Possible mechanism for the influence of geomagnetic storms on biological systems based on experimental data

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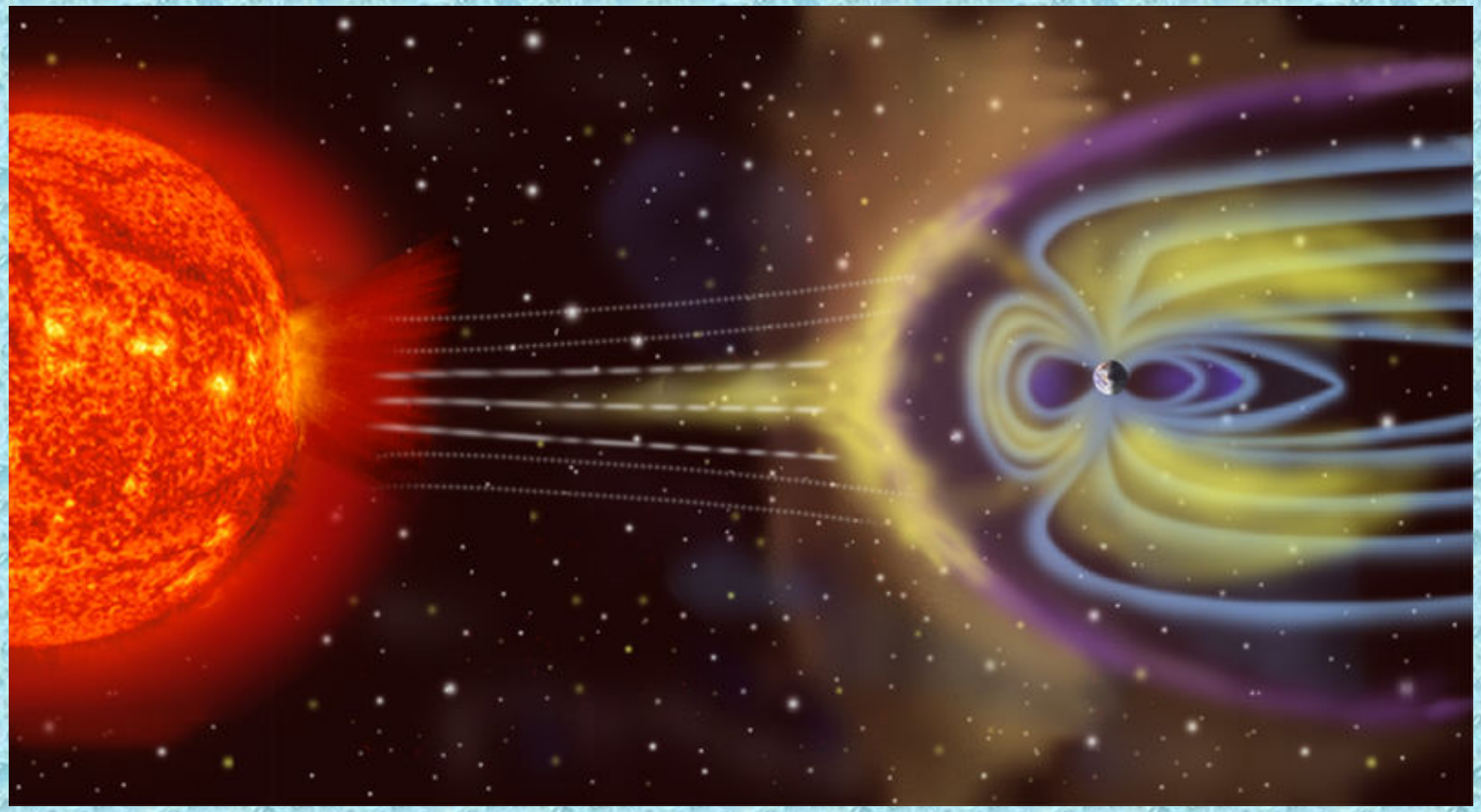
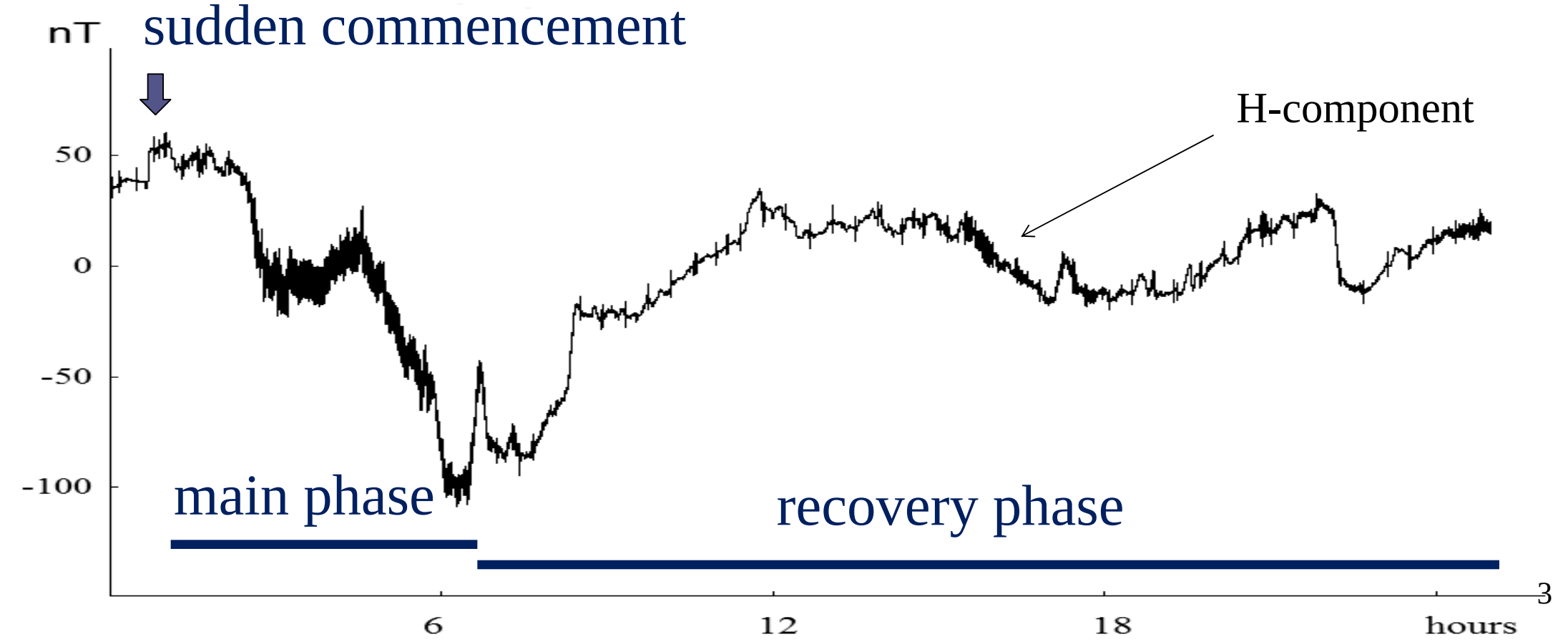
- A geomagnetic storm (GMS) is a global disturbance of the Earth's magnetosphere caused by a solar wind shock wave of magnetic field, which interacts with the Earth's magnetic field and accompanies with alternating of the indices of geomagnetic activity.

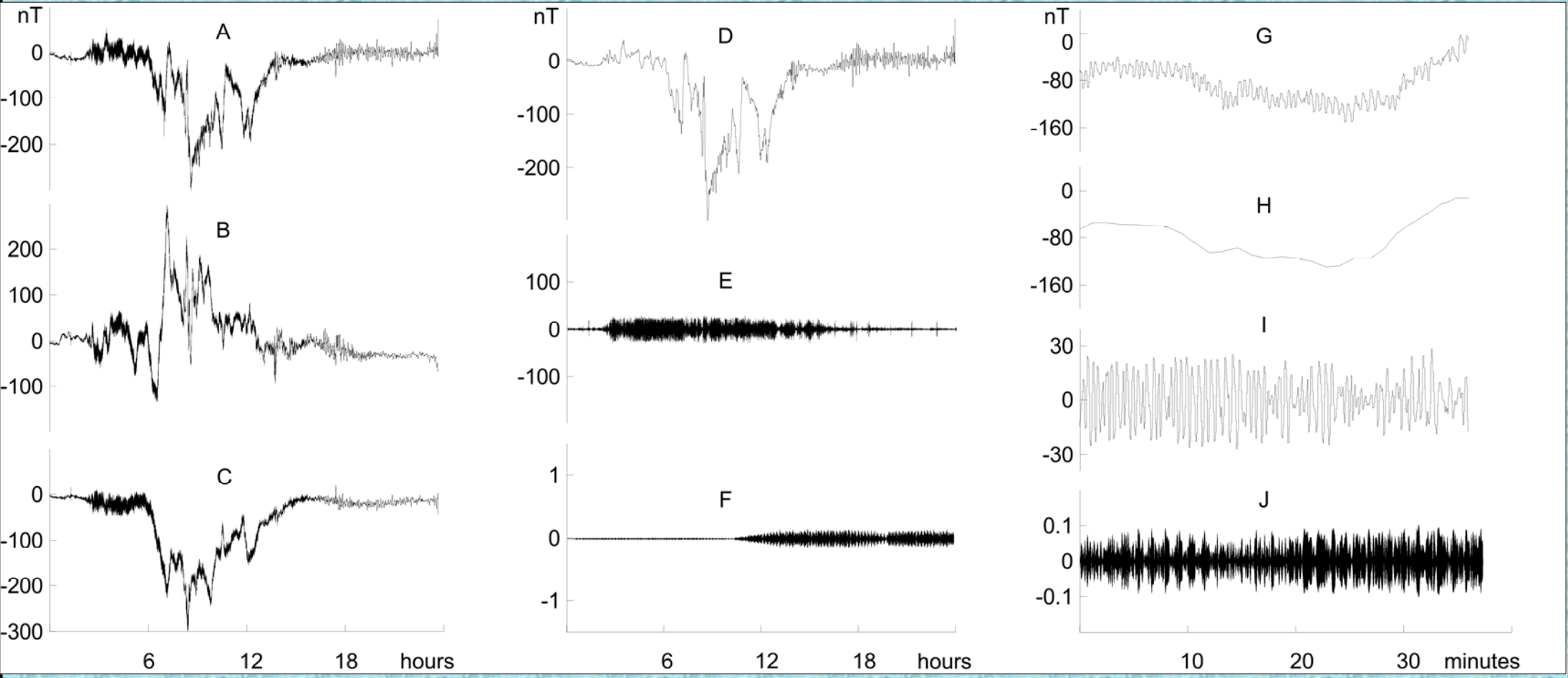


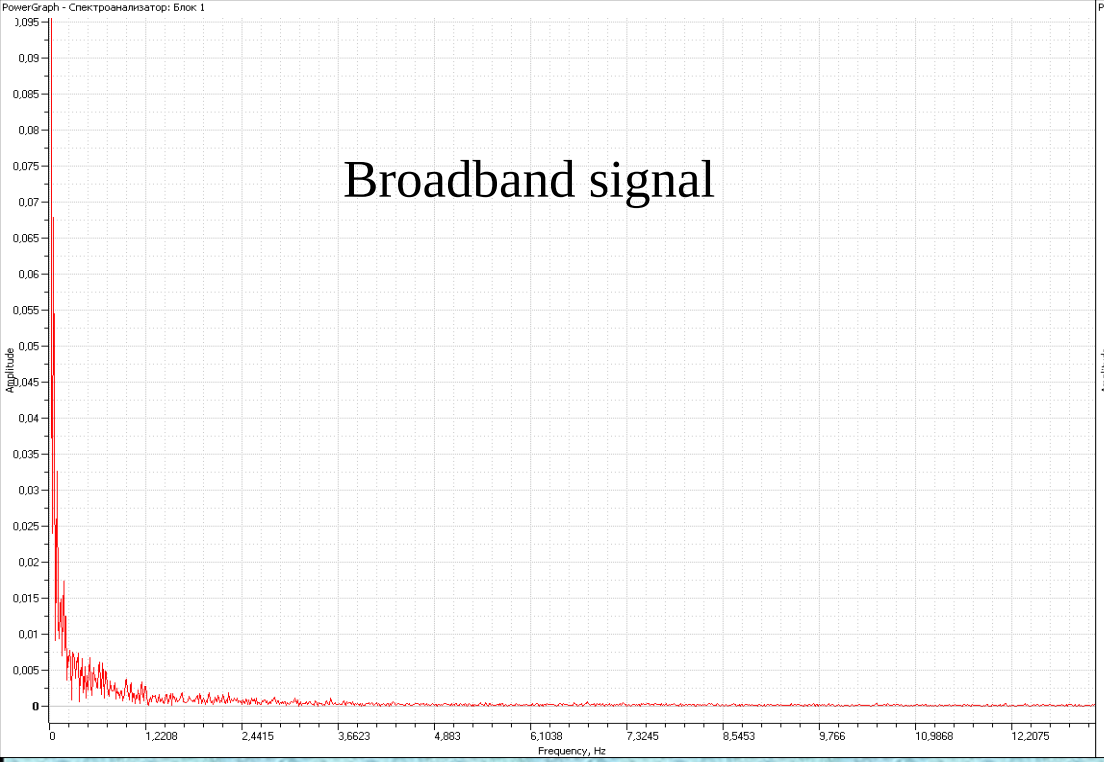
Slow changes in the strength and the direction of the Earth's magnetic field (on the order of hundred nT) are associated with the peculiarities of a perturbed solar wind and Earth's magnetosphere interactions. It divides into typical temporal intervals: **storm sudden commencement** which characterized by horizontal H-component of Earth's magnetic field increasing (by 20 to 50 nT in tens of minutes), **main phase** – defined by dramatic fluctuations of the Earth's magnetic field, and **recovery phase** – the period when Earth's magnetic field changes from minimum value to its quiet time value.

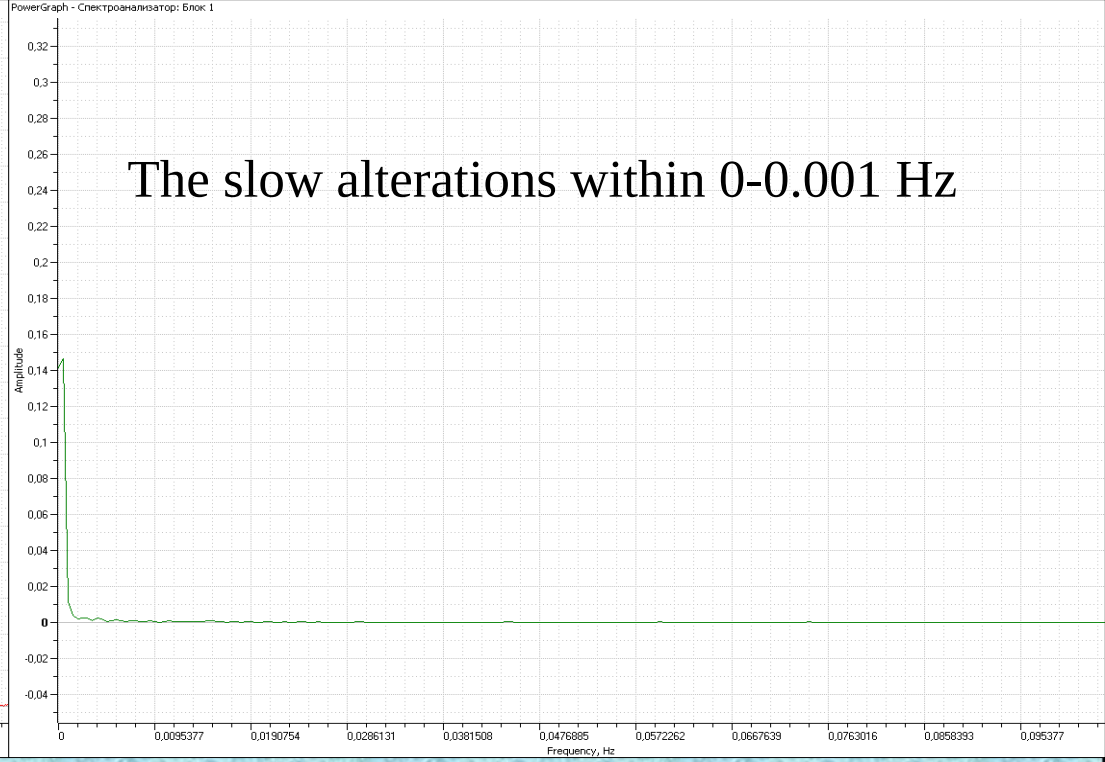


The fluctuations of geomagnetic field during the GMS may be conventionally divided into following frequency ranges: **the slow alterations within 0-0.001 Hz** with amplitude excursion about hundreds nT **(D and H on the picture)** and **the low-frequency alternations within 0.001-5 Hz** with amplitude excursion up to 50 nT **(E and I on the picture)**. Some authors incline to establish relation between the records of occurred **Pc 1 pulsations (F and J on the picture)** and different medical effects.

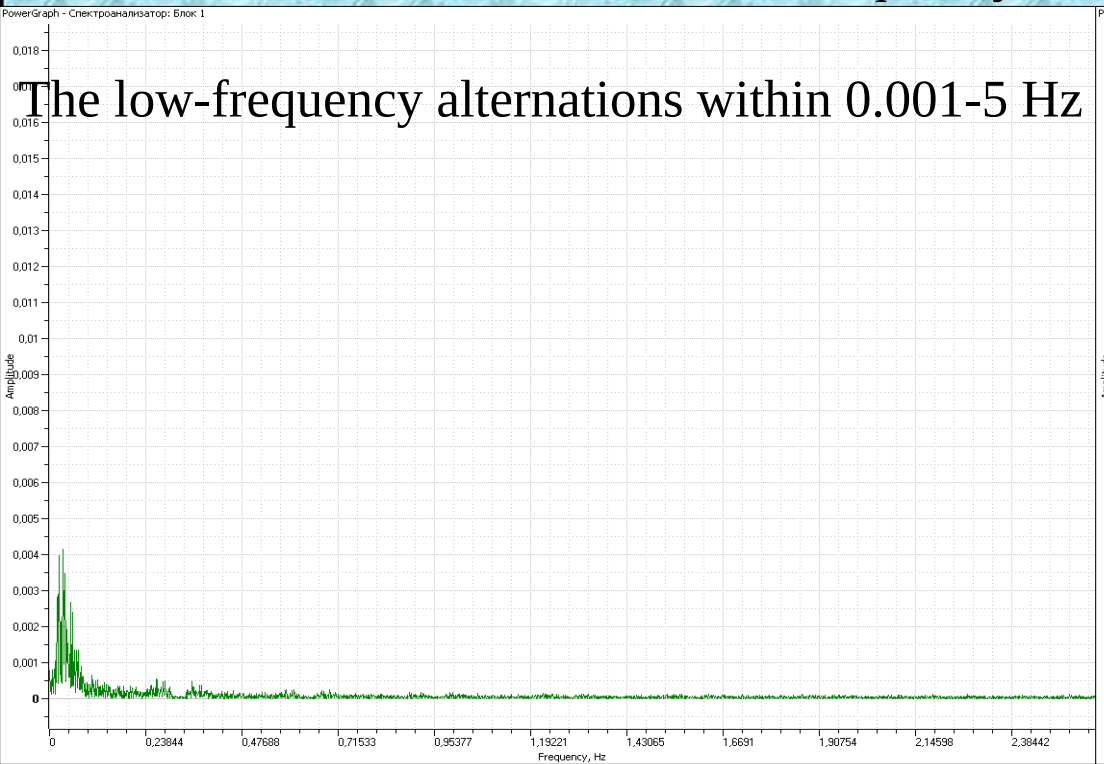
The broadband fluctuations of the geomagnetic field shown as A, B, C and G on the picture

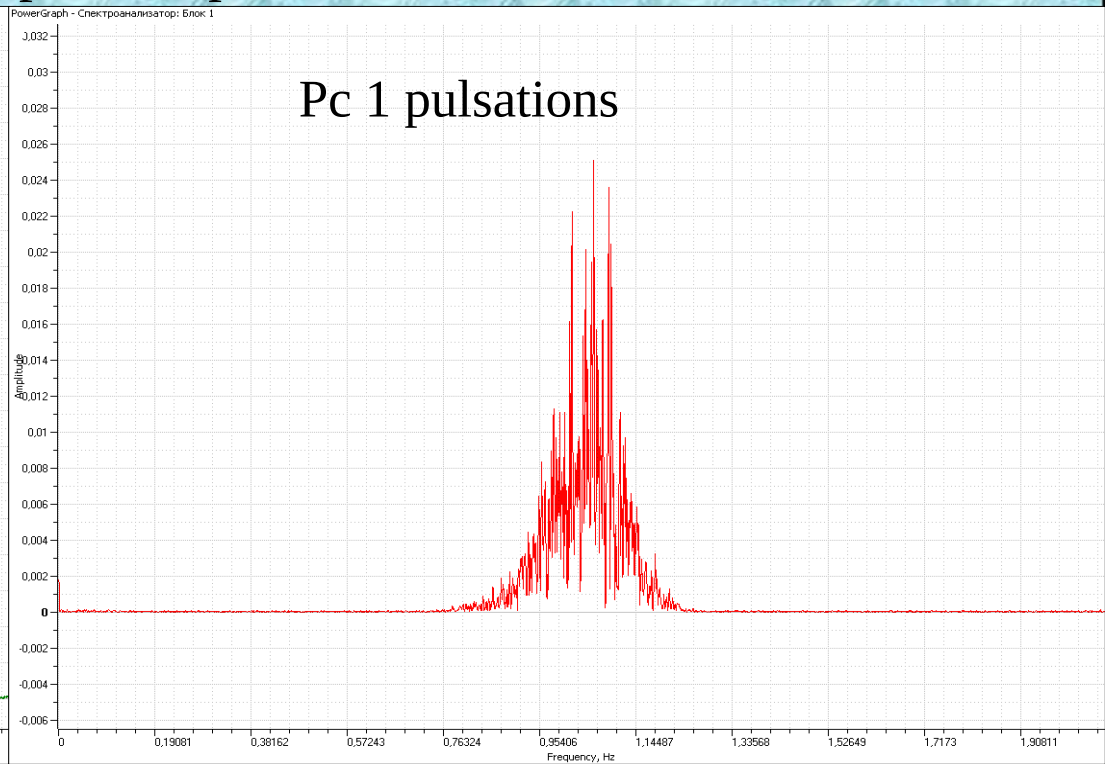




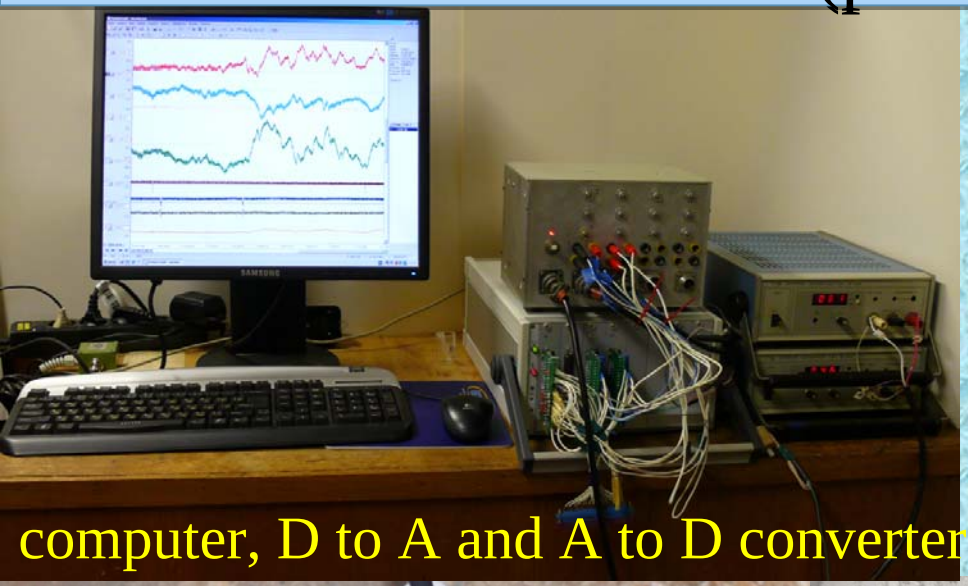


Frequency-amplitude spectra

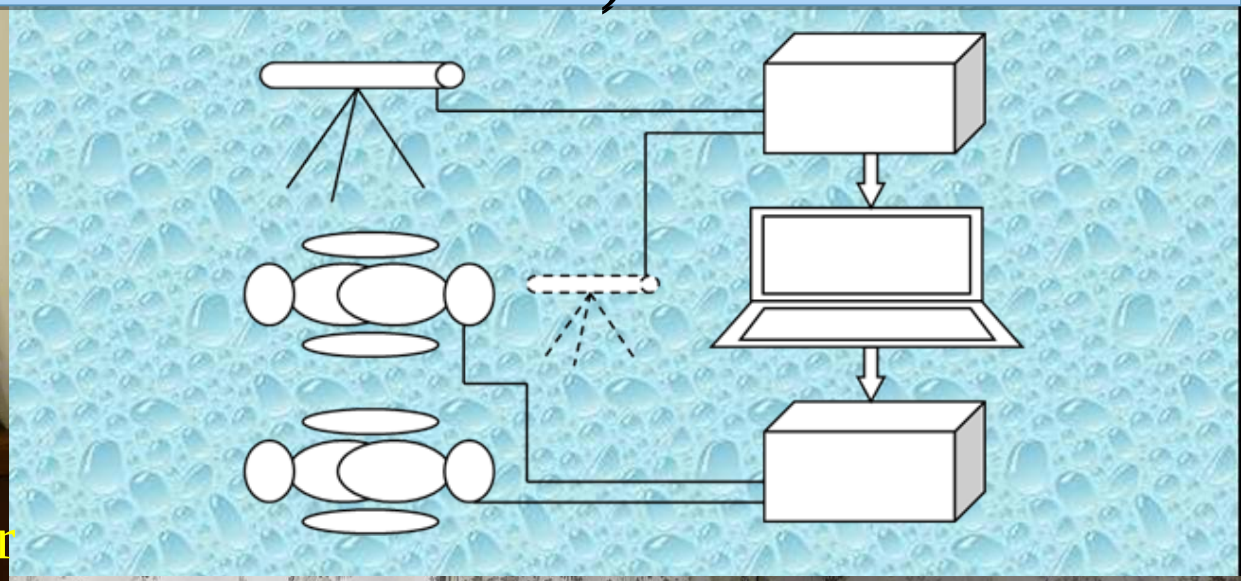


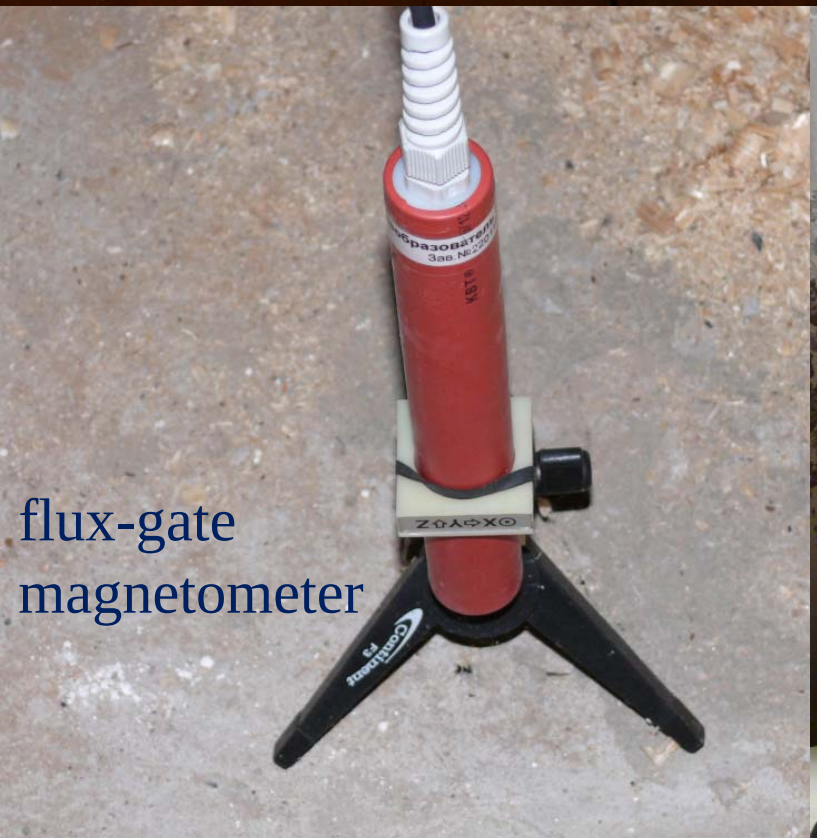


The experimental setup for generation-compensation of magnetic fields (patent RU 108640 U1)



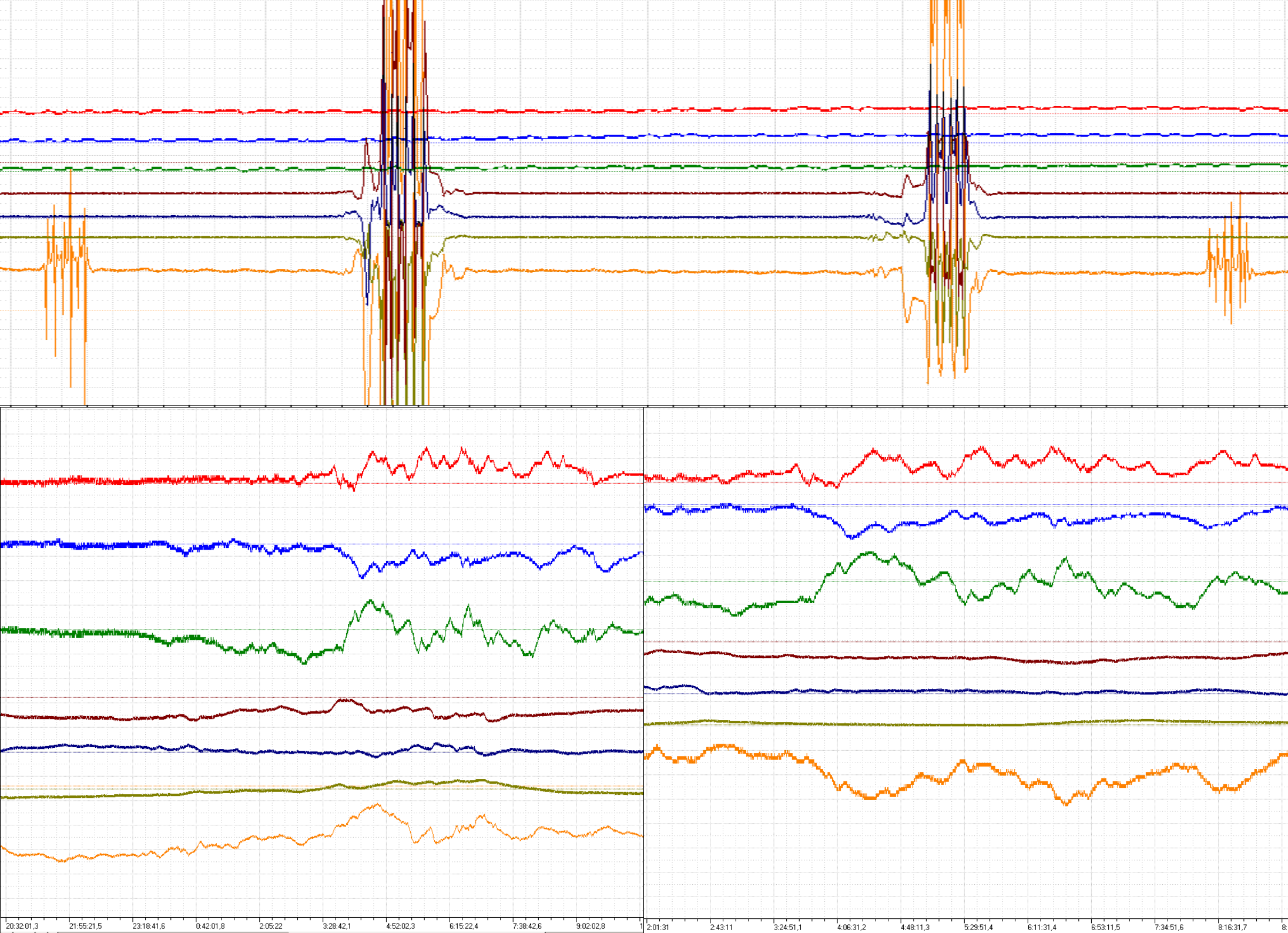
computer, D to A and A to D converter





flux-gate magnetometer

exposure system


20:32:01,3
21:55:21,5
23:18:41,6
0:42:01,8
2:05:22
3:28:42,1
4:52:02,3
6:15:22,4
7:38:42,6
9:02:02,8
2:01:31
2:43:11
3:24:51,1
4:06:31,2
4:48:11,3
5:29:51,4
6:11:31,4
6:53:11,5
7:34:51,6
8:16:31,7

The effects of geomagnetic storm on a mitotic activity and intracellular RNA content.

The effects of geomagnetic storm on a mitotic activity in embryos of roach (Rutilus rutilus) and bream (Abramis brama).

Simultaneous experiments.

	roach				bream	
	replication 1		replication 2			
	control	GMS	control	GMS	control	GMS
Blastocyte count	12 525	13 050	13 000	4 390	4 200	5 910
Mitosis count	157	289	173	100	82	214
Mitotic index, ‰	12.5±0.6	22.1±2.9*	13.3±1.1	22.8±1.9*	19.5±4.1	36.2±2.5*
Mitoses, in % of MI:						
Normal	94.8±3.3	90.0±2.4	92.3±2.6	93.2±3.5	88.9±3.0	90.2±3.5
Abnormal	5.2±3.3	9.9±2.4	7.7±2.6	6.8±3.5	11.0±3.0	9.8_3.5

The effects of geomagnetic storm on a mitotic activity in embryos of roach (Rutilus rutilus) in 2010 – 2011.

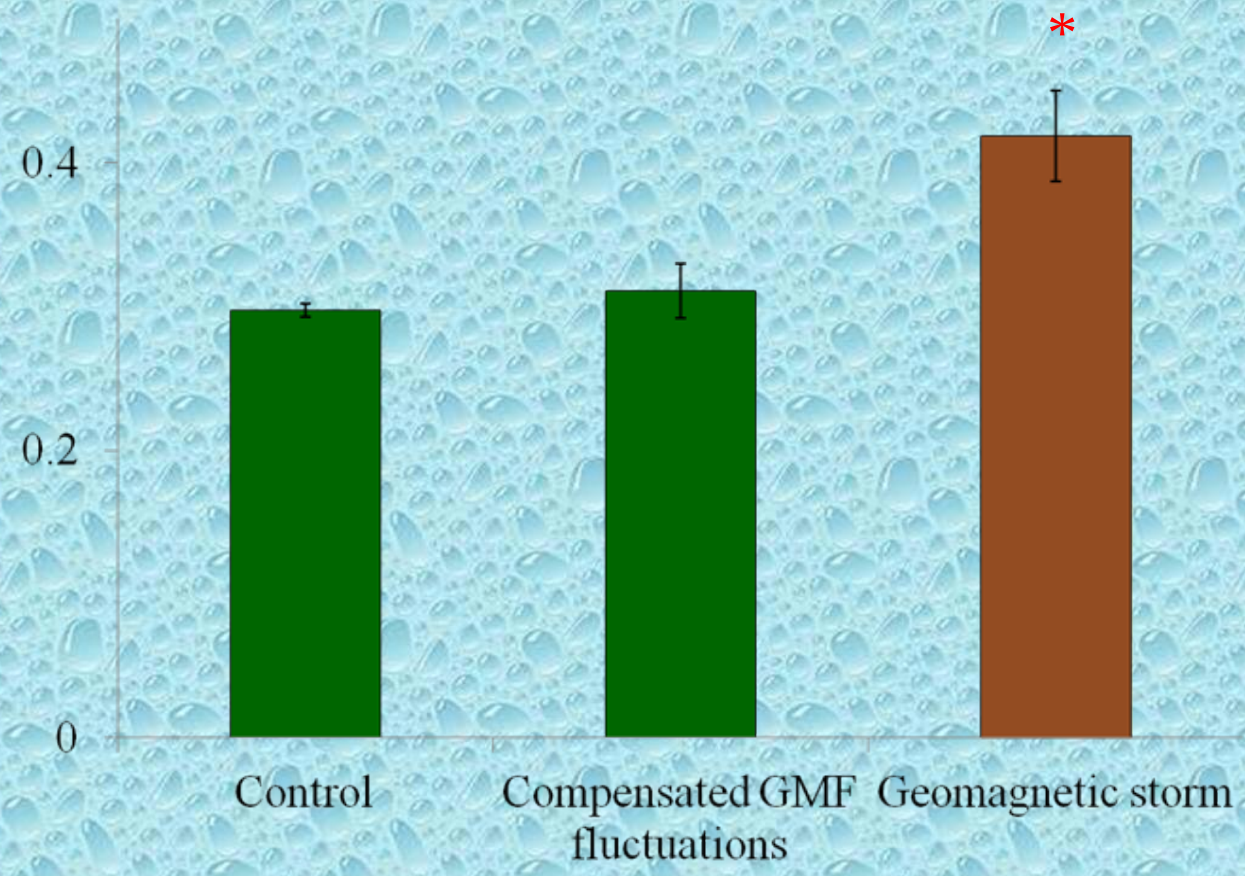
	2010		2011	
	control	GMS	control	GMS
Blastocyte count	25 525	17 440	19 150	16 340
Mitosis count	330	389	869	909
Mitotic index, ‰	12.6 ± 0.5	22.2 ± 1.8*	45.8 ± 1.9	56.7 ± 2.4*
Stages of mitosis, ‰:				
- metaphase, normal	6.3 ± 0.4	9.3 ± 1.2*	18.3 ± 1.1	23.4 ± 1.1*
- metaphase, abnormal	0.4 ± 0.2	0.8 ± 0.2	2.1 ± 0.4	2.4 ± 0.4
- anaphase+telophase, normal	5.5 ± 0.5	11.1 ± 0.7*	21.7 ± 1.1	27.9 ± 2.2*
- anaphase+telophase, abnormal	0.4 ± 0.2	1.1 ± 0.4	3.7 ± 0.5	2.9 ± 0.5
Total count of mitosis, ‰				
- normal	11,8 ± 0.3	20.3 ± 1.7*	40.0 ± 1.6	51.3 ± 2.3*
- abnormal	0.8 ± 0.3	1.9 ± 0.5	5.8 ± 0.8	5.4 ± 0.8

	control	GMS
The first hatching, hours	216	196
Average time of hatching, hours	240	228
Survivability, %	39.6	28.3
Body length, mm	5.96 ± 0.04	6.07 ± 0.02*
Body weight, mg:		
- Wet	1.226 ± 0.047	1.331 ± 0.092
- Dry	0.171 ± 0.032	0.184 ± 0.046
Morphological diversity, μ	7.847	6.417*
n	50-100	50-100

The effects of geomagnetic storm on a mitotic activity in meristem of *Allium cepa*

	hard water		distilled water	
	control	GMS	control	GMS
Counted cells	20 900	27 900	25 000	45 100
Counted mitosis	503	899	503	791
Mitotic index, ‰	20.1 ± 2.6	32.6 ± 2.3*	19.6 ± 2.0	18.1 ± 1.2
Stages of mitosis, ‰:				
- metaphase, normal	10.5 ± 0.4	13.8 ± 1.4*	8.7 ± 0.9	8.9 ± 0.5
- metaphase, abnormal	0.9 ± 0.1	1.6 ± 0.2*	1.1 ± 0.2	0.5 ± 0.1*
- anaphase+telophase, normal	9.1 ± 0.7	8.0 ± 0.9	4.3 ± 0.7	4.4 ± 0.5
- anaphase+telophase, abnormal	3.8 ± 0.3	9.1 ± 0.7*	5.5 ± 0.8	4.2 ± 0.4
Total count of mitosis, ‰				
- normal	16.5 ± 2.1	22.1 ± 2.0*	13.1 ± 1.4	13.3 ± 0.9
- abnormal	4.6 ± 0.4	10.7 ± 0.8*	6.6 ± 0.9	4.7 ± 0.5

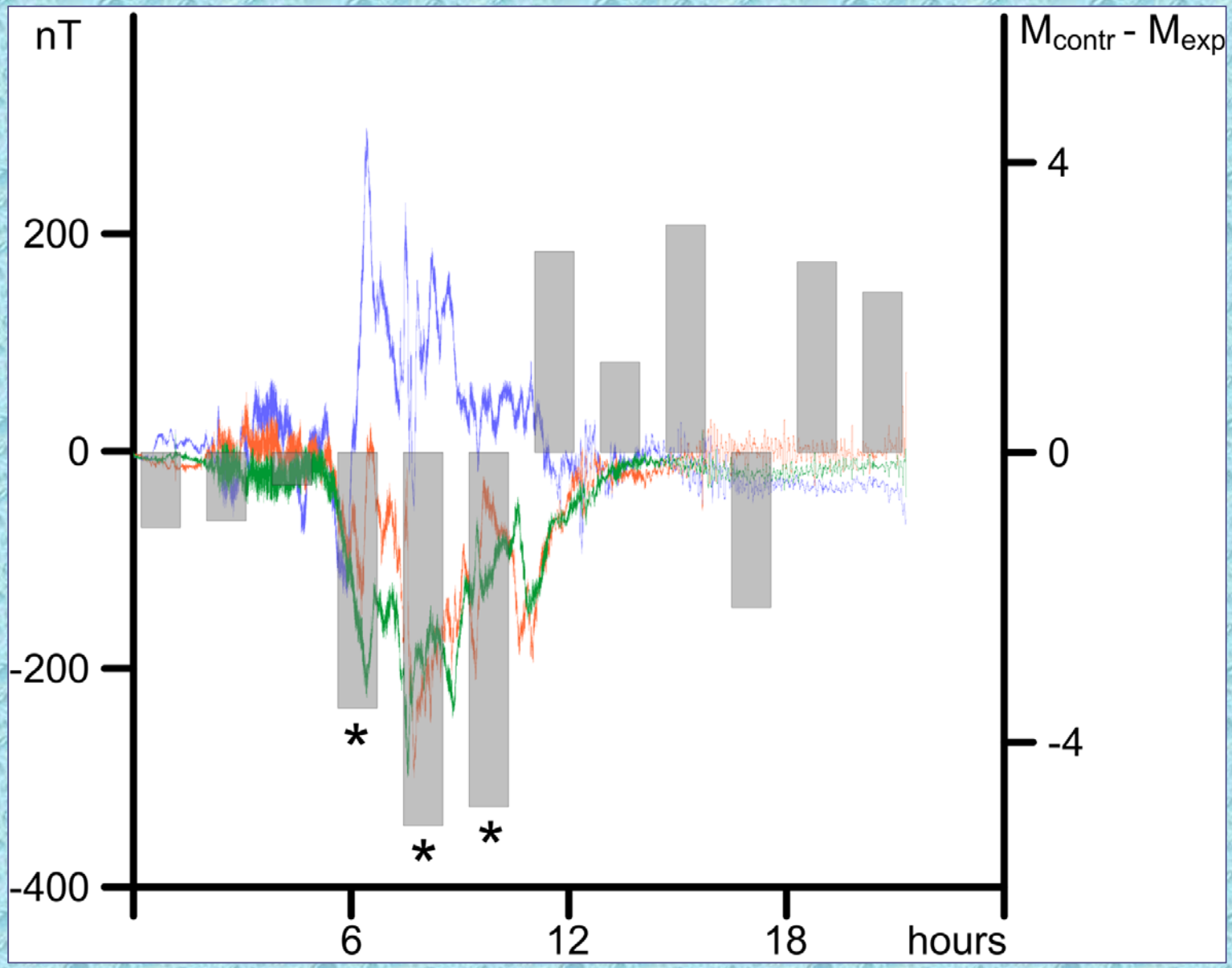
Total RNA content (µg/ml) in *Daphnia magna* after exposure to geomagnetic storm.



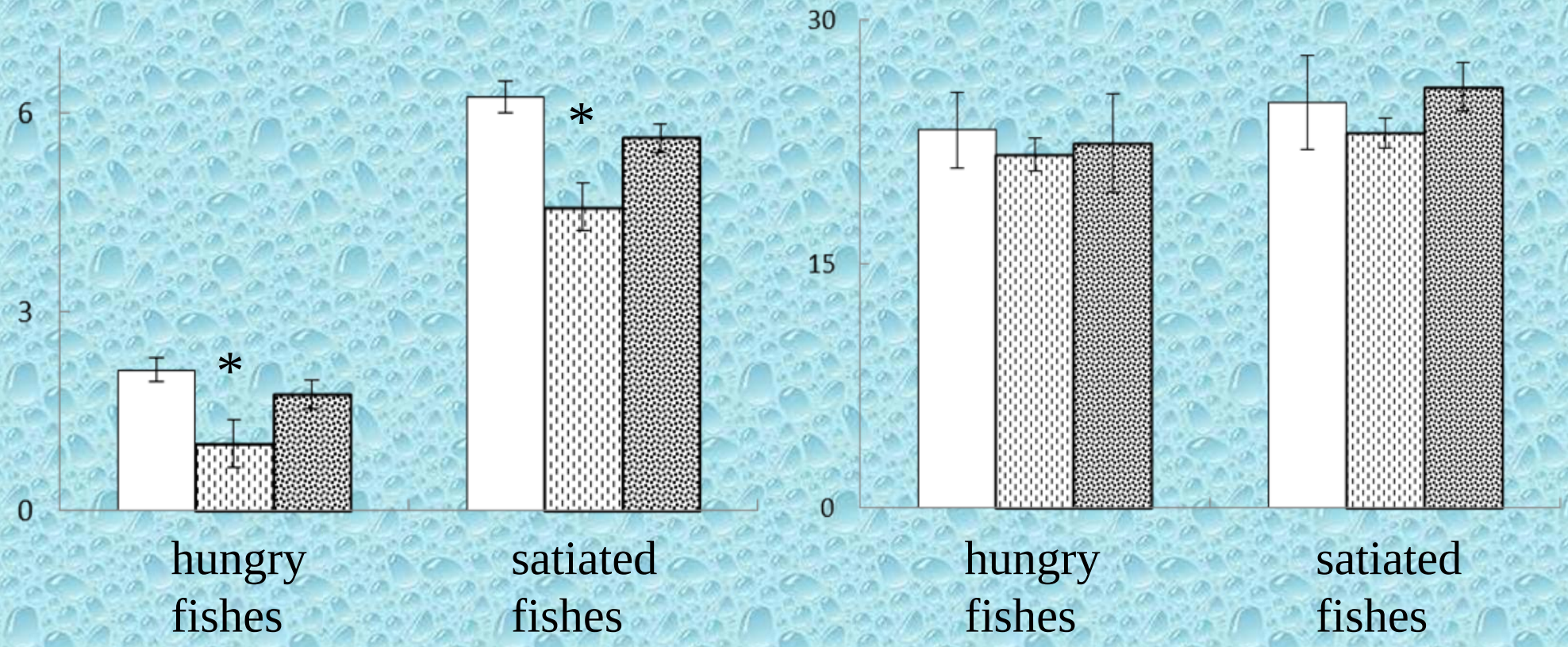
The increase of total RNA content in Daphnia cells was **no related to** the genes of **28 S rRNA** **HSP 70**

The biological effects of different phases and intervals of geomagnetic storm.

The gravitropic response of flax (*Linum bienne*) to 2-hour intervals of geomagnetic storm

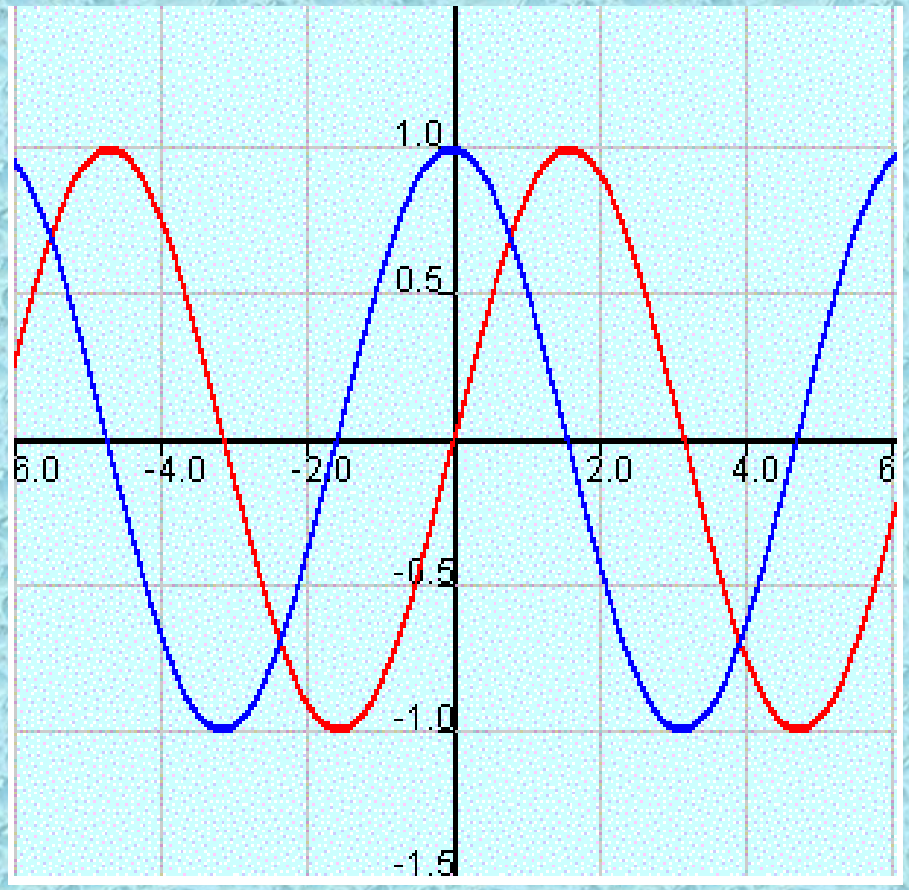


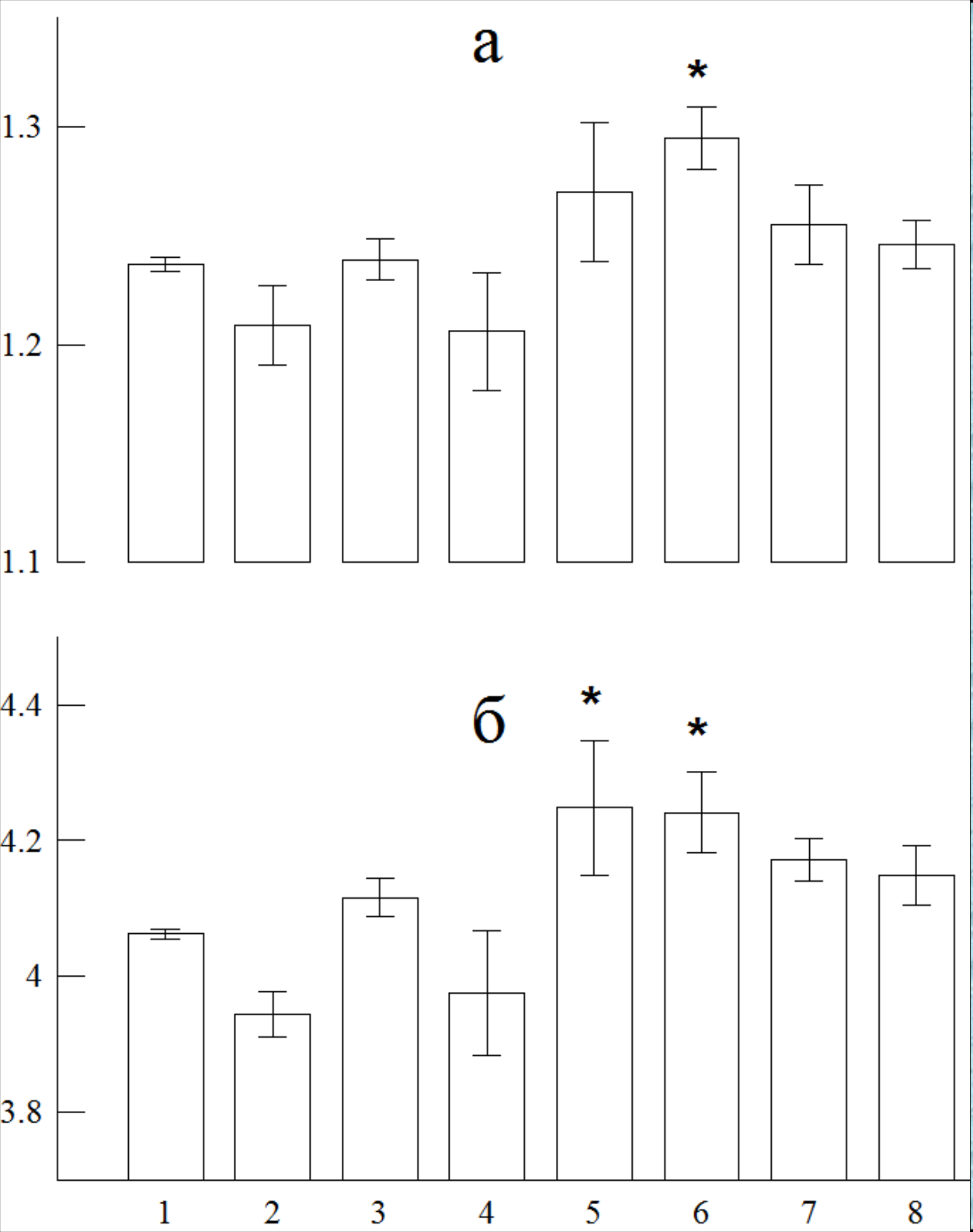
The impact of main phase and recovery phase of geomagnetic storm on the amylolytic activity (right) and proteolytic activity (left) in carp, μmol/g min.



- control; - the main phase of geomagnetic storm; - the recovery phase of geomagnetic storm.

The biological effects of different frequency ranges of geomagnetic storm and effects of Pc1-pulsations .





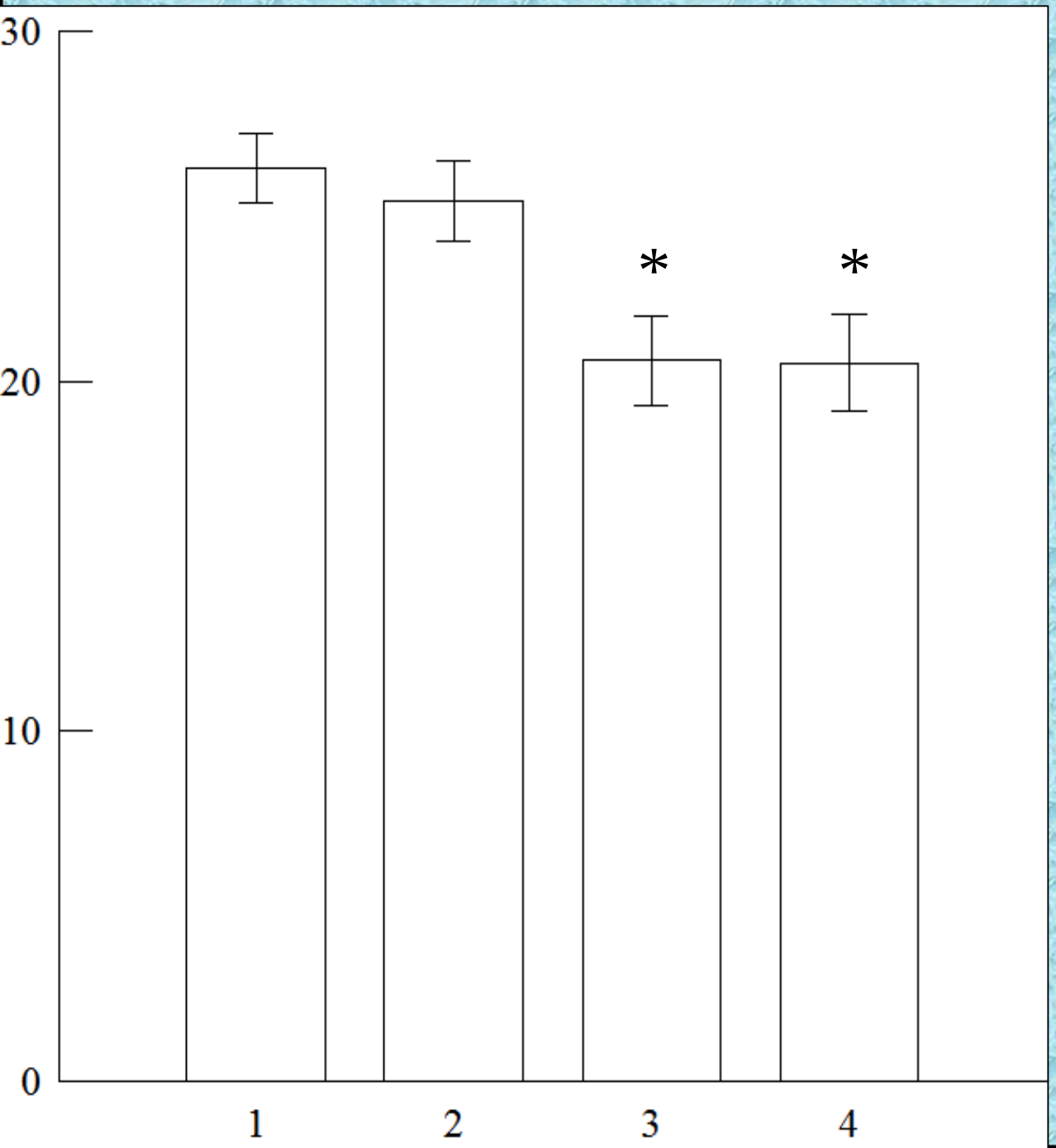
The concentration of diene conjugate (а) and Schiff base (б) content (conventional unit) in tissues of pea (*Pisum sativum*).

control (1),
Pc1-pulsations 2 hours (2),
Pc1-pulsations 1 hour (3),
Pc1-pulsations 0.5 hours (4),
the main phase of GMS 2 hours (5),
the main phase of GMS + Pc1-pulsations 2 hours (6),
the main phase of GMS 0.5 hour (7),
the main phase of GMS + Pc1-pulsations 0.5 hour (8).

Asterisk indicates a significant difference relative to control ($p < 0.05$) based on Dunnett's ANOVA test

Effect	Wilks	d.f. 1	d.f. 2	F
Pc1-pulsations	0,996911	2	168	0,26
the main phase of GMS	0,964756	2	168	3,069*
Interaction between Pc1 and GMS	0,999680	2	168	0,027

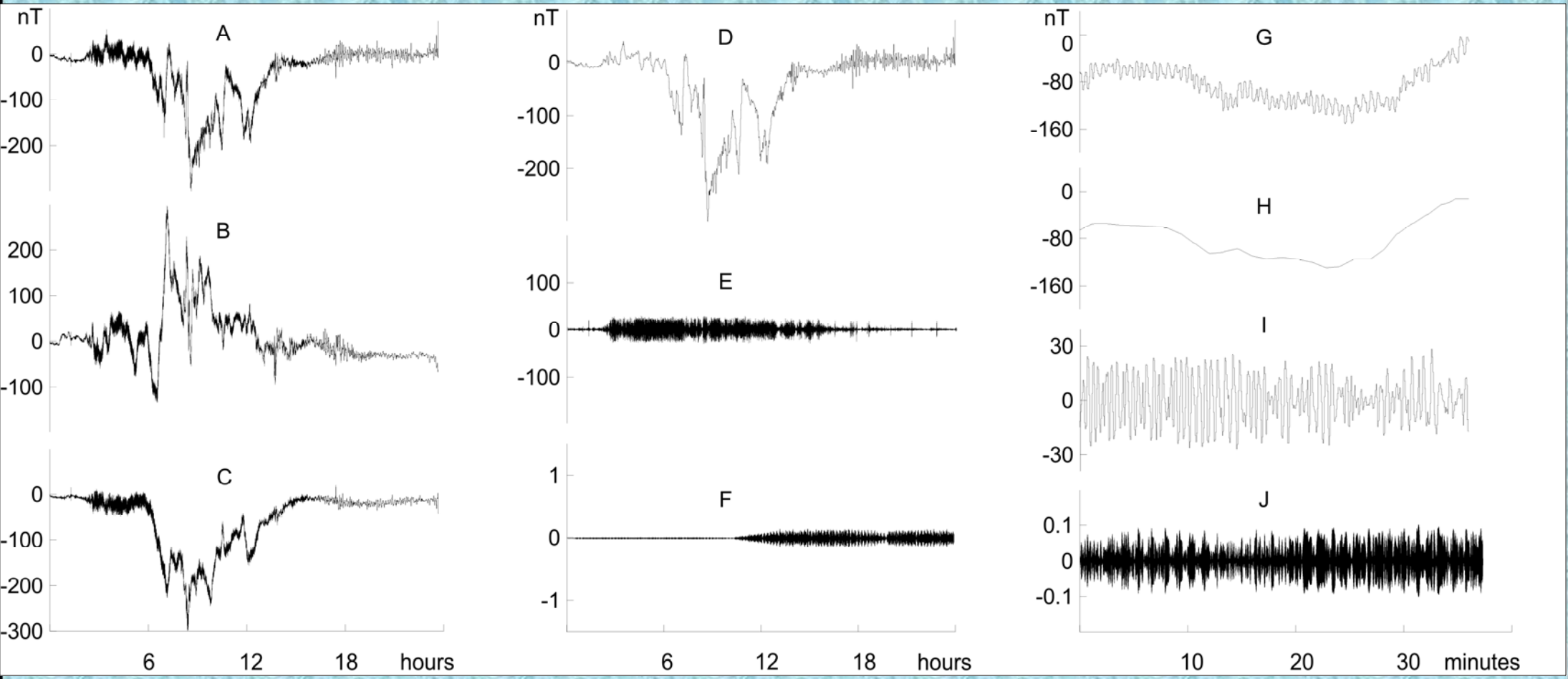
The angle of gravitropic response of flax (*Linum bienne*) footstalk.



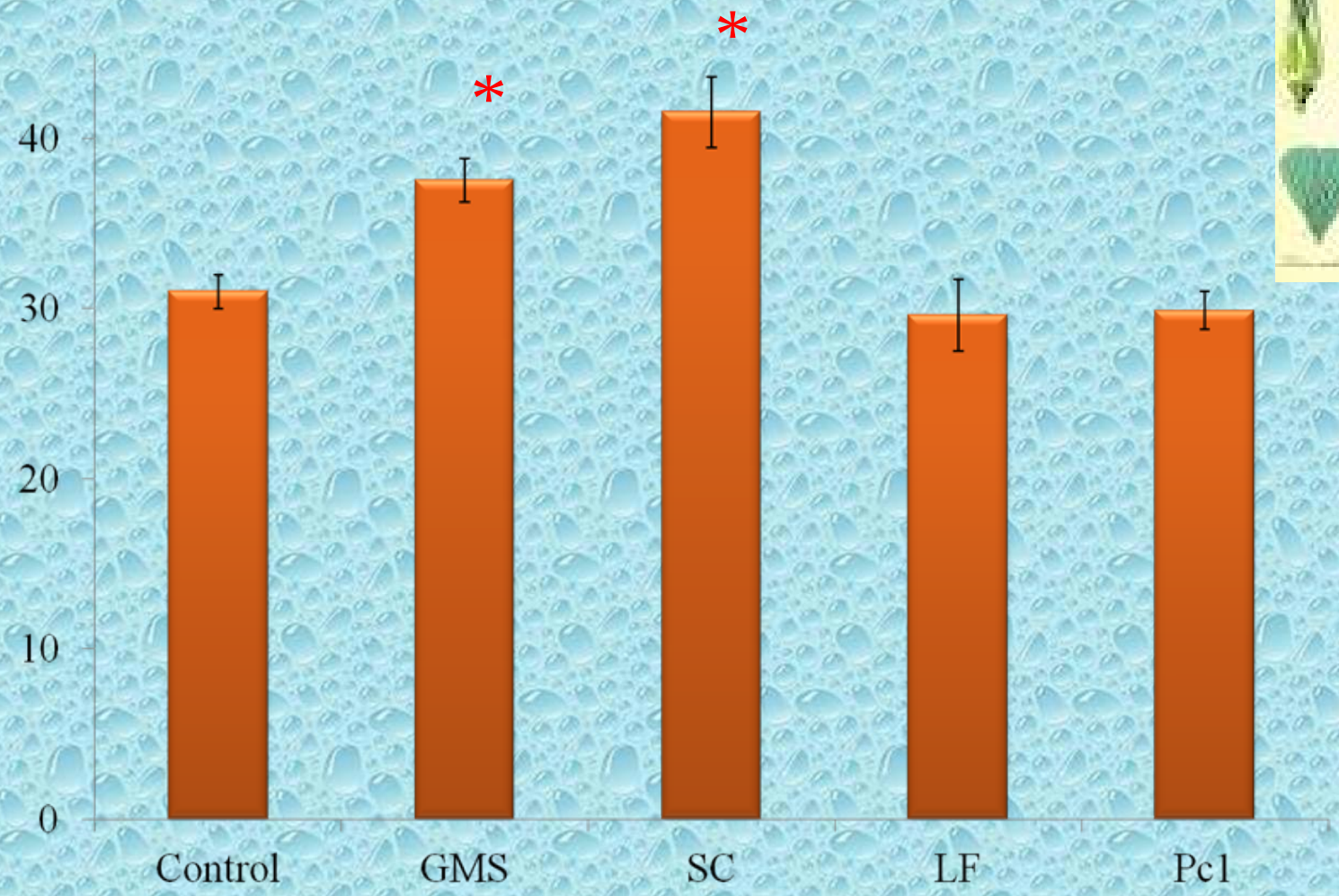
control (1),
Pc1-pulsations 2 hours (2),
the main phase of GMS 2 hours (3),
the main phase of GMS
+ Pc1-pulsations 2 hours (4).

Asterisk indicates a significant difference relative to control ($p < 0.05$) based on Dunnett's ANOVA test

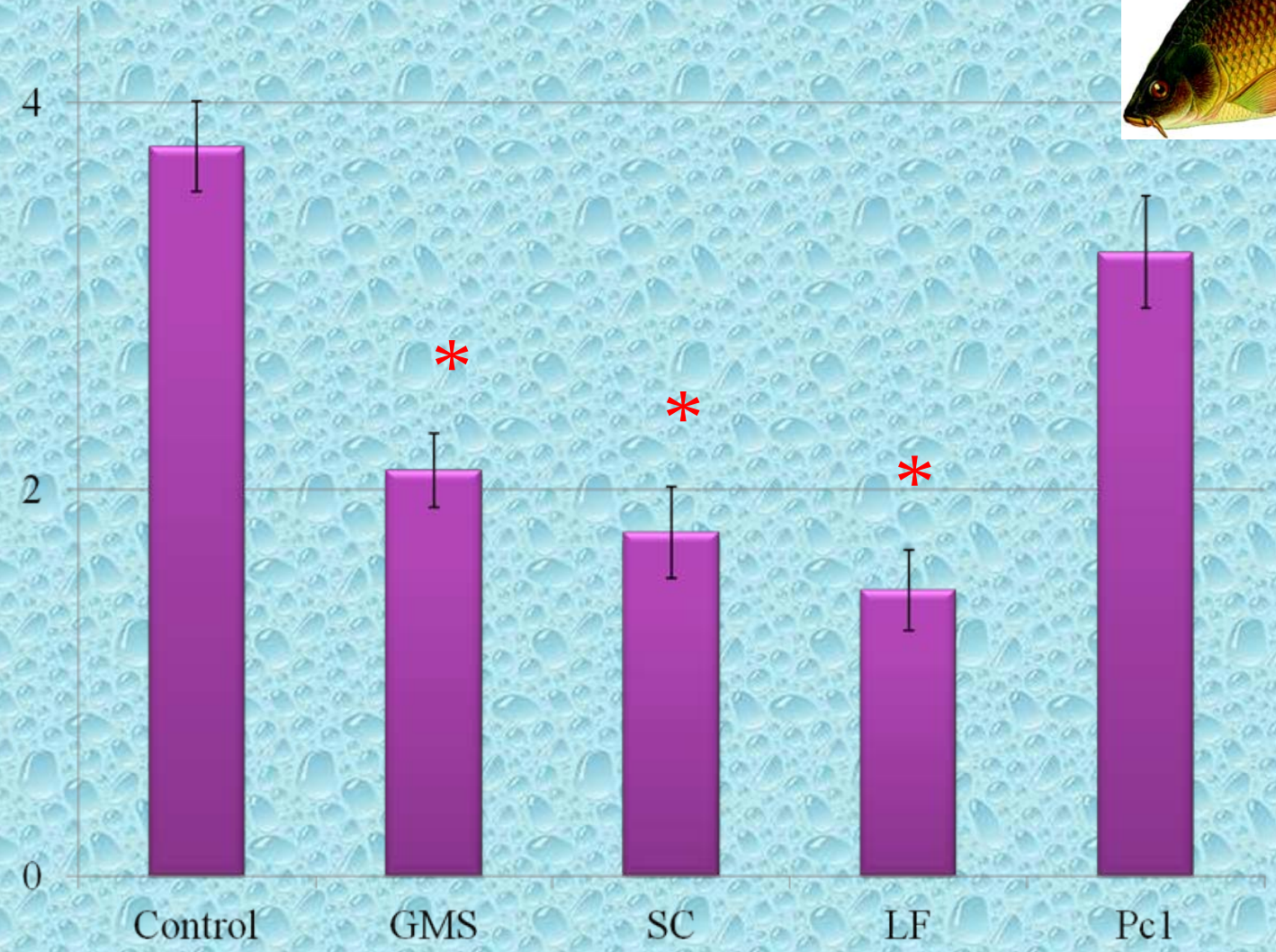
Effect	d. f.	MS	F
Pc1-pulsations	1	0,03	0,0004
the main phase of GMS	1	806,72	8,6703**
Interaction between Pc1 and GMS	1	1,74	0,0187
Error	153	93,04	


nT
A
0
-100
-200
B
200
100
0
-100
C
0
-100
-200
-300
6
12
18
hours
nT
D
0
-100
-200
E
100
0
-100
F
1
0
-1
6
12
18
hours
nT
G
0
-80
-160
H
0
-80
-160
I
30
0
-30
J
0.1
0
-0.1
10
20
30
minutes

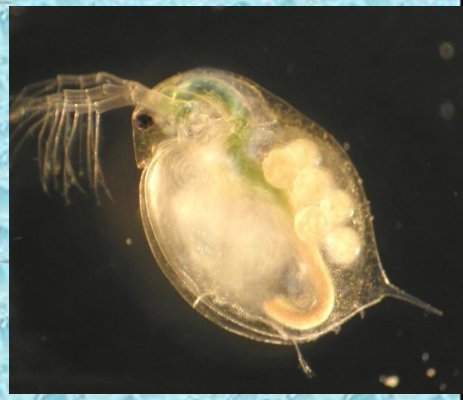
The angle of gravitropic response of flax (*Linum bienne*) footstalk.

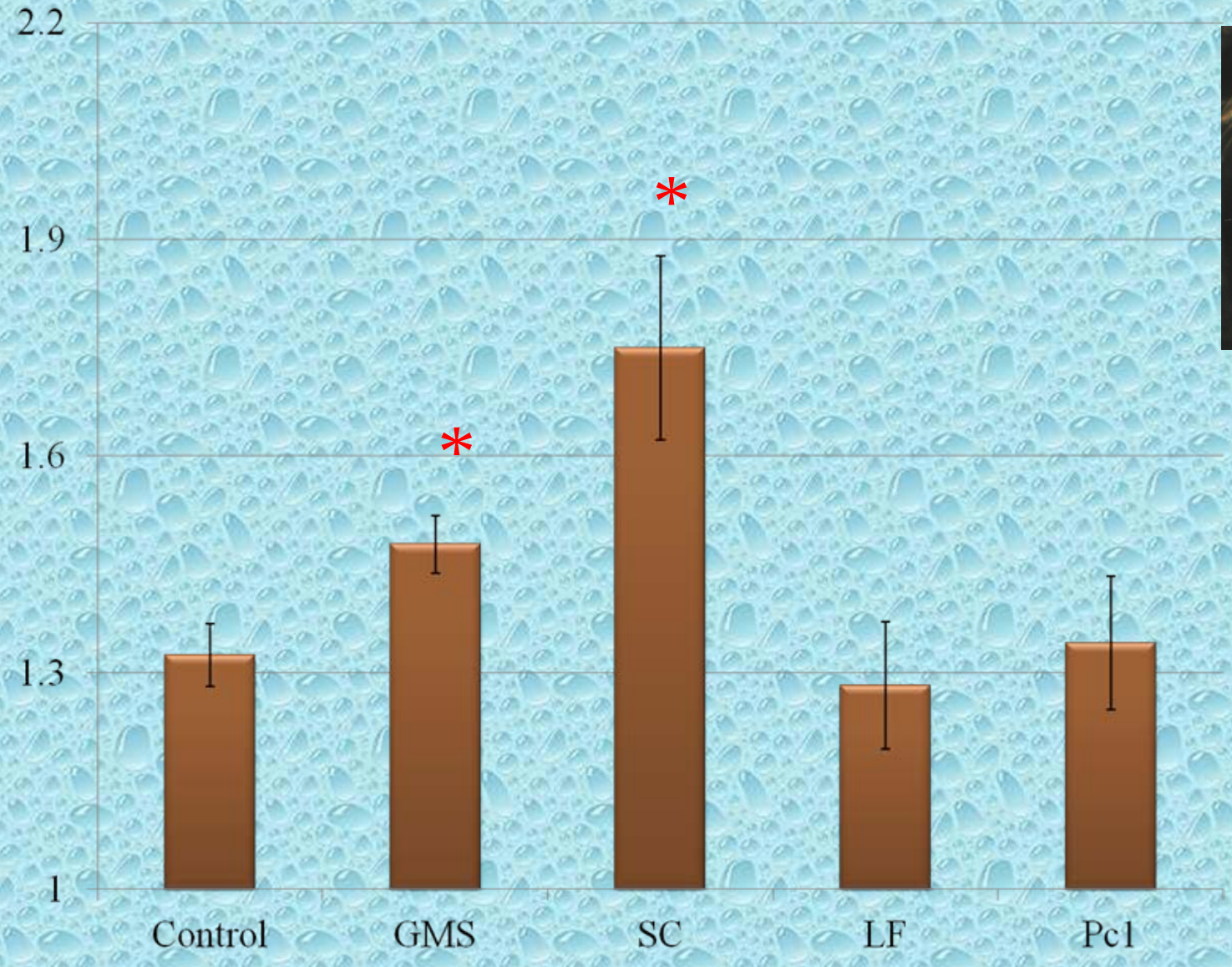


The proteolytic activity in carp, μmol/g min.

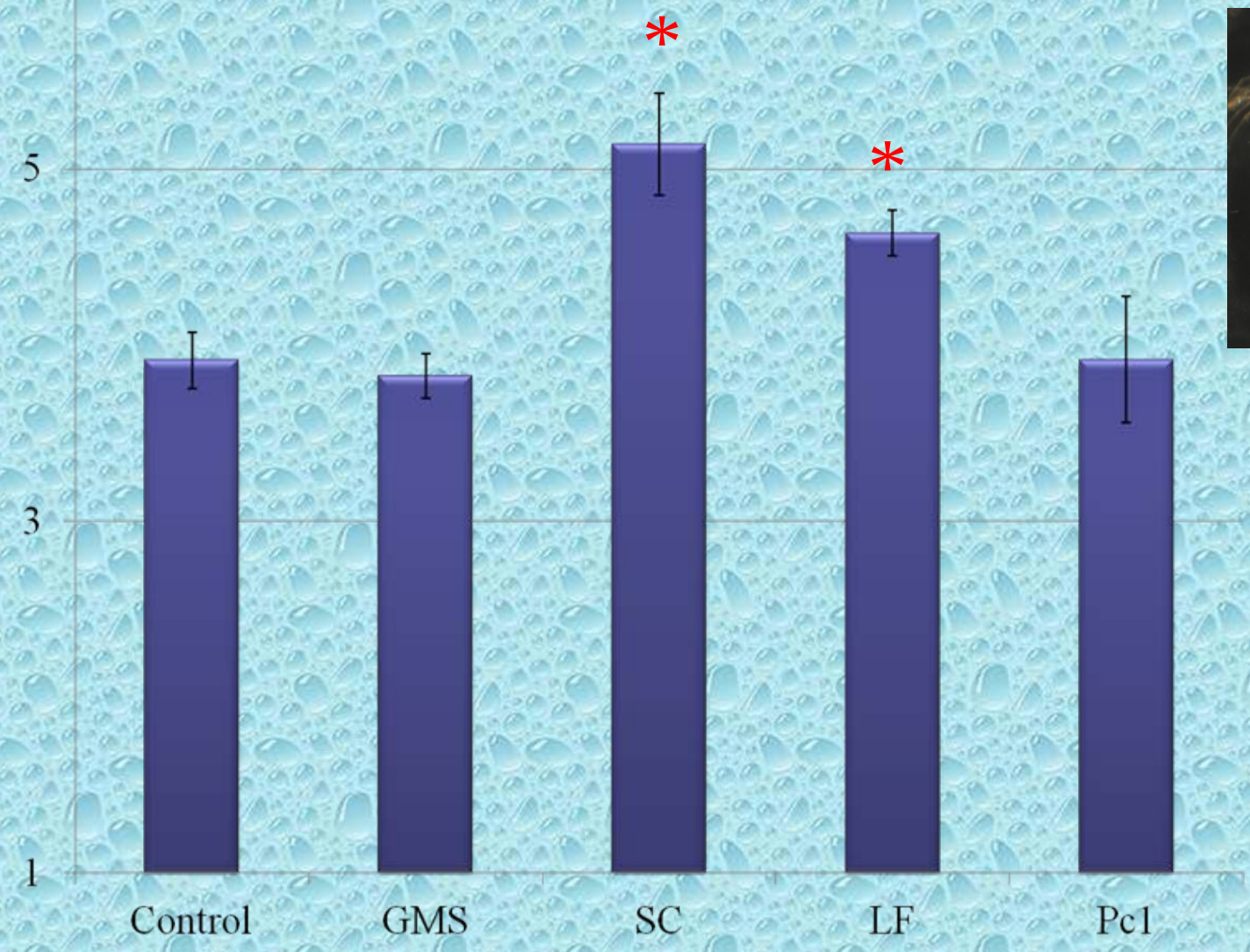


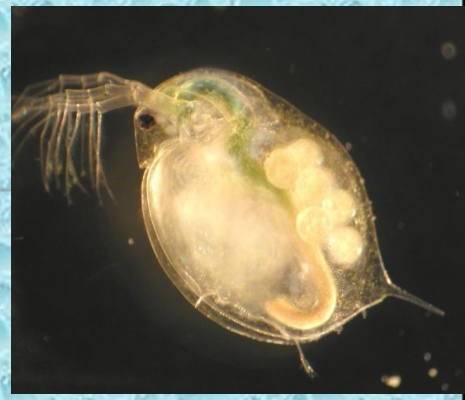
The concentration of malondialdehyde in *D. magna*, pmol / mg protein



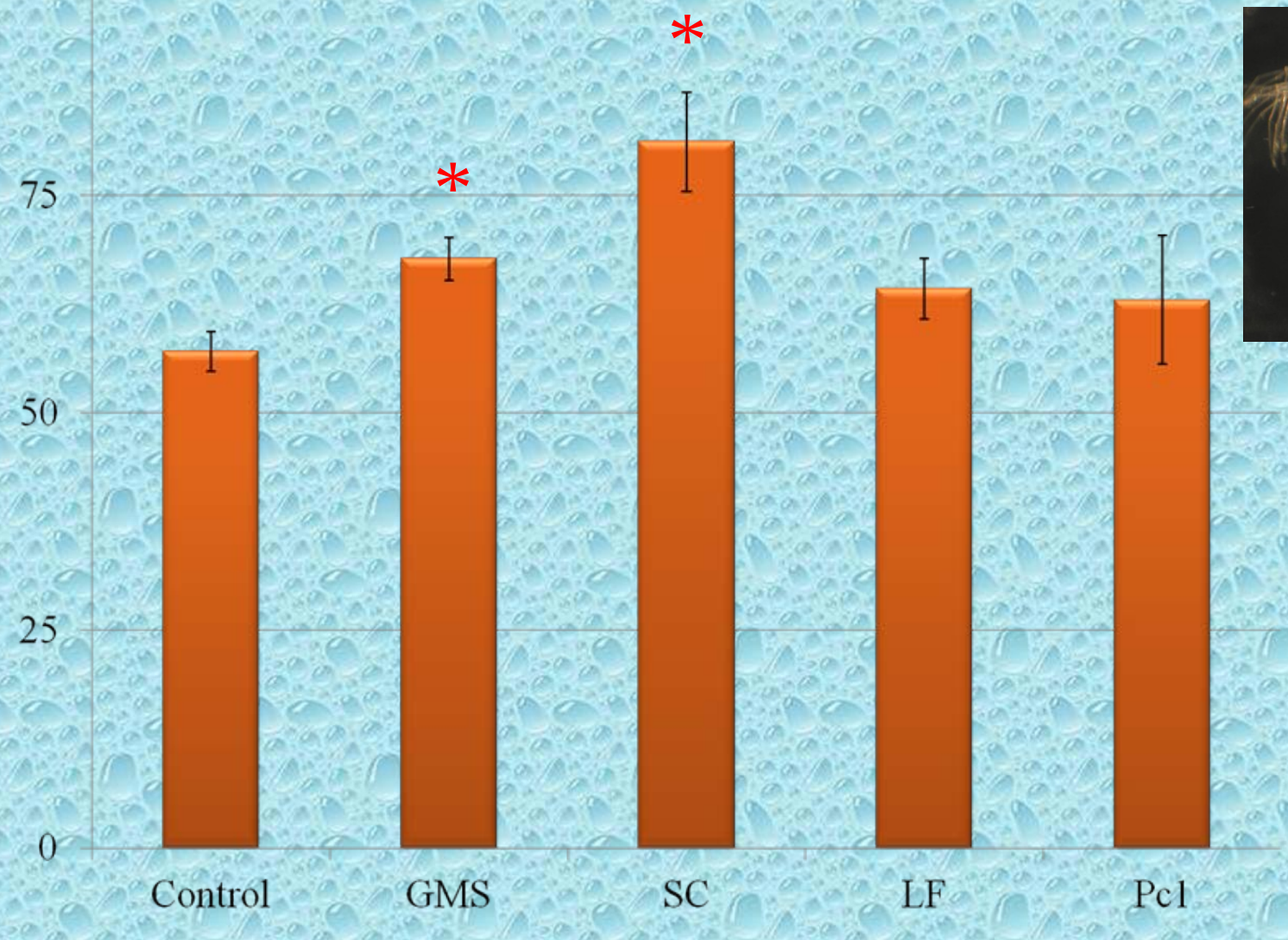


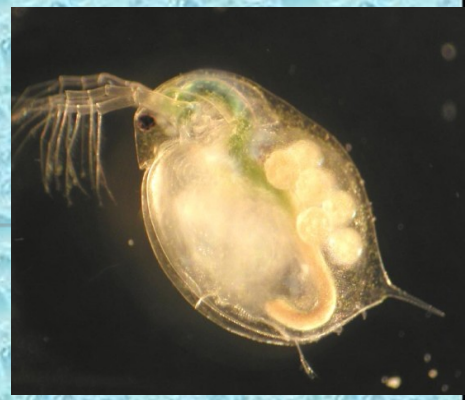
Catalase activity in *D. magna*, nmol / µg protein / min



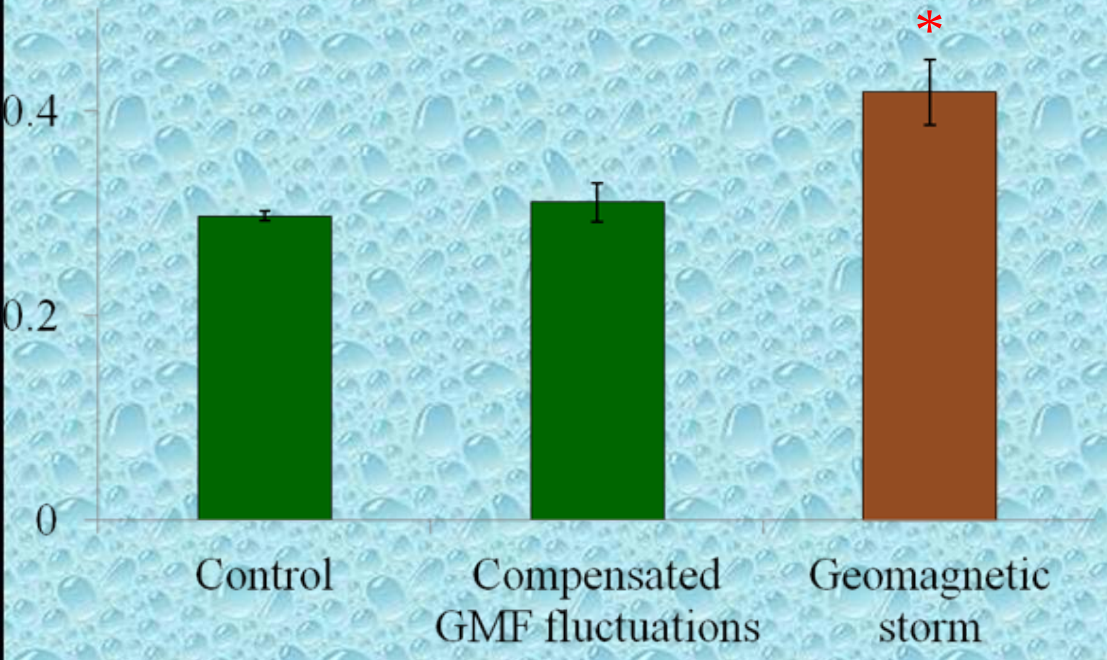


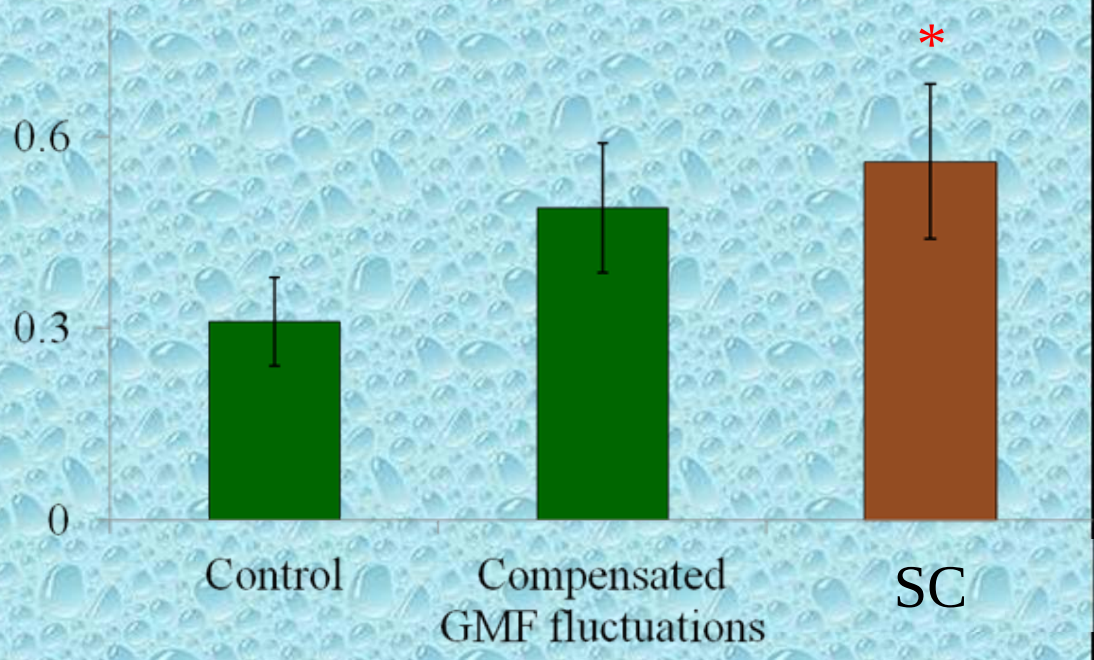
Superoxide dismutase activity in *D. magna*, nmol / µg protein / min

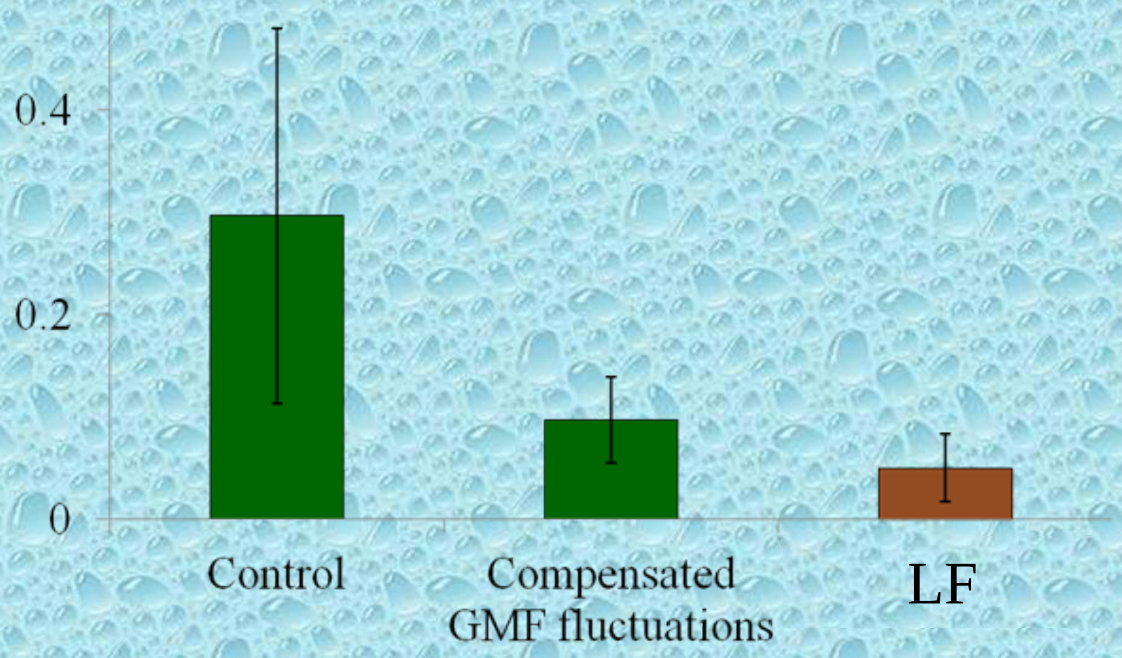




Total RNA content (µg/ml) in *Daphnia magna* after exposure to geomagnetic storm and its components

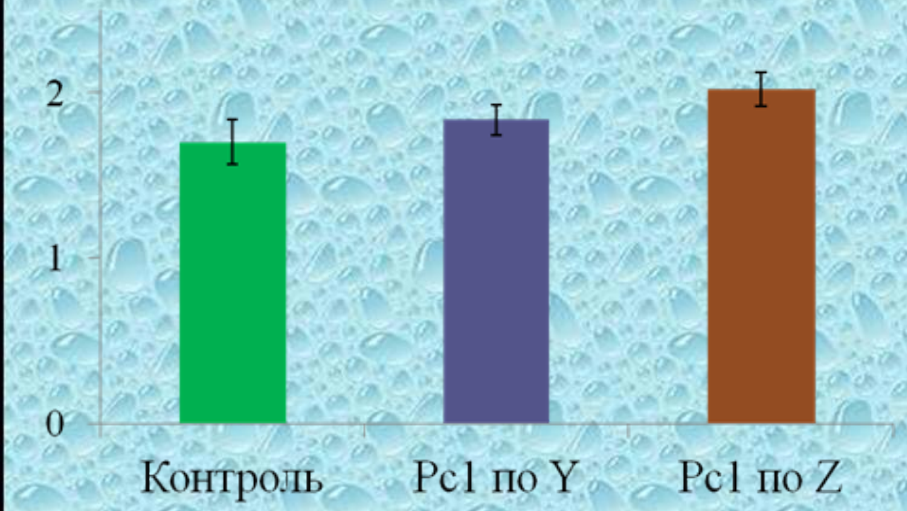




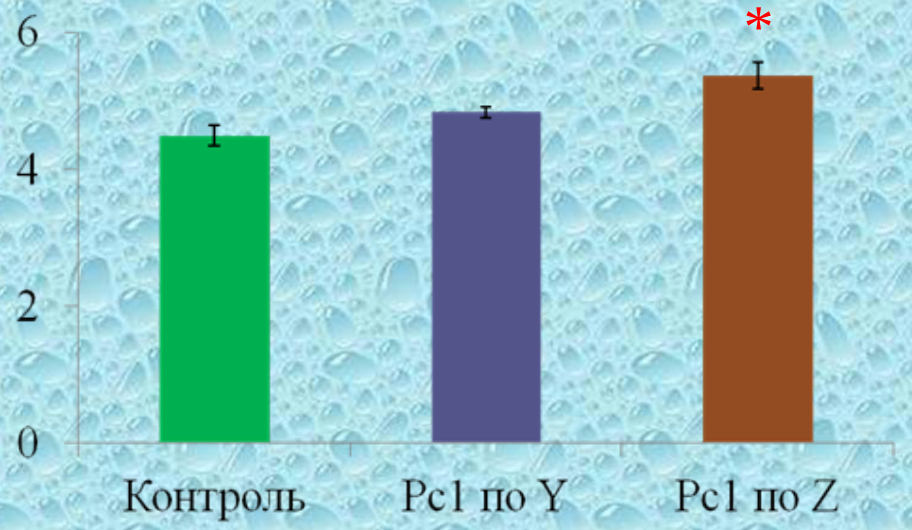


The impact of Pc1 pulsations directed perpendicular or collinear to the geomagnetic field on biochemical characteristics in *D. magna*

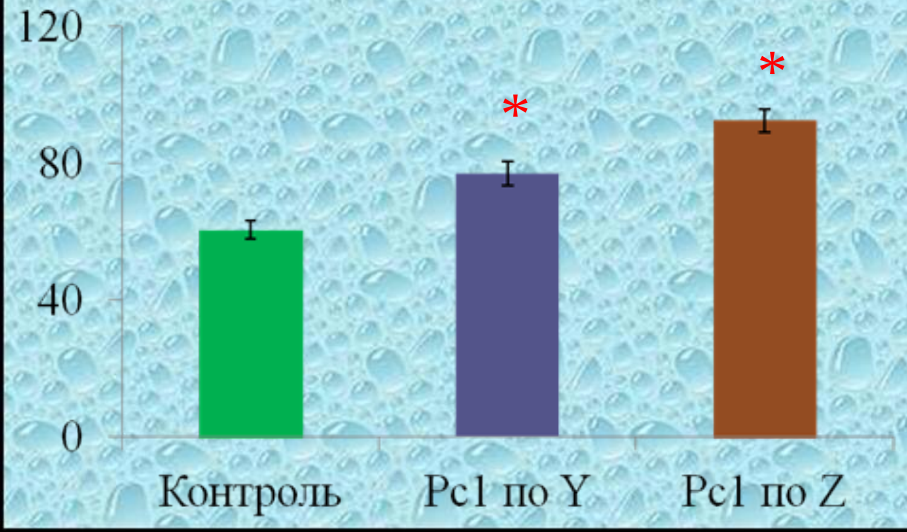
The concentration of malondialdehyde, pmol / mg protein



Catalase activity, nmol / µg protein / min

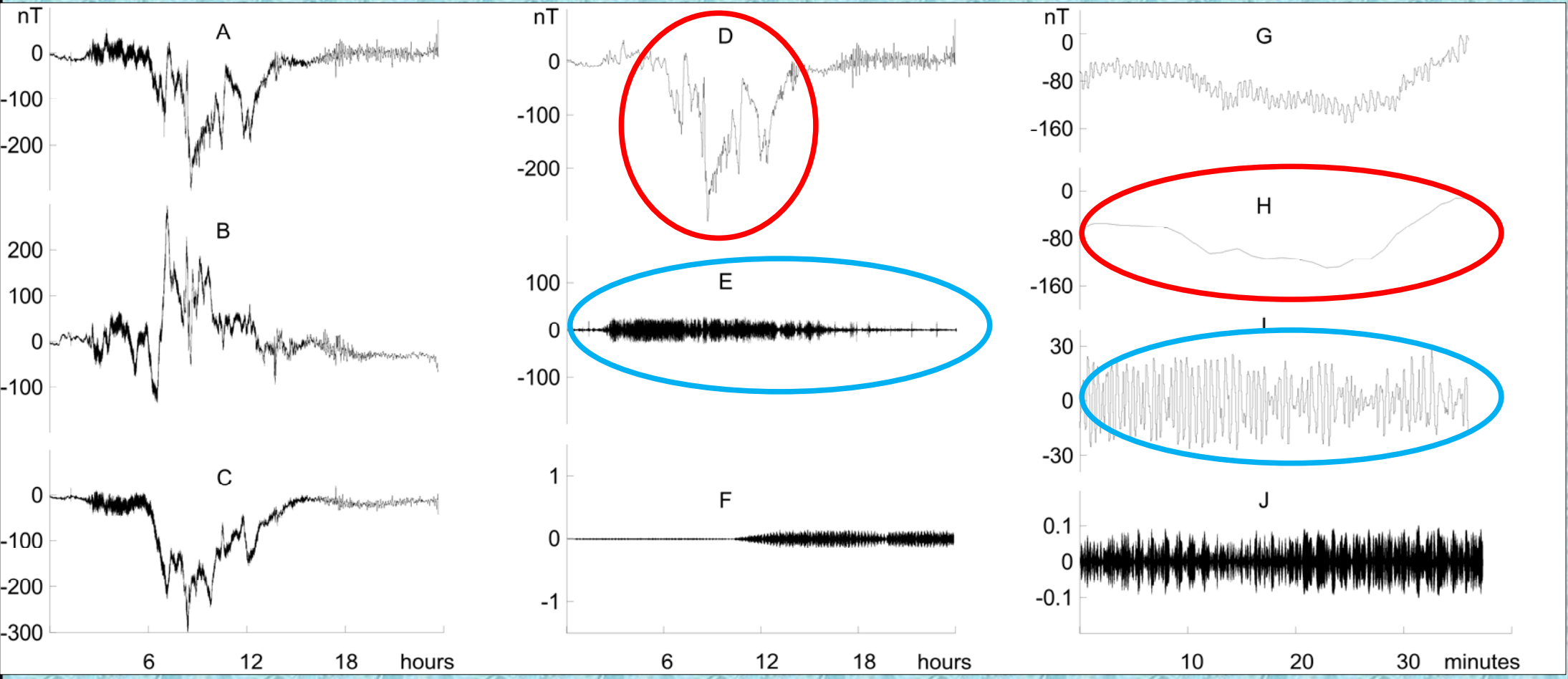


Superoxide dismutase activity, nmol / µg protein / min



Asterisk indicates a significant difference relative to control ($p < 0.05$) based on Dunnett's ANOVA test

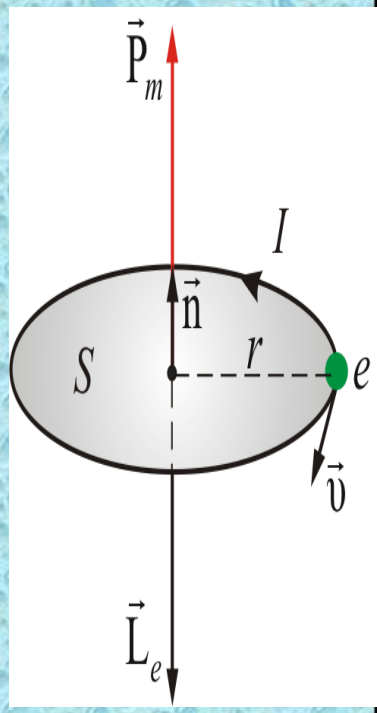
1. The angle of gravitropic response of flax (*Linum bienne*) footstalk
2. The proteolytic activity in carp (*Cyprinus carpio*)
3. The concentration of malondialdehyde and superoxide dismutase activity in *D. magna*
4. The concentration of diene conjugate and Schiff base content in pea (*Pisum sativum*)
5. Total RNA content (µg/ml) in *Daphnia magna*

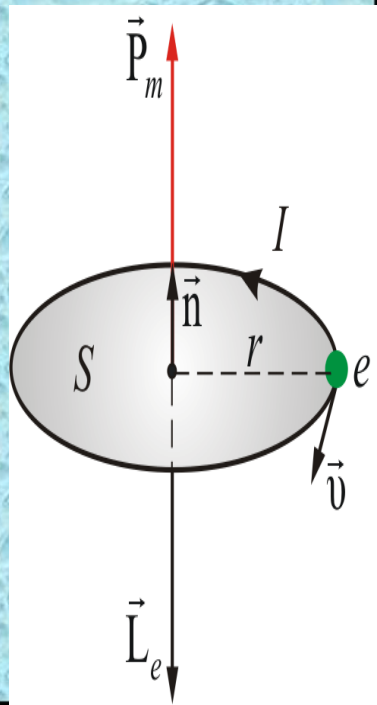


1. The proteolytic activity in carp (*Cyprinus carpio*)
2. Catalase activity in *D. magna*

Take account of “unperiodicity” and slowness of effective signals (slow changes in range of 0-0.001 Hz), we suppose that that biological effects of GMS are not connected with the alternating fluctuations of geomagnetic field during this process.

The resonance mechanisms of the biological effects of weak combined magnetic fields are well studied and confirmed by numerous experiments (Blanchard and Blackman, 1994; Lednev, 1991; Liboff, 1985). According to some of these models, the frequency of the self-oscillations of ions into protein cavities changes depending on mass and charge with changing in the GMF taken as static component of combined magnetic fields (see, for example, Lednev, 1991). Another model postulates that the frequency of the Larmor precession of nuclear spin of atom changes depending on gyromagnetic ratio with changes in the GMF (Belova et al., 2007; Belova et al., 2010). These self-oscillation processes in biological systems have resonance (and thereby can be detected) at application of an external alternate magnetic field (alternating component of combined magnetic fields) with the strength and frequency matched with described oscillatory processes (Belova and Panchelyuga, 2010). We suppose that above mentioned self-oscillations there selves are involved in biological processes. In this case the modulation of particles' oscillations may be provoked by the changes in the GMF.





A possible mechanism:

In accordance with the works devoted to the parametric resonance in biological systems, changes of GMF about 100 nT (moderate GMS) lead to the shift of the frequency of self oscillations of ions depending on mass and charge,

$$f_n = \frac{1}{2\pi}\frac{q}{m}B_{DC}$$

and the frequency of the Larmor precession of nuclear spin of atom changes depending on gyromagnetic ratio

$$\omega_L = \frac{e\vec{B}}{2m} = \gamma\vec{B}_{DC}$$

about 0.2 – 0.4 % from its initial value. At first sight, this change seems negligible, but we have to take into account following. All of the self-oscillations which depend on magnetic field are shift when GMS occurs. In contrast, only specified particles are target when an alternating magnetic field applies against the GMF background. In addition, ions with different mass simultaneously change the frequency of self-oscillations on different value when the GMF intensity during GMS changes. It may be perceptible, for example, for the enzymes consumed simultaneously two or more different ions as a coenzyme

Besides the obvious effects of slow gradient changes of intensity of geomagnetic field, the low-frequency fluctuation of the geomagnetic field in the range of frequency up to 5 Hz and amplitude to 40 nT affect enzymes activity in two experiments. These fluctuations (when strength and frequency become specific values) may impact on of the Larmor precession of nuclear spin of atoms which contains in biological objects in accordance with Lednev's model. But the cumulative data show the efficiency of this factor considerably less than slow gradient changes of intensity of the geomagnetic field during GMS.

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