# Frequency-pattern data analysis to estimate the functional structure of the human body from external magnetic fields

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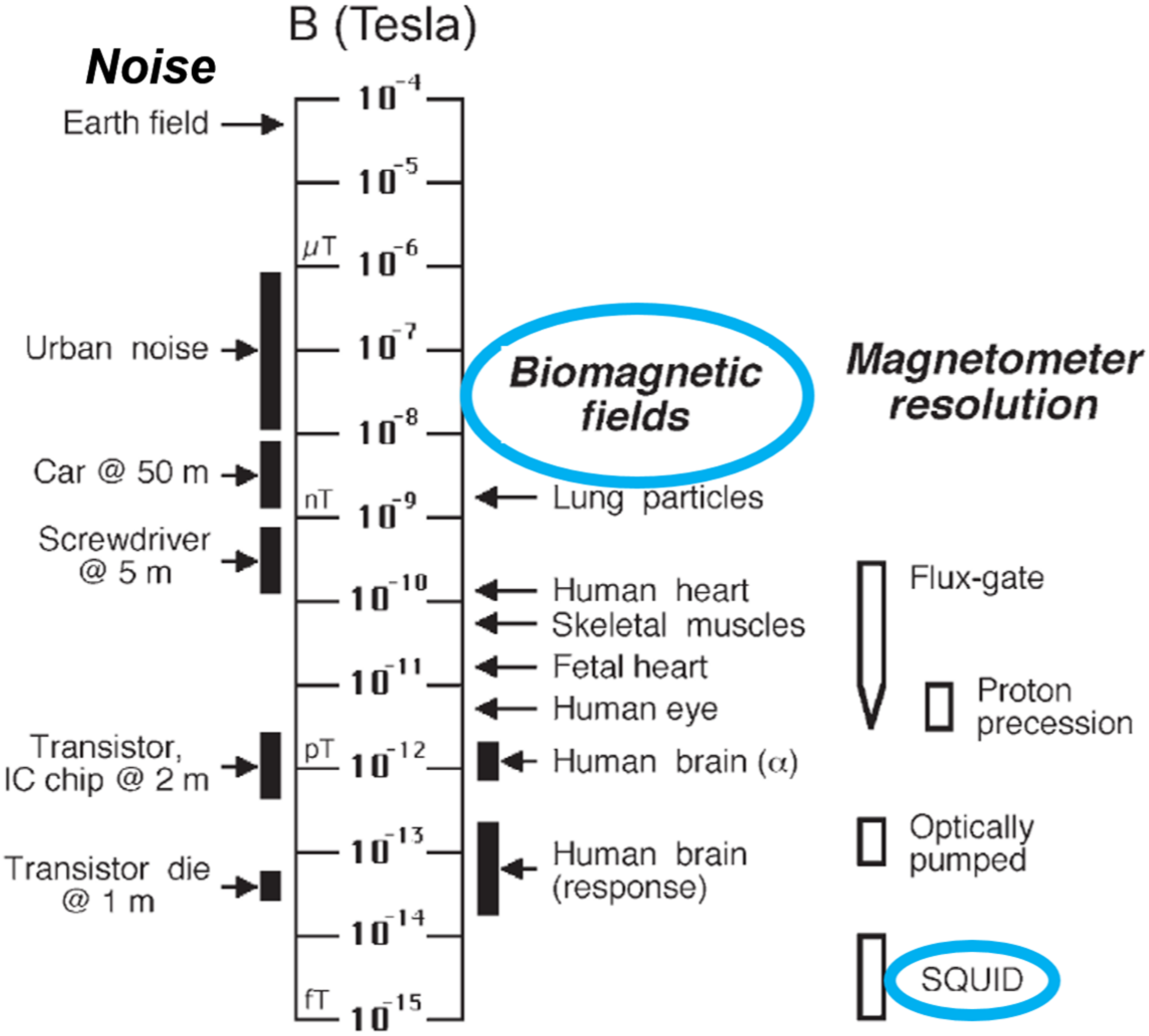
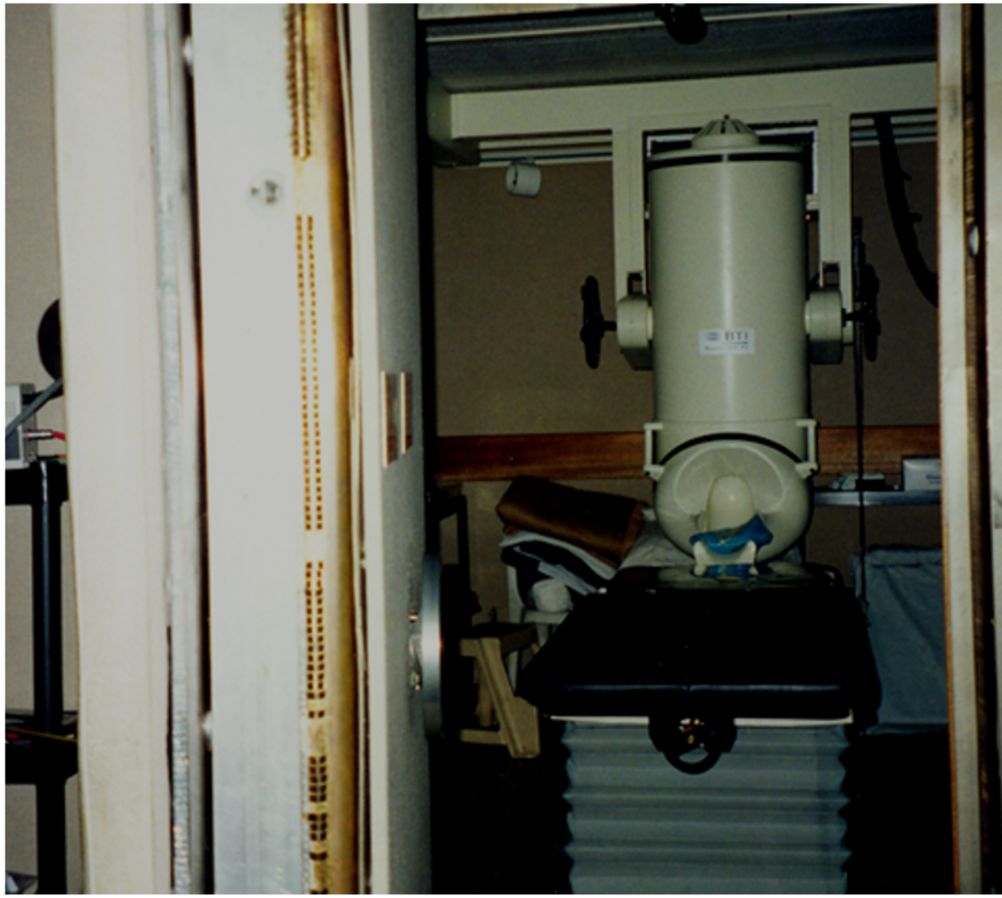



**Cryogenic sensors at liquid He temperatures**



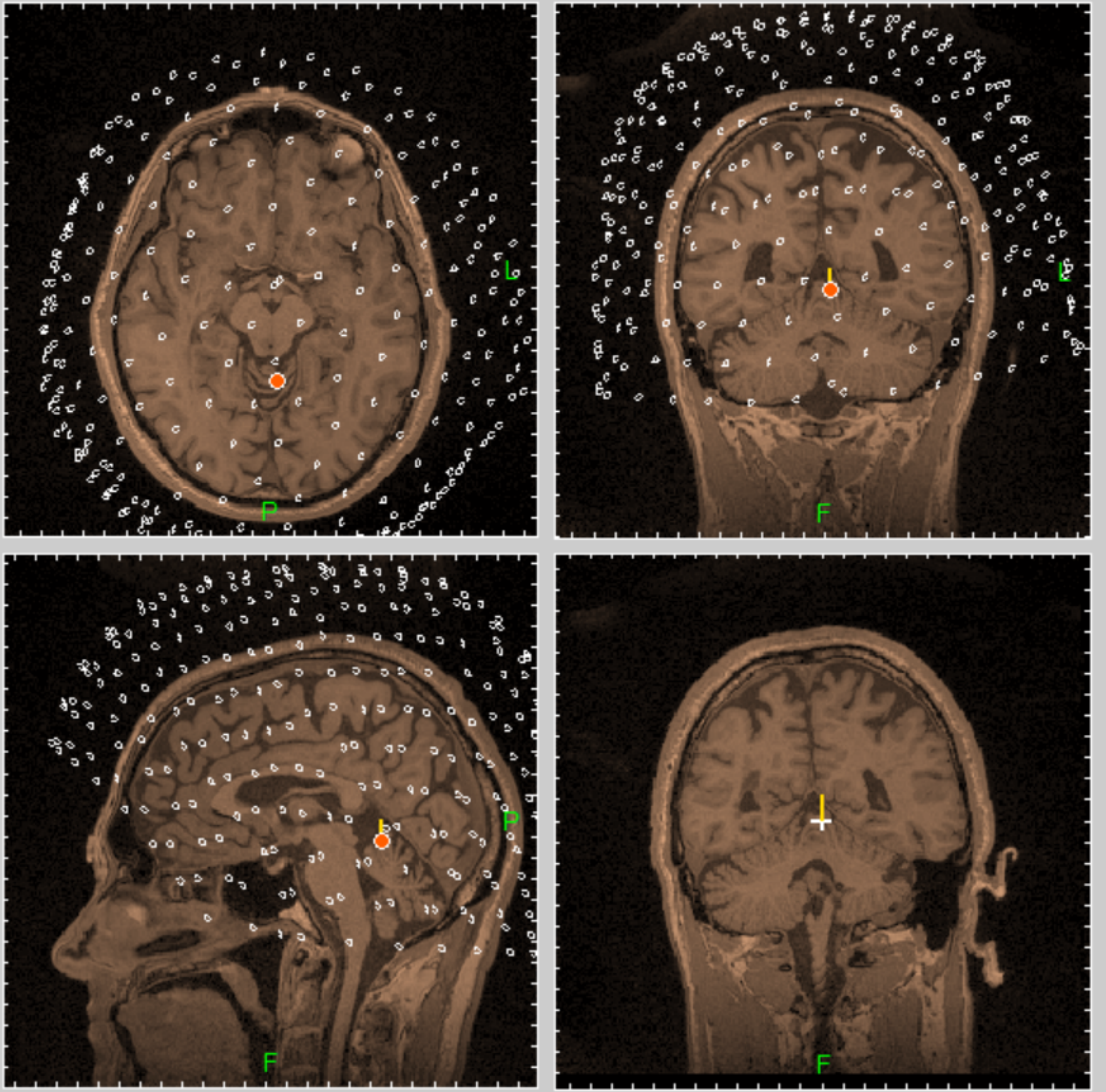
**located in magnetically shielded room**

# Instruments and Methods

The experimental data are obtained on two devices:

- Head shaped gradiometer of the first order, 275 channels, VSM Medtech, installed in the New York University Center for Biomagnetism, New York, USA
- Planar gradiometer of the second order, 7 channels, Cryoton Co. LTD, installed in the National Research Center “Kurchatov Institute”, Moscow, Russia

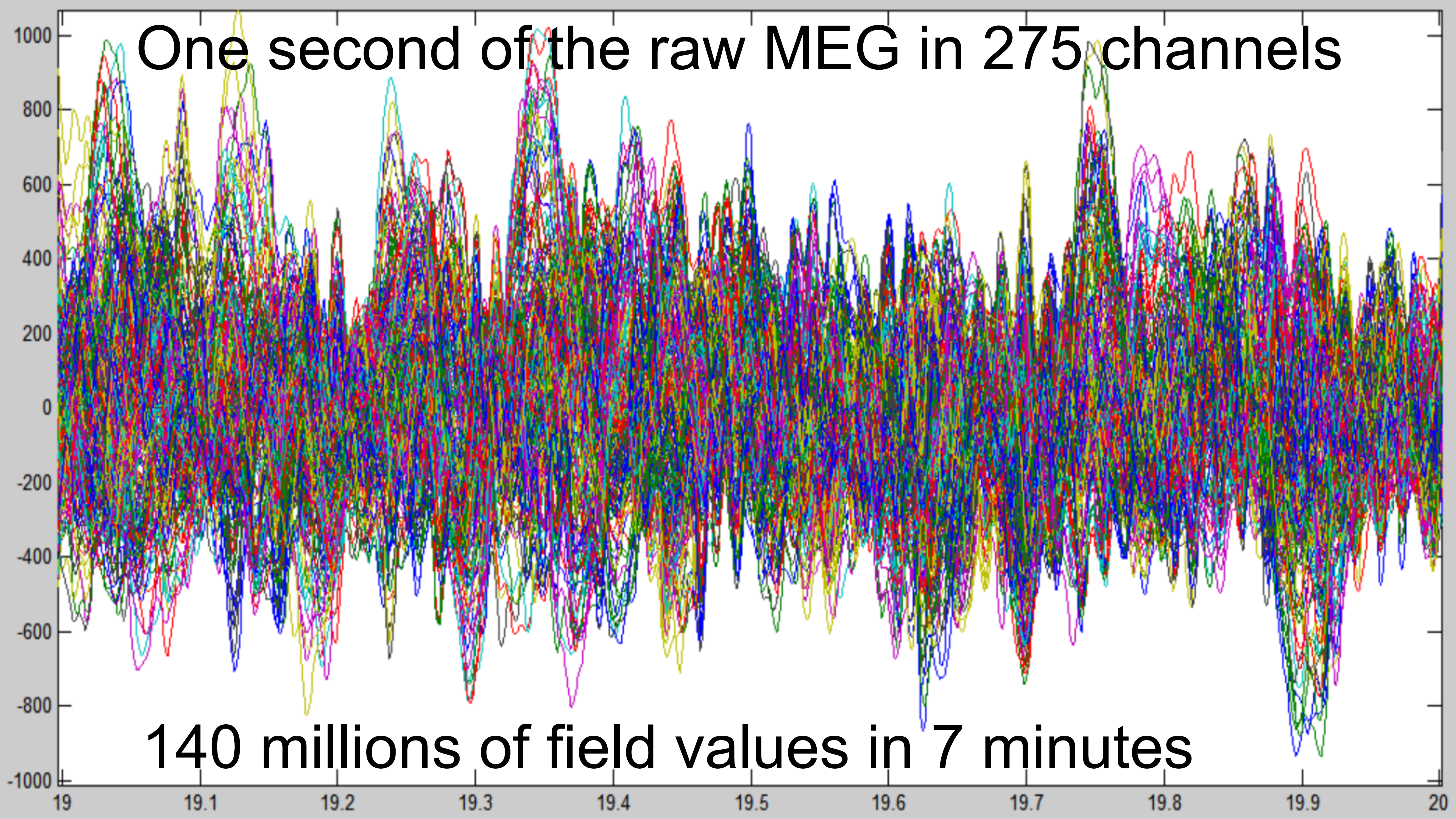
- Methods of data analysis are developed in the Institute of Mathematical Problems of Biology RAS, Pushchino, Russia




# Magnetic Encephalography

*general layout of the experiment*

White circles –gradiometer sensors.


One second of the raw MEG in 275 channels
140 millions of field values in 7 minutes
1000
800
600
400
200
0
-200
-400
-600
-800
-1000
19
19.1
19.2
19.3
19.4
19.5
19.6
19.7
19.8
19.9
20

The multichannel Fourier transform calculates a set of spectra for experimentally measured $\tilde{B}_k(t)$ functions

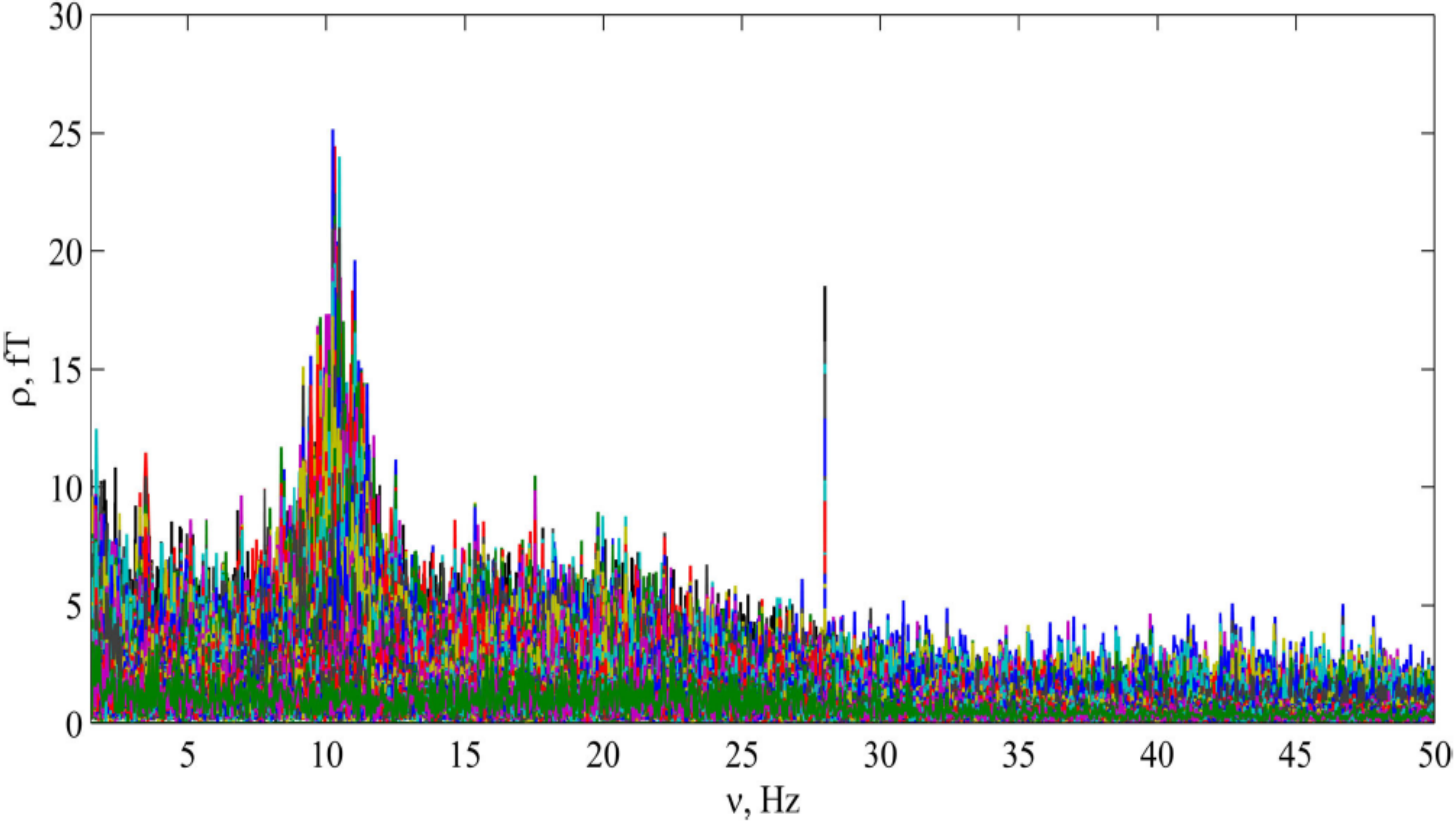
$$a_{0k} = \frac{2}{T}\int_0^T \tilde{B}_k(t)dt,\ a_{nk} = \frac{2}{T}\int_0^T \tilde{B}_k(t)\cos(2\pi\nu_n t)dt,$$

$$b_{nk} = \frac{2}{T}\int_0^T \tilde{B}_k(t)\sin(2\pi\nu_n t)dt,$$

$$B_k(t) = \frac{a_{0k}}{2} + \sum_{n=1}^{N} \rho_{nk}\sin(2\pi\nu_n t + \varphi_{nk}),\quad \nu_n = \frac{n}{T},\quad N = \nu_{\max}T,$$

$$\rho_{nk} = \sqrt{a_{nk}^2 + b_{nk}^2},\ \varphi_{nk} = \operatorname{atan2}(a_{nk}, b_{nk})$$

# MULTICHANNEL FOURIER SPECTRUM OF THE MAGNETIC ENCEPHALOGRAM



## INVERSE FOURIER TRANSFORM FOR EACH FREQUENCY

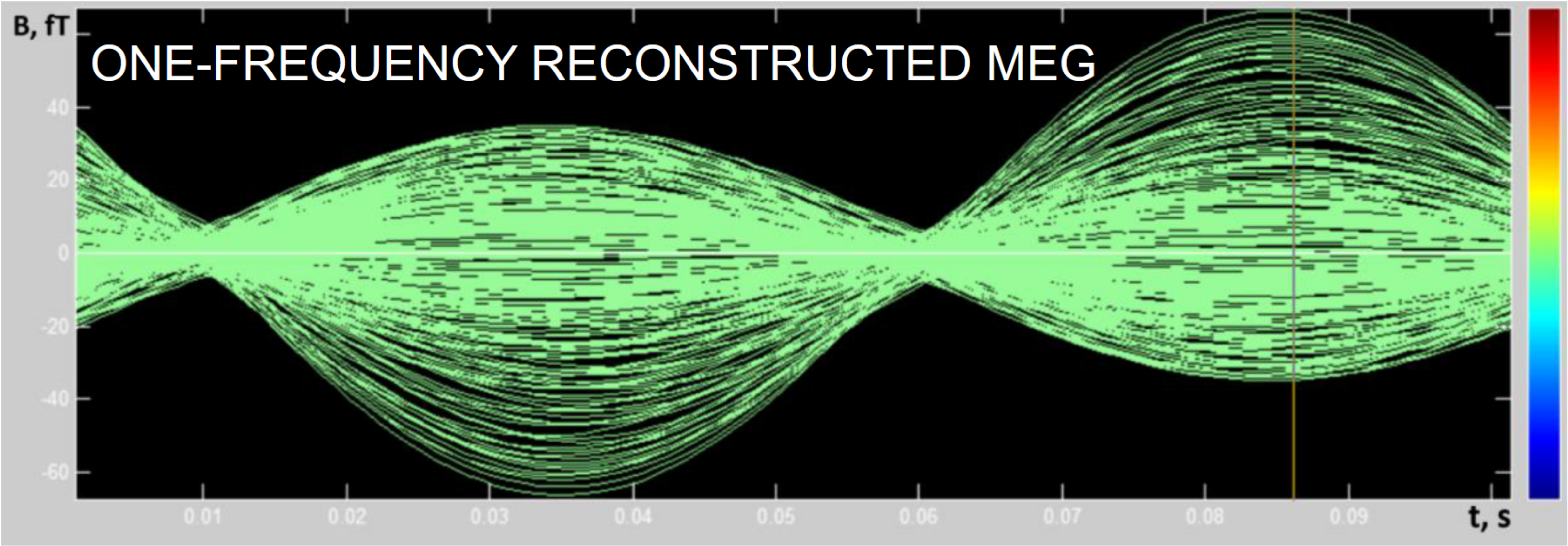
$$B_{nk}(t) = \rho_{nk} \sin(2\pi \nu_n t + \varphi_{nk}),$$

$$t \in [0, T_{\nu_n}],\ k = 1, \ldots, K$$

$$T_{\nu_n} = \frac{1}{\nu_n}$$

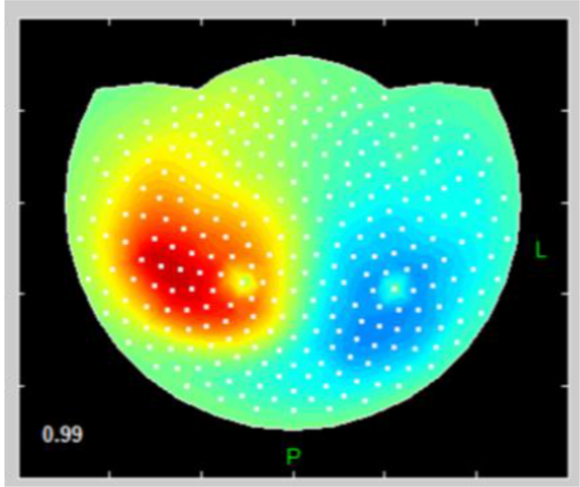
## COHERENT OSCILLATION – SEPARATION OF TIME AND SPACE

$$B_{nk}(t) = \rho_{nk} \sin(2\pi \nu_n t + \varphi_n)$$



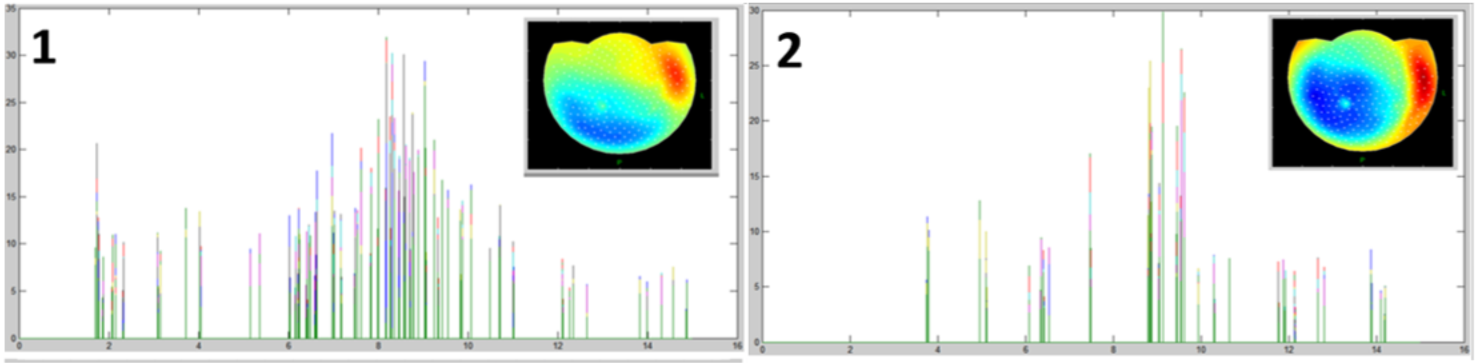

RECONSTRUCTED
FIELD
PATTERN $\rho_{nk}$

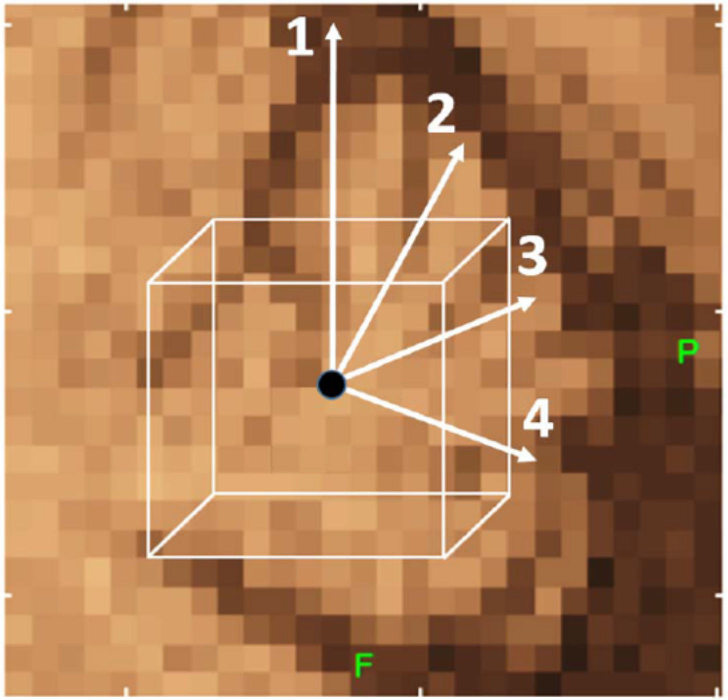
AT $\nu_n$= 9.87 Hz

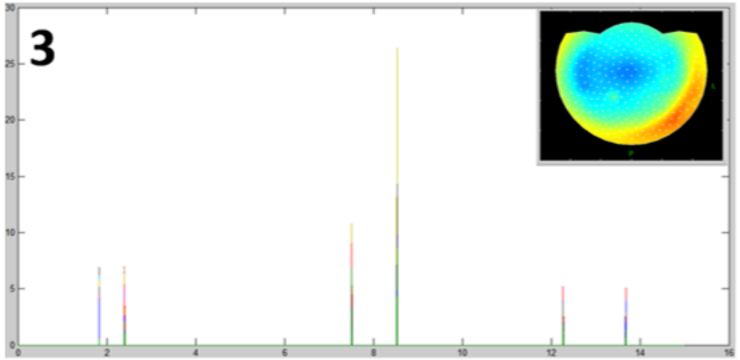


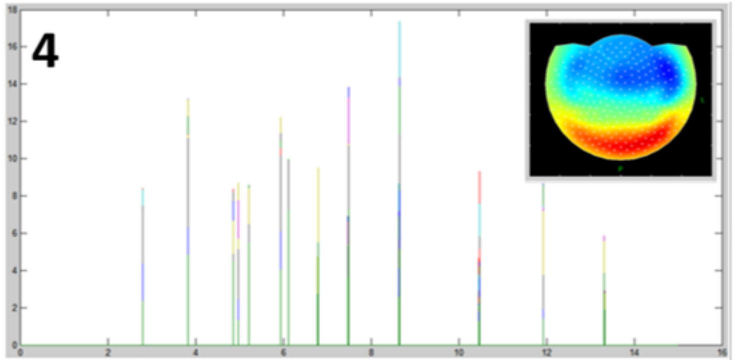
# GENERATION OF THE SET OF TRIAL PATTERNS:

In the volume $25x25x25\ cm^3$ with the step 3 mm over 2 millions of trial patterns are calculated



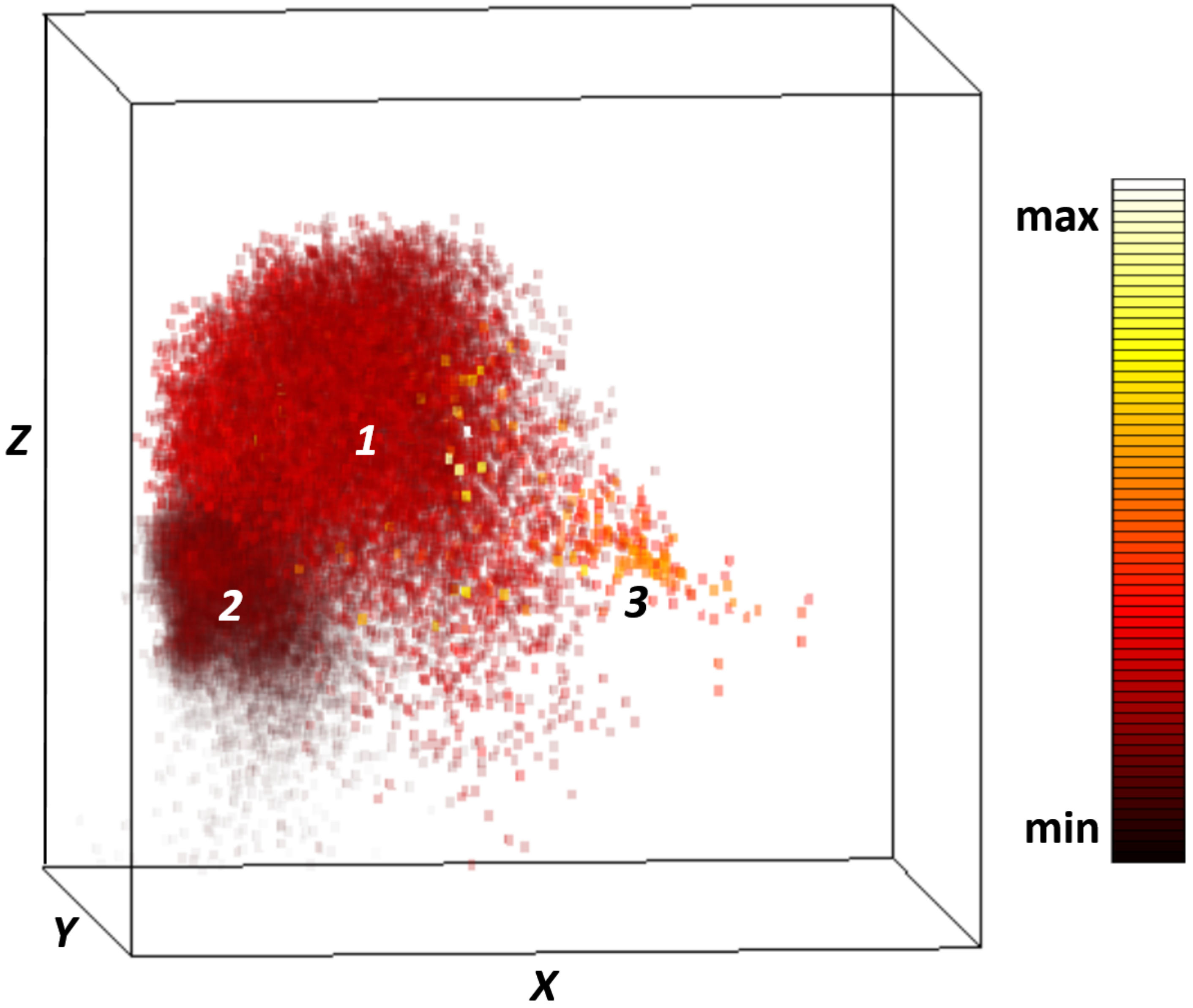

Trial dipoles in one voxel, field patterns and partial spectra

For each elementary coherent oscillation, unique dipolar source is localized by the exhaustive search, selecting the best trial source from 2.5 million, distributed in the whole space of the MRI.

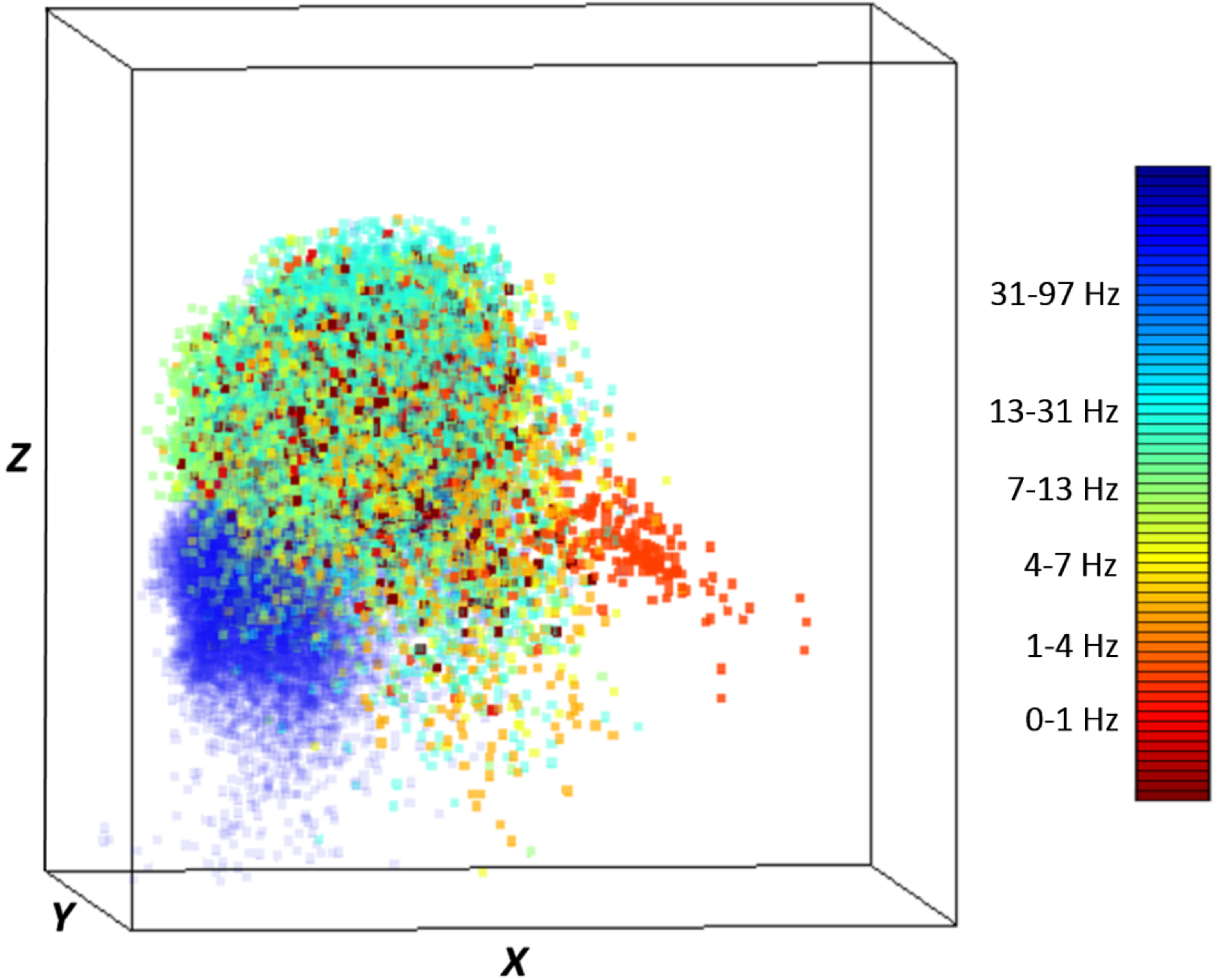
It means that no a-priori limitations are used for the location of sources, and their combined representation with MRI may provide new information.

Using normalized patterns, one can obtain localization of weak sources, if they are extracted from Fourier analysis, with precision equal to the precision of localization of strong sources.

It opens new possibilities to study deep brain sources.



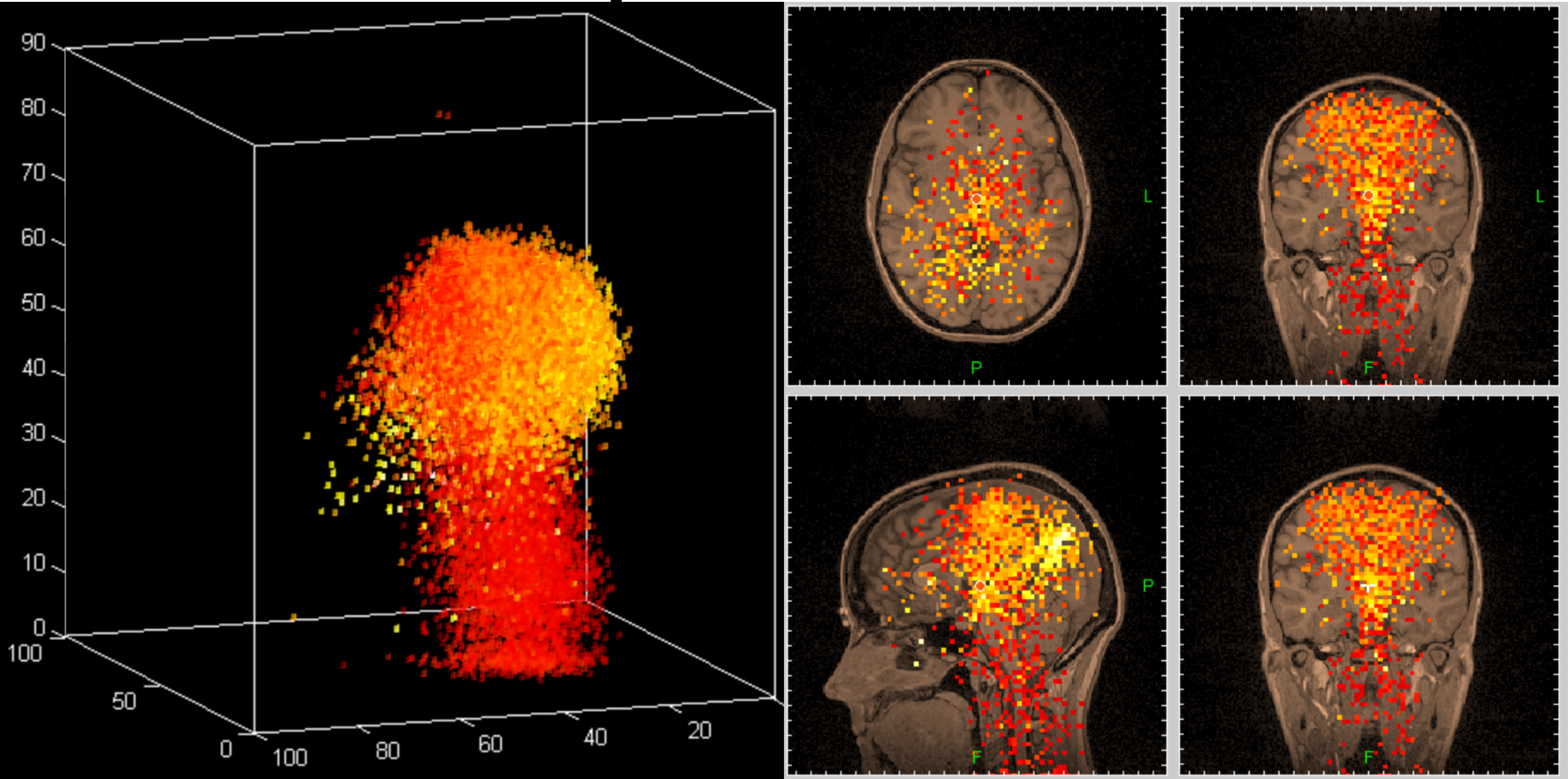

Functional tomogram of a brain (1), neck muscles (2), and olfactory system (3) in the frequency band 0.003-100 Hz with spatial resolution 3mm



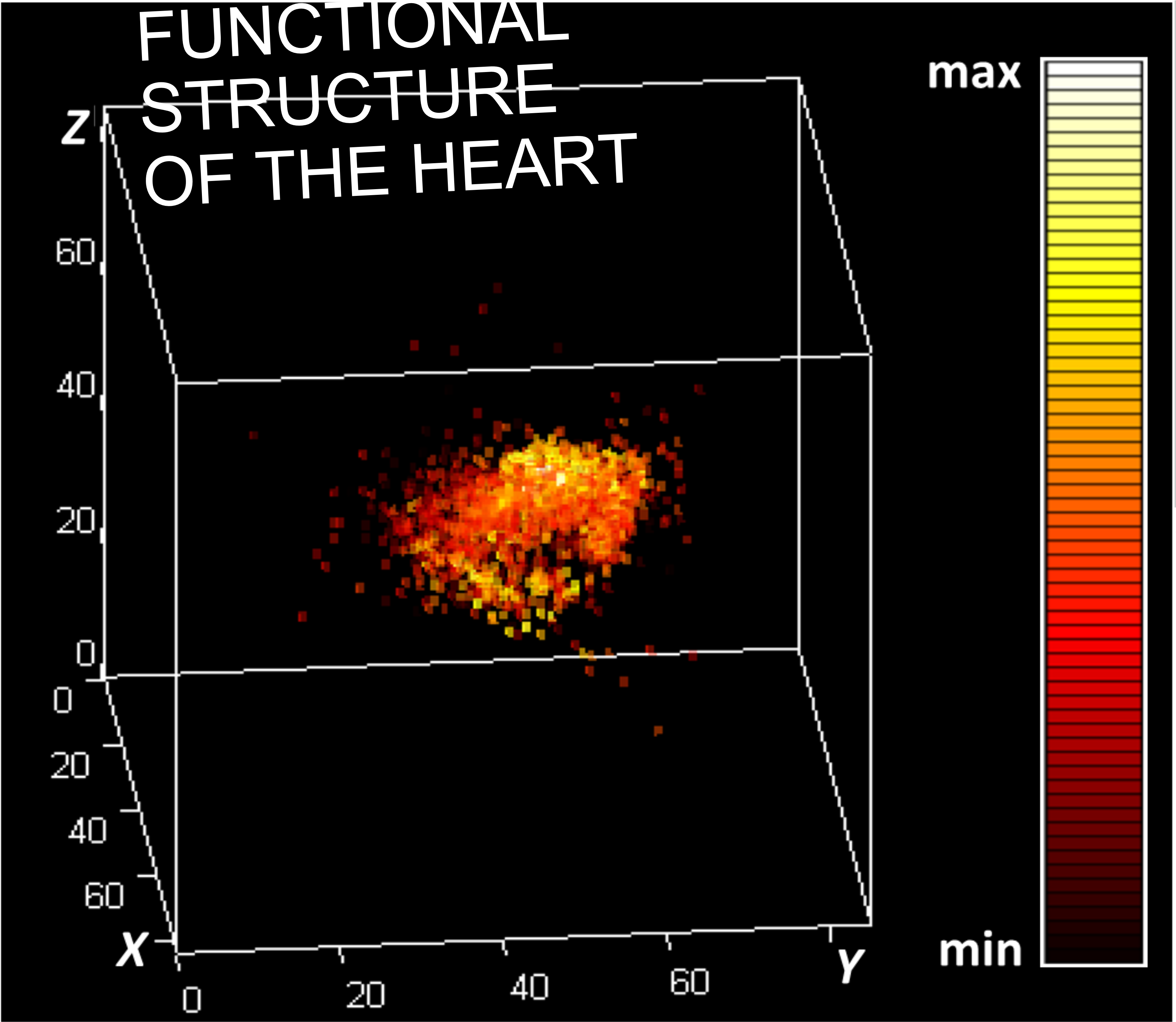

Functional tomogram of the same subject in different frequency bands.

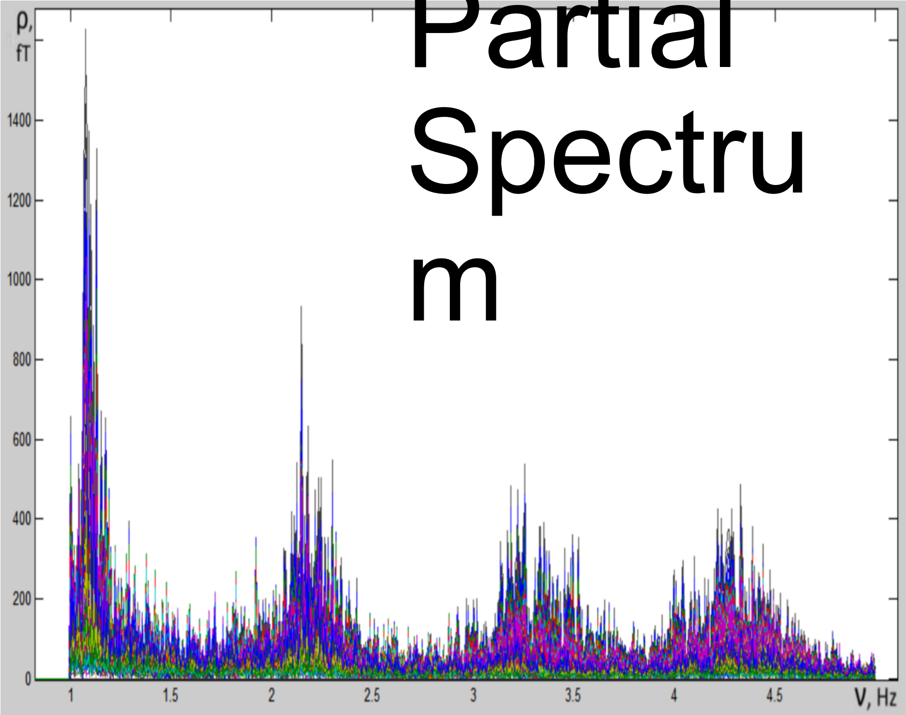
# Magnetic encephalography

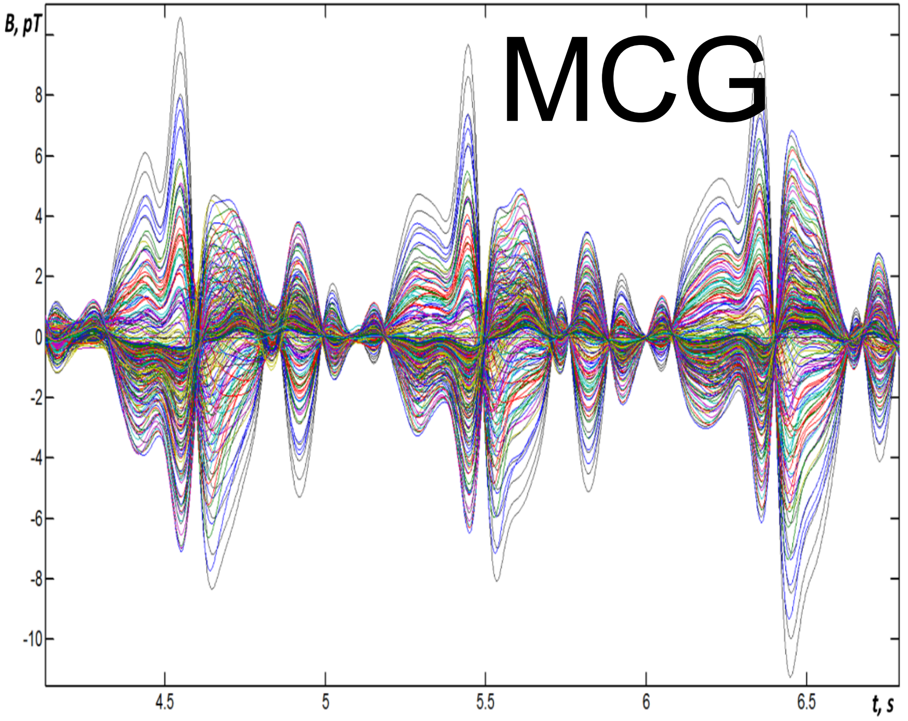
# Functional tomogram in the frequency band 0-100 Hz, shown over the subject's MRI



# Magnetic cardiography

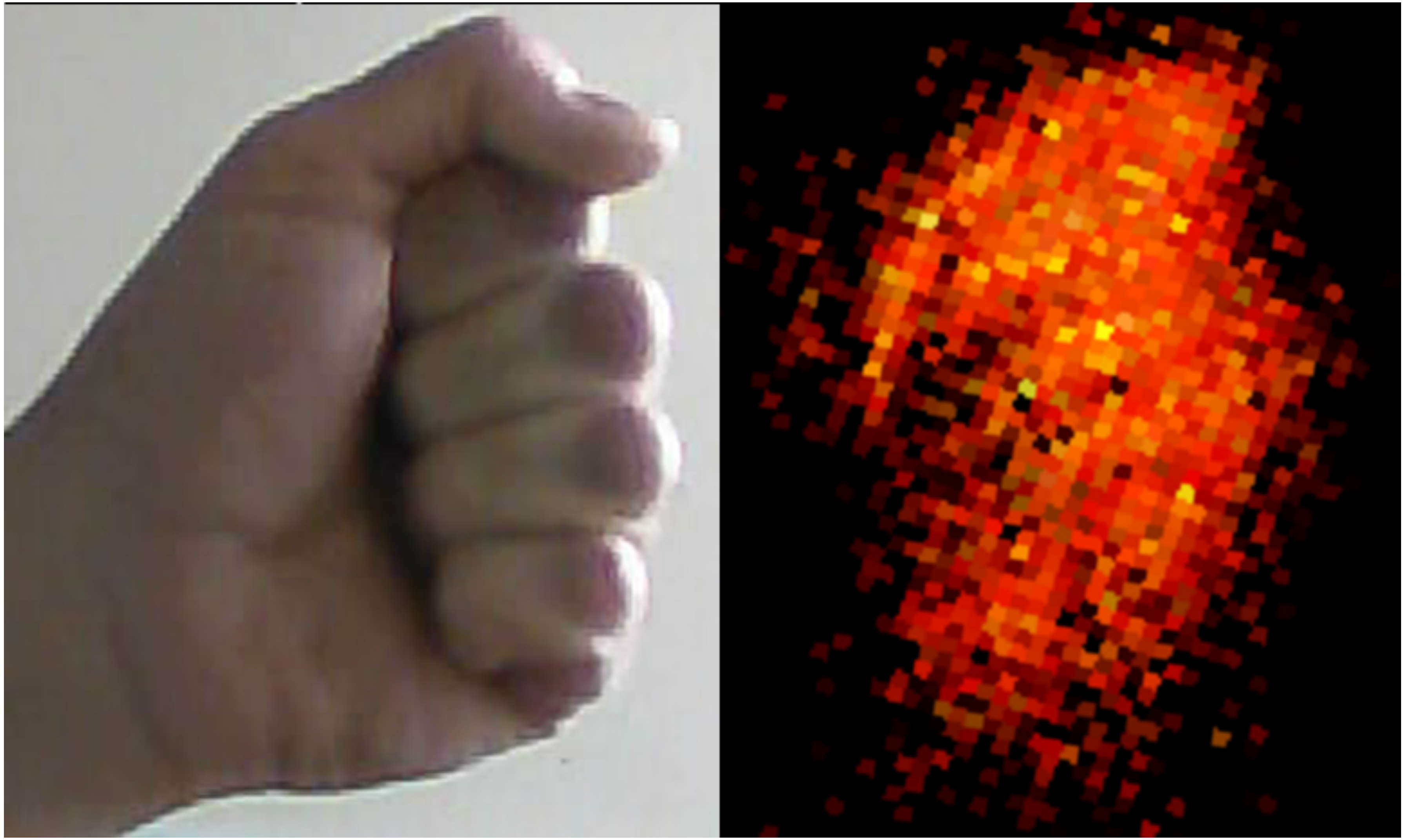

FUNCTIONAL STRUCTURE OF THE HEART
max
min
Z
60
40
20
0
0
20
40
60
X
0
20
40
60
Y

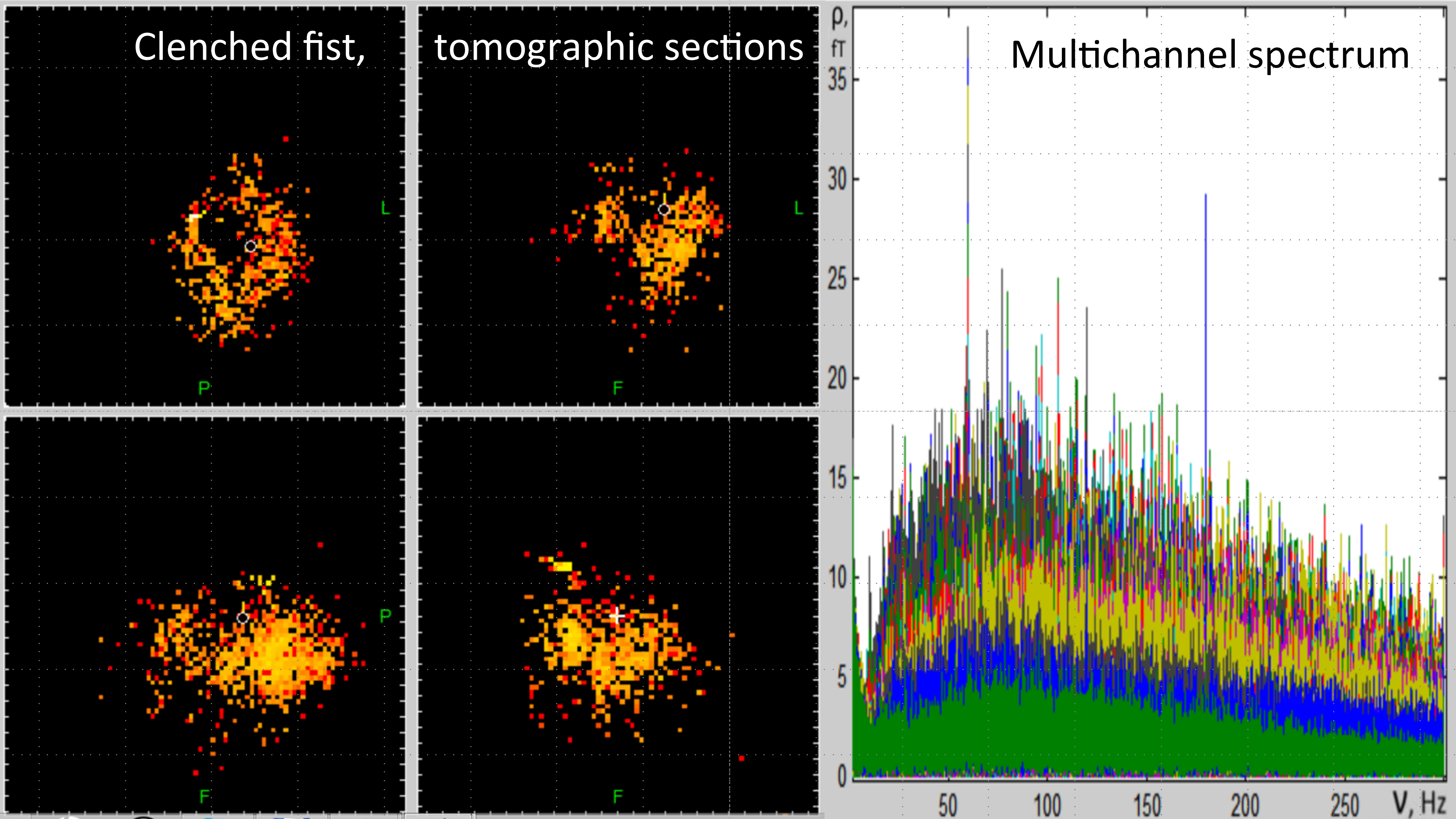

Partial Spectrum
ρ, fT
1400
1200
1000
800
600
400
200
0
1
1.5
2
2.5
3
3.5
4
4.5
V, Hz


MCG
B, pT
8
6
4
2
0
-2
-4
-6
-8
-10
4.5
5
5.5
6
6.5
t, s

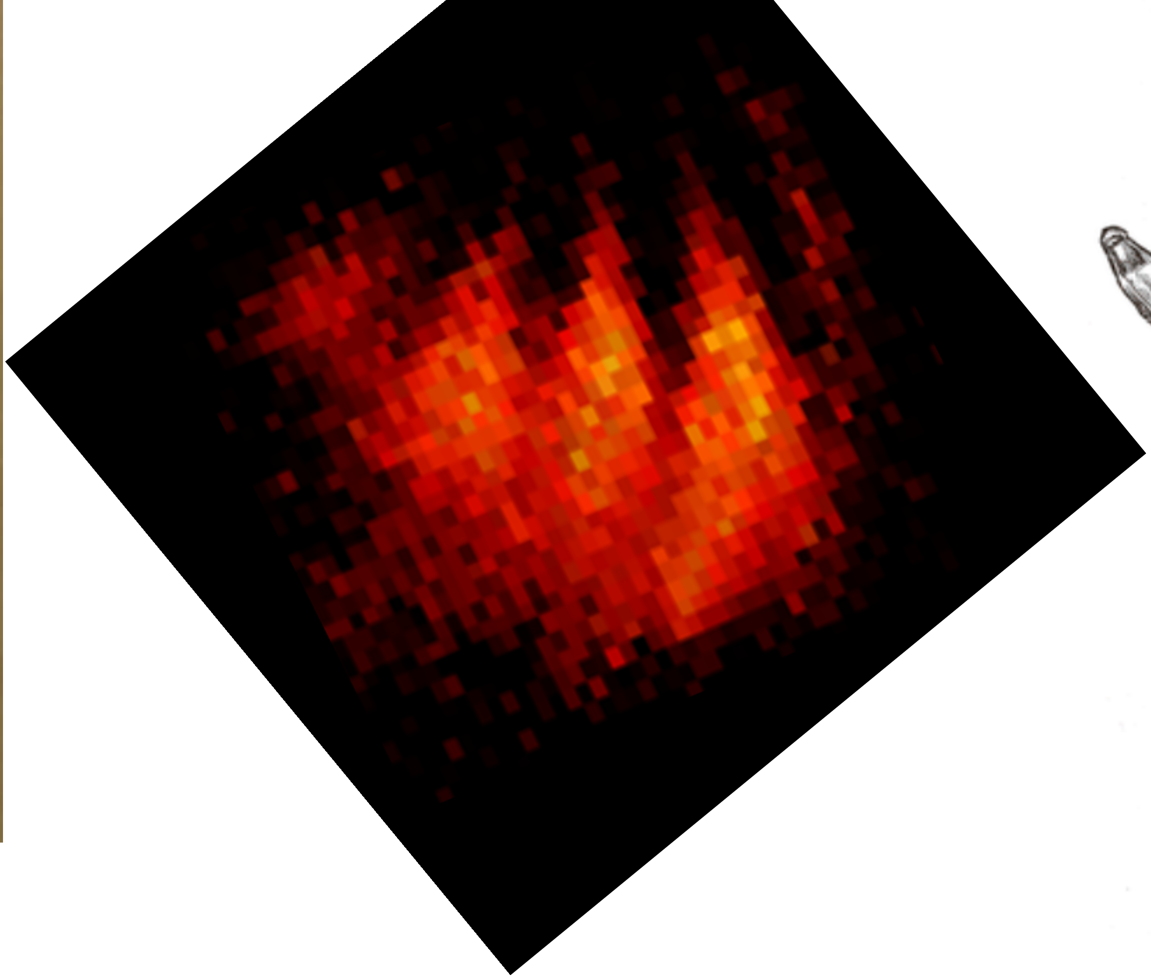
# Magnetic myography

# FUNCTIONAL STRUCTURE OF THE HAND



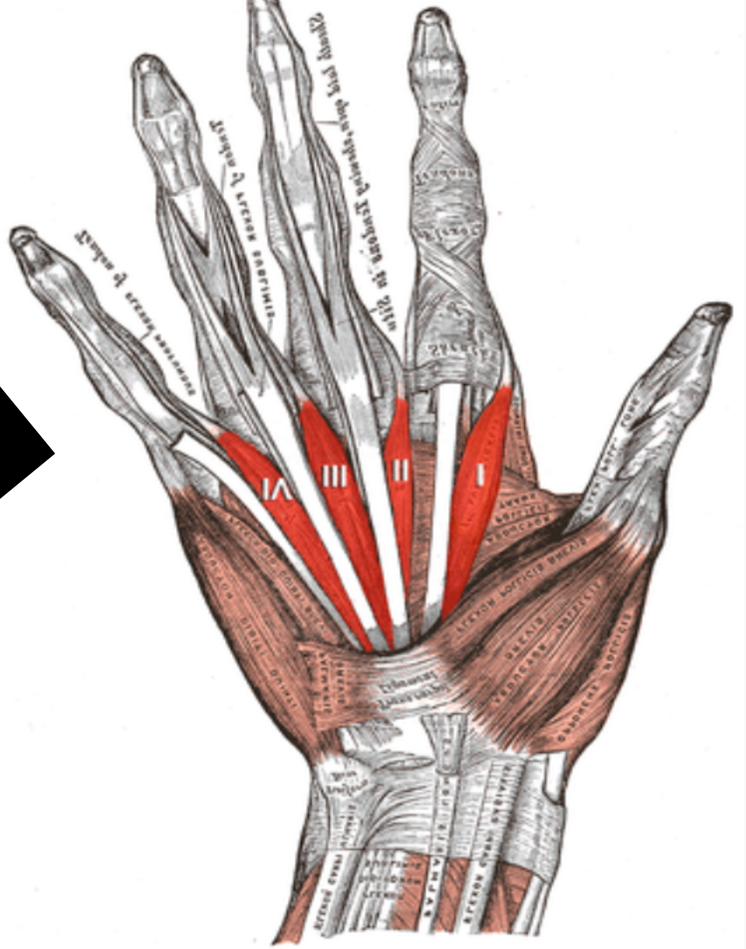

Clenched fist,
tomographic sections
L
P
L
F
P
F
F
Multichannel spectrum
ρ, fT
35
30
25
20
15
10
5
0
50
100
150
200
250
V, Hz

Experiment:
Magnetic field of the static hand, compressing an apple, was recorded for 1 minute in 275 channels.



Functional structure of the hand lumbrical muscles, reconstructed from the magnetic field.

The brightness is proportional to the muscle electrical activity.



Lumbrical muscles, anatomy.

Shown in red.

The method of frequency-pattern analysis of the multichannel magnetic data makes it possible to reconstruct the functional structure of the human body.

Partial spectra of the various body areas can be calculated and the time series can be reconstructed.

- Llinás R.R., Ustinin M.N. *Precise Frequency-Pattern Analysis to Decompose Complex Systems into Functionally Invariant Entities*: U.S. Patent. US Patent App. Publ. 20160012011 A1. 01/14/2016.
- Llinás R.R., Ustinin M.N., Rykunov S.D., Boyko A.I., Sychev V.V., Walton K.D., Rabello G.M., Garcia J. Reconstruction of human brain spontaneous activity based on frequency-pattern analysis of magnetoencephalography data // Front. Neurosci., Vol. 9, oct 2015.
- Llinás R.R., Ustinin M.N. Frequency-pattern functional tomography of magnetoencephalography data allows new approach to the study of human brain organization. *Front. Neural Circuits*. *2014. V. 8. P. 43.*

# RESEARCH TEAM AND INSTITUTIONS

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