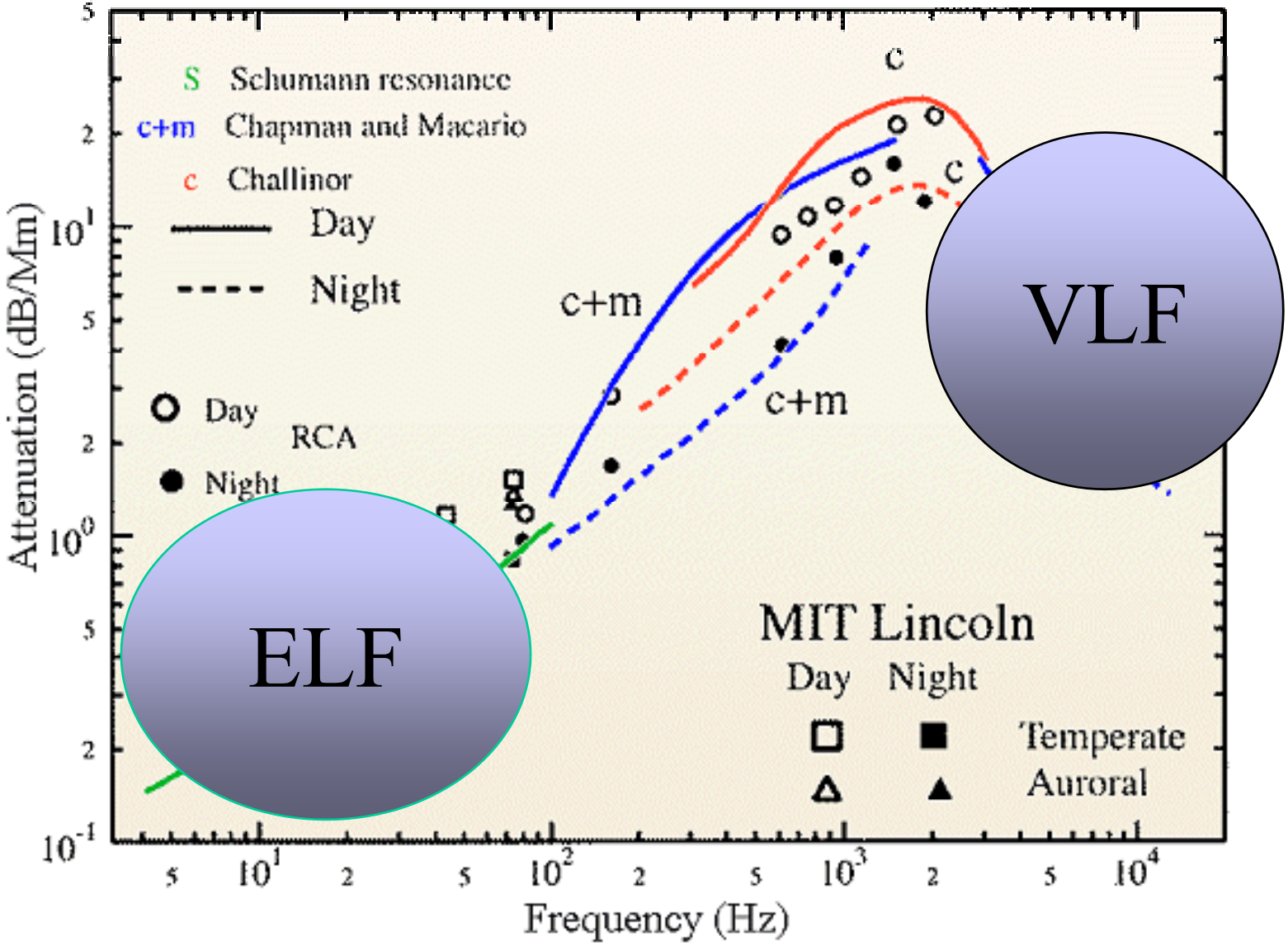


Figure 6 ULF/ELF/VLF path attenuation (dB/Mm) versus frequency

ELF = Extremely Low Frequency < 100 Hz

$$f_n = \frac{c}{2\pi a}\sqrt{n(n+1)}$$

Schumann (1952)

~ 8, 14, 20,… Hz

Theory

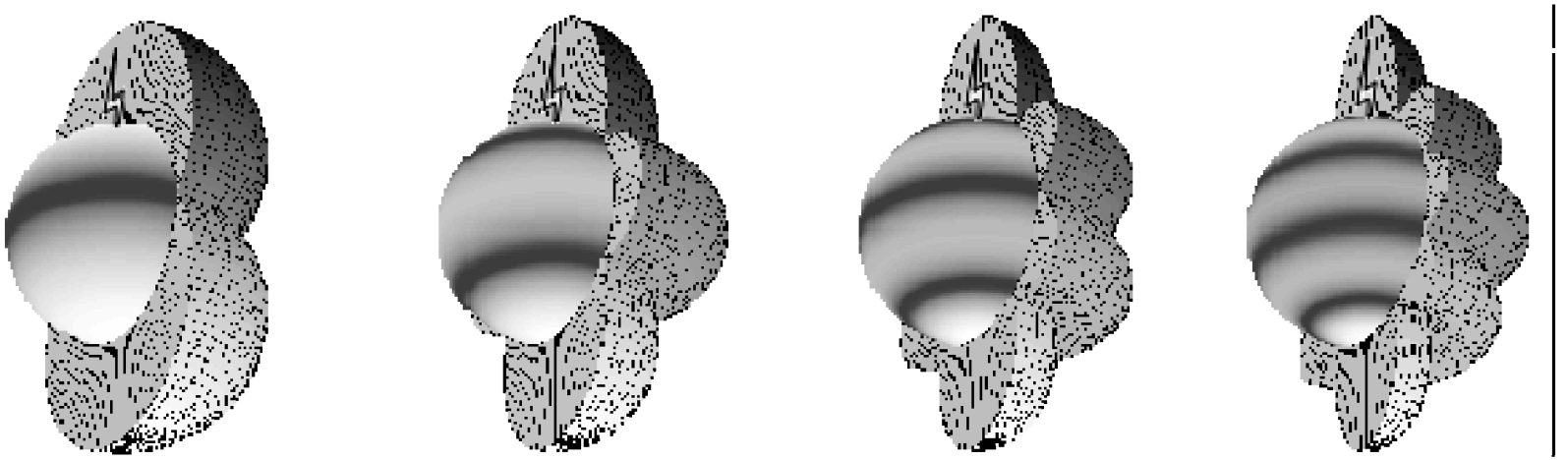
$$E_r(\omega) = -\frac{M_c(\omega)}{4\pi\varepsilon_0 h a^2}\,\frac{i\nu(\nu+1)}{\omega}\sum_{n=0}^{\infty}\frac{(2n+1)P_n(\cos\theta)}{n(n+1)-\nu(\nu+1)}$$

$$H_\varphi(\omega) = \frac{M_c(\omega)}{4\pi h a}\sum_{n=1}^{\infty}\frac{(2n+1)P_n^1(\cos\theta)}{n(n+1)-\nu(\nu+1)}$$

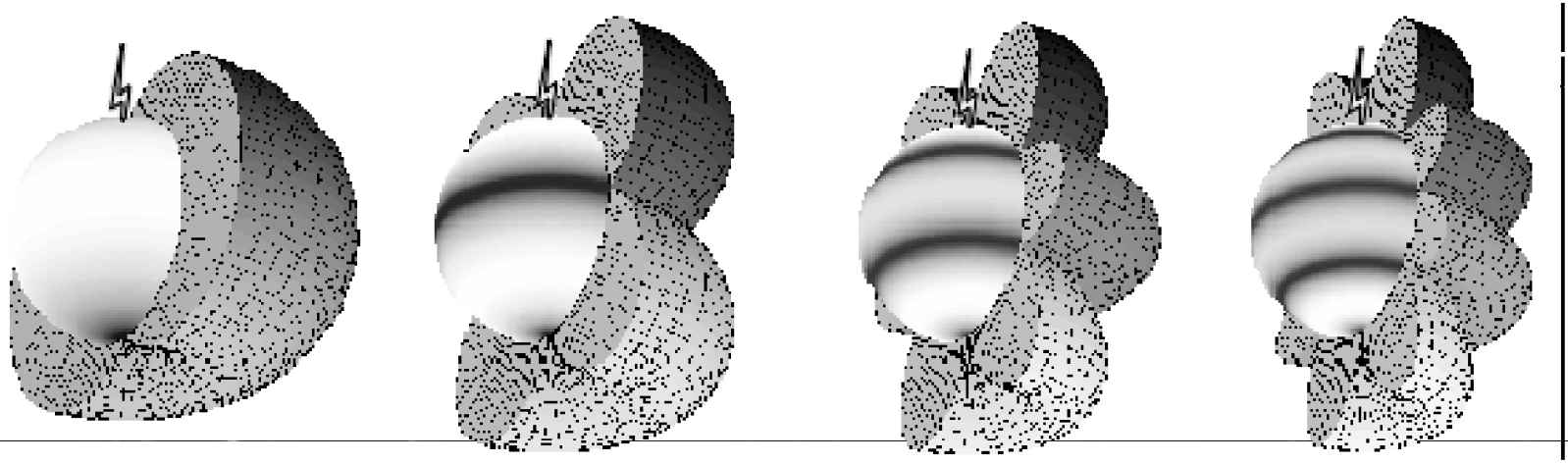
ω = angular frequency
Θ = great circle angle from lightning to the observer
ε_0 = vacuum permittivity;
a = radius of the Earth;
h = the height of the Ionosphere;
$P_n(\cos\theta)$ and $P_n^1(\cos\theta)$ are Legendre and associated Legendre functions of degree n and order 0,1 respectively
ν, the modal eigenvalue related to the propagation constant of the Earth-Ionosphere spherical-shell cavity
$M_c(\omega)$ is the vertical charge moment of the lightning ground flash.

Angular Distributions of Schumann Resonance Modes

Electric

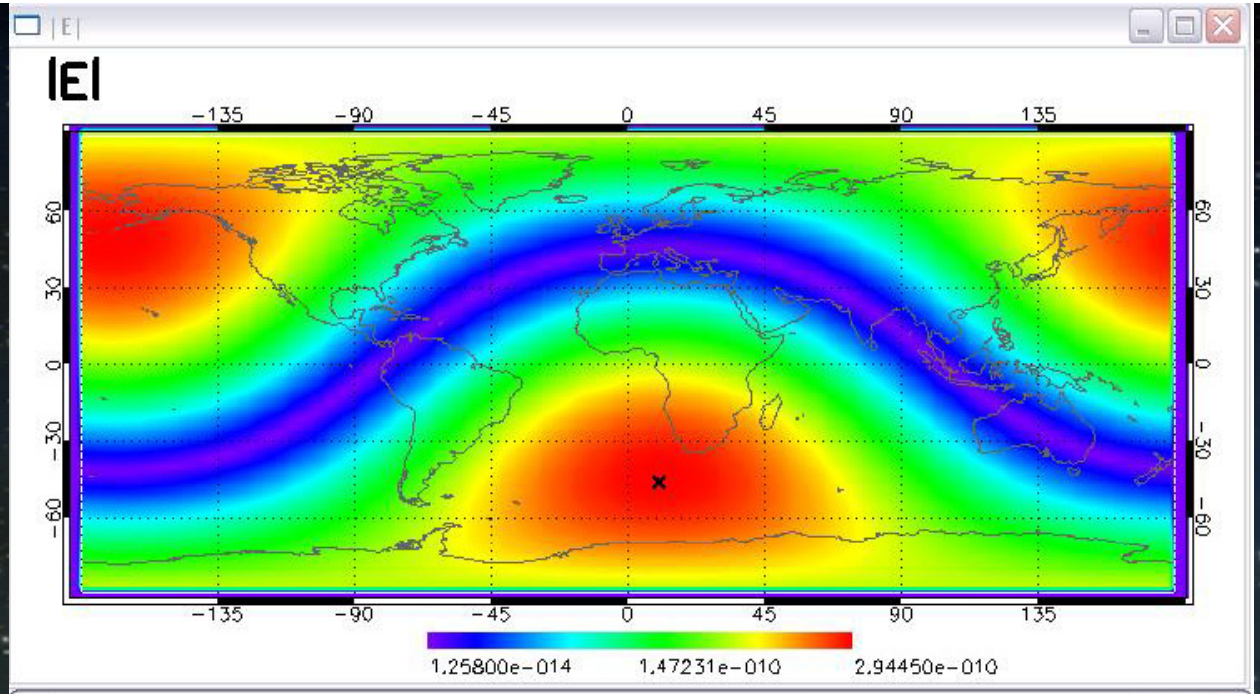


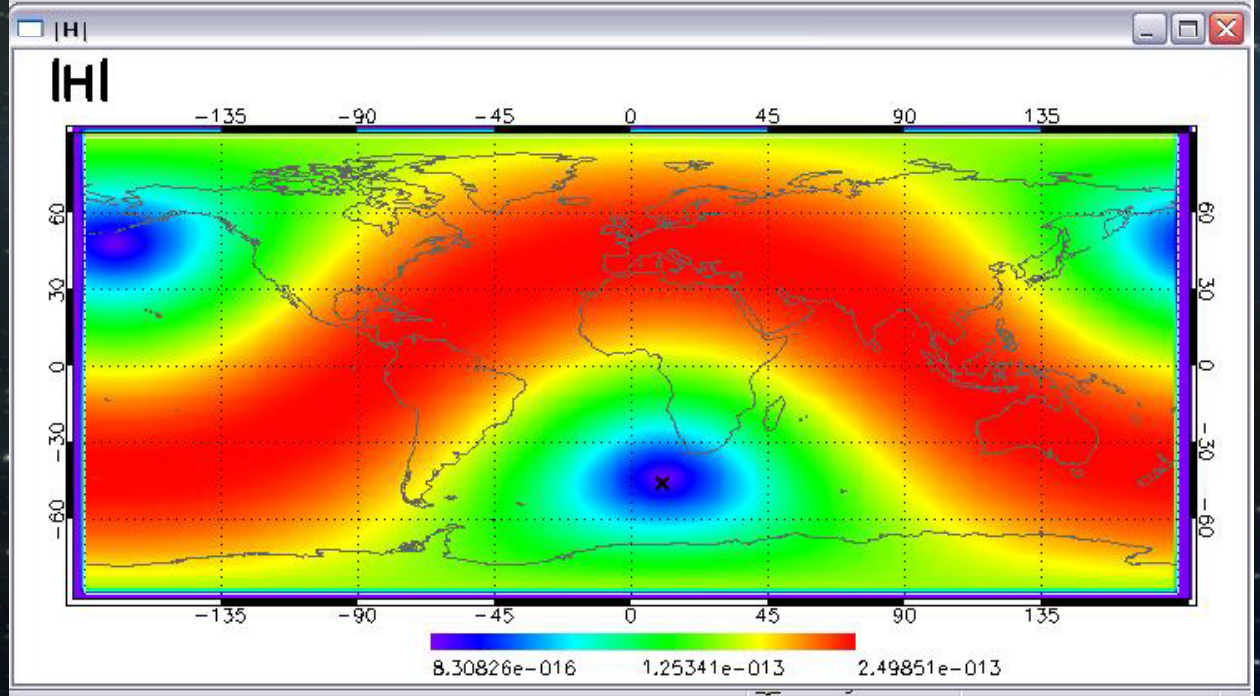
f=8 Hz 14 Hz 20 Hz 26 Hz



Magnetic

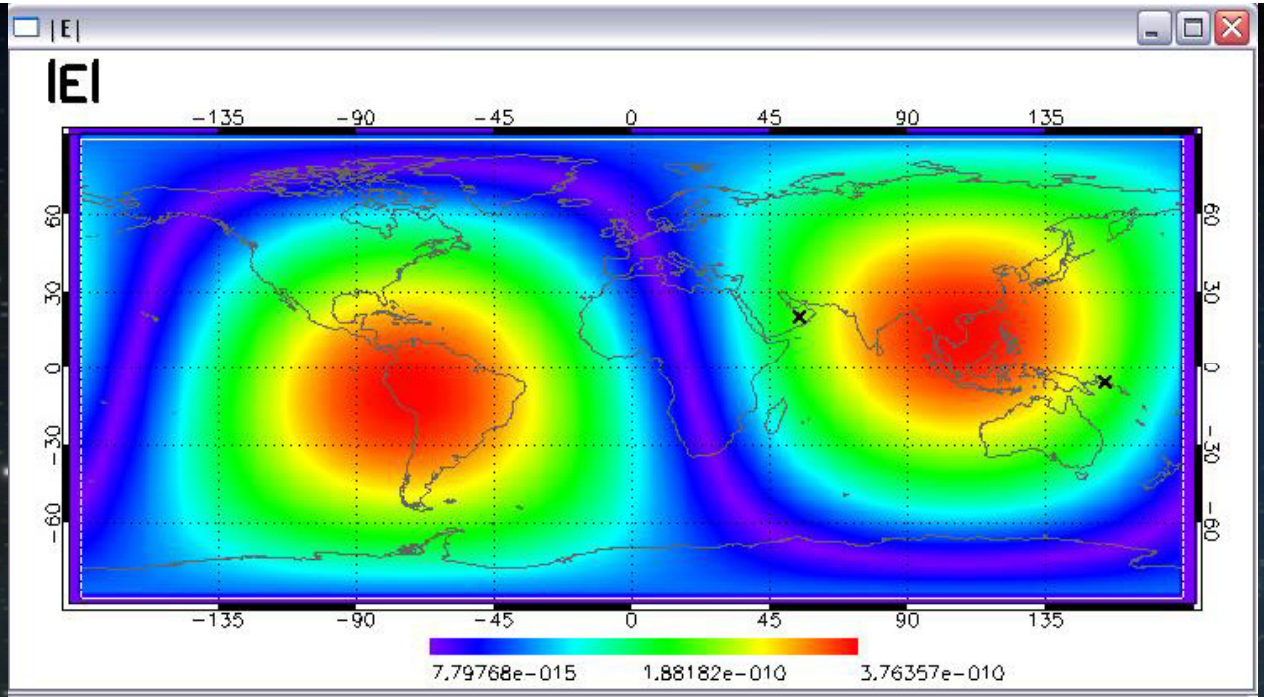
8 Hz

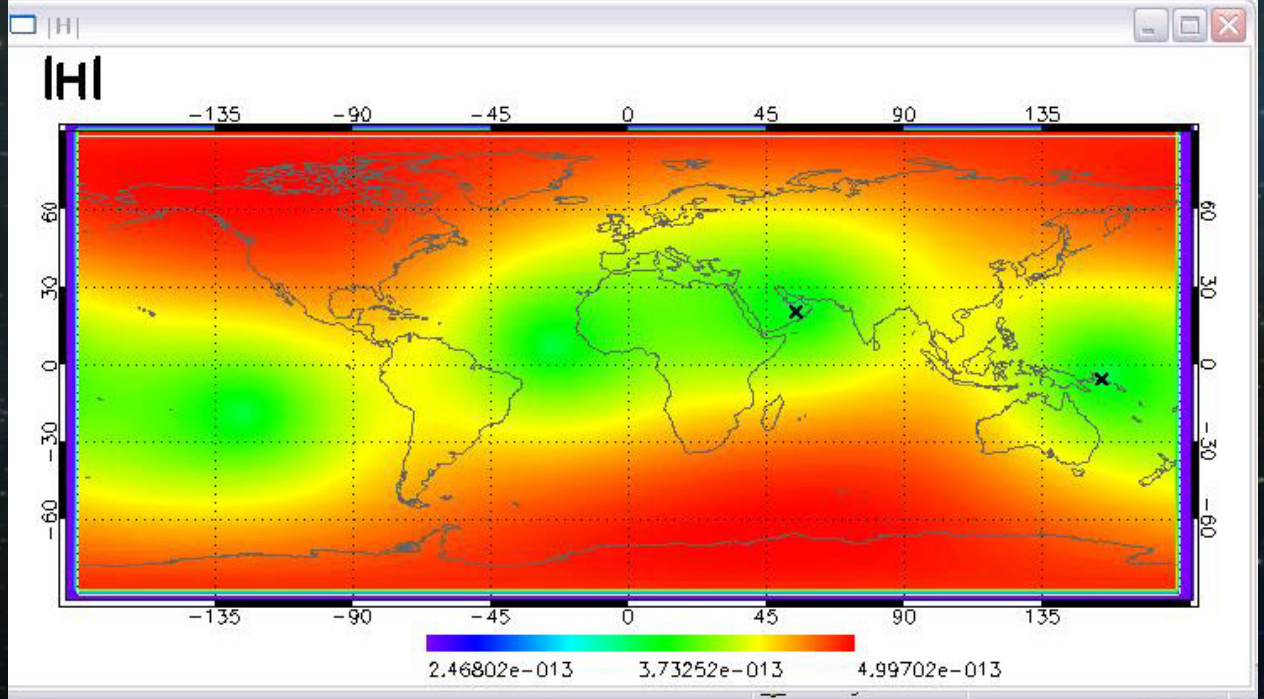

|E|
|E|
−135 −90 −45 0 45 90 135
60 30 0 −30 −60
1.25800e−014 1.47231e−010 2.94450e−010


|H|
|H|
−135 −90 −45 0 45 90 135
60 30 0 −30 −60
8.30826e−016 1.25341e−013 2.49851e−013

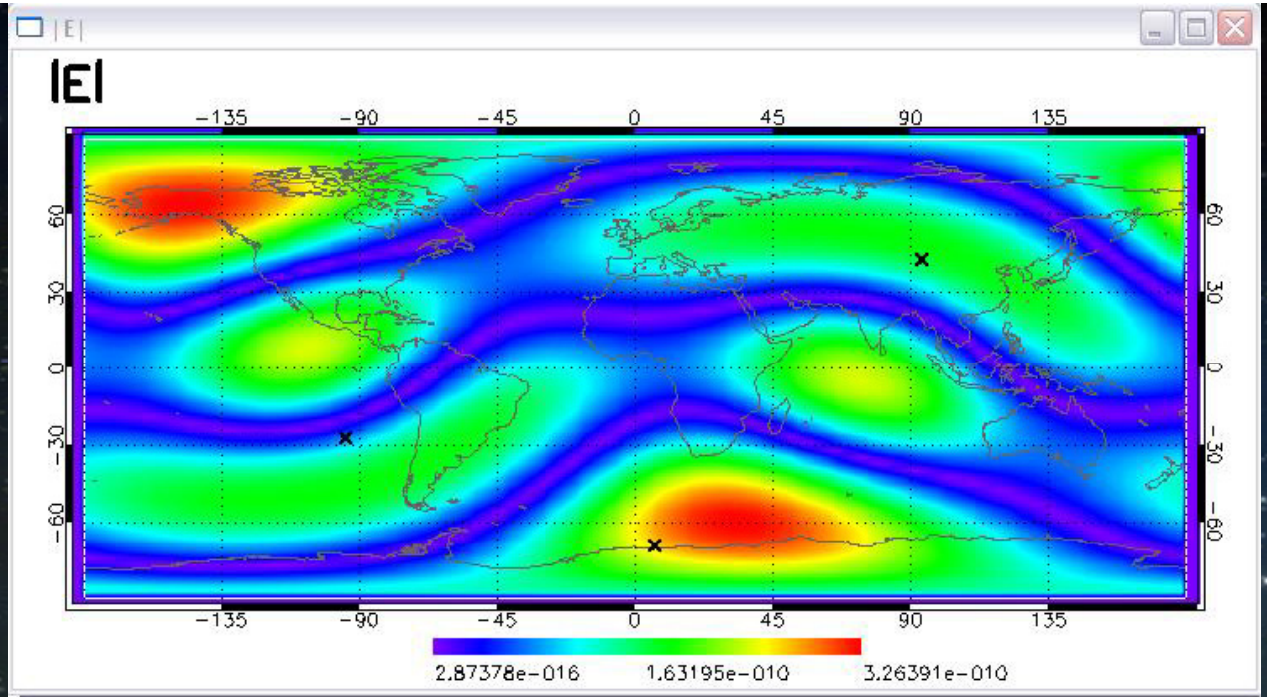

|E/H|

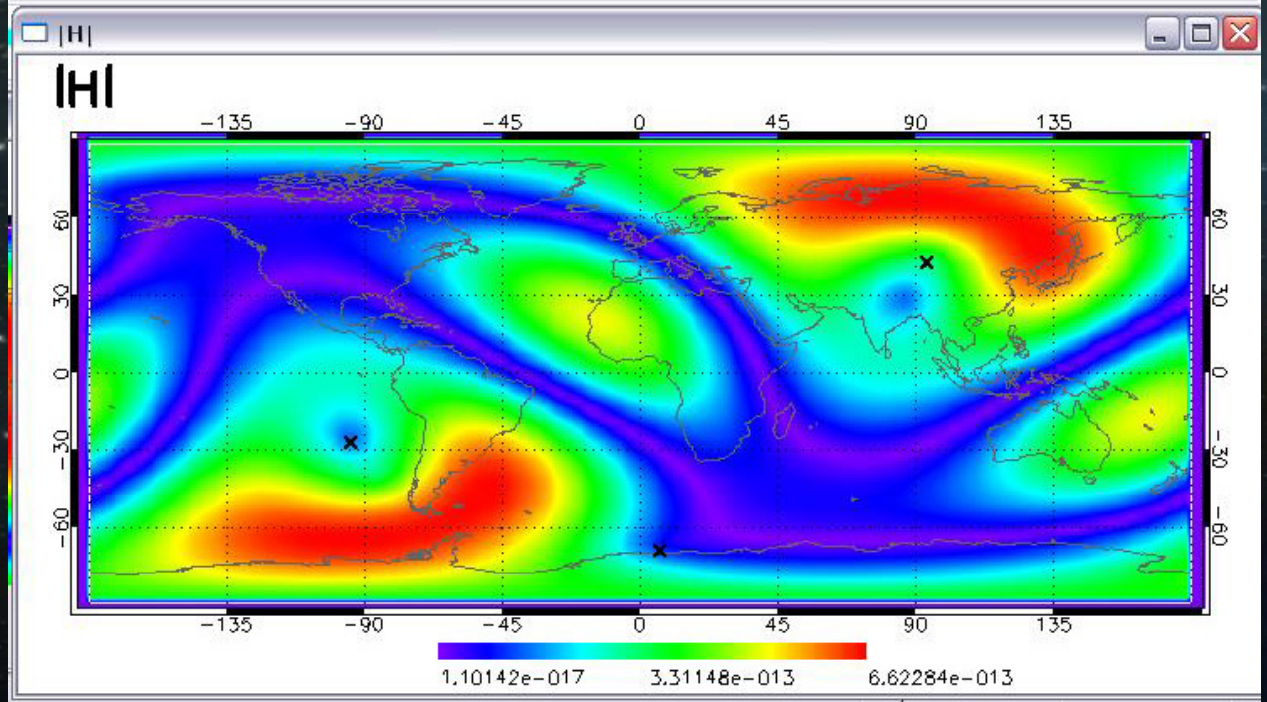
8 Hz
2 flashes



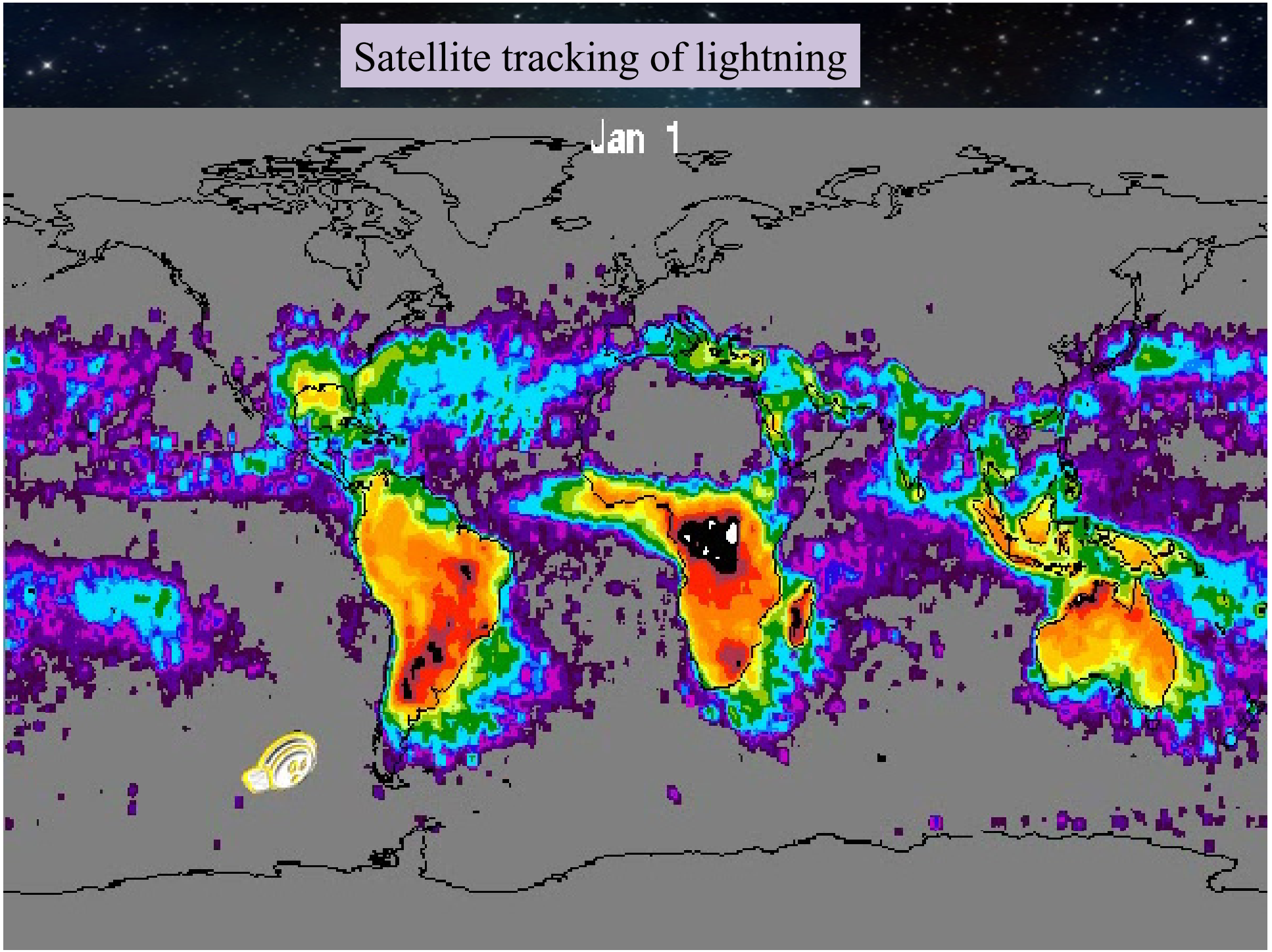


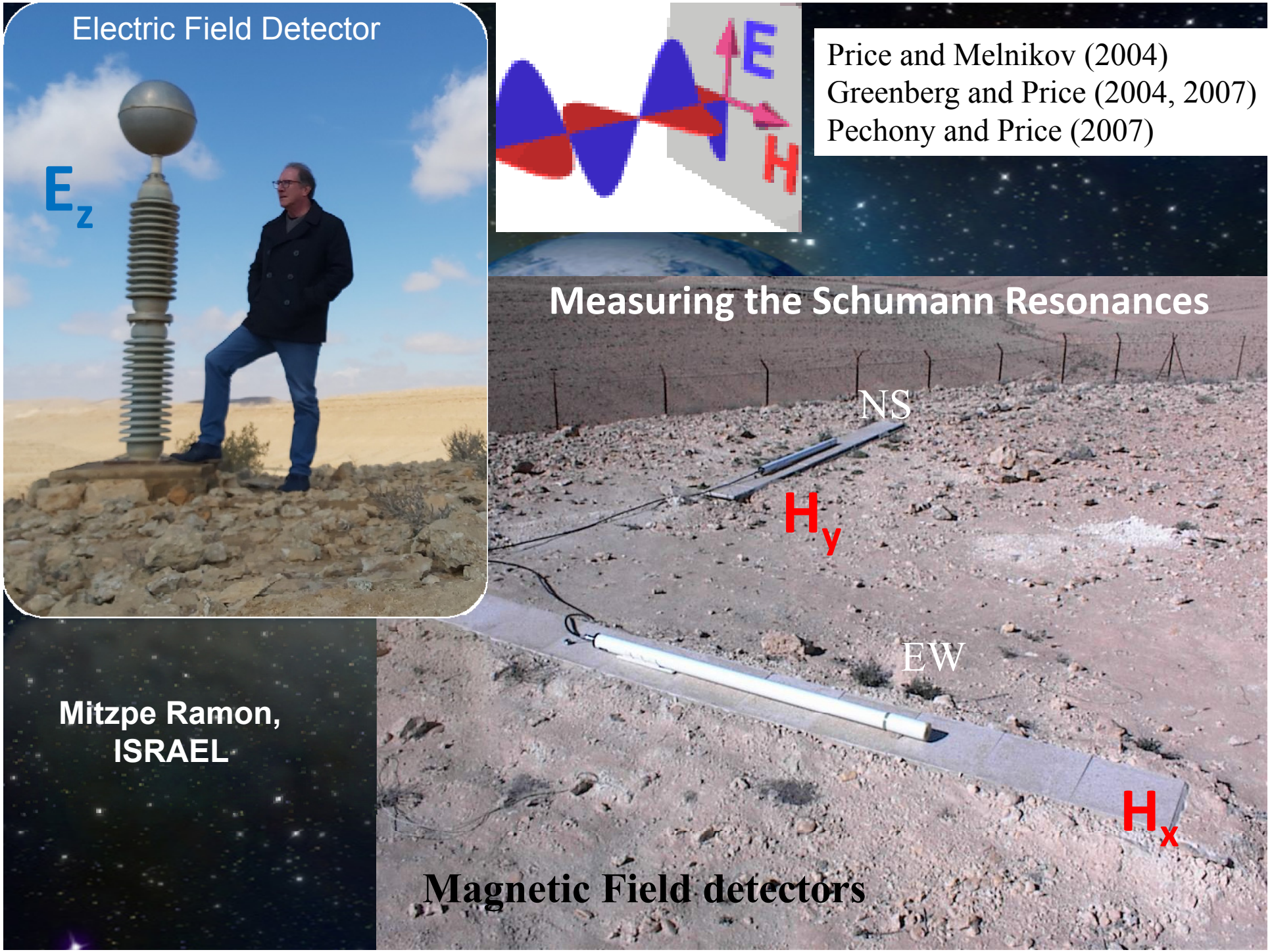
8 Hz
3 flashes



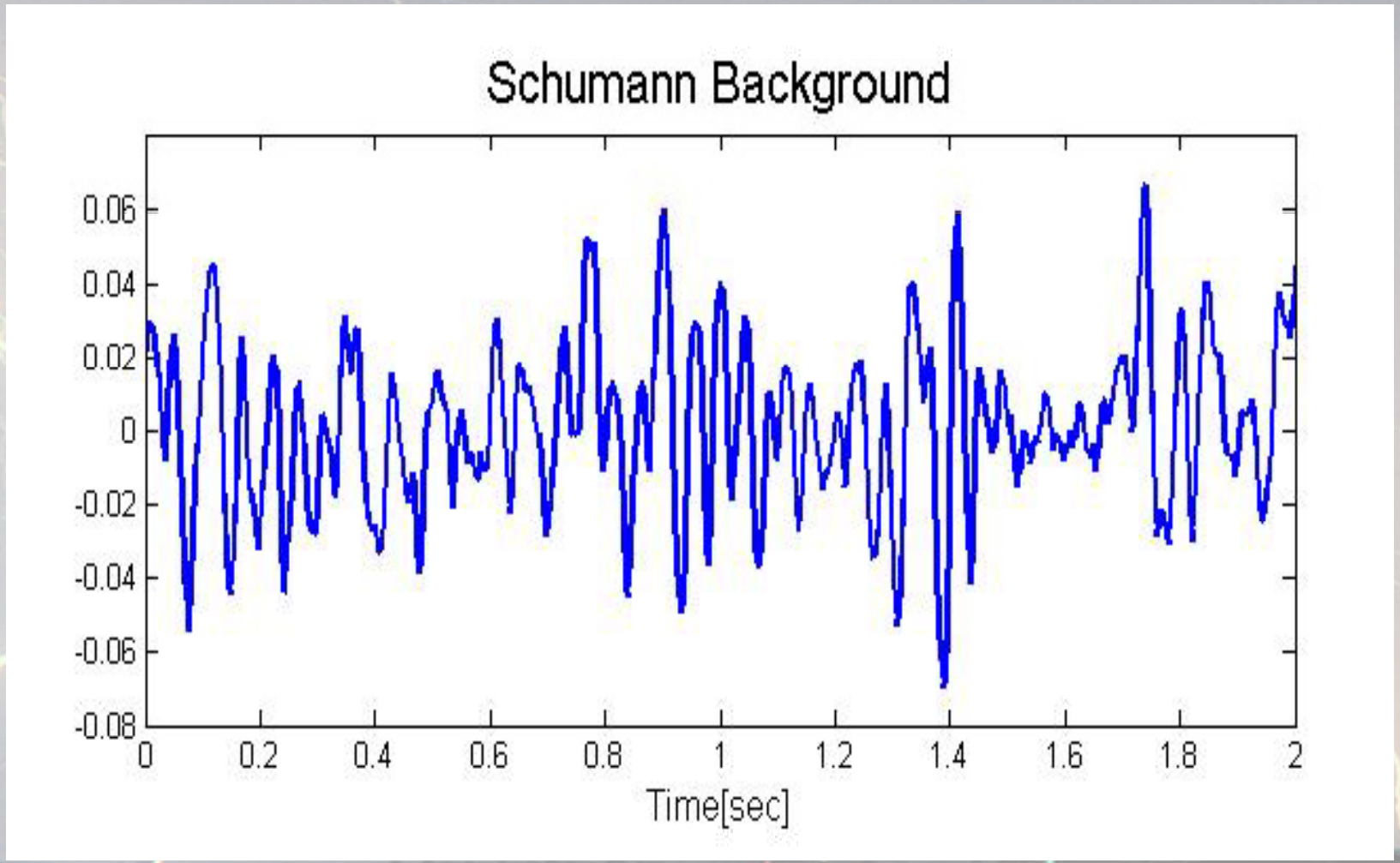


Satellite tracking of lightning

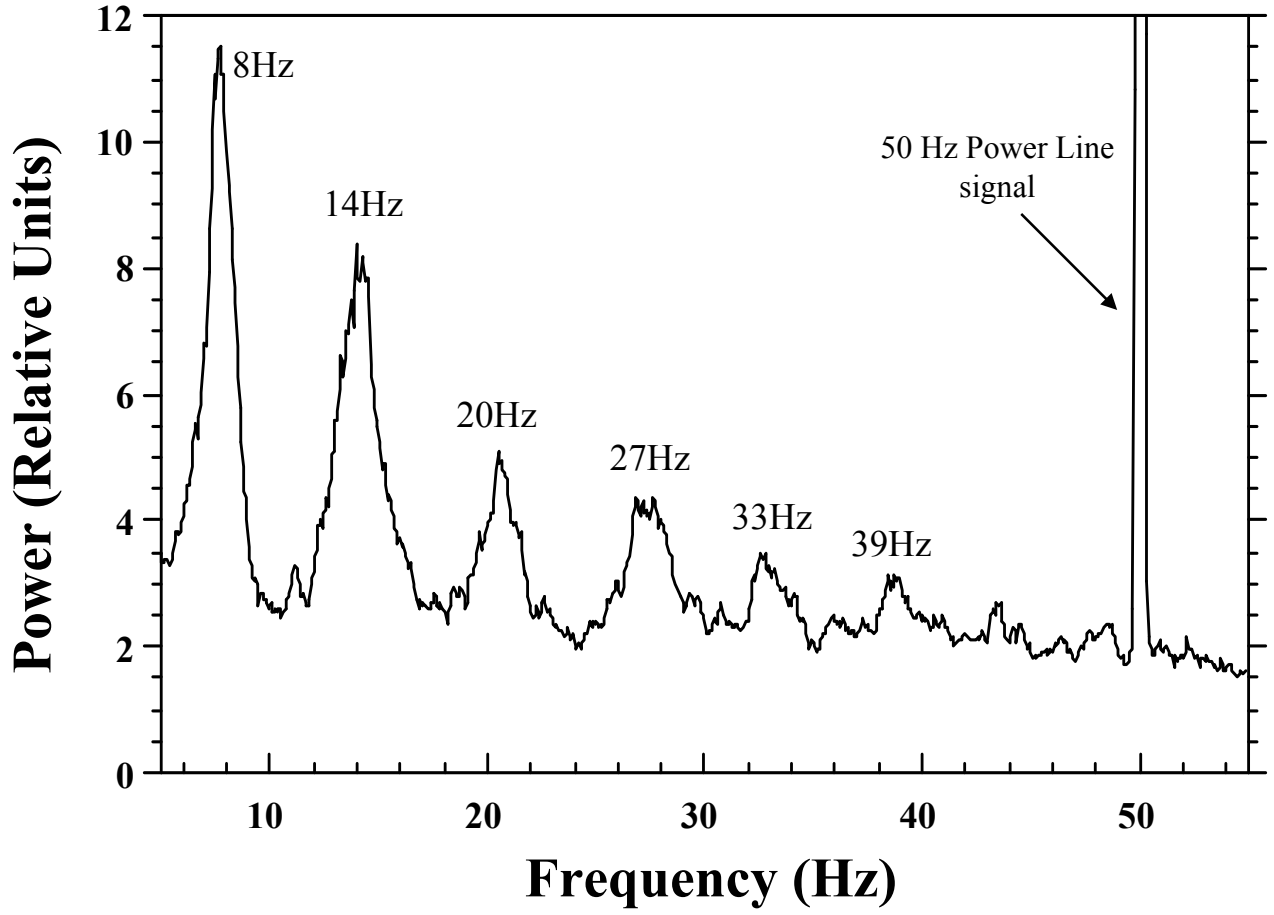



Electric Field Detector
E_z
E
H
Price and Melnikov (2004)
Greenberg and Price (2004, 2007)
Pechony and Price (2007)
Measuring the Schumann Resonances
NS
H_y
EW
H_x
Mitzpe Ramon,
ISRAEL
Magnetic Field detectors

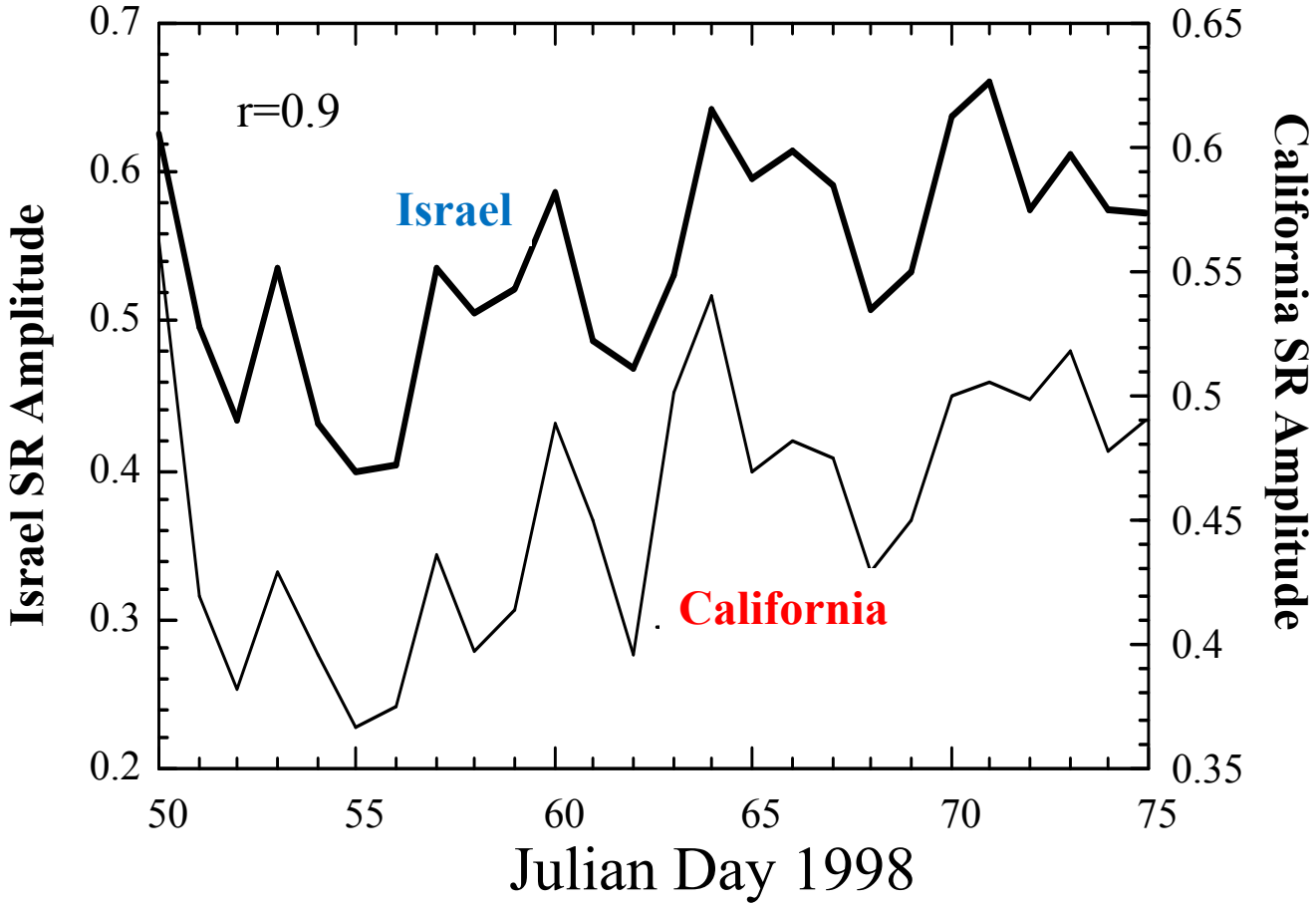
ELF (1-50 Hz) Magnetic field time series (2 seconds) observed in the Negev Desert, Israel.

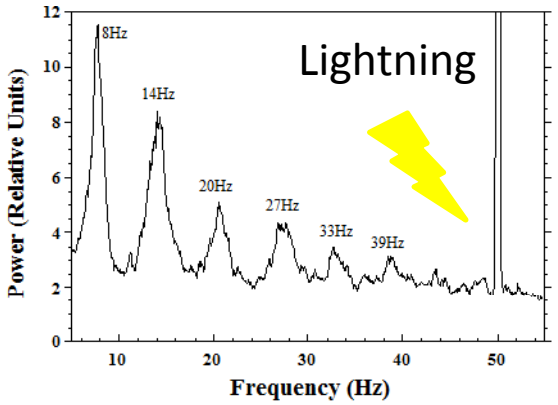


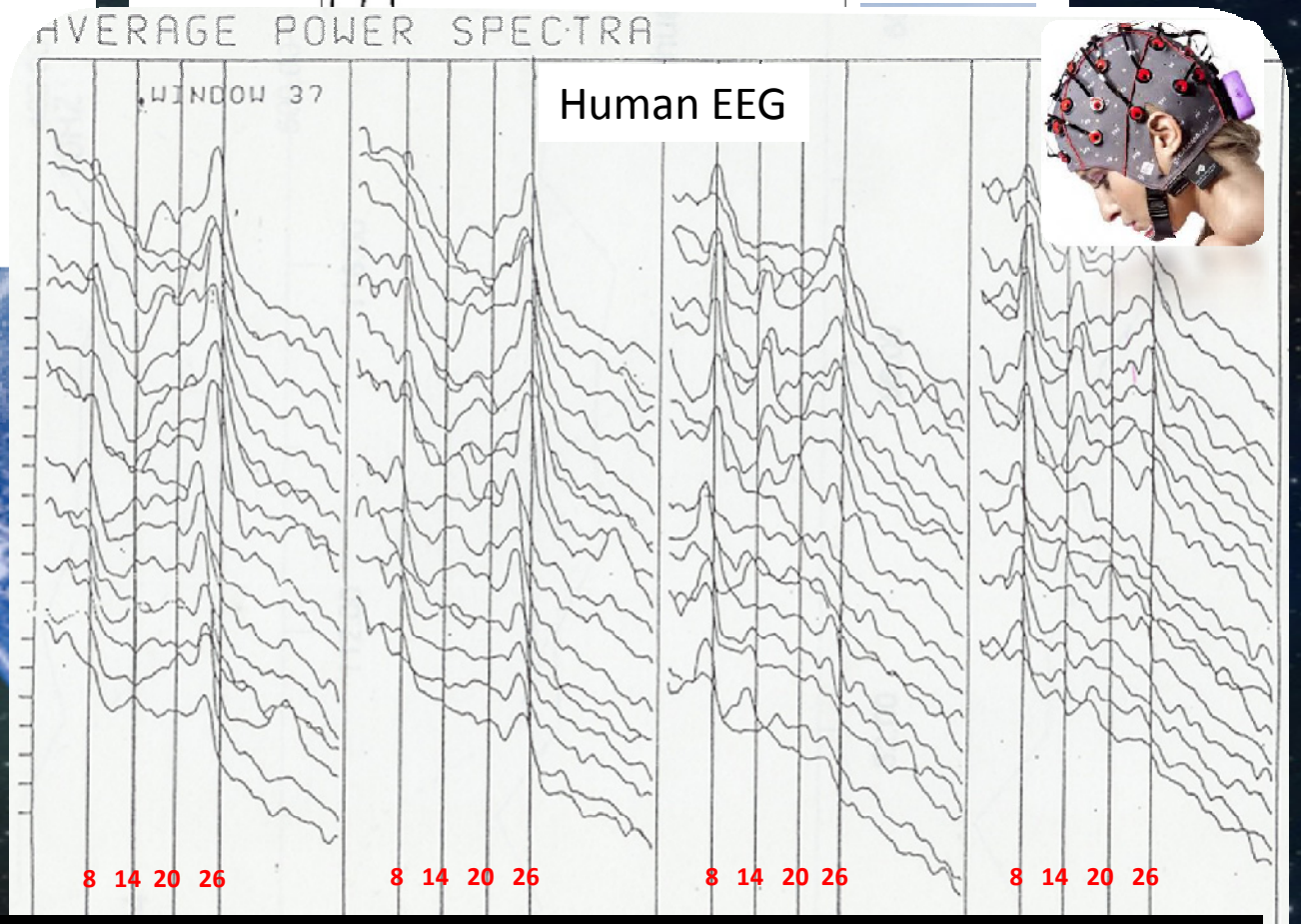
Negev Desert, Israel, spectrum of the previous time series showing Schumann Resonances



Variability of the daily mean 8Hz SR signal observed simultaneously in Israel and California

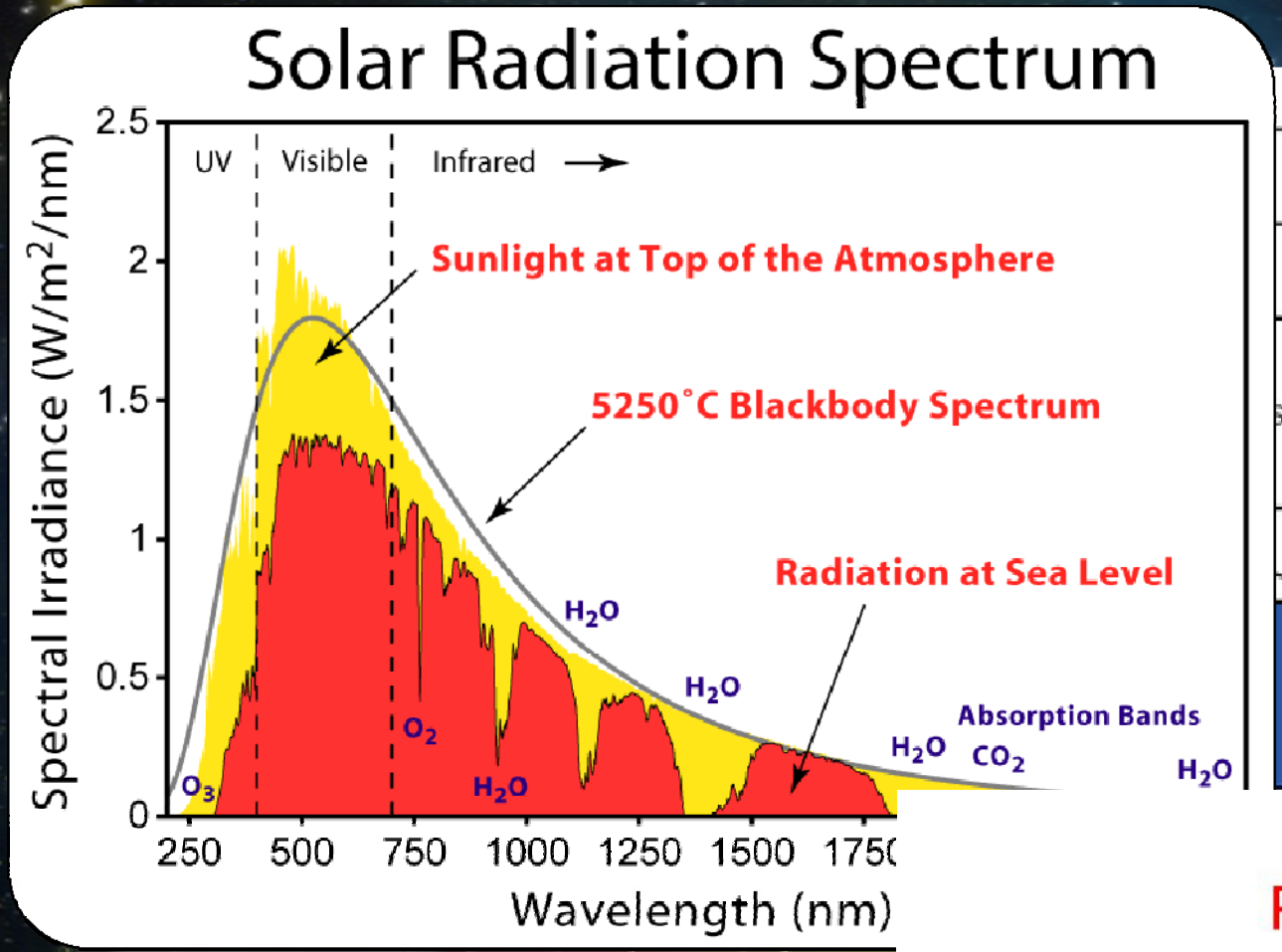


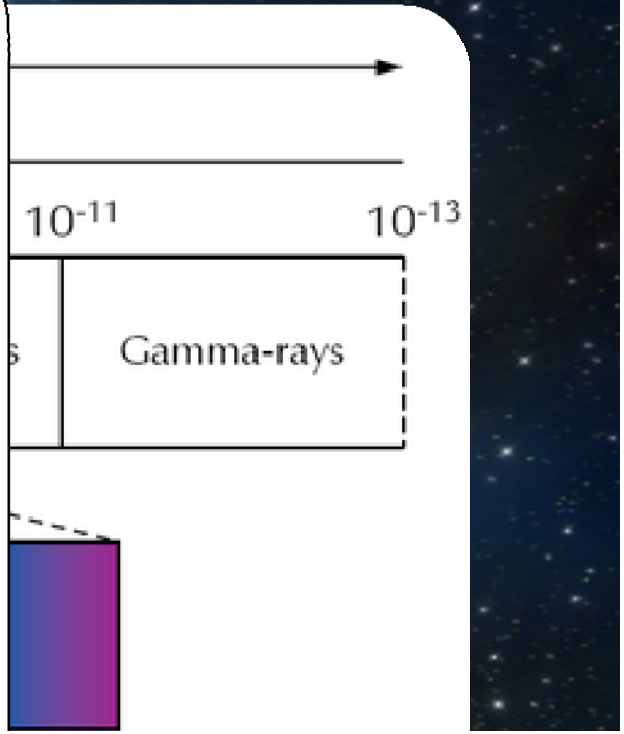




Have these weak fields (ELF) had any impact on the evolution of living organisms on Earth?

Why do all animals see in the VISIBLE part of the EM spectrum?

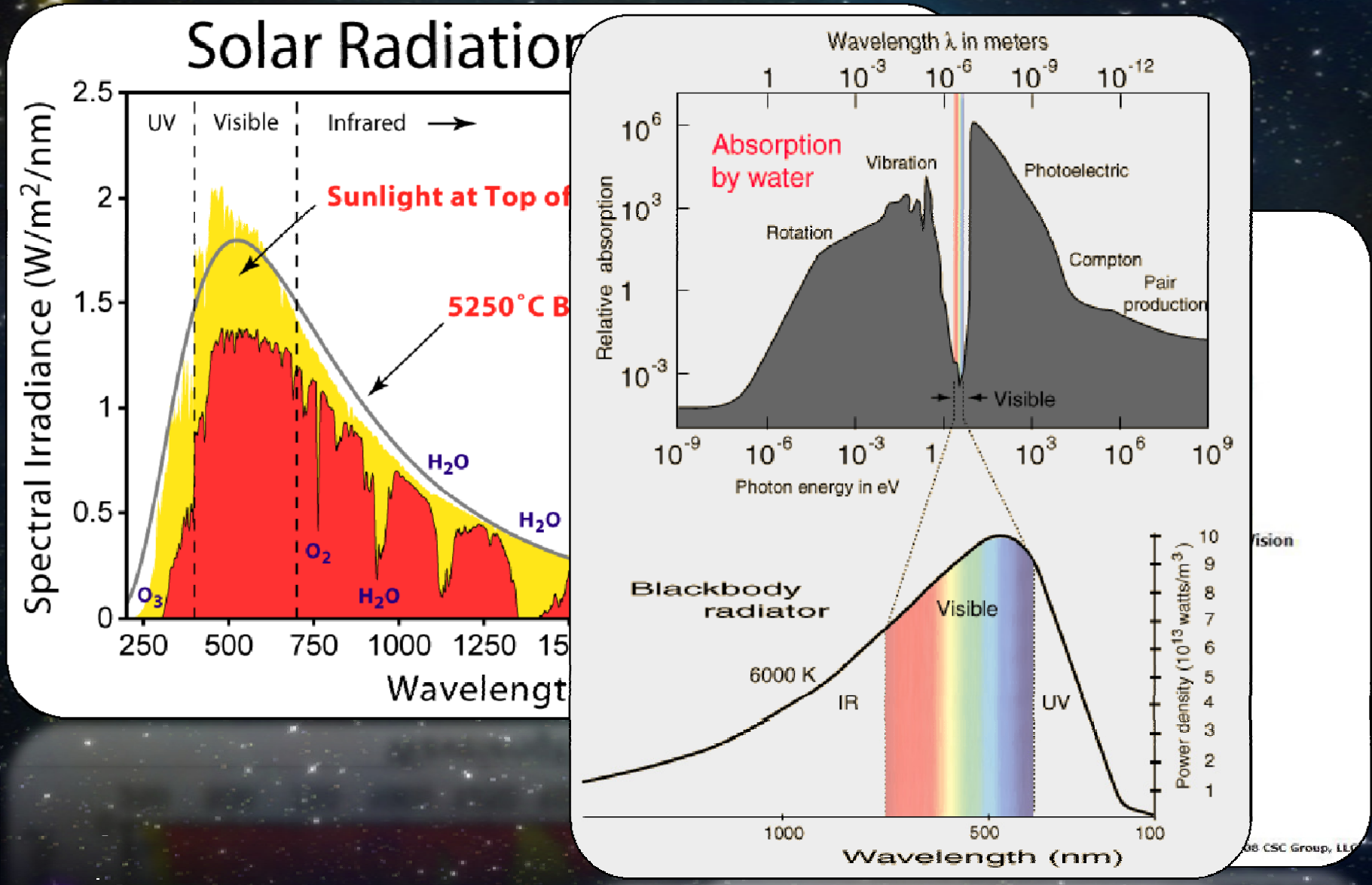


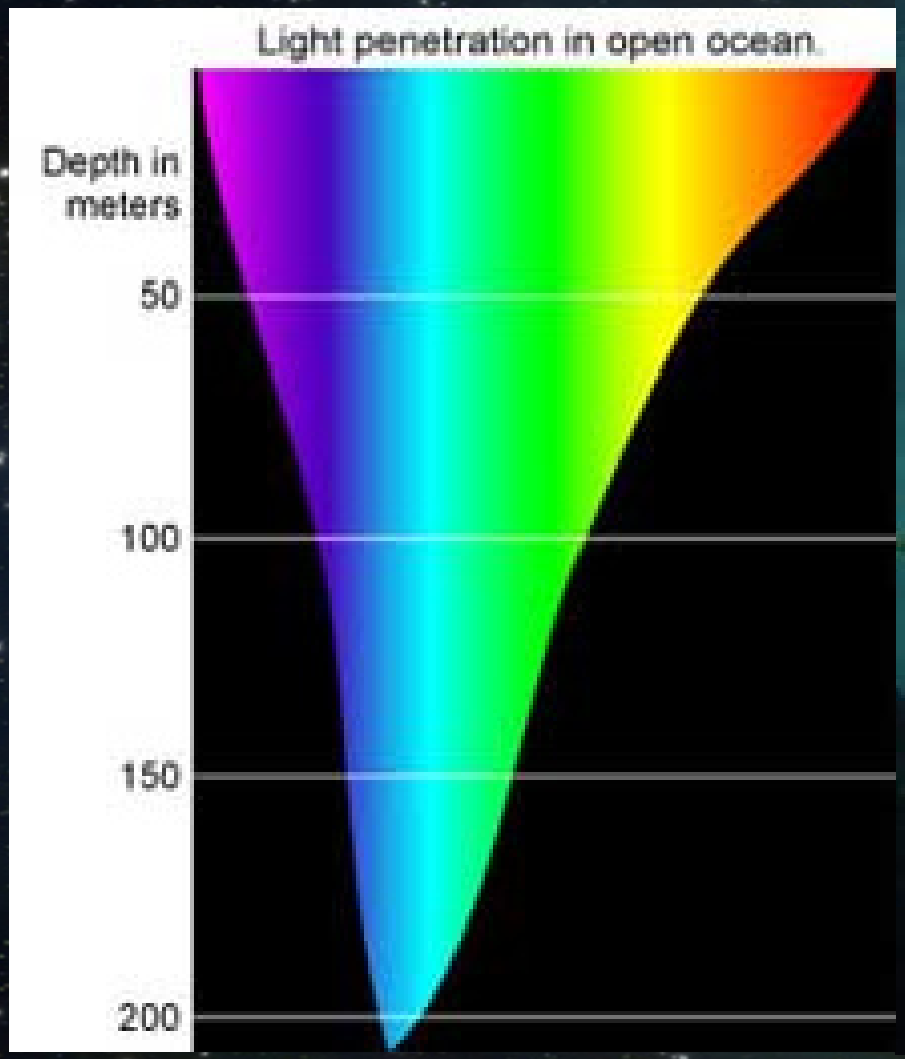


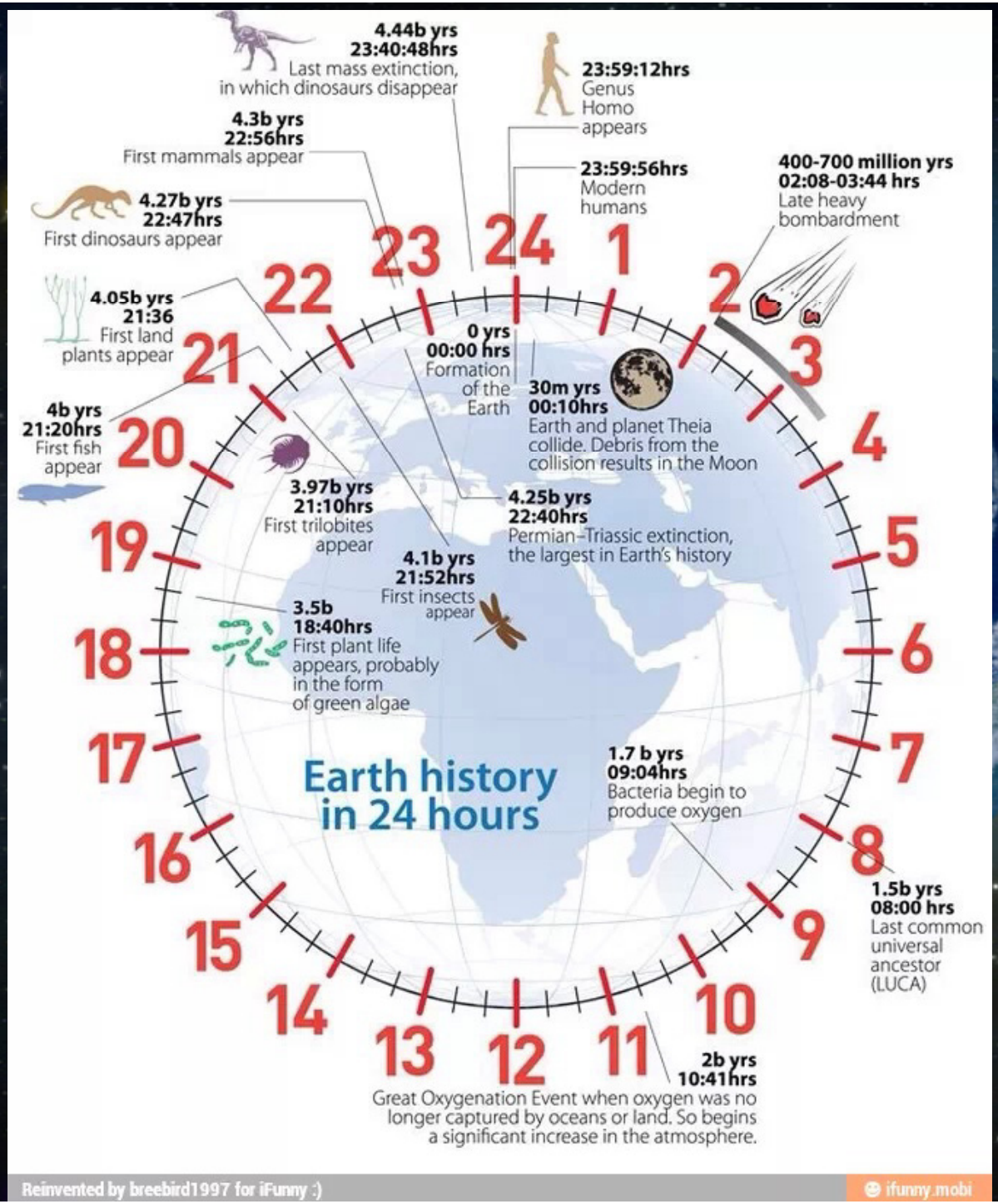
Planck's Function

$$B_\lambda(T) = \frac{2hc^2}{\lambda^5 (e^{hc/k_B \lambda T} - 1)}$$

Why do all animals see in the VISIBLE part of the EM spectrum?

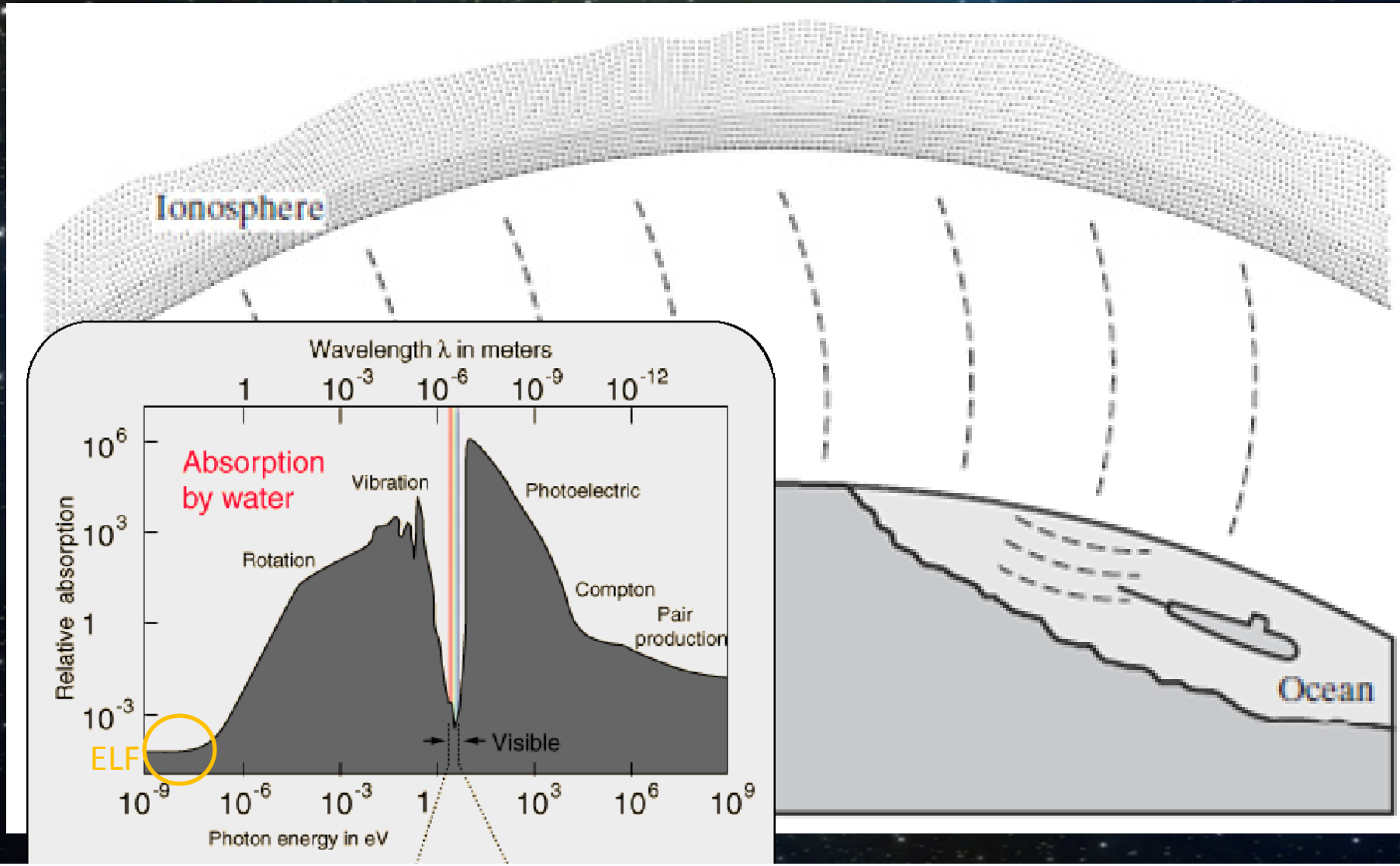



Light penetration in open ocean
Depth in meters
50
100
150
200



- ✓ Since the Earth has had an atmosphere, it has had an ionosphere, and hence an Earth-ionosphere waveguide.
- ✓ Since the Earth has had an atmosphere there has been lightning (volcanoes, thunderstorms, dust storms).
- ✓ Hence, for billions of years the Earth has been bathed in the ELF SR fields, and evolution of living beings has occurred in these fields.

ELF waves penetrate into oceans



ELF Links to Biology?

Circadian Rhythms (Wever 1967, 1973)

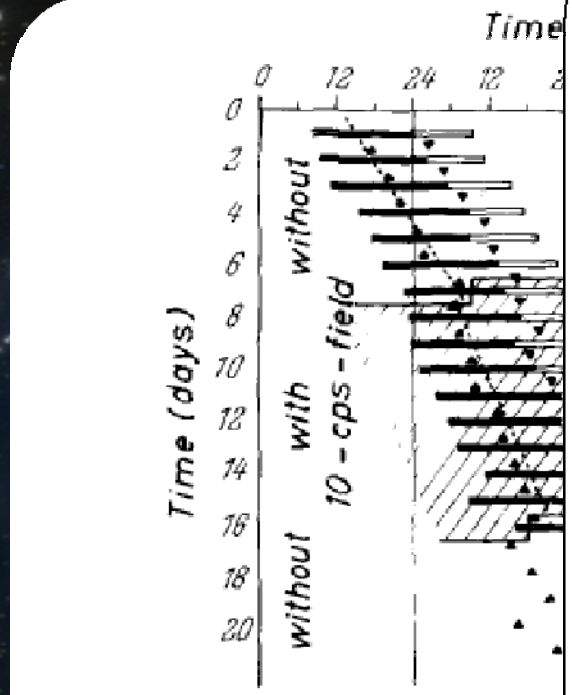


Fig. 3. Free-running circadian r
under constant conditions
section, and under the in
field during the second se
Internal desynchronizatio
(1968).

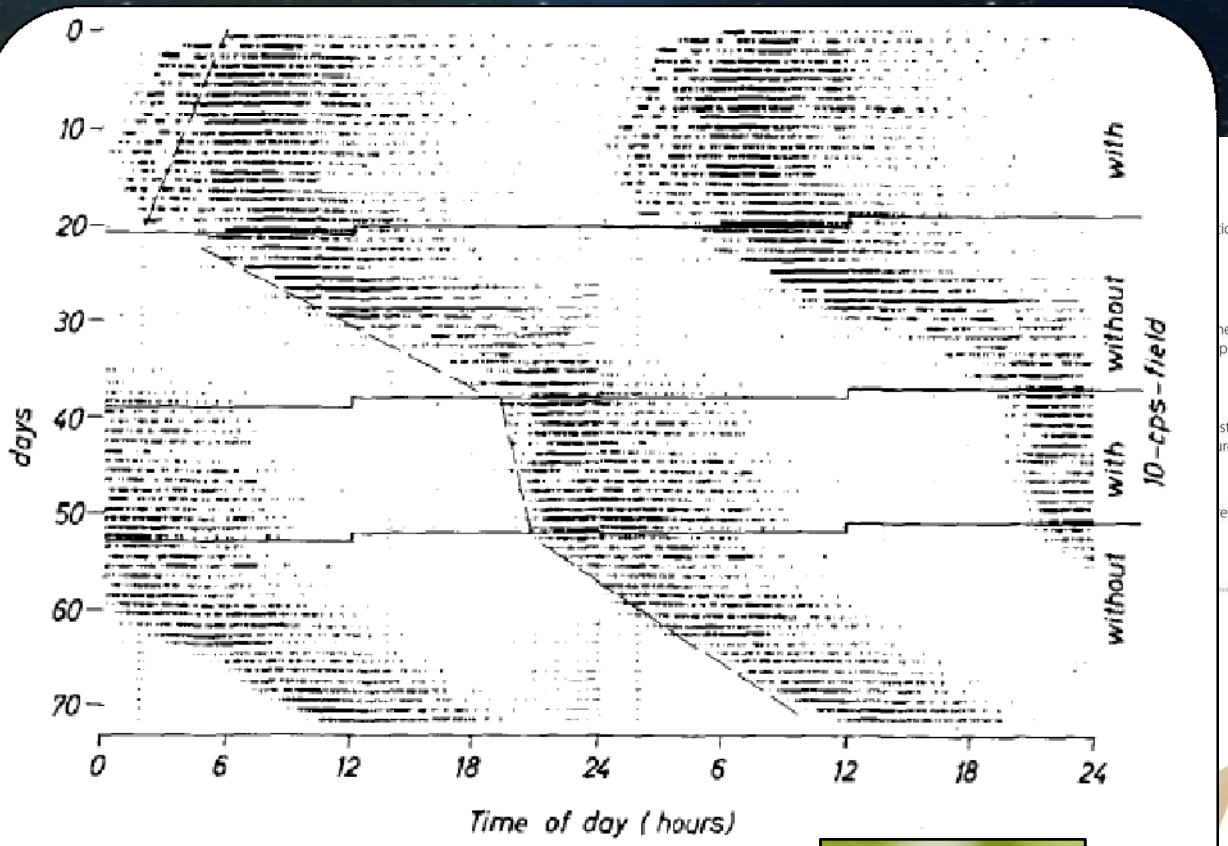


Fig. 4. Actogram of a green finch, showing a free-r rhythm measured under constant conditions; under t artificial electric 10-cps-field during the first an nd without field during the second and fourth se local time; ordinate: time of the experiment. For vity records have been duplicated.

ELF Magnetic Fields Improve Spinal Cord Injury

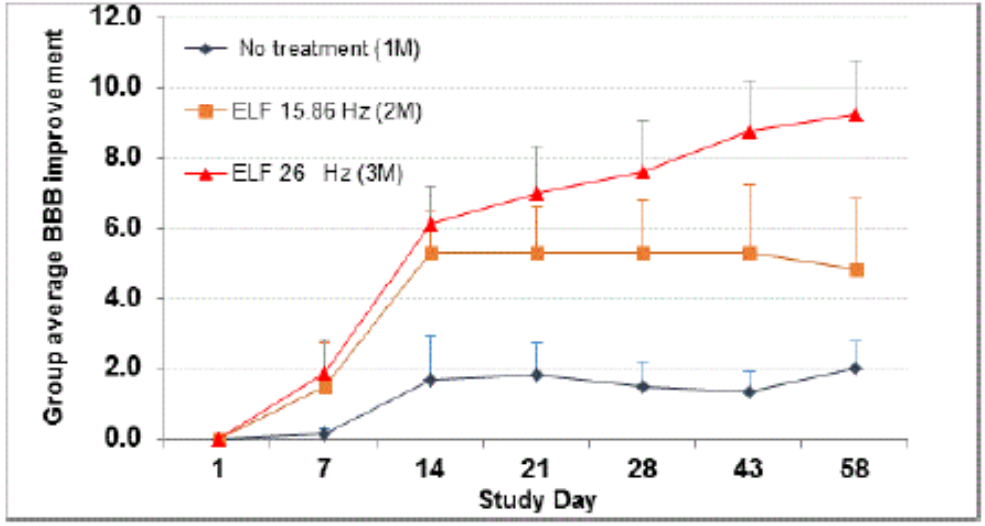


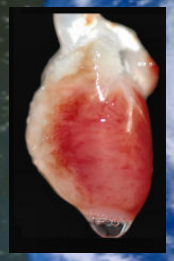
Figure 2: BBB shows clinical result of recovery from lower spinal cord injury. Both VLIFE treatment frequencies show significant recovery (results are mean±SE, difference from baseline, P for M2 and M3 <0.005).

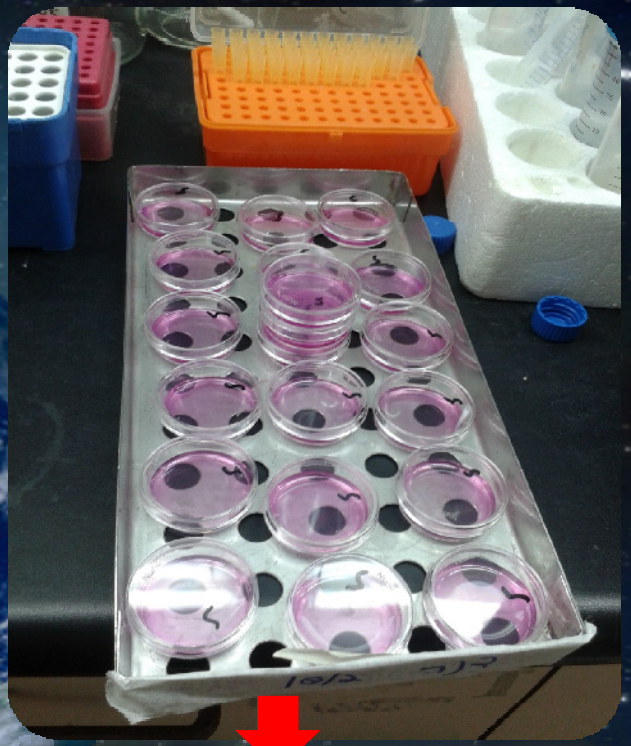
Segal et al. (2016)
BrainQ

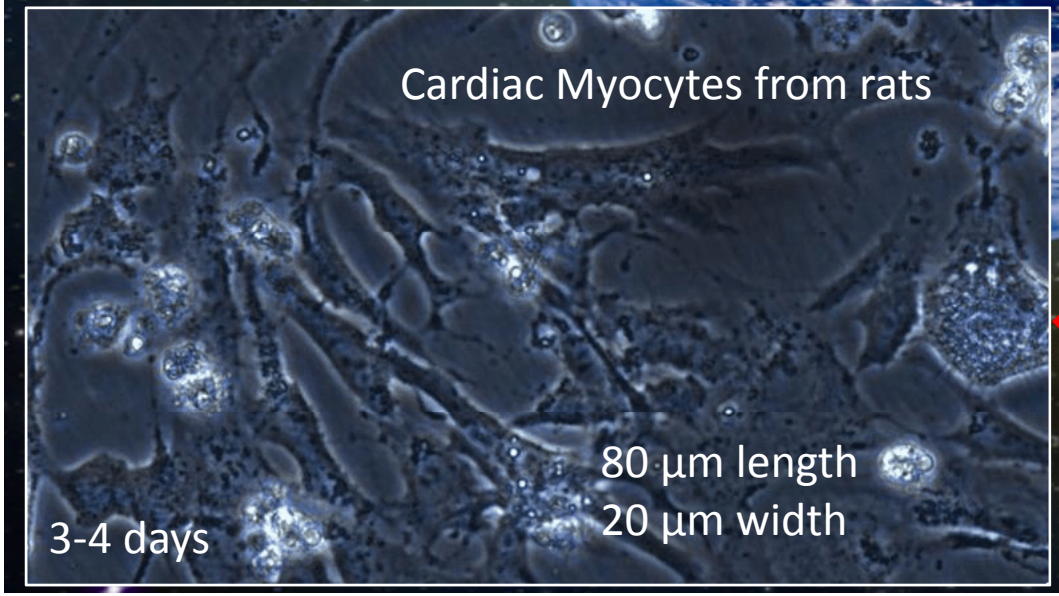
Our Experiment!!

Effect of SR on rat heart cells

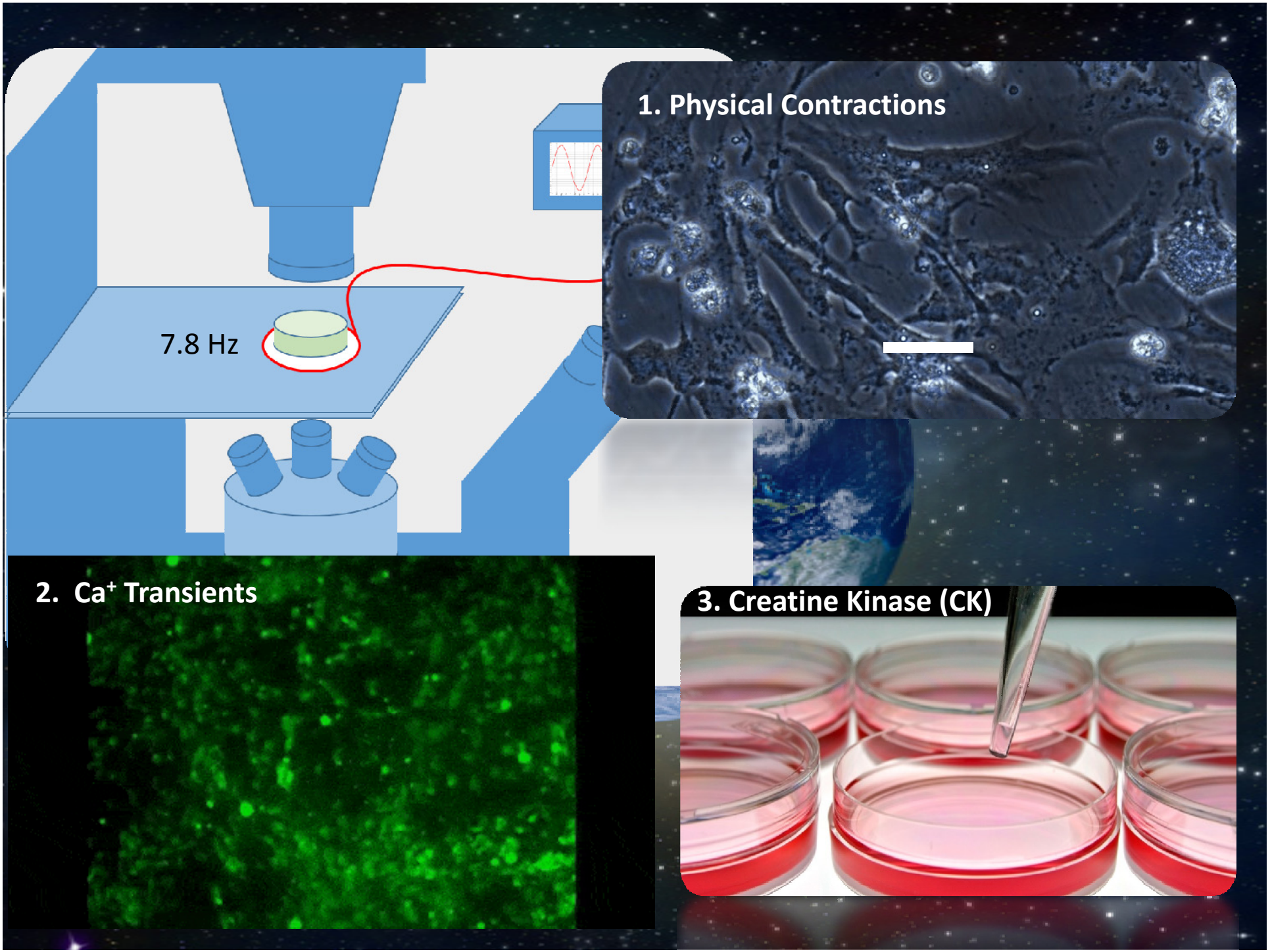
Elhalel et al. (2019)



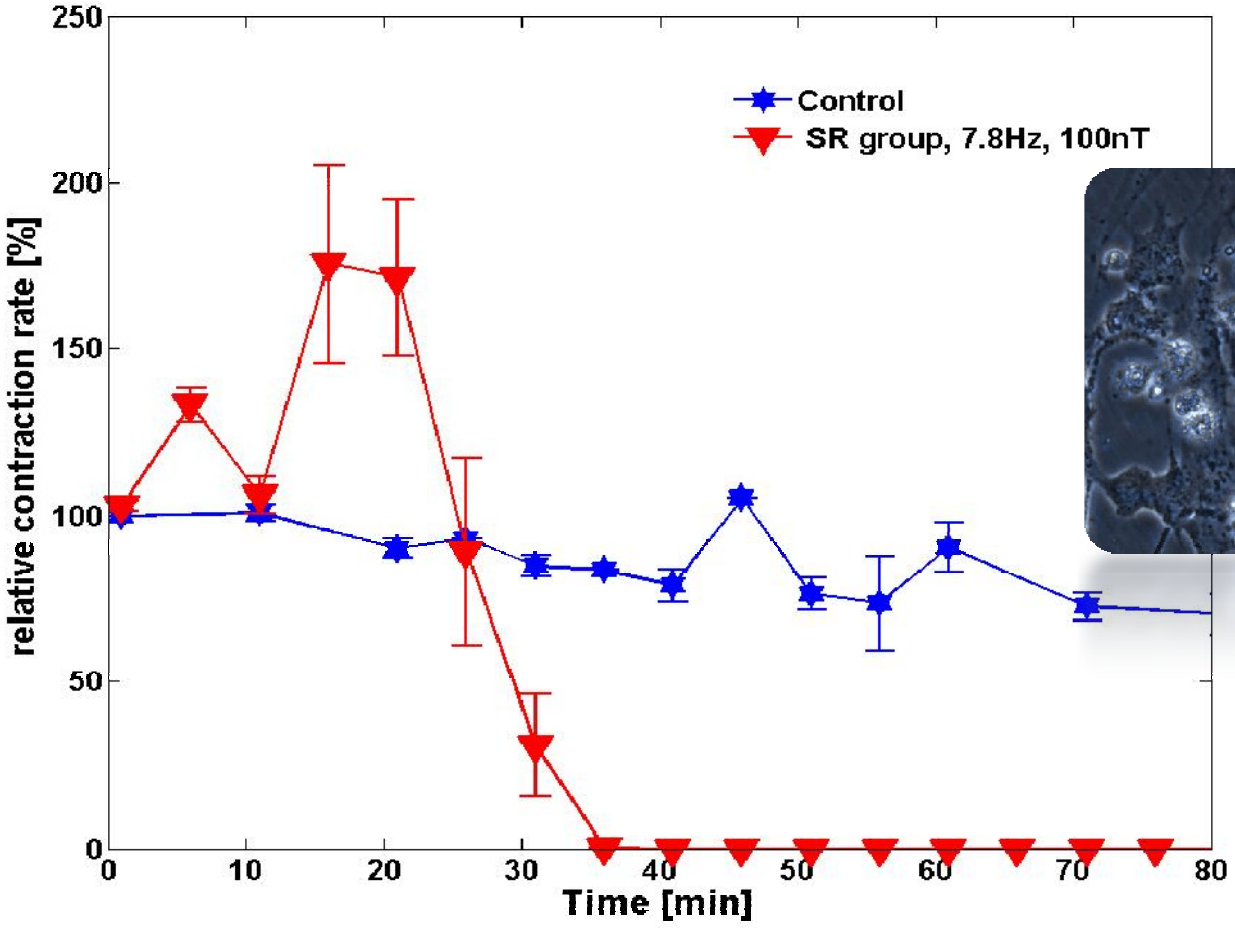


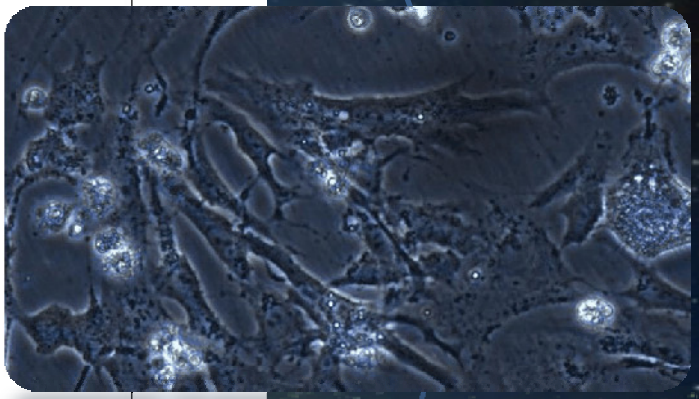


37 C, CO_2

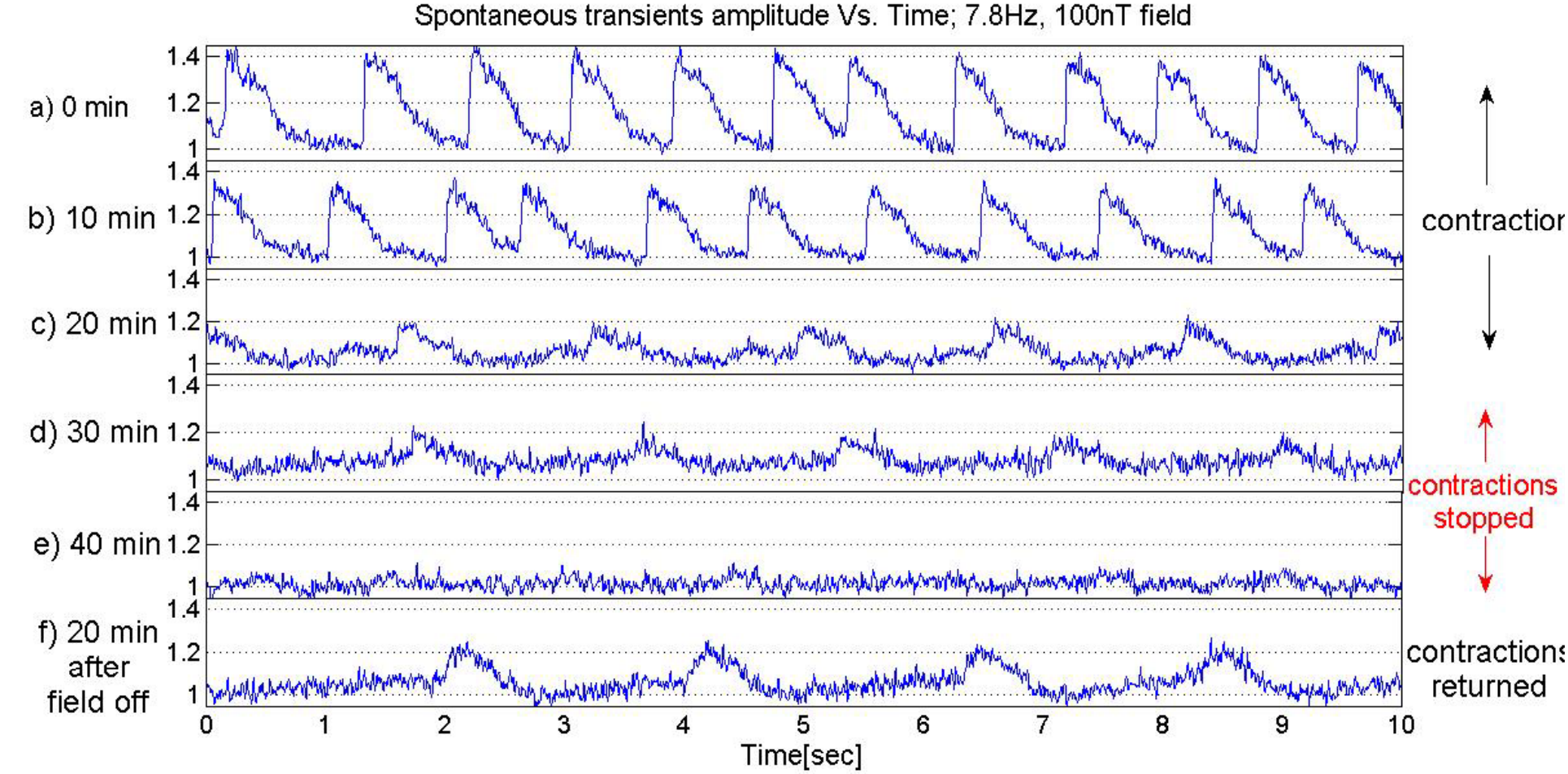

7.8 Hz
1. Physical Contractions
2. Ca+ Transients
3. Creatine Kinase (CK)

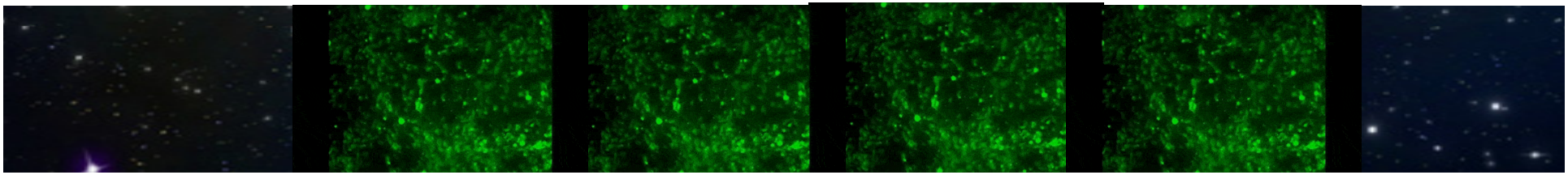
Spontaneous contraction rate



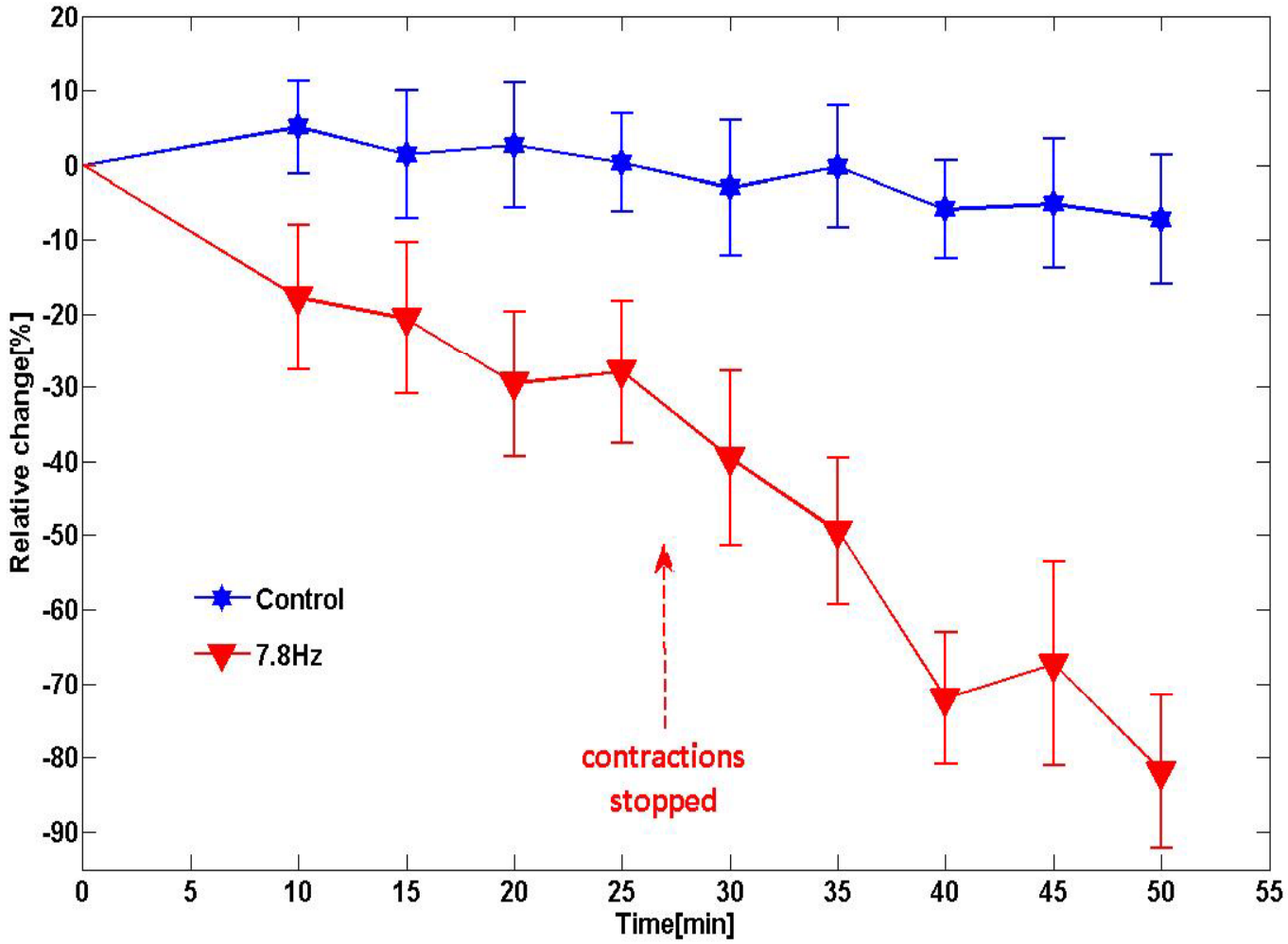


Spontaneous calcium transients

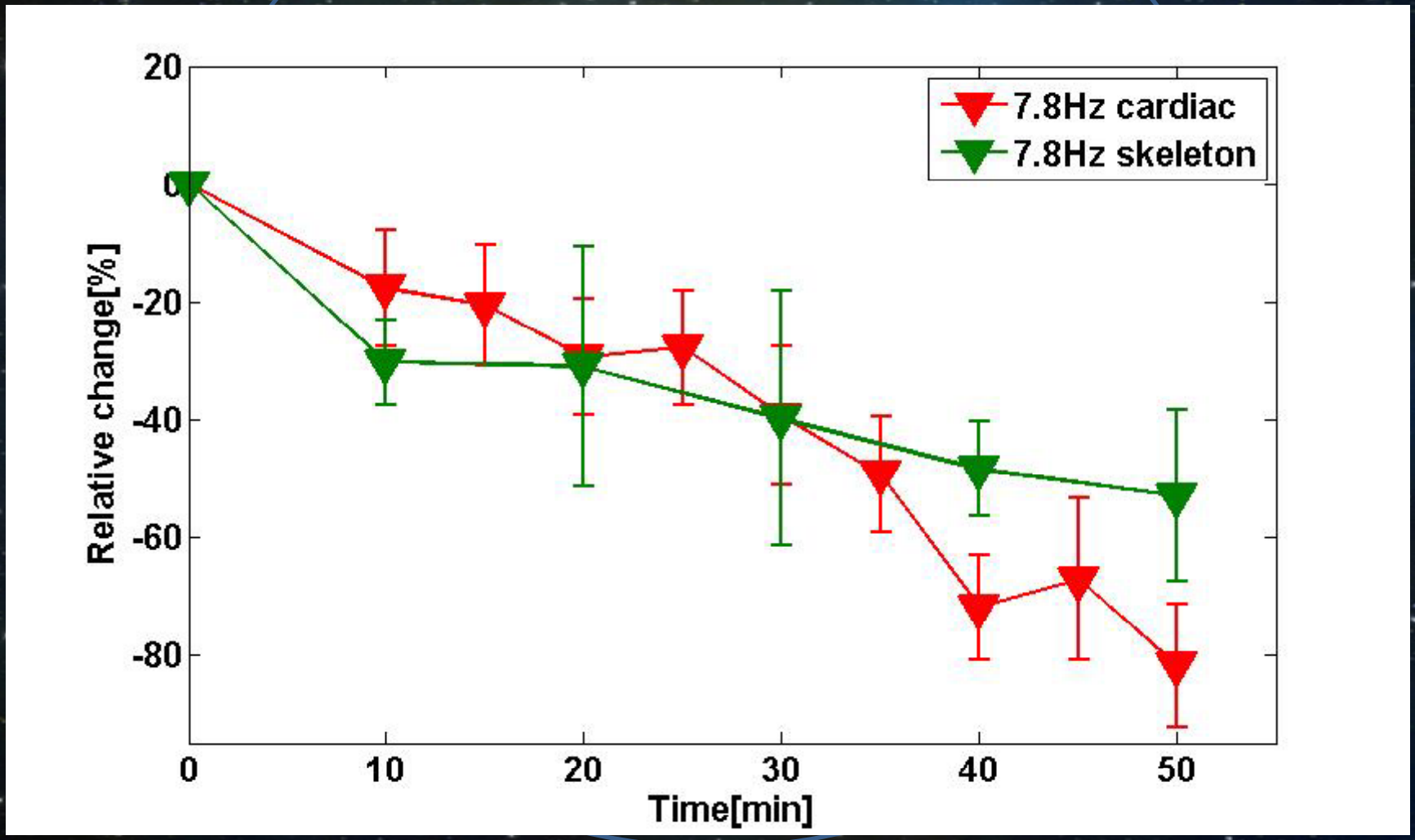




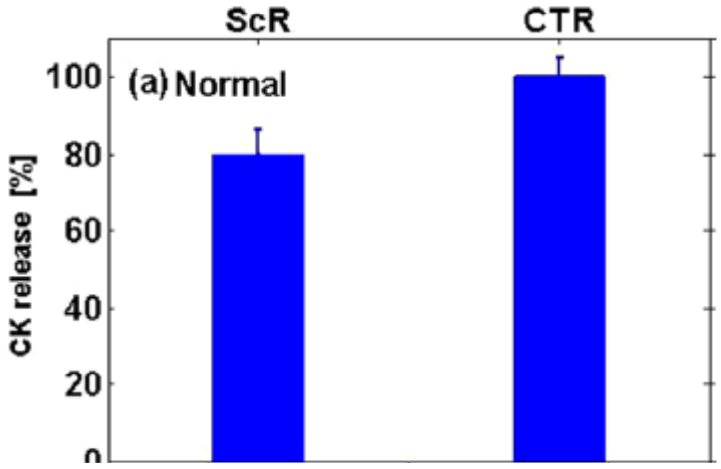
Spontaneous calcium transients



Spontaneous calcium transients

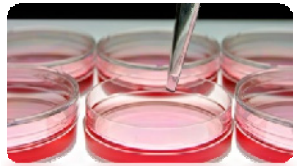


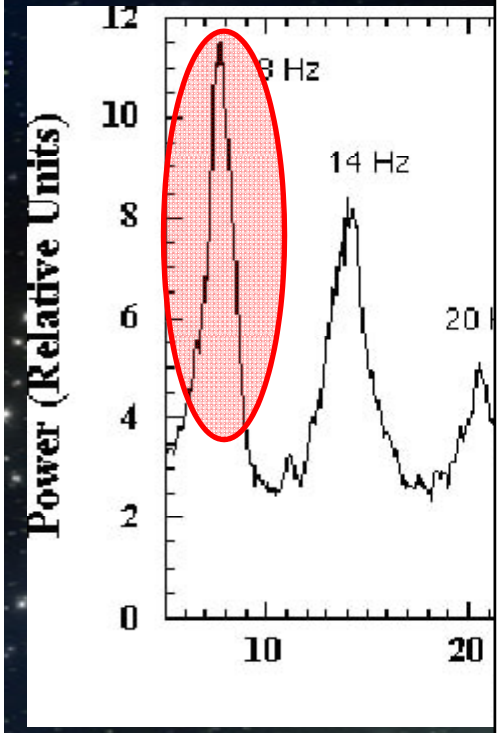
Cell Protection from Stress



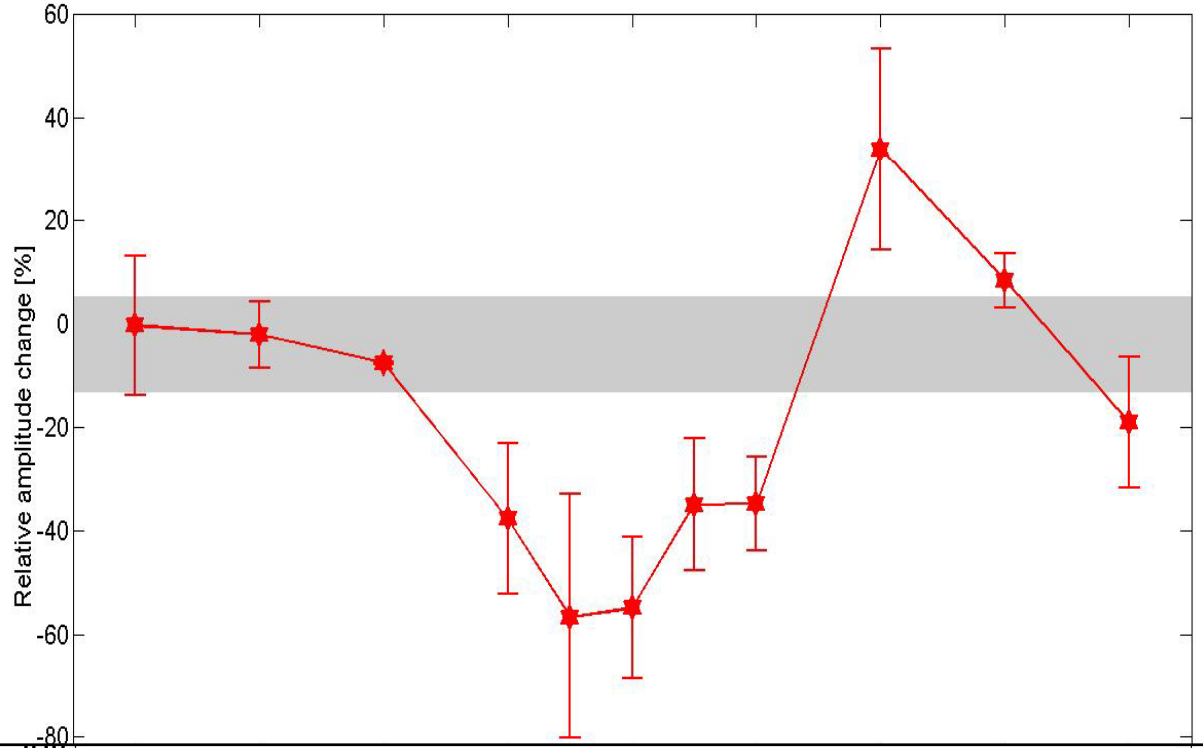
Hypoxia= too little O_2

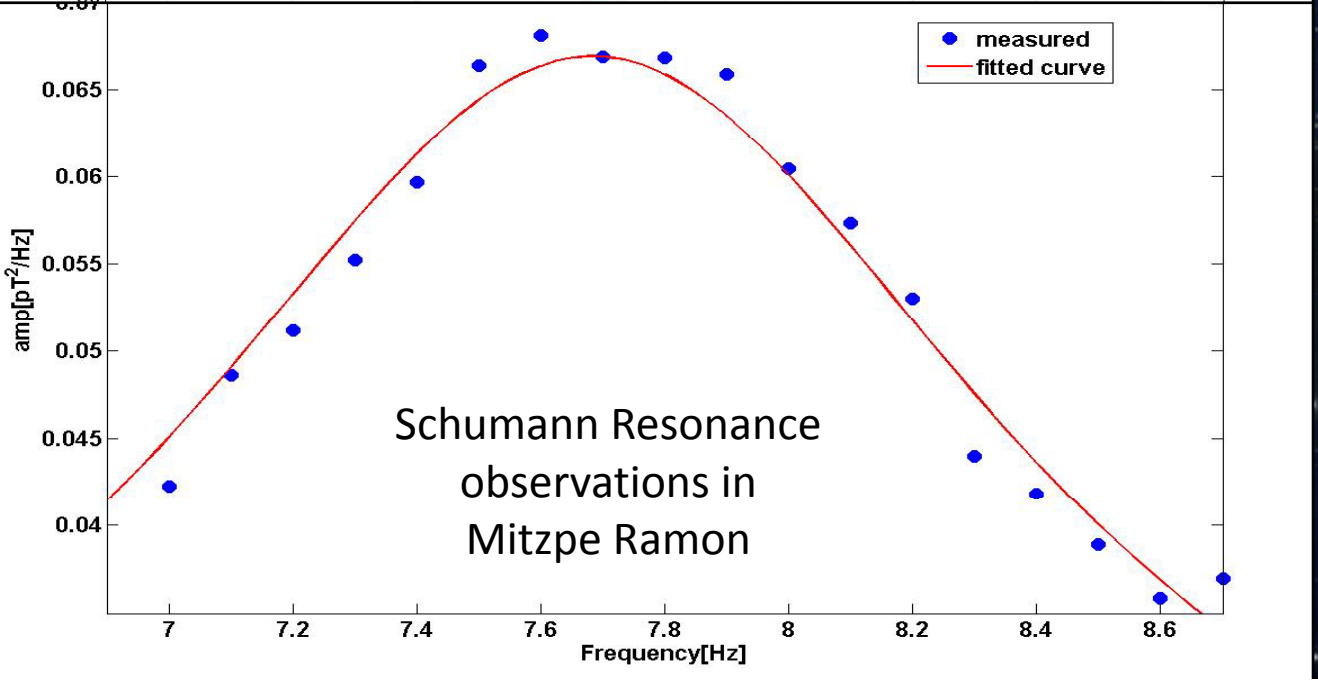
H_2O_2 = too much O_2





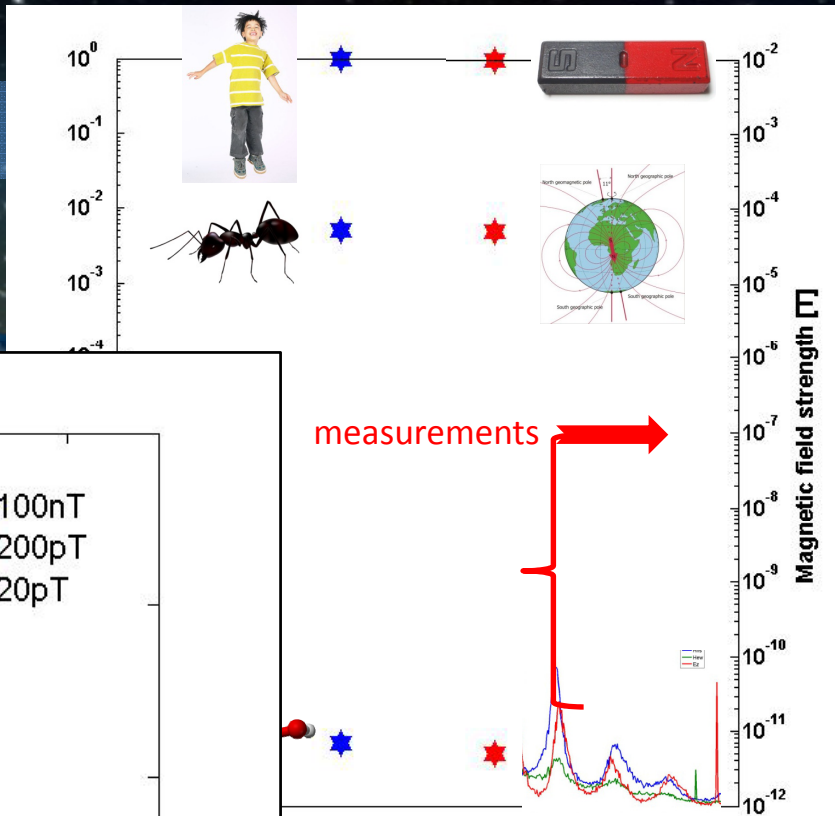
• What about oth

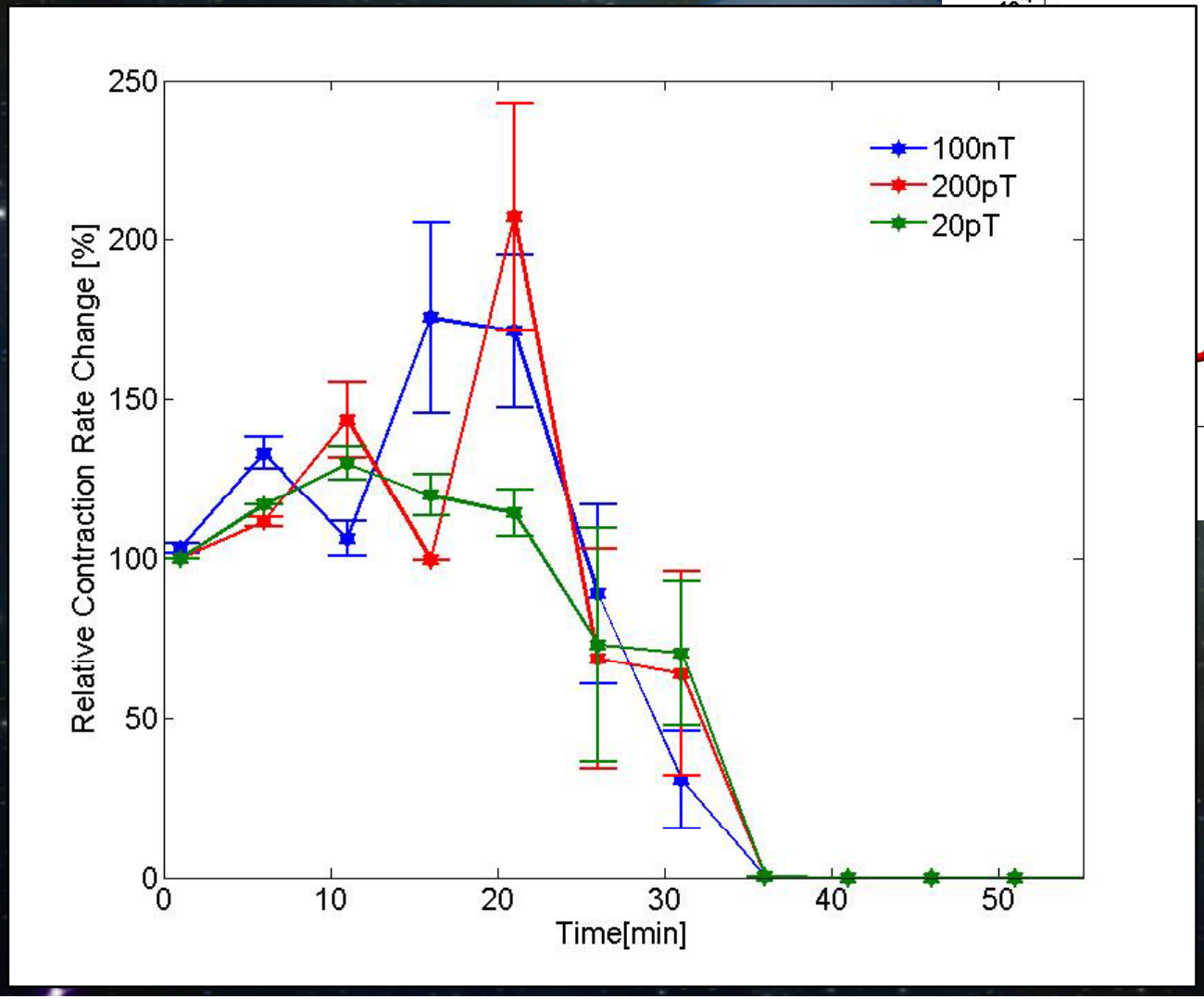




Schumann Resonance observations in Mitzpe Ramon

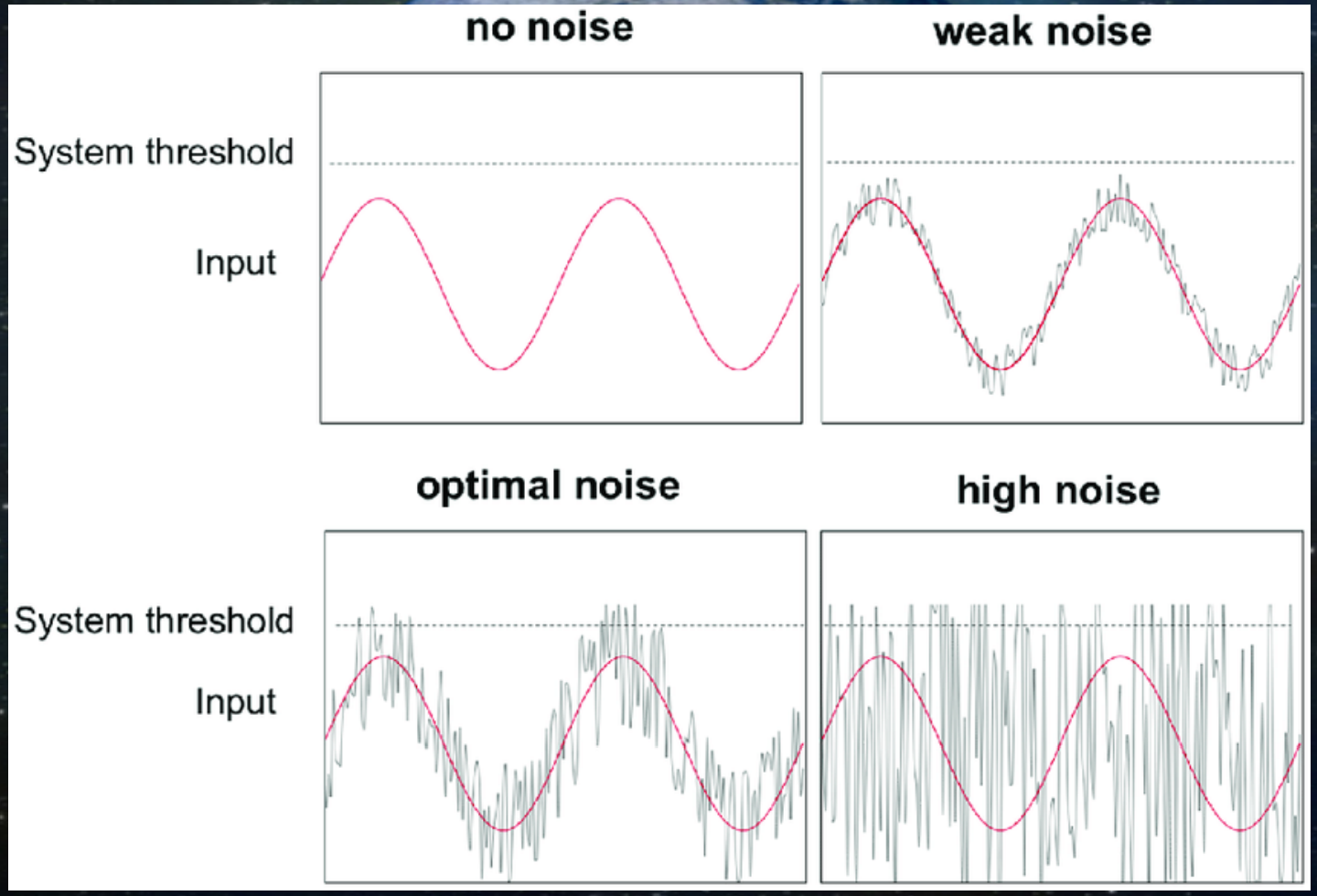
•What about magnetic field amplitude?

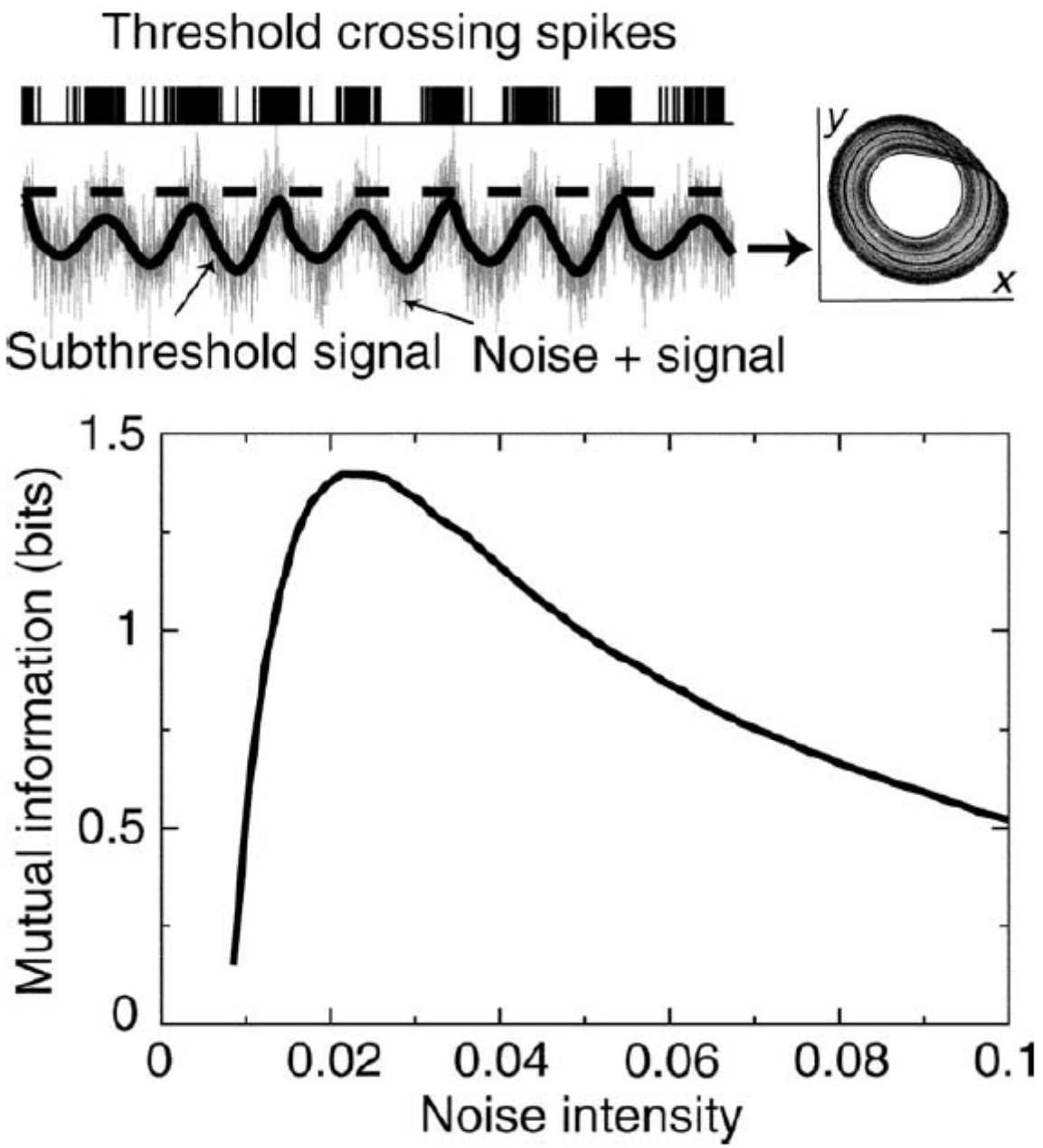




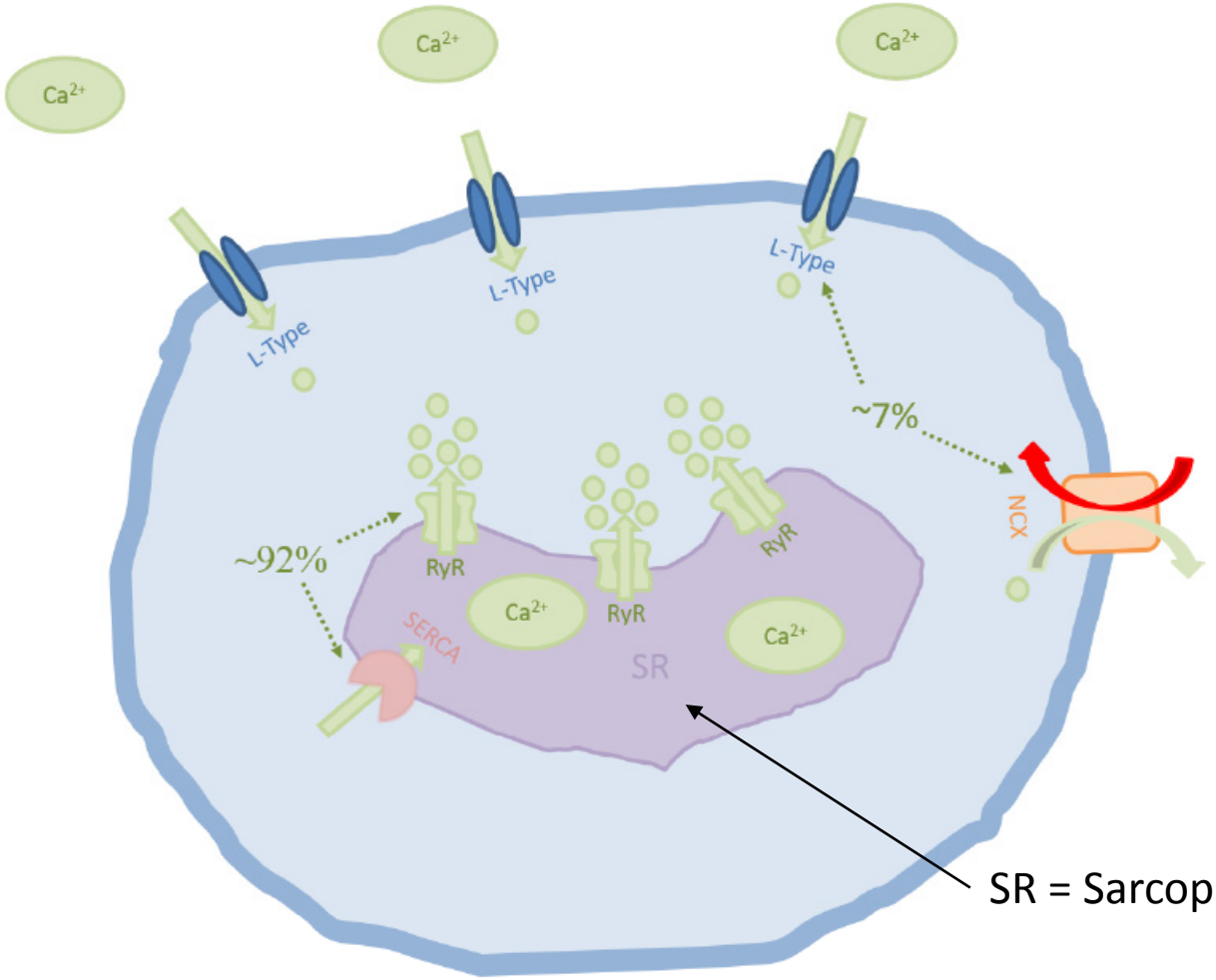
How can such weak fields impact biological systems?

Stochastic Resonance

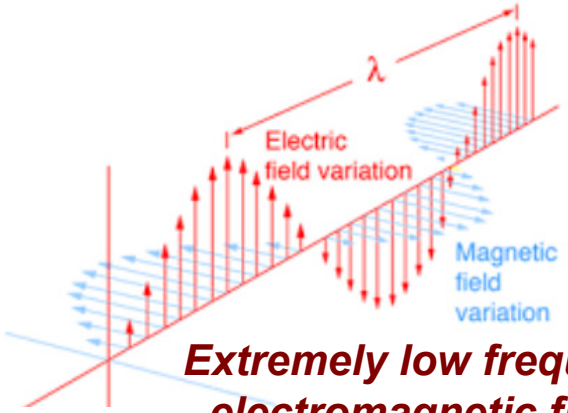



Threshold crossing spikes
y
x
Subthreshold signal
Noise + signal
Mutual information (bits)
1.5
1
0.5
0
0
0.02
0.04
0.06
0.08
0.1
Noise intensity

Four Main mechanisms of Ca+



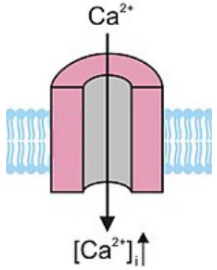
1. L-type Voltage Dependent Calcium Channels (L-VDCC) at cell membrane
2. RyR – Ryanodine receptors release of intracellular Calcium
3. NCX – Na+/Ca2+ exchanger transfers Na and Ca at cell membrane
4. SERCA – Replacement of Ca2+ ions to SR reservoir.



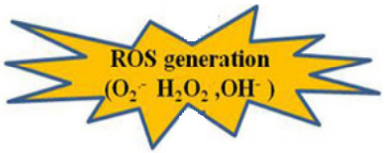
Extremely low frequency electromagnetic fields

Potential primary targets of EMFs in plants

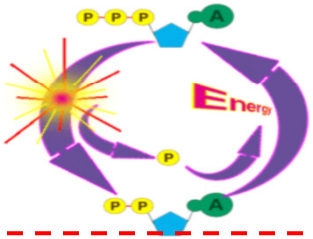
Changes in Ca^{2+} transport



Changes in ROS production



Changes in activity of electron transport chains



Reactive oxygen species (**ROS**): H_2O_2, $\cdot O_2^-$, $^1O_2$, $\cdot OH$

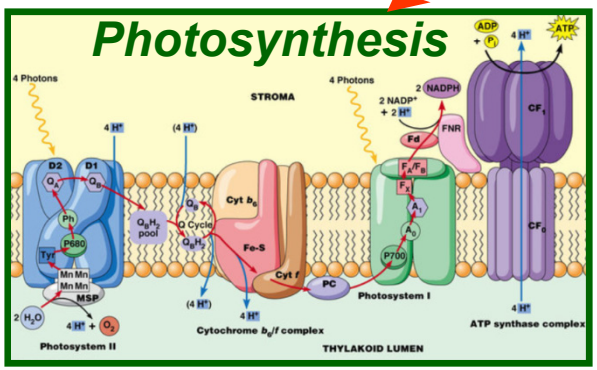
Ca^{2+} signaling
ROS signaling

Electrical signaling
Phytohormones

Changes in productivity

?

Photosynthesis

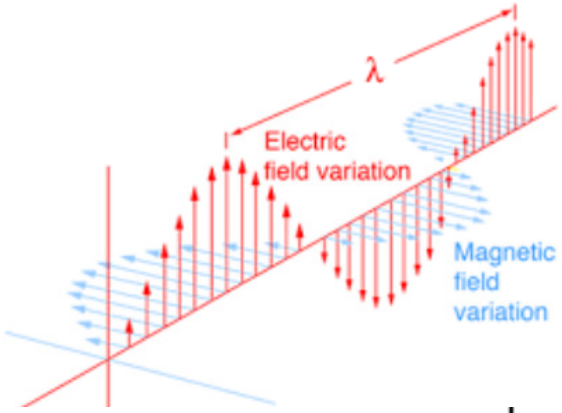


?

Changes in stress tolerance

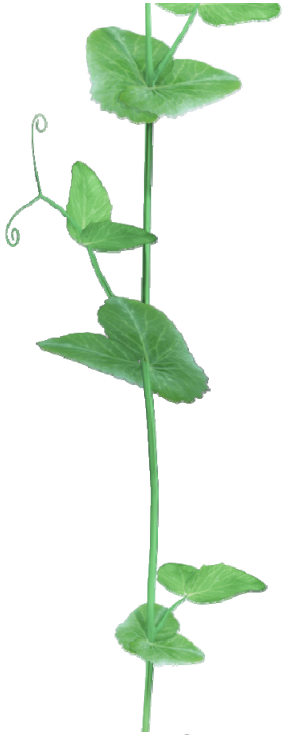
Hypothetical ways of influence of extremely low frequency EMFs on productivity and stress tolerance of plants.

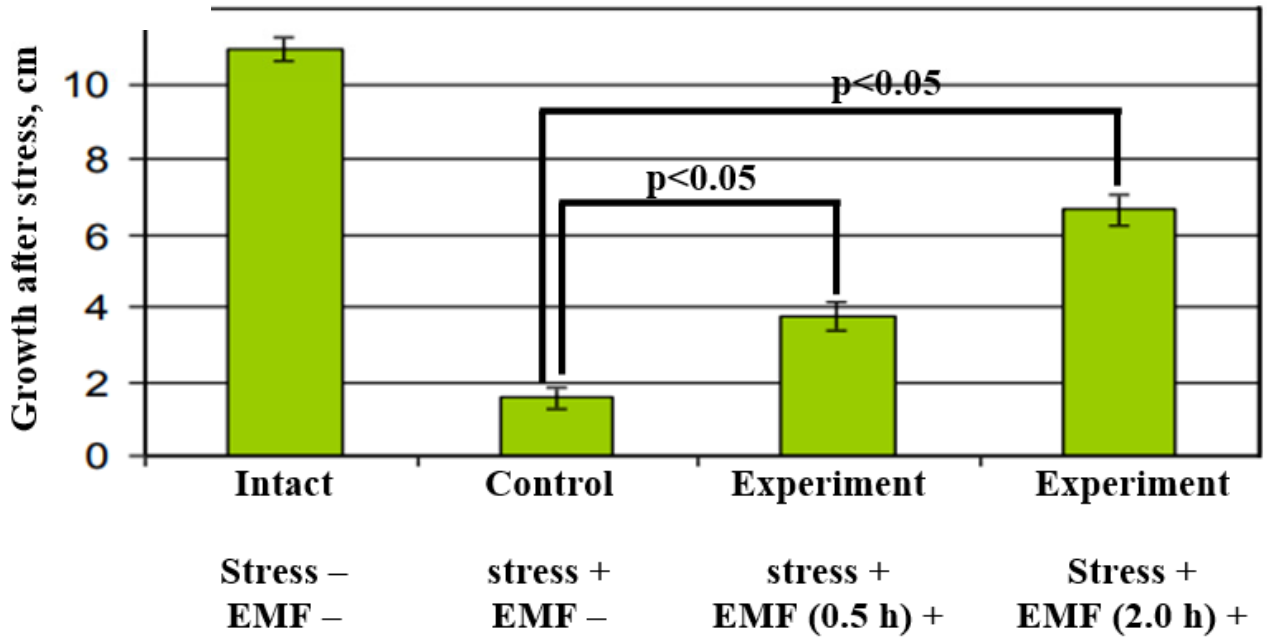
Sukhov V, Sukhova E, Vodeneev V Progress in Biophysics and Molecular Biology, 2019



High intensity
electromagnetic field:

15 Hz
1,5 Tl
0.5 hours





Preliminary results, supporting a positive influence
of low frequency electromagnetic fields (EMF) on the stress tolerance of plants

Sukhova et al., 2017

Summary and Conclusions

International Journal of Biometeorology
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SPECIAL ISSUE: ATMOSPHERIC ELECTRICITY AND BIOMETEOROLOGY

Check for updates

Natural ELF fields in the atmosphere and in living organisms

Colin Price[1] · Earle Williams[2] · Gal Elhalel[1] · Dave Sentman[3]

Received: 13 October 2019 / Revised: 9 January 2020 / Accepted: 13 January 2020

Abstract
Most electrical activity in vertebrates and invertebrates occurs at extremely low frequencies (ELF), with characteristic maxima below 50 Hz. The origin of these frequency maxima is unknown and remains a mystery. We propose that over billions of years during the evolutionary history of living organisms on Earth, the natural electromagnetic resonant frequencies in the atmosphere, continuously generated by global lightning activity, provided the background electric fields for the development of cellular electrical activity. In some animals, the electrical spectrum is difficult to differentiate from the natural background atmospheric electric field produced by lightning. In this paper, we present evidence for the link between the natural ELF fields and those found in many living organisms, including humans.