LOFAR meeting, APC Laboratory, Paris, 17-18 January, 2008

Low Frequency Radio Astronomy with the existing and future radio telescopes

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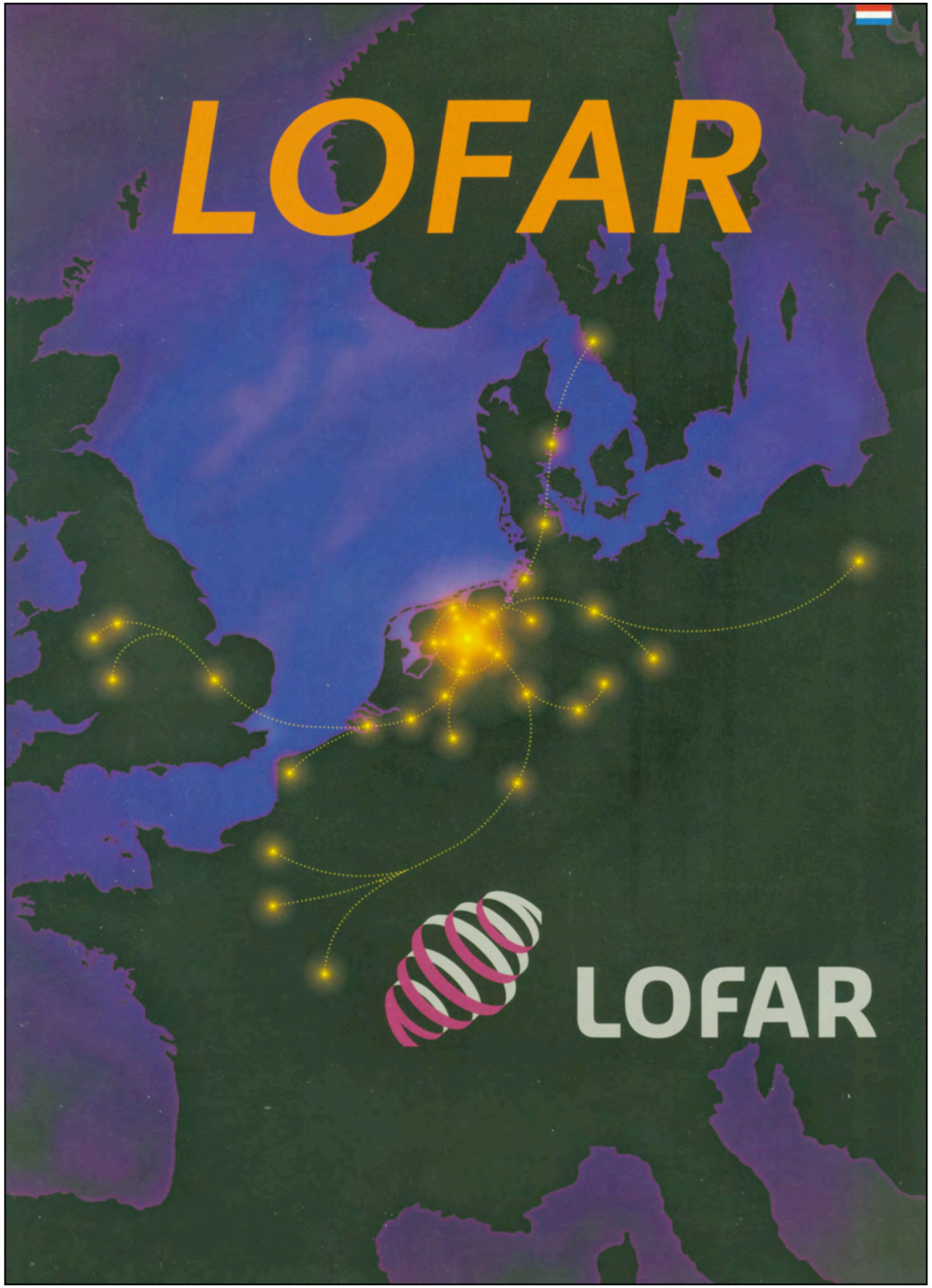
ABSTRACT. ***Radio astronomical investigations at low frequencies (meter-, decameter range) are very important for the astrophysics science. Just at low frequency a lot of physical events in the Universe become most pronounced and even unique. In particular, such phenomena were described in detail in the "LOFAR scientific application" edited by M. van Haarlem. Mention above work represents a list of problems which are important for the future investigation with the new generation telescopes. In the given review we prove an availability of future research by the demonstration and generalization the results of studying solar system, galaxy and metagalaxy with the existing largest wide-band instruments (UTR-2, URAN1…URAN4, NDA). We show the earlier results as well as the modern, for instance, we present the Saturn electrostatic discharges which were recently observed by the UTR-2 telescope. In the Ukraine begin a realization of new program for perspective development of the low frequency radio astronomy. This program includes the further modernization of UTR-2 radio telescope and also the creation of new large telescope of 10 – 70 MHz frequency range. The combination of LOFAR and already existing instruments will permit to get unexampled angular resolution due to the reaching the base in order of 2000 km.***



LOw Frequency Array

The Nethelands, USA

F = 20-90 MHz,

110-250 MHz

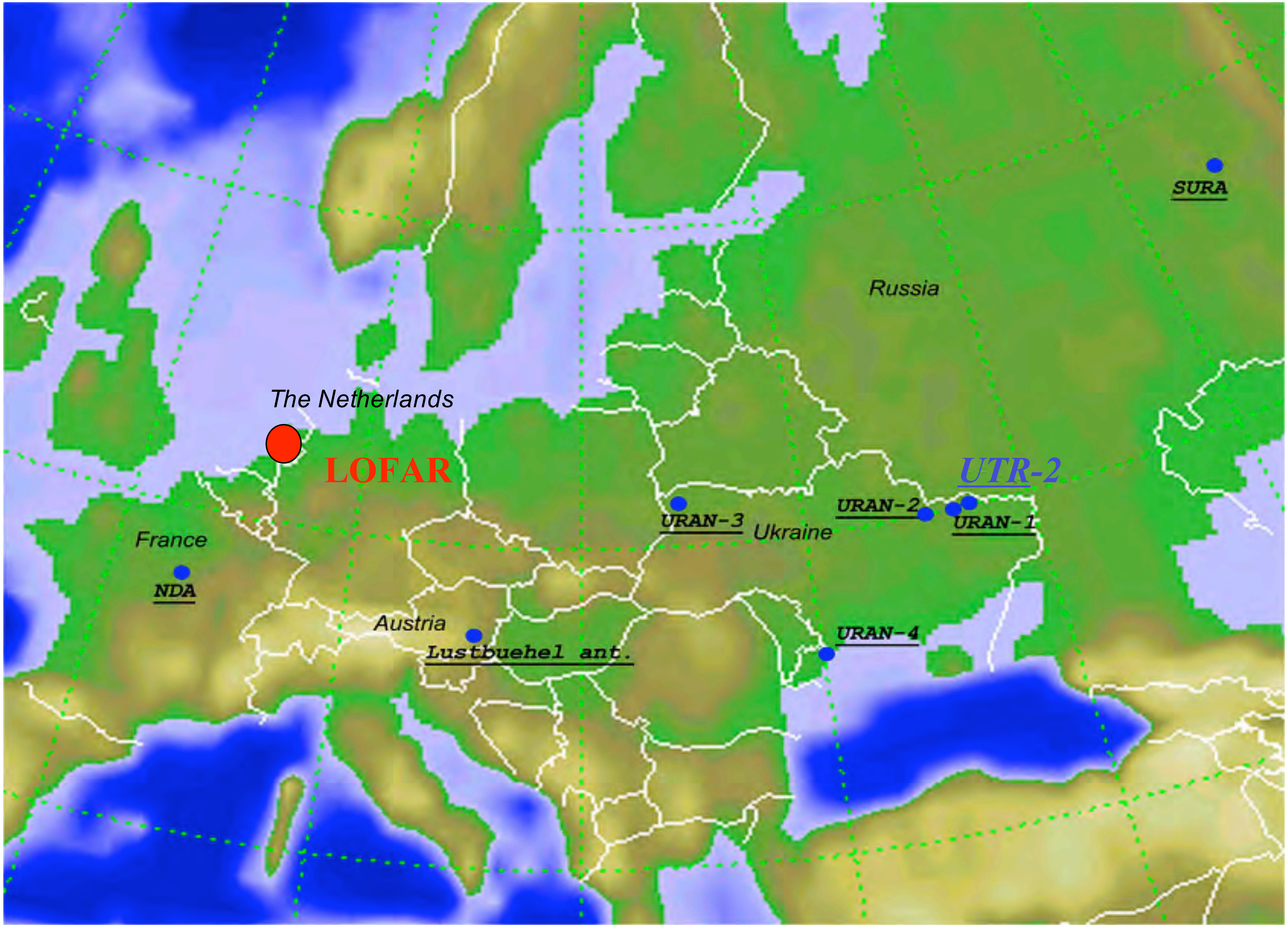
A = 1 000 000 sq.m

D = 400 km

Start in operation **2009.**

LOFAR antenna elements

(April, 2007, Emmen, “Astrophisycs in the LOFAR era”)



The low-frequency radio telescopes in Europe

The UTR-2 radio telescope, N-S arm (1.8 km×60m)

f = 8…32 MHz, **$A_{eff\,max}$ = 150 000 sq.m**

The UTR-2 radio telescope, E-W arm (900m×60m)

March 23, 2007




URAN-1…URAN-4 radio telescopes

Existing instrumentation [1-4]

In Fig.1 the distribution of existing decameter radio telescopes on European territory is shown. Fig.2, 3 illustrate the view of largest antennas, and their parameters are summarized in Table 1. During the last year new high performance back-end facilities were installed into this antennas.

Digital spectral processor (DSP):

frequency band 12.5 MHz; number of channels 1024; frequency res. 12kHz; time resolution 1 ms; dynamic range (12 - bit ADC) 70 dB.

Digital spectral processor II (ROBIN)):

frequency band 14 MHz; number of channels 2048; frequency res. 400 Hz-7kHz; time resolution 0.5 ms; dynamic range (12 - bit ADC) 70 dB.

Digital spectral processor III (DSP):

frequency band 33 MHz; number of channels 16000; frequency res. 400 Hz-7kHz; time resolution 0.5 ms; dynamic range (16 - bit ADC) 80 dB.

Wave form receiver (WFR):

frequency band 12.5 MHz; time, frequency res. - practically unlimited; dynamic range (12 - bit ADC) 70 dB.

Filter bank (FB):

frequency band 10-30 MHz; number of channels 60; frequency res. 0.3-10 kHz; time resolution 10 ms.

Digital autocorrelometer (DAC):

frequency band 1-30 MHz; number of channels 4096; frequency res. < 1 kHz; 1- bit ADC.

Many experiments were carried out with this instrumentation.

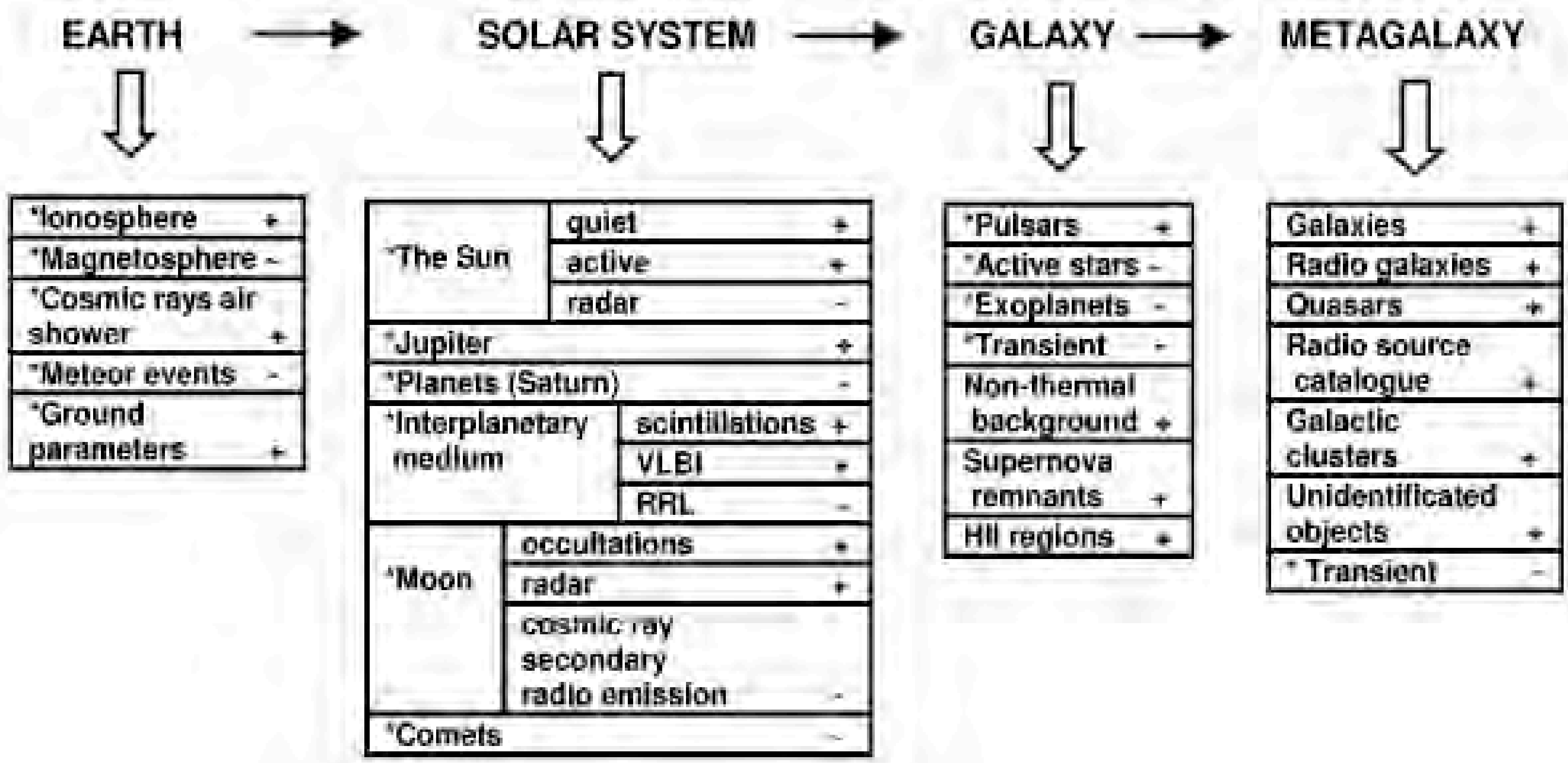
Table 1: Main parameters of existing decameter wavelengths radio telescopes

Radio telescopes	Locations	Frequency range, MHz	Maximum effective area, m^2	Number of elements, polarization	Distance to UTR-2 (LOFAR), km	Angular resolution at 25 MHz
UTR-2	Kharkov, Ukraine	8 – 32	150 000	2040 1 linear	0 ($\sim$ 2000)	$25' \times 25'$
URAN-1	Zmiev, Ukraine	8 – 32	5500	96 2 linear	42 ($\sim$ 1900)	60"
URAN-2	Poltava, Ukraine	8 – 32	28 000	512 2 linear	120 ($\sim$ 1800)	21"
URAN-3	Lviv, Ukraine	8 – 32	14 000	256 2 linear	915 ($\sim$ 1000)	2.7"
URAN-4	Odessa, Ukraine	8 – 32	7300	128 2 linear	613 ($\sim$ 1500)	4.0"
NDA	Nancay, France	8 – 88	2×4000	2×72 2 circular	3000 ($\sim$ 500)	$\sim$ 1.0" (potentially)
SURA	N.Novgorod, Russia	4 – 9	40 000	144 2 linear	1500	Trans. power $\sim$ 150 MWt

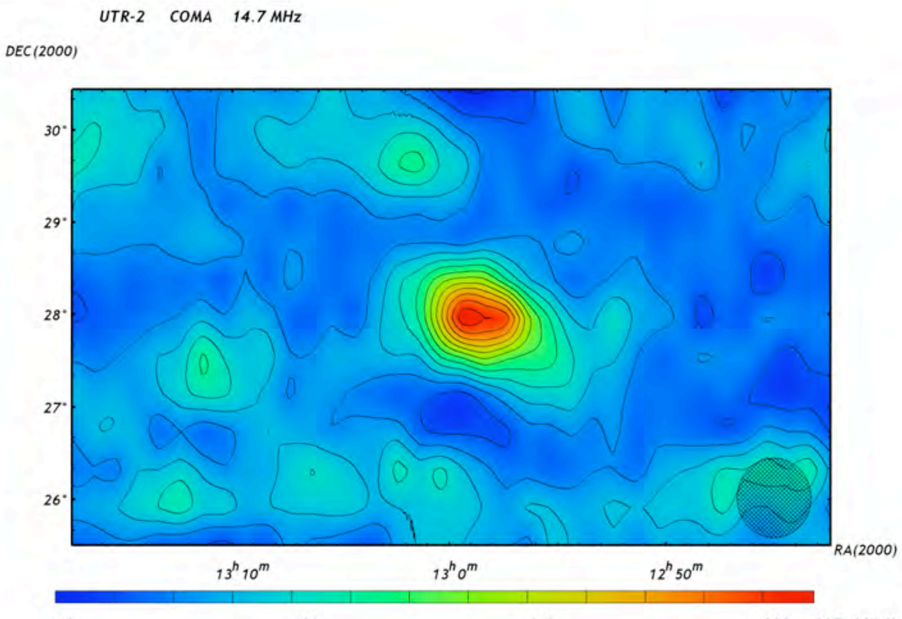
Table 2: *Comparison of existing and future low-frequency instruments principal parameters*

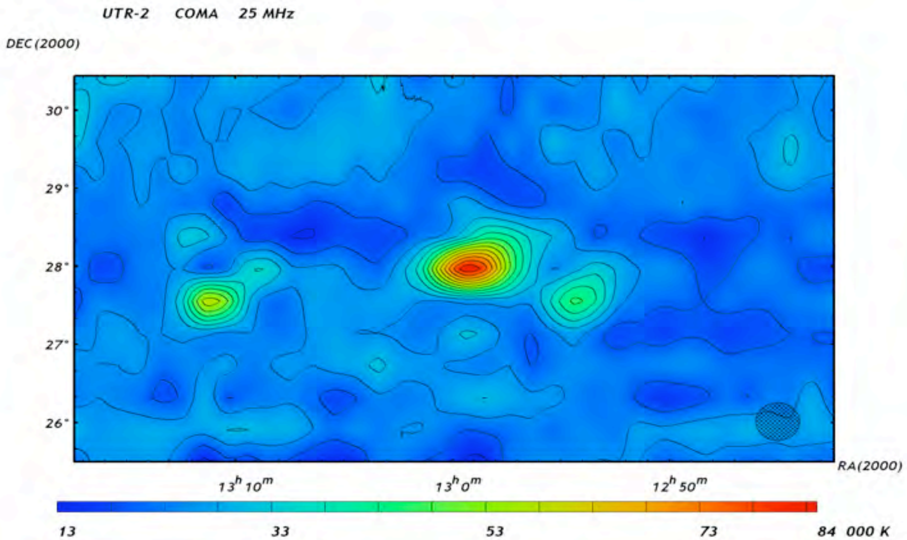
Nr.	Parameter	UTR-2, URAN, NDA	LOFAR	LWA
1	Frequency range, MHz	8...32 (NDA-8...88)	10...240	20...80
2	Number of stations	6	100	50
3	Total number of elements	~ 3000	$\sim 13\,000$	$\sim 12\,500$
4	Total number of antenna elements for one polarization	~ 4000	$\sim 26\,000$	$\sim 25\,000$
5	Number of elements per station	96 ... 1440	128	250
6	Station size, m	$28 \times 240 \ldots 60 \times 1900$	$\sim 100 \times 100$	~ 100 diameter
7	Maximum baseline, km	950	~ 350	~ 400
8	Minimum baseline, km	~ 0.1	~ 0.1	~ 0.1
9	Maximum angular resolution (25 MHz)	$\sim 3''$	$\sim 6''$	$\sim 6''$
10	Field of view, degree	2...20	all-sky	3...12
11	Electronic steering, degree	± 80	multi-beaming	multi-beaming
12	Polarization	2 (5 stations)	2	2
13	Maximum observable bandwidth, MHz	10 ... 20	32	3
14	Spectral resolution, kHz	0.1...12	< 1	< 1
15	Time resolution, ms	1...100	1	10
16	Summarized total effective area (25 MHz), m^2	$\sim 200\,000$	350 000	900 000
17	Virtual core (VC) size, km	2×1 (UTR-2)	2×2	5×5
18	VC max. eff. area (25 MHz), m^2	150 000 (UTR-2)	100 000	300 000
19	VC stations number	12 (UTR-2)	~ 25	~ 17
20	VC elements number per station	150 and 180 (UTR-2)	128	250
21	Limit of the confusion effect sensitivity for the continuum point radio source (25 MHz)	< 1000 mJy	< 1 mJy	< 1 mJy
22	Sensitivity of radio emission without the confusion effect (25 MHz, $\tau = 1$ h, $B = 4$ MHz)	~ 10 mJy	~ 1.5 mJy	~ 1.5 mJy

The diagramme bellow illustrates the set of objects and tasks which are investigated with the UTR-2 , URAN-1...URAN-4. It can been seen that this set is in good accordance with the future scientific program of LOFAR [5-7].



Continuum stationary radio emission



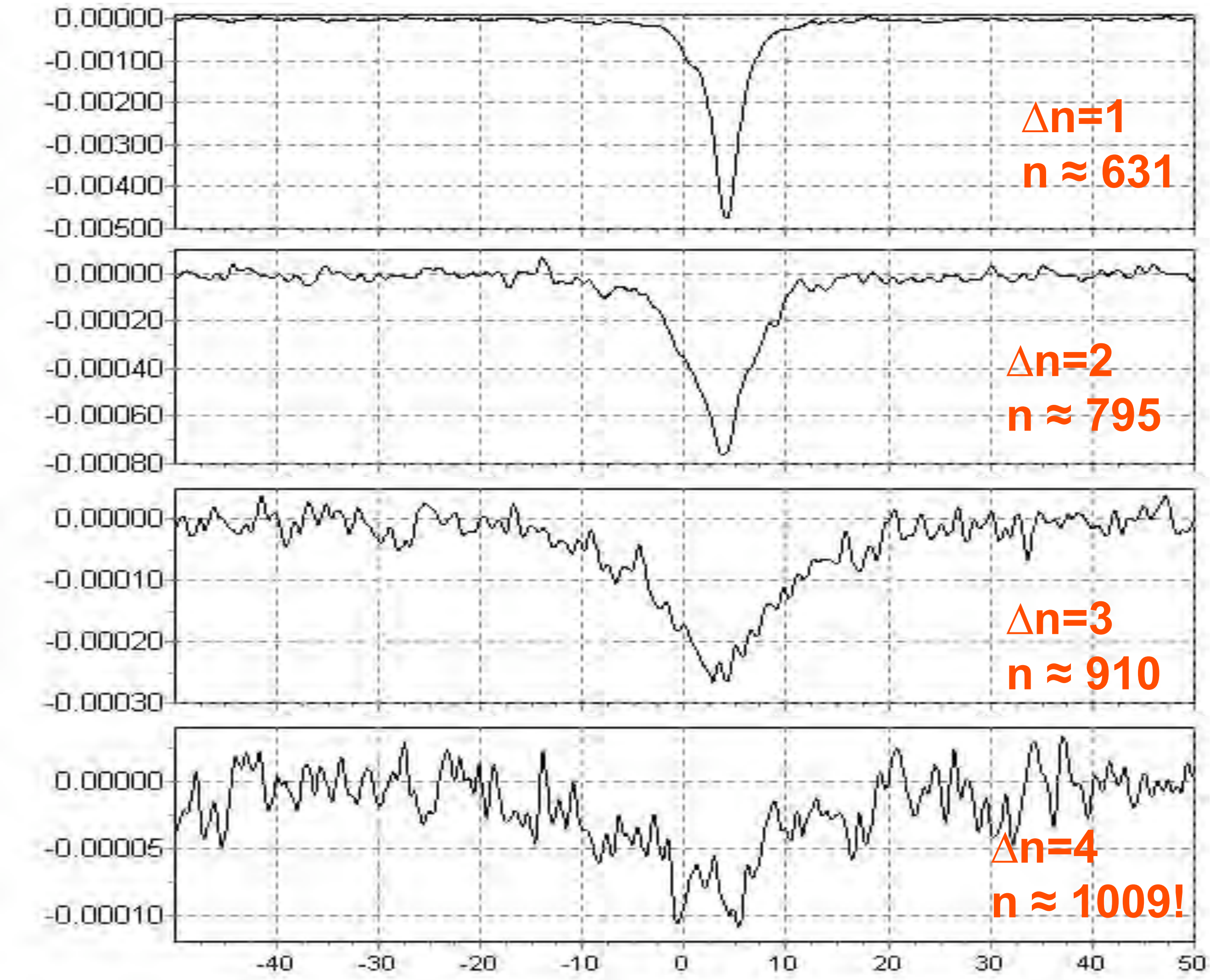


Here we present some illustrations of the UTR-2 and URAN results for the astrophysical objects with the fine structure of spectral, temporal and spatial radio emissions. These results demonstrate the high astrophysical significance of the low-frequency radio astronomy and good perspectives for the investigations with the future new generation giant radio telescopes.

UTR-2 radiomap of Coma cluster (Krymkin, Sidorchuk). The sensitivity for this kind radio emission is limited by the confusion effect (for UTR-2 it is near 1 Jy)

Fine spectral structure radio emission

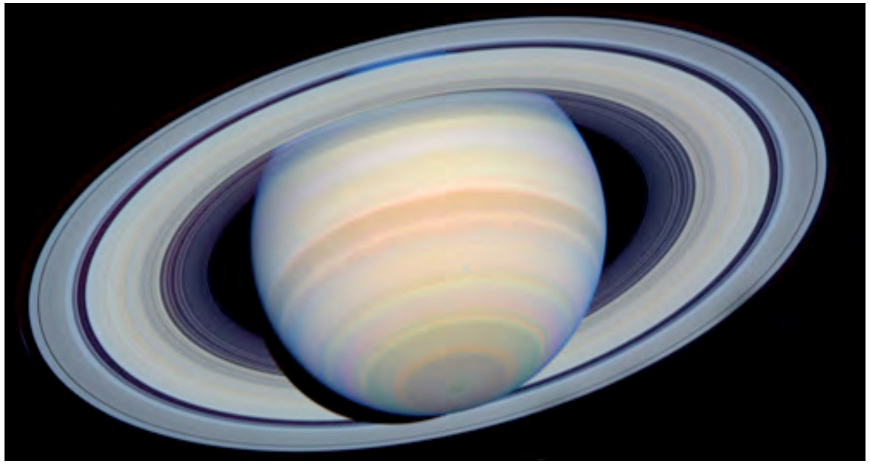
Carbon RRL‘s towards Cas A, UTR-2, 26 MHz

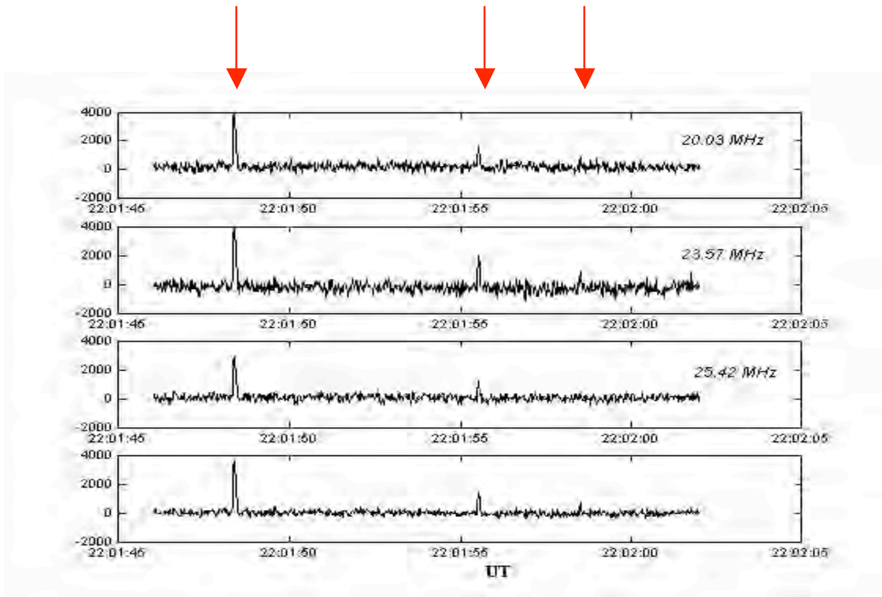


Detection of carbon RRL‘s with recordly high principal quantum number n~1000 (Stepkin, Konovalenko, Kantharia, Udaya Shankar). There is no restriction by the confusion effect (reached sensitivity after time and lines averaging is at the level of few mJy).

D ≈ 0.1mm !

Fine time structure radio emission





Detection of SED by the ground-based instrument
(UTR-2, 20-25 MHz, February, 2006)

New instrumentation and methods for the ground-based SED search

UTR-2 Radio Telescope (IRA NASU, Kharkov, Ukraine) is the world largest decameter array:

-frequency range B = 8...32 MHz (there is overlap with the Cassini RPWS receiver, i.e. 8...16 MHz);

-time of the electronic steering t = 8 h per day;

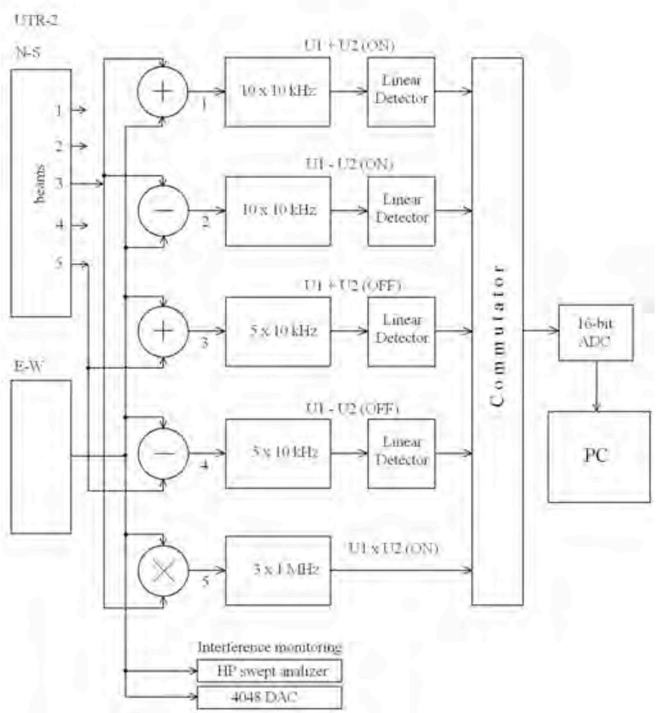
-beam width Θ = 25 arcmin;

-max effective area A = 150, 000 sq. m;

-highest sensitivity at 20...25 MHz (for time and frequency resolutions of 0.1 s and 1 MHz)

$$\mathbf{\delta S_{min} = 5\ Jy << S_{Earth} \approx 10^3\ Jy\ (!!!)}$$

SED search with UTR-2



The criteria for UTR-2 SED detection:

1. Presence in ON_1 regime (Central beam (N3)); $(U_{NS} + U_{EW})^2{}_{3.}$
2. Absence in OFF_1 regime (Central beam (N3)); $(U_{NS} - U_{EW})^2{}_{3.}$
3. Presence in ON_2 regime(Central beam (N3) – pencil beam:
   $(U_{NS} + U_{EW})^2{}_3 - (U_{NS} - U_{EW})^2{}_3 = (4\ U_{NS}\ U_{EW})_3$.
4. Absence in OFF_2 regime (shifted beam up to ~ 1^0 (N5):
   $(U_{NS} + U_{EW})^2{}_5 - (U_{NS} - U_{EW})^2{}_5 = (4\ U_{NS}\ U_{EW})_5$.
5. Presence on all frequencies simultaneously in the range 20-25 MHz.
6. Presence in central beam (N3) of another broad band more sensitive channel receiver (3x 1 MHz, distributed in the range 20-25 MHz) – ON_3 :
   $U_{NS} \times U_{EW3}$.
7. Absence for large distance from Saturn sky position.
8. Absence in calibration regime when noise generator is instead of antenna.
9. Presence of more than one event during the experiments.
10. Coincidence with Cassini data taking in to account time delay (~ 67 min) and Saturn-Cassini – Earth position.

Some examples of the UTR-2 SED detection on 30 January 2006

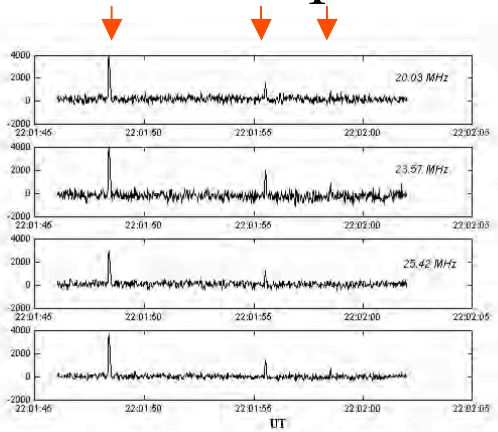


Fig.1. Broadband (ON 3)

	Criteria N
Fig.1	**5, 6, 9, 10**
Fig.2	**1, 5, 9, 10**
Fig.3	**2**
Fig.4	**3, 5, 9, 10**
Fig.5	**4**

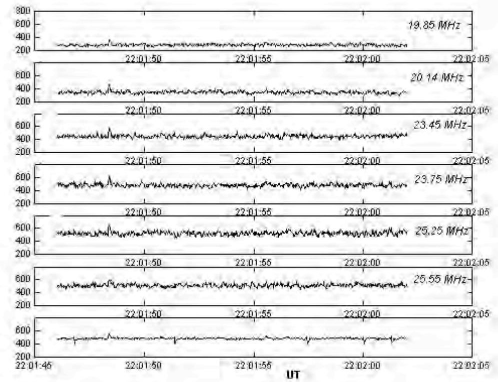


Fig.2. Narrowband (ON 1)

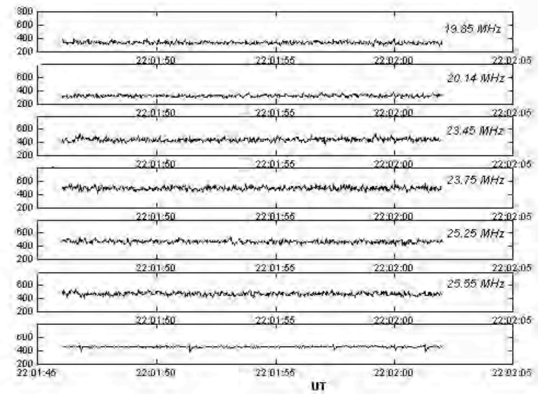


Fig.3. Narrowband (OFF 1)

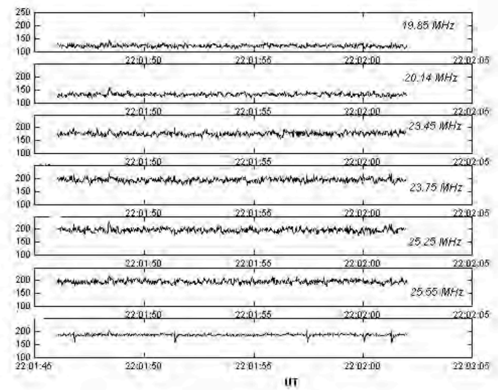


Fig.4. Narrowband (ON 2)

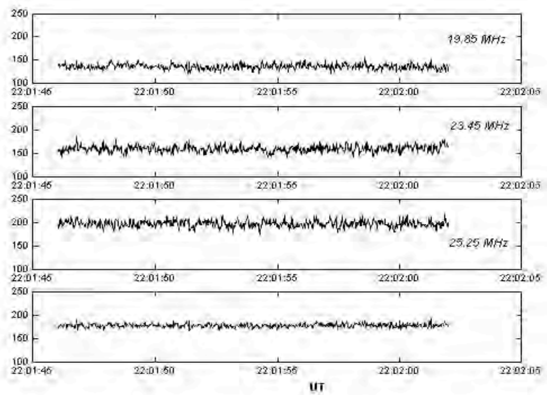
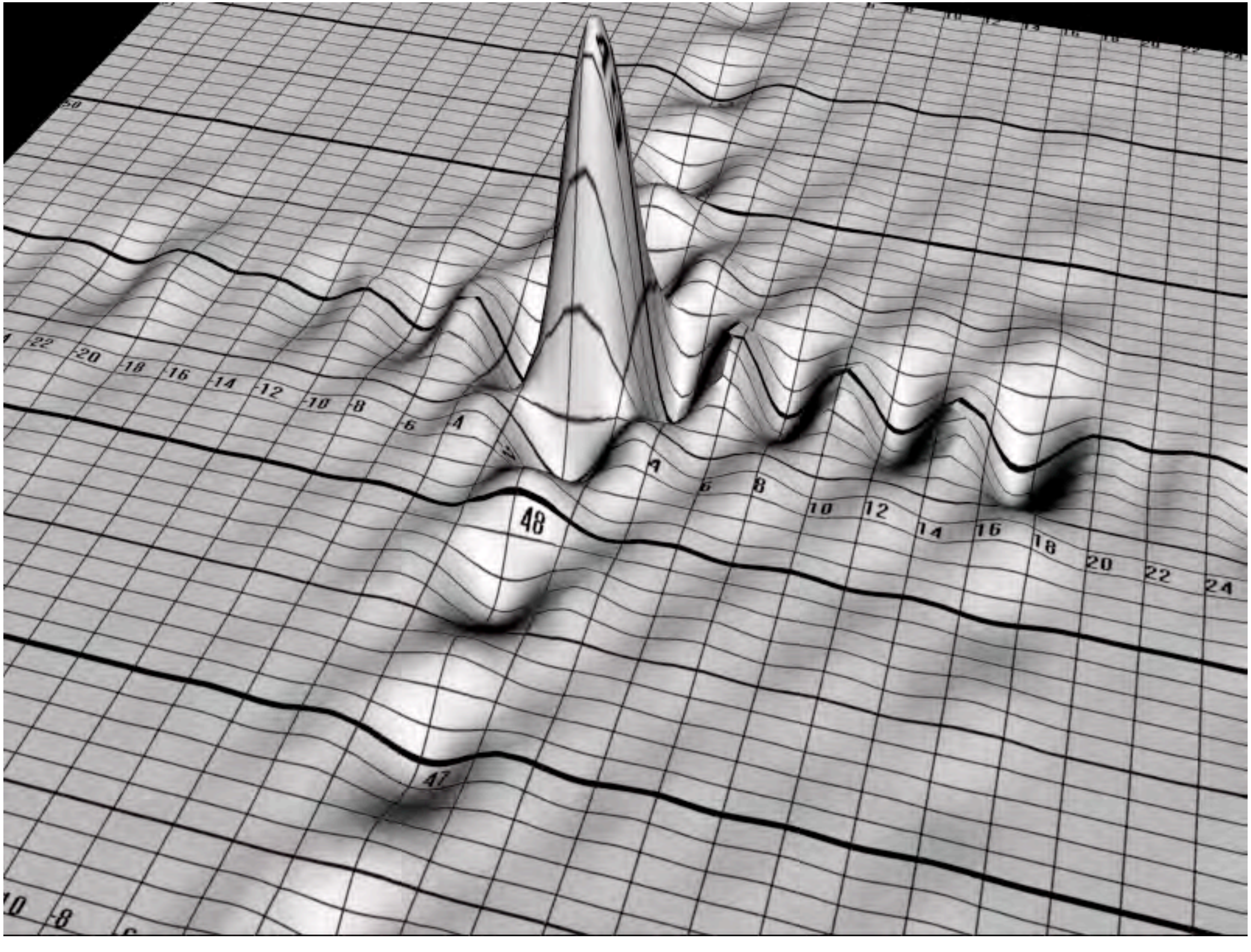
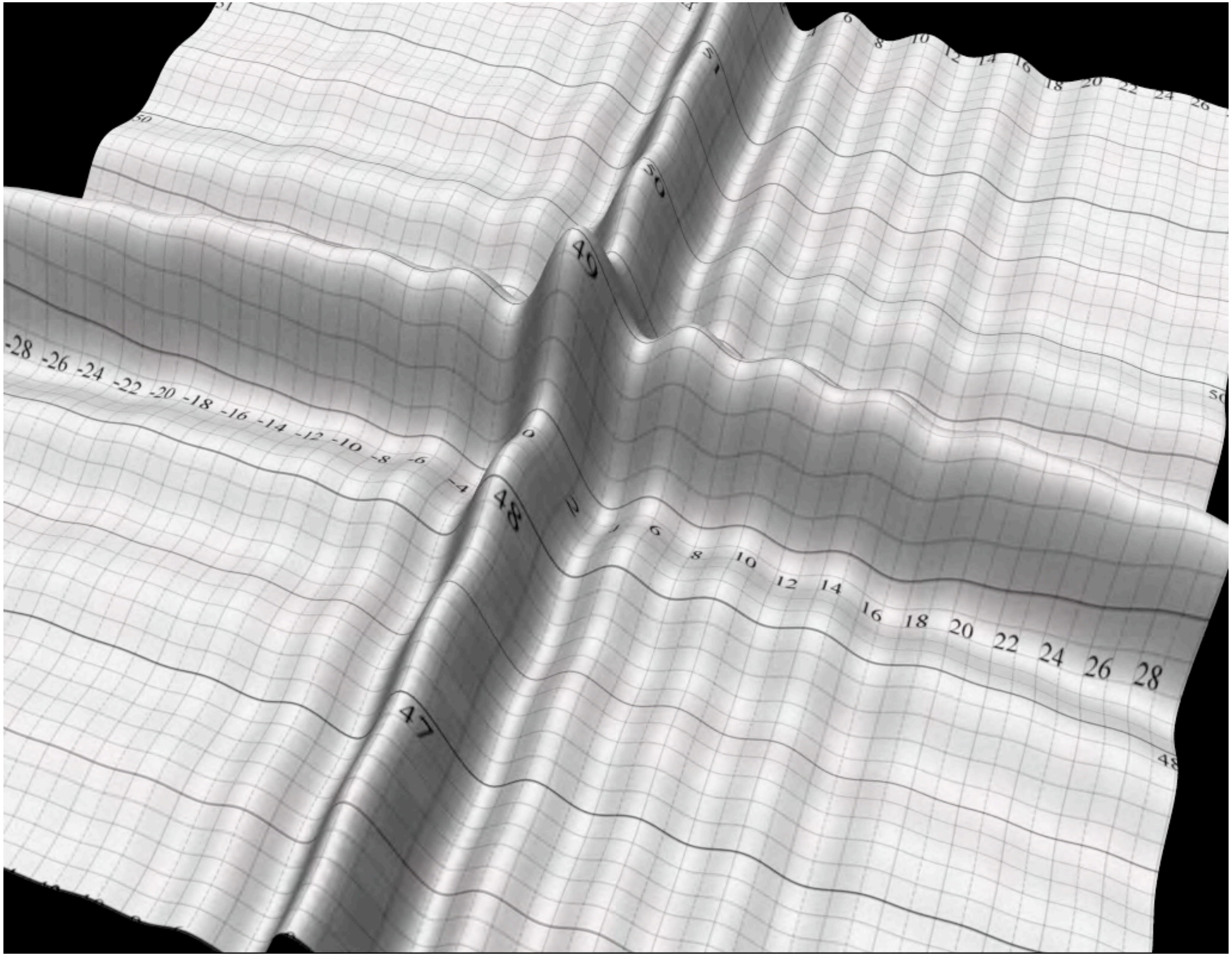


Fig.5. Narrowband (OFF 2)

UTR-2: (N-S)×(E-W)

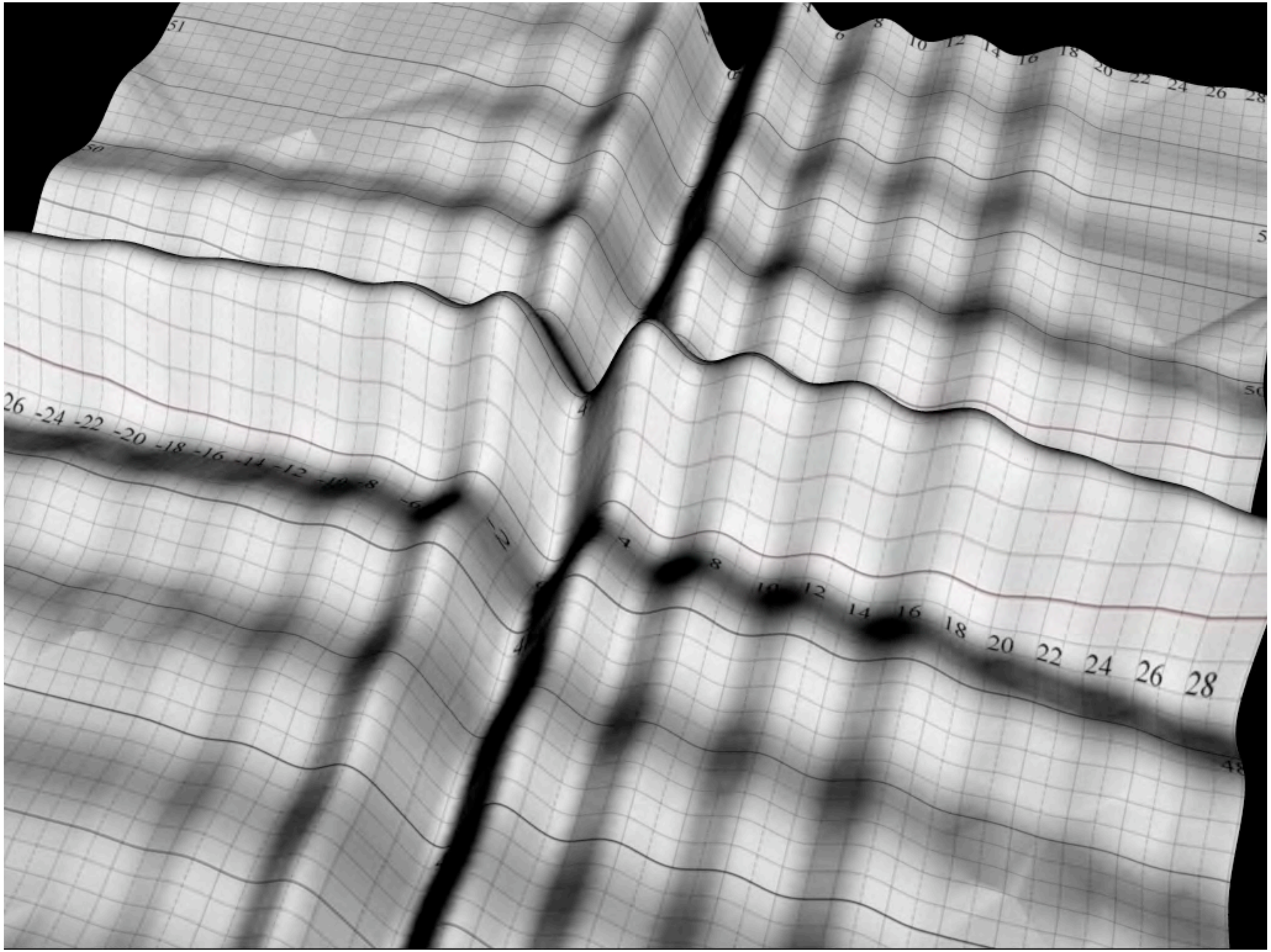


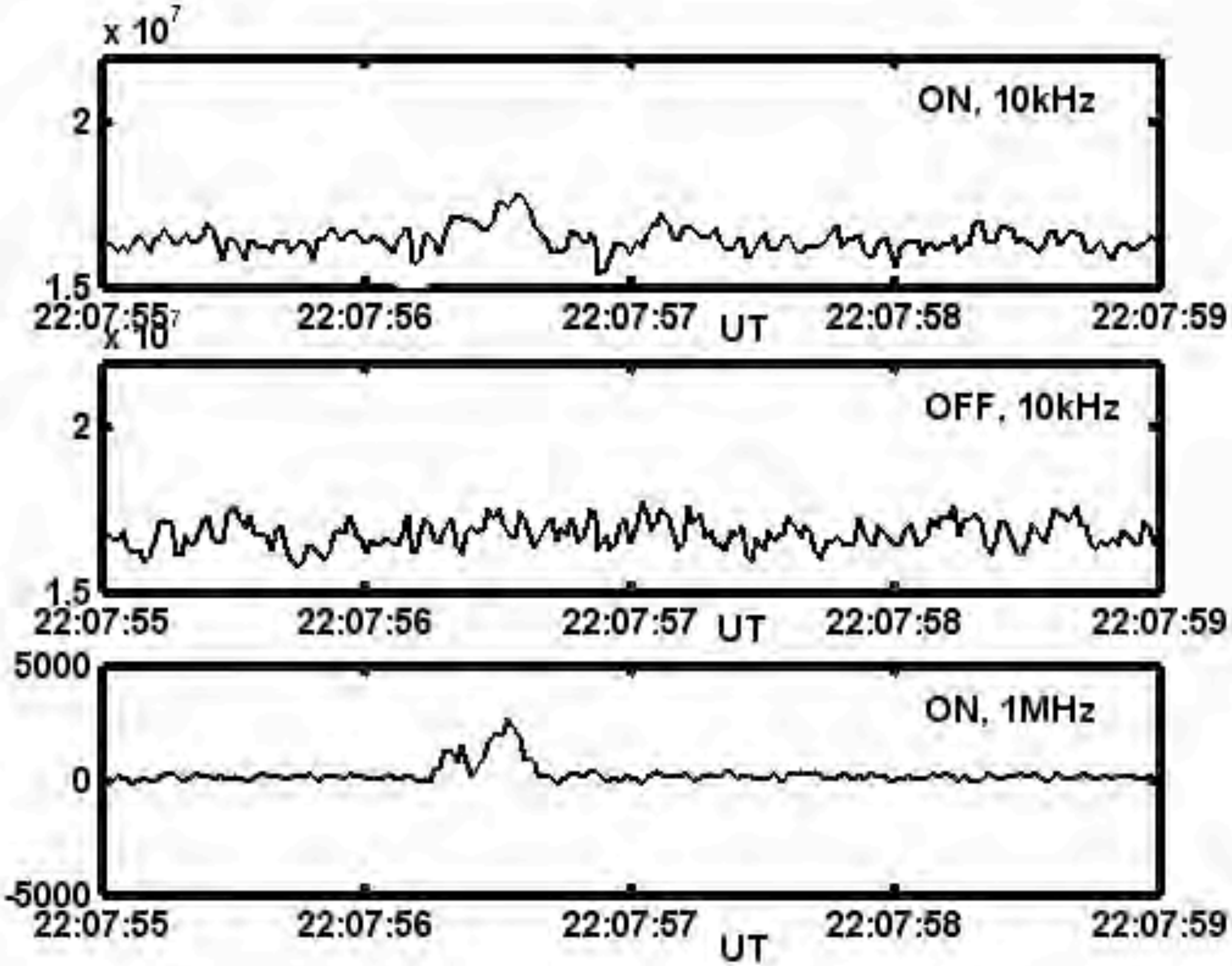
(N-S)+(E-W)

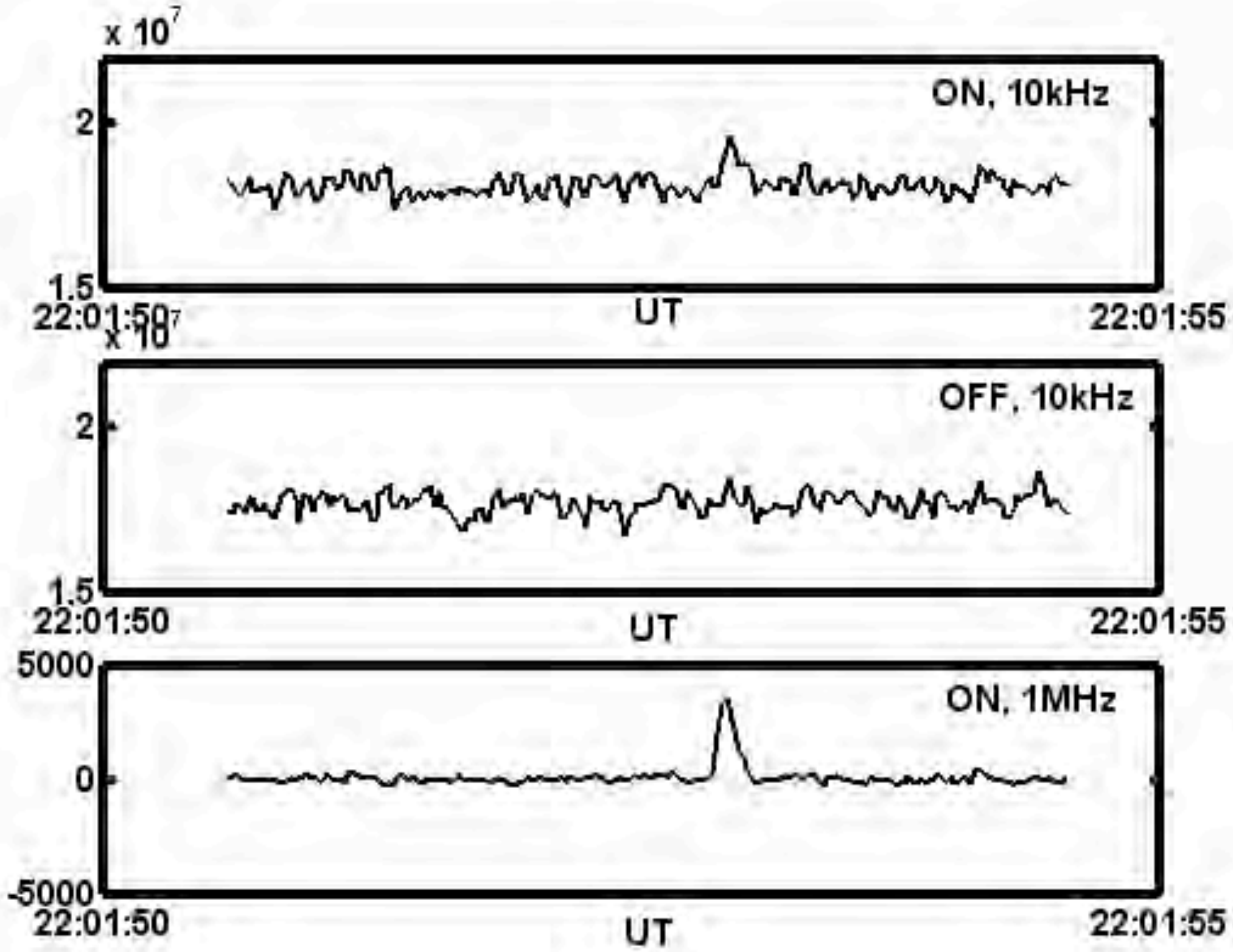


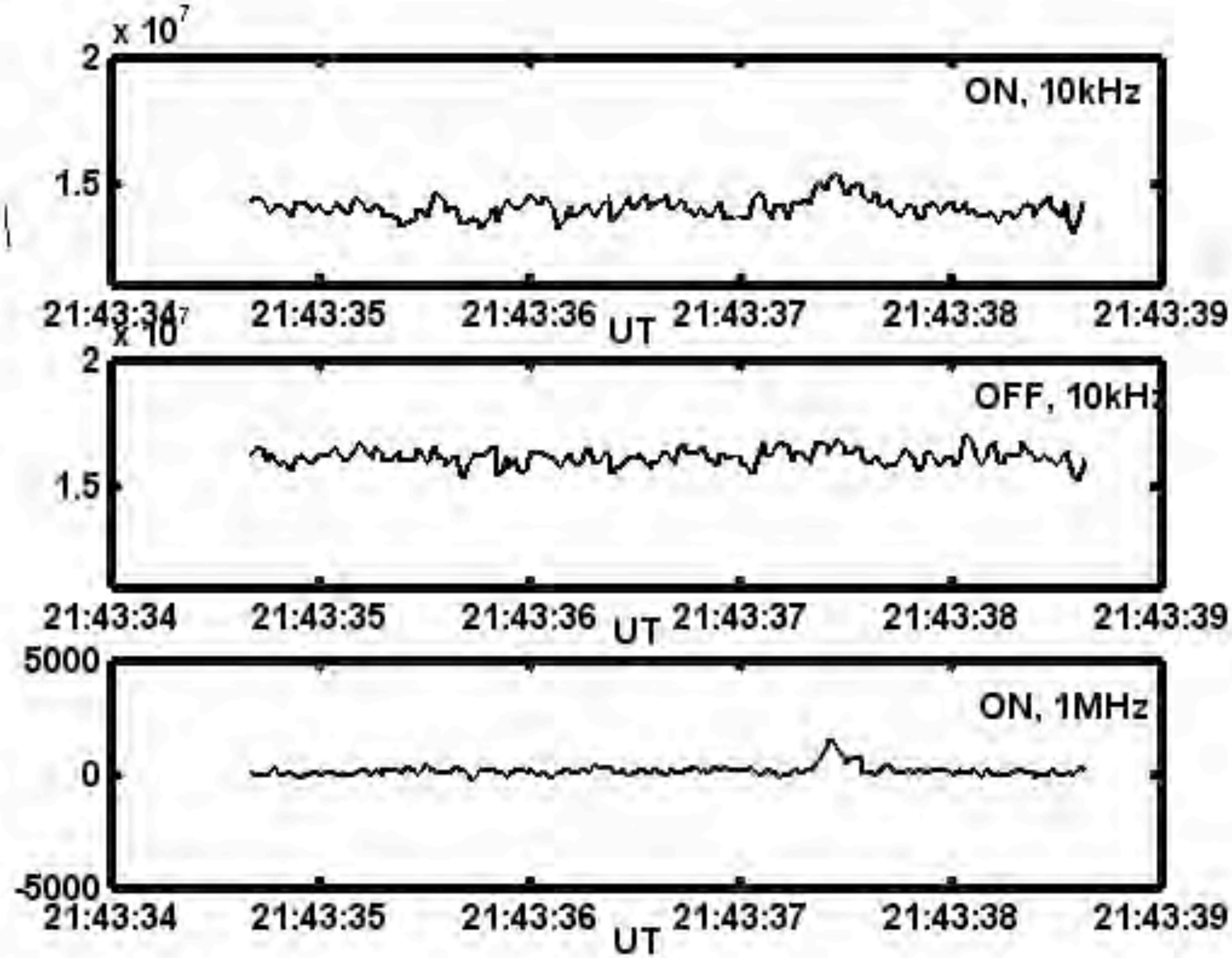
51
50
49
48
47
-28 -26 -24 -22 -20 -18 -16 -14 -12 -10 -8 -6 -4
0
2
6 8 10 12 14 16 18 20 22 24 26 28

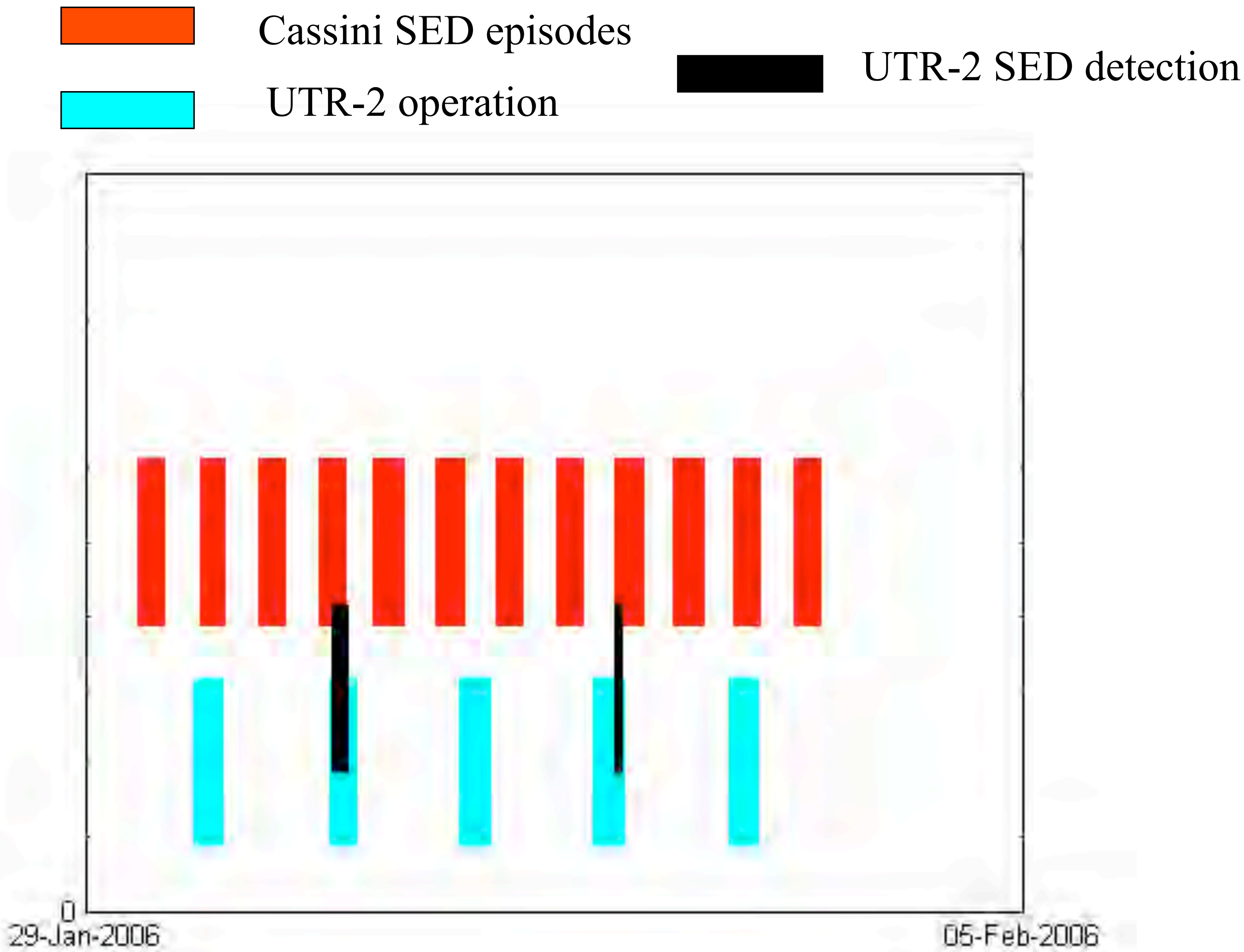
(N-S)-(E-W)


-26 -24 -22 -20 -18 -16 -14 -12 -10 -8 -6
4 8 10 12 14 16 18 20 22 24 26 28
6 8 10 12 14 16 18 20 22 24 26 28

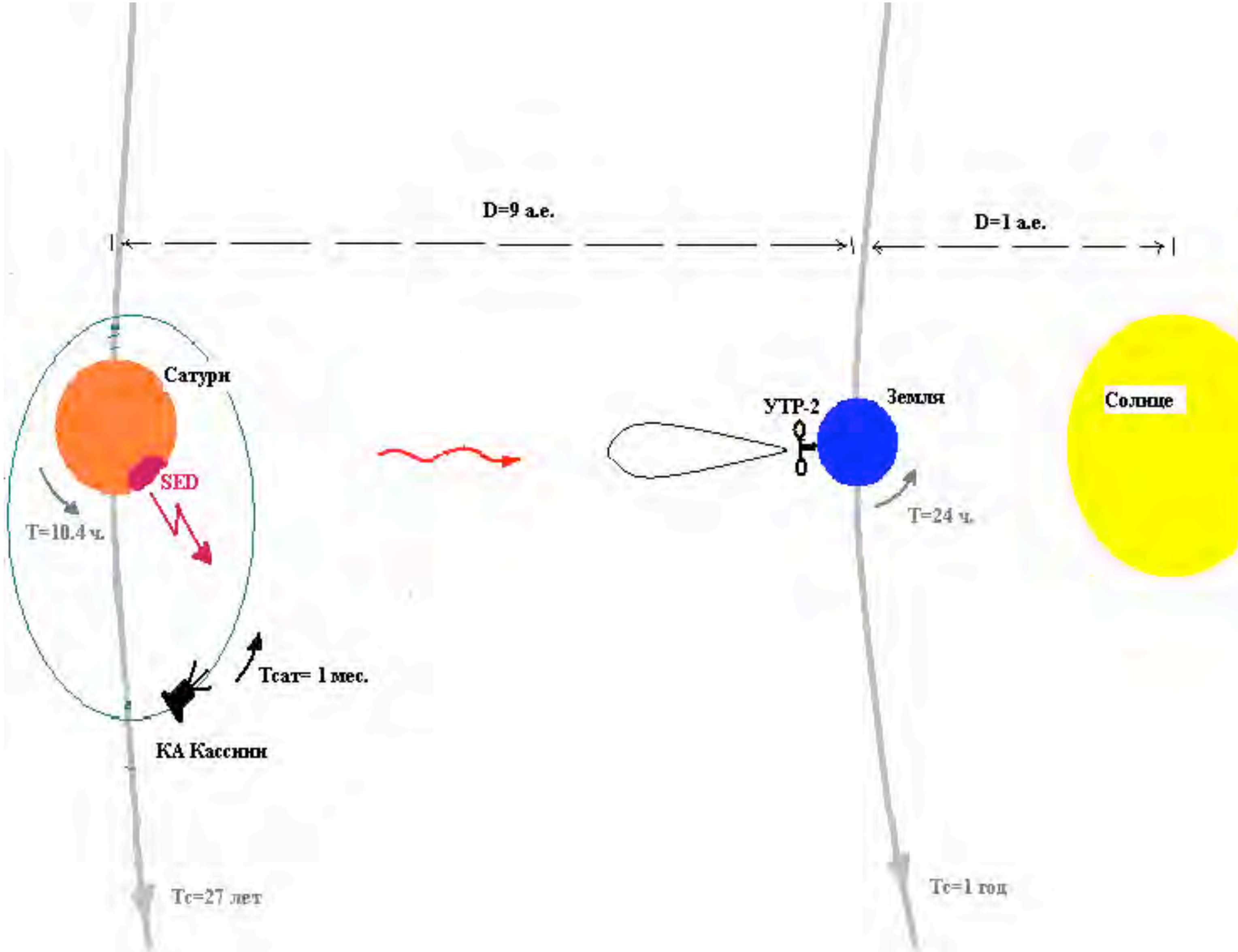

x 10^7
ON, 10kHz
2
1.5
22:07:55
22:07:56
22:07:57
22:07:58
22:07:59
UT
x 10^7
OFF, 10kHz
2
1.5
22:07:55
22:07:56
22:07:57
22:07:58
22:07:59
UT
5000
ON, 1MHz
0
-5000
22:07:55
22:07:56
22:07:57
22:07:58
22:07:59
UT

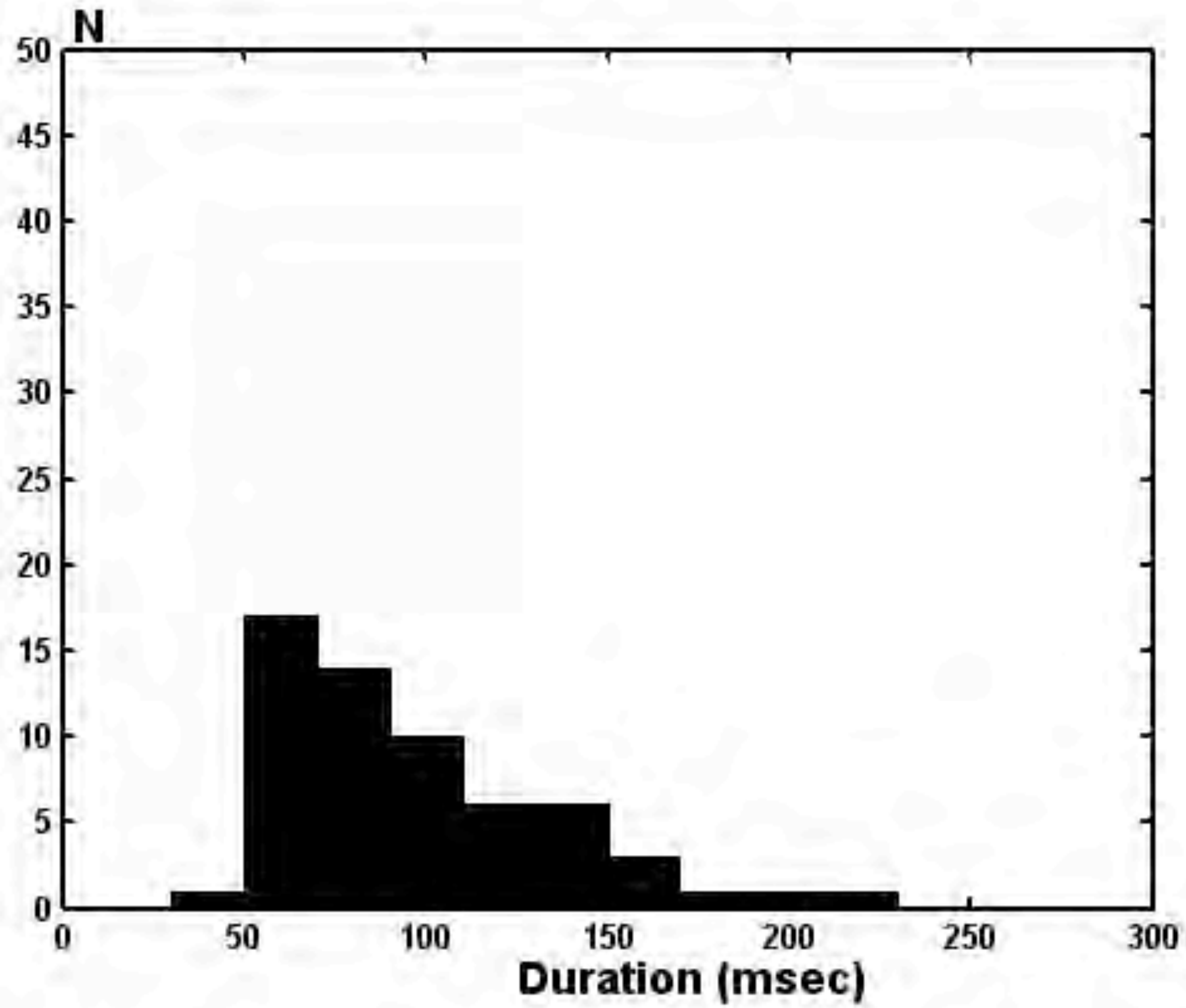

x 10^7
ON, 10kHz
2
1.5
22:01:50
UT
22:01:55
x 10^7
OFF, 10kHz
2
1.5
22:01:50
UT
22:01:55
5000
ON, 1MHz
0
-5000
22:01:50
UT
22:01:55


x 10^7
2
1.5
ON, 10kHz
21:43:34
21:43:35
21:43:36
21:43:37
21:43:38
21:43:39
UT
x 10^7
2
1.5
OFF, 10kHz
21:43:34
21:43:35
21:43:36
21:43:37
21:43:38
21:43:39
UT
5000
0
-5000
ON, 1MHz
21:43:34
21:43:35
21:43:36
21:43:37
21:43:38
21:43:39
UT

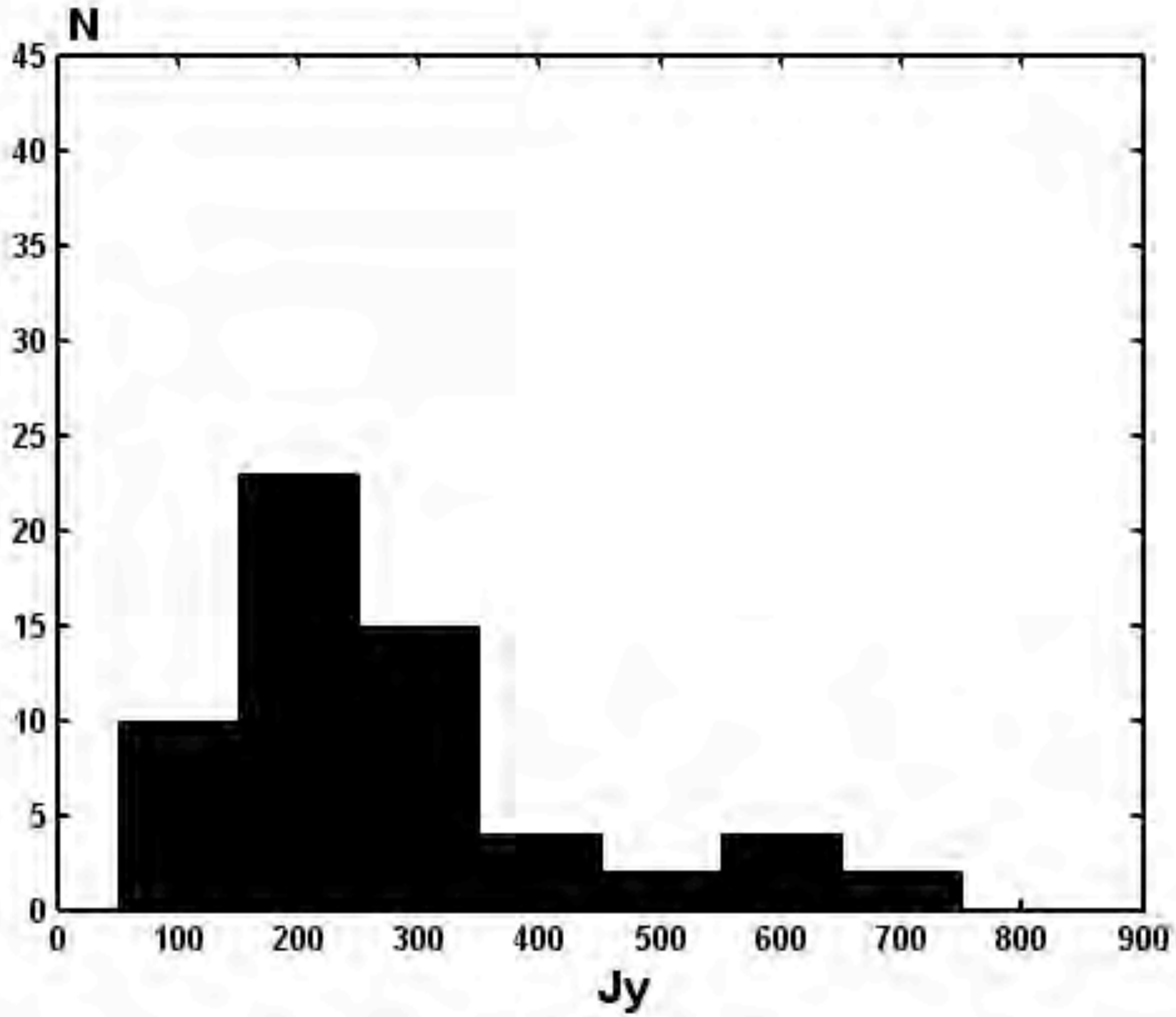


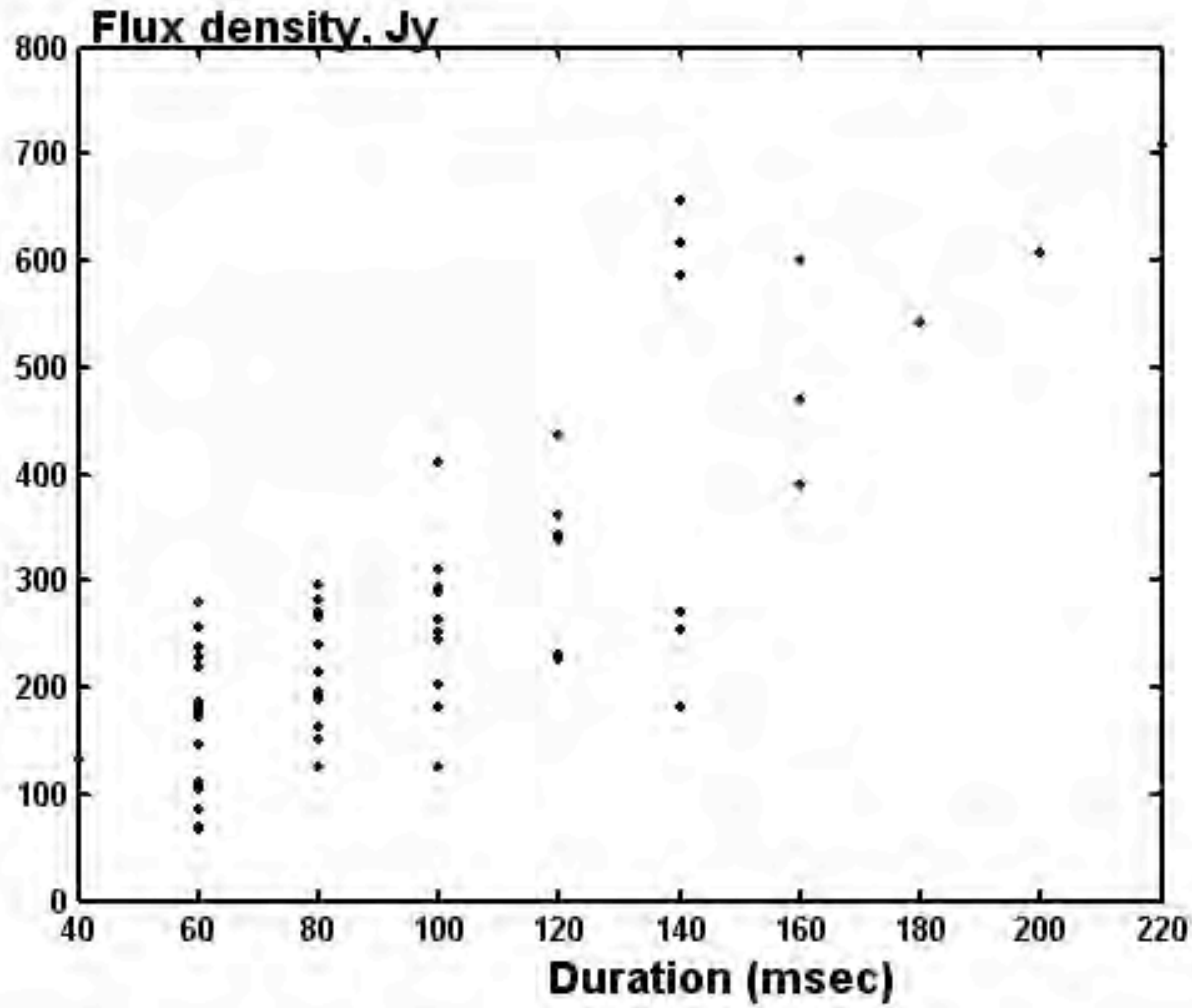
Cassini SED episodes
UTR-2 operation
UTR-2 SED detection
0
29-Jan-2006
05-Feb-2006


D=9 а.е.
D=1 а.е.
Сатурн
SED
T=10.4 ч.
Tсат= 1 мес.
КА Кассини
Tс=27 лет
УТР-2
Земля
Солнце
T=24 ч.
Tс=1 год

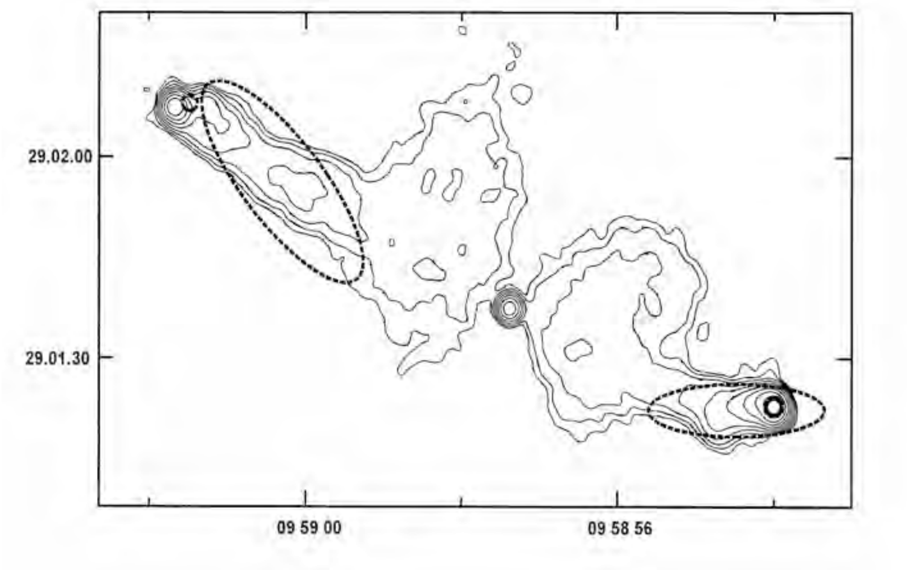


N
50
45
40
35
30
25
20
15
10
5
0
0
50
100
150
200
250
300
Duration (msec)

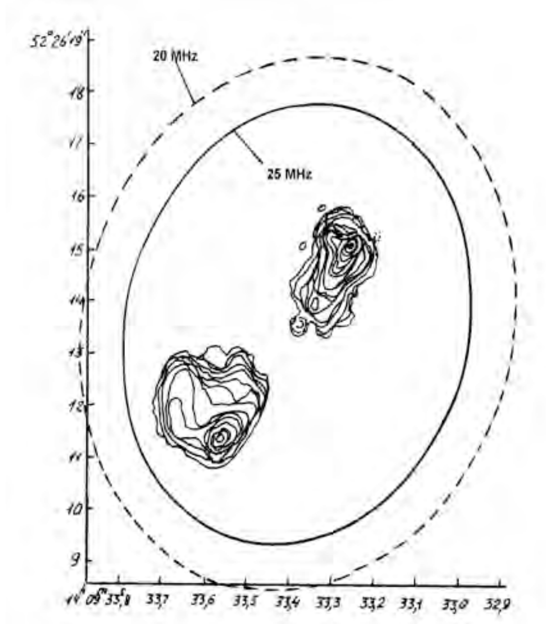

N
45
40
35
30
25
20
15
10
5
0
0
100
200
300
400
500
600
700
800
900
Jy


Flux density, Jy
800
700
600
500
400
300
200
100
0
40
60
80
100
120
140
160
180
200
220
Duration (msec)

Fine spatial structure radio emission



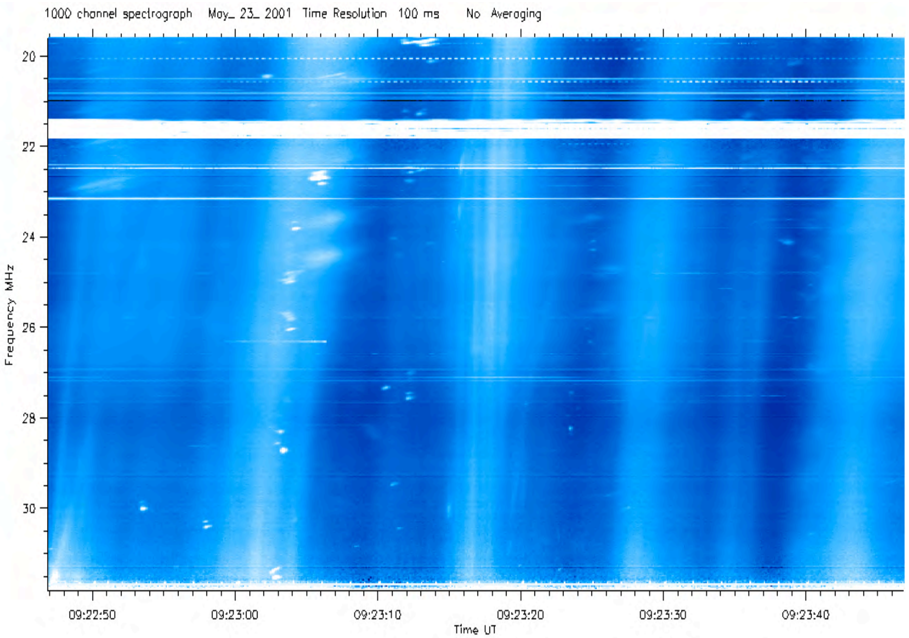
Structure of 3C234



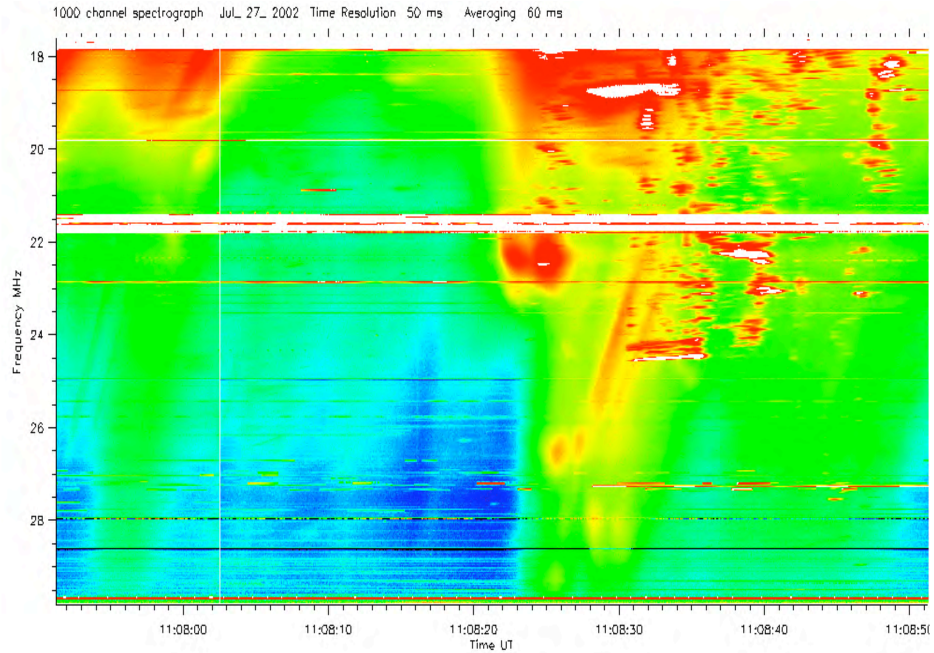
Structure of 3C295

Radio interferometry observations by UTR-2 – URAN VLBI system (Braude, Megn, Rashkovsky, Shepelev, et al.) in comparing with high frequency imaging of radio sources.

Complex fine time-spectral structure radio emission



Type III solar bursts



Spike-like radio emission

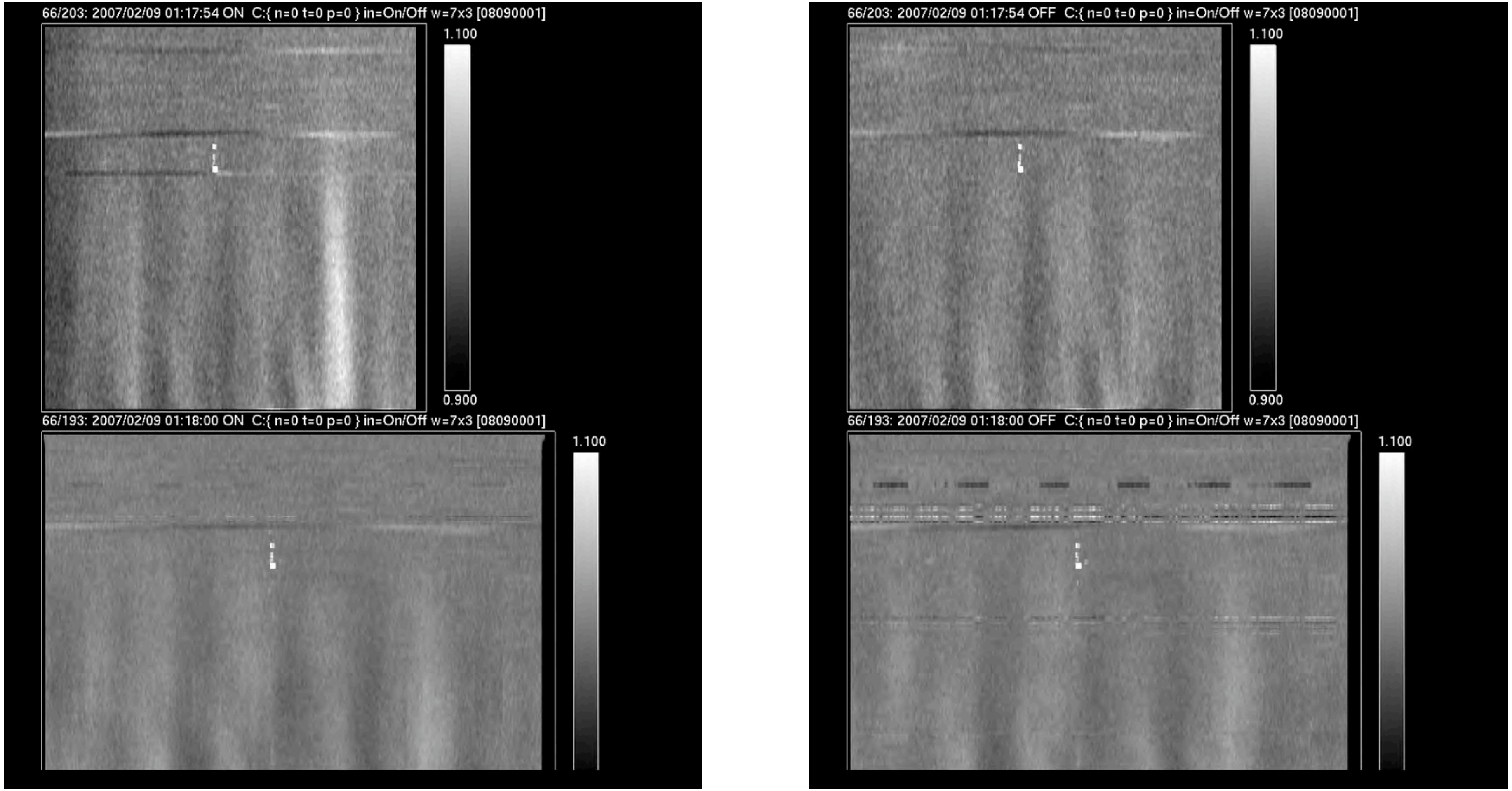
Solar sporadic radio emission with the fine time-frequency structure detected by UTR-2 (Melnik, Konovalenko, Rucker, Lecacheux, Abranin, Stanislavsky, Dorovsky).

B = 33 MHz
f = 8…32 MHz
N = 16 000
Δf = 2 kHz
Δt = 1 ms
ADC 16 bit

Search of exo-planets radio emission with UTR-2 and new digital receiver (Ukraine - France – Austria– Japan), December, 2006 – March, 2007

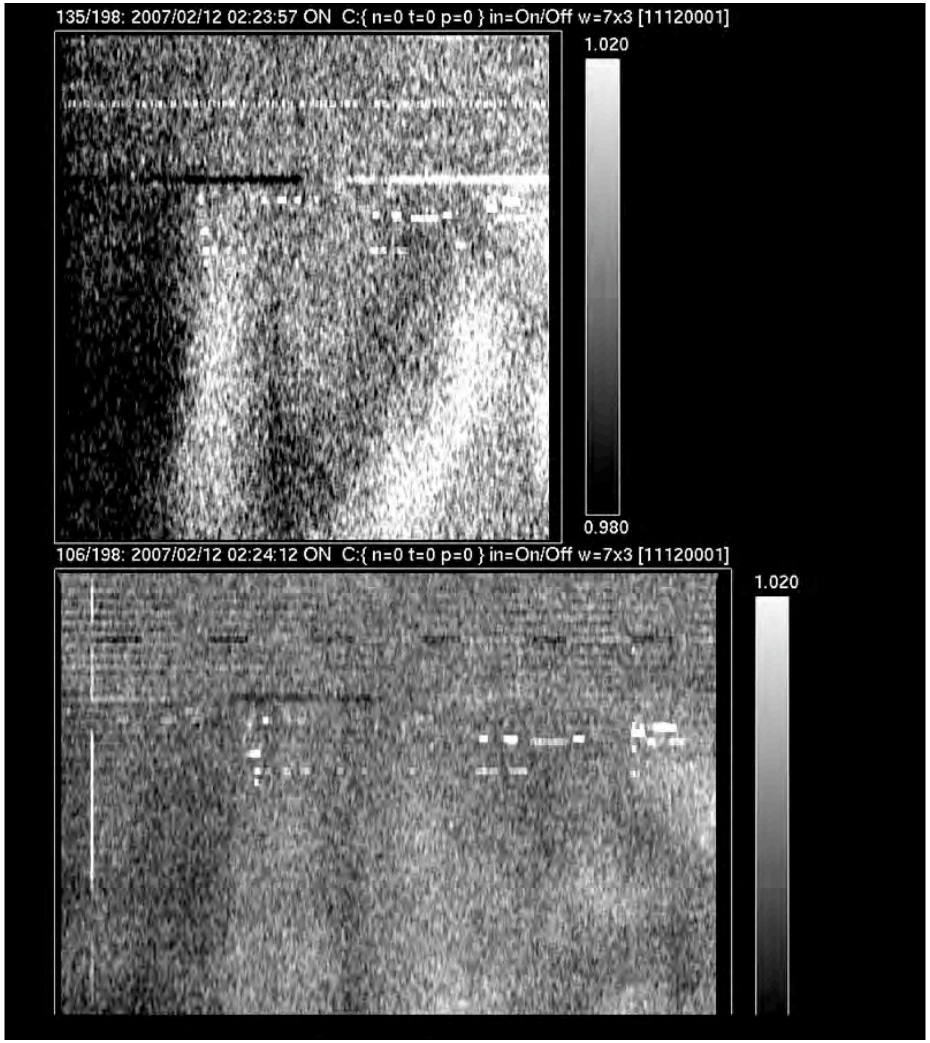
B = 12 MHz
f = 18…30 MHz
N = 1024
Δf = 12 kHz
Δt = 1 ms
ADC 12 bit

Search of flare stars radio emission with UTR-2 and DSP, ROBIN, February 2-12, 2007 (Ukraine – Austria – France)

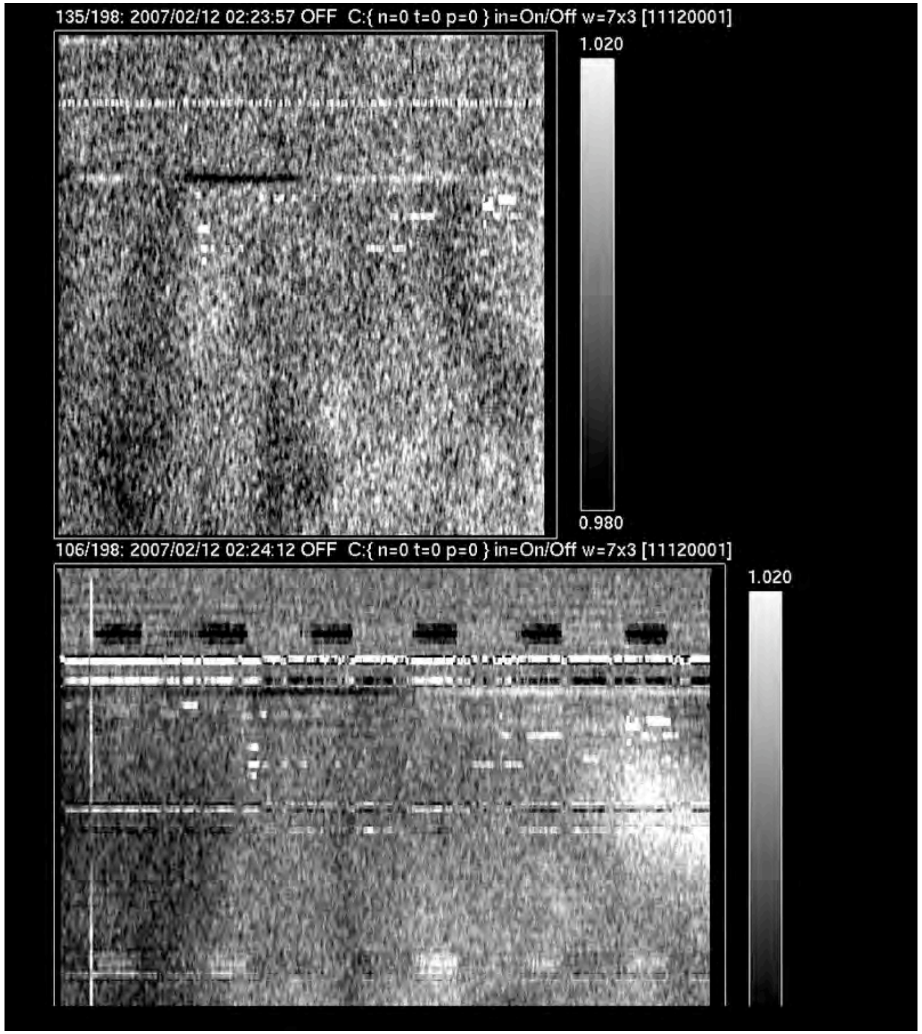


ON **OFF**

UTR-2 + DSP + ROBIN, ADLeo, Feb. 2007



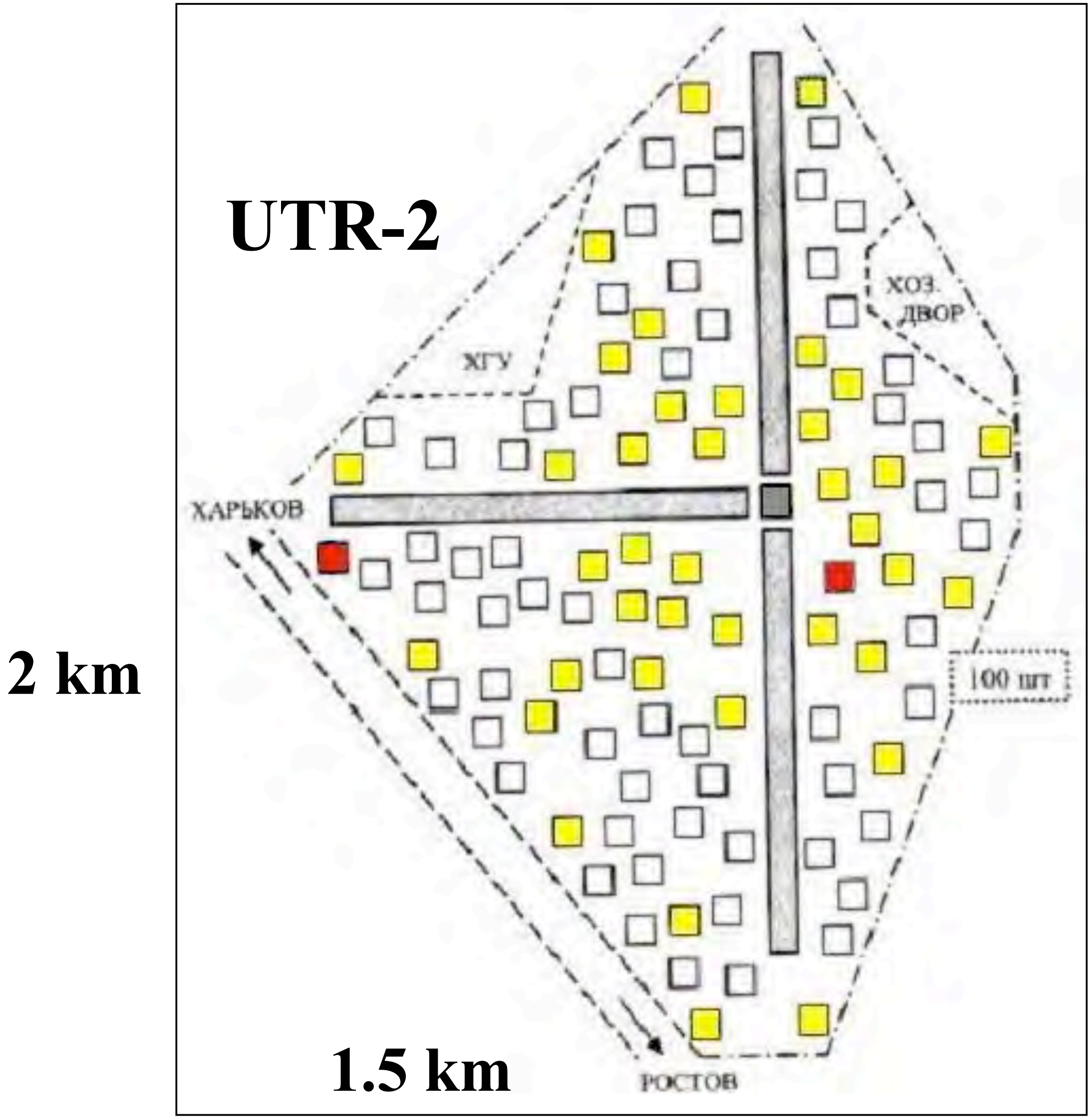
ON



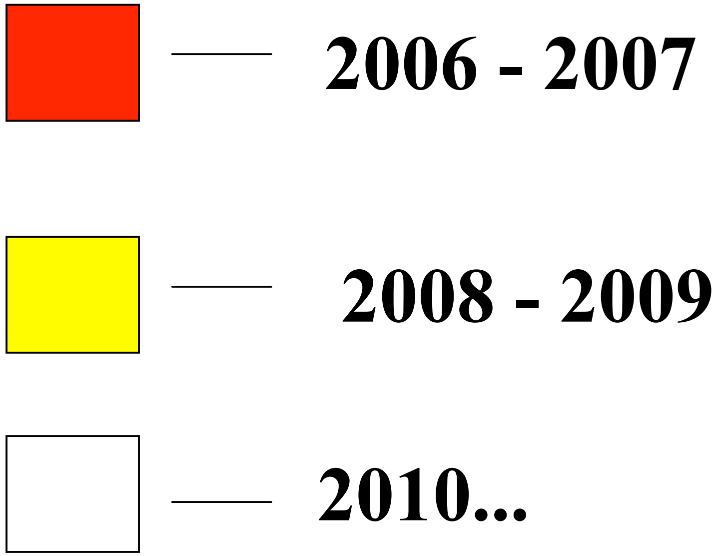
OFF

UTR-2 + DSP + ROBIN, ADLeo, Feb. 2007

Possible distribution of new active antenna elements array (f = 10…70 MHz) on UTR-2 observatory (S = 1 500 000 sq.m)



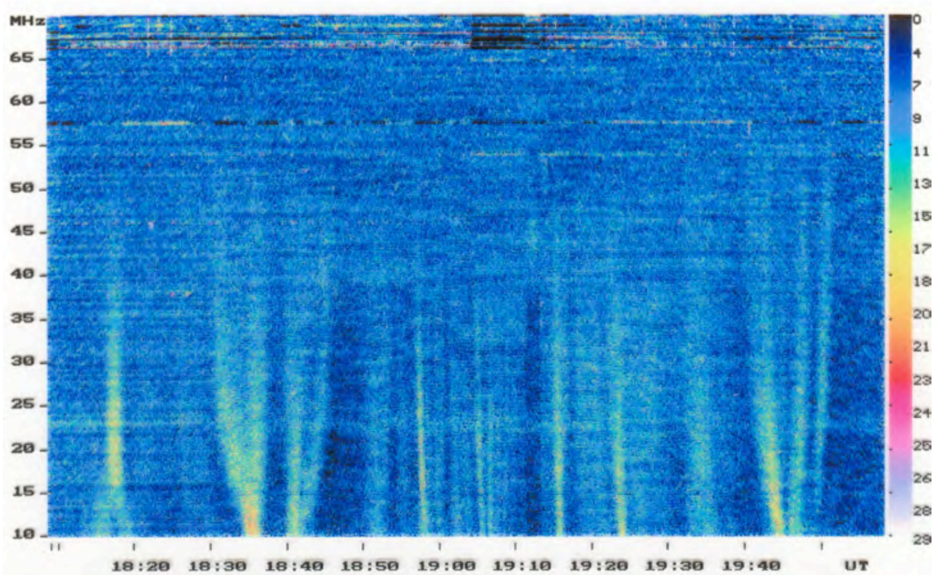
It should be compatible with LOFAR format



Ukrainian plan for the perspective development of low-frequency radio astronomy (Order of Presidium of National Academy of Sciences of Ukraine N 357 from 01.04.2006 with the corresponding financial support).

Test array on UTR-2 observatory, 2000 year [8]

Cas A observations

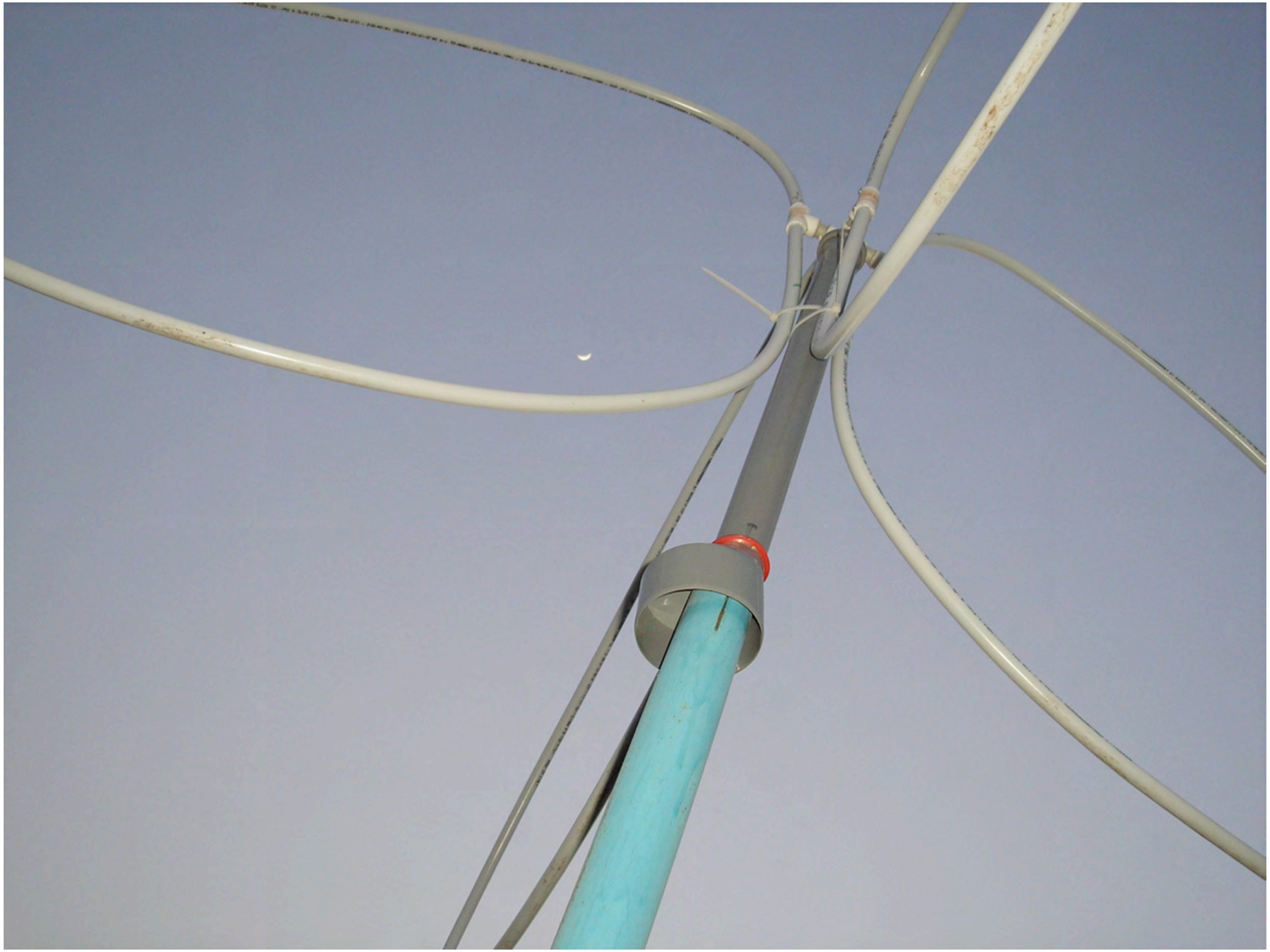


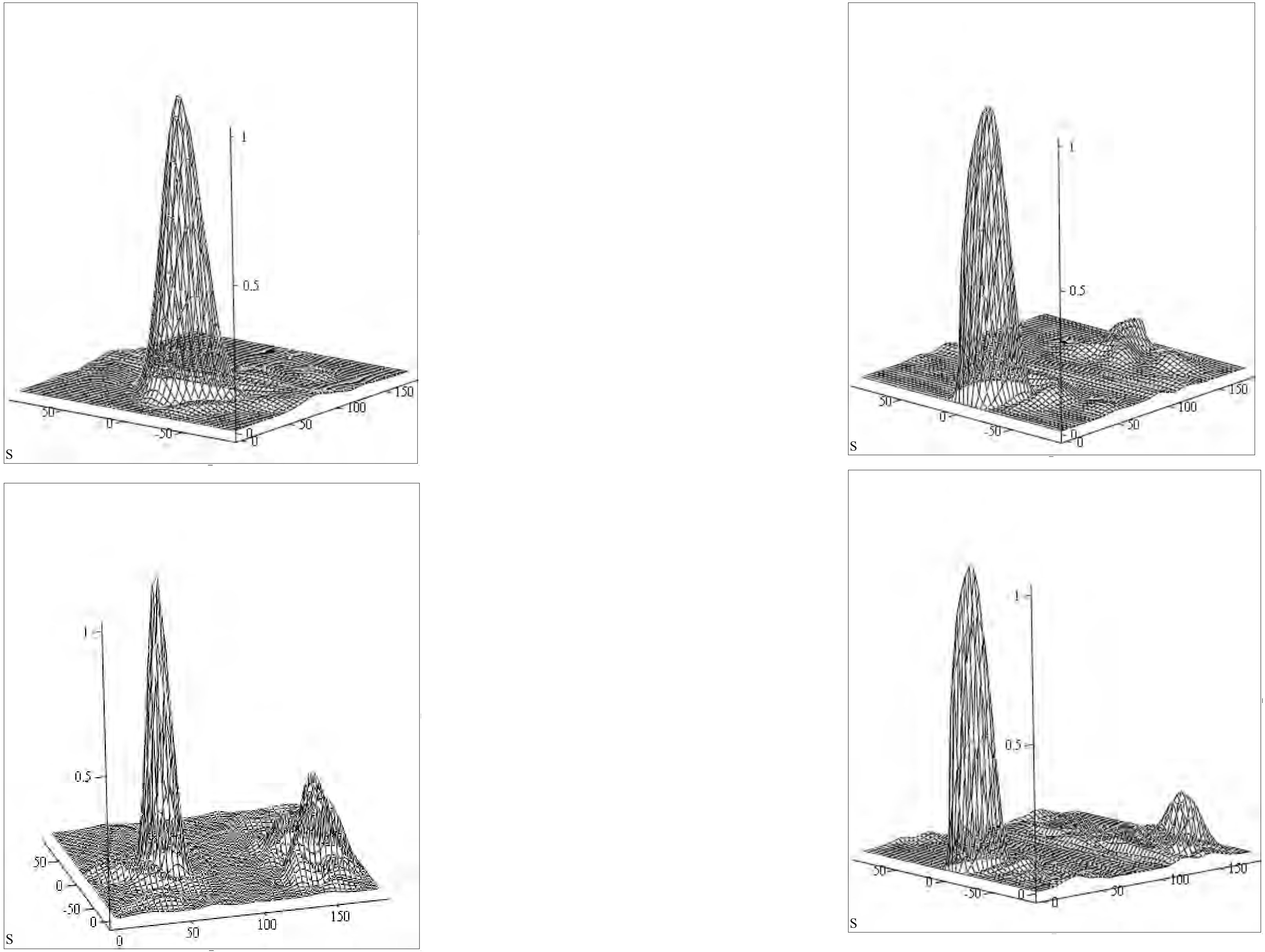
f = 10…70 MHz

New 25-elements test array, 2006 year

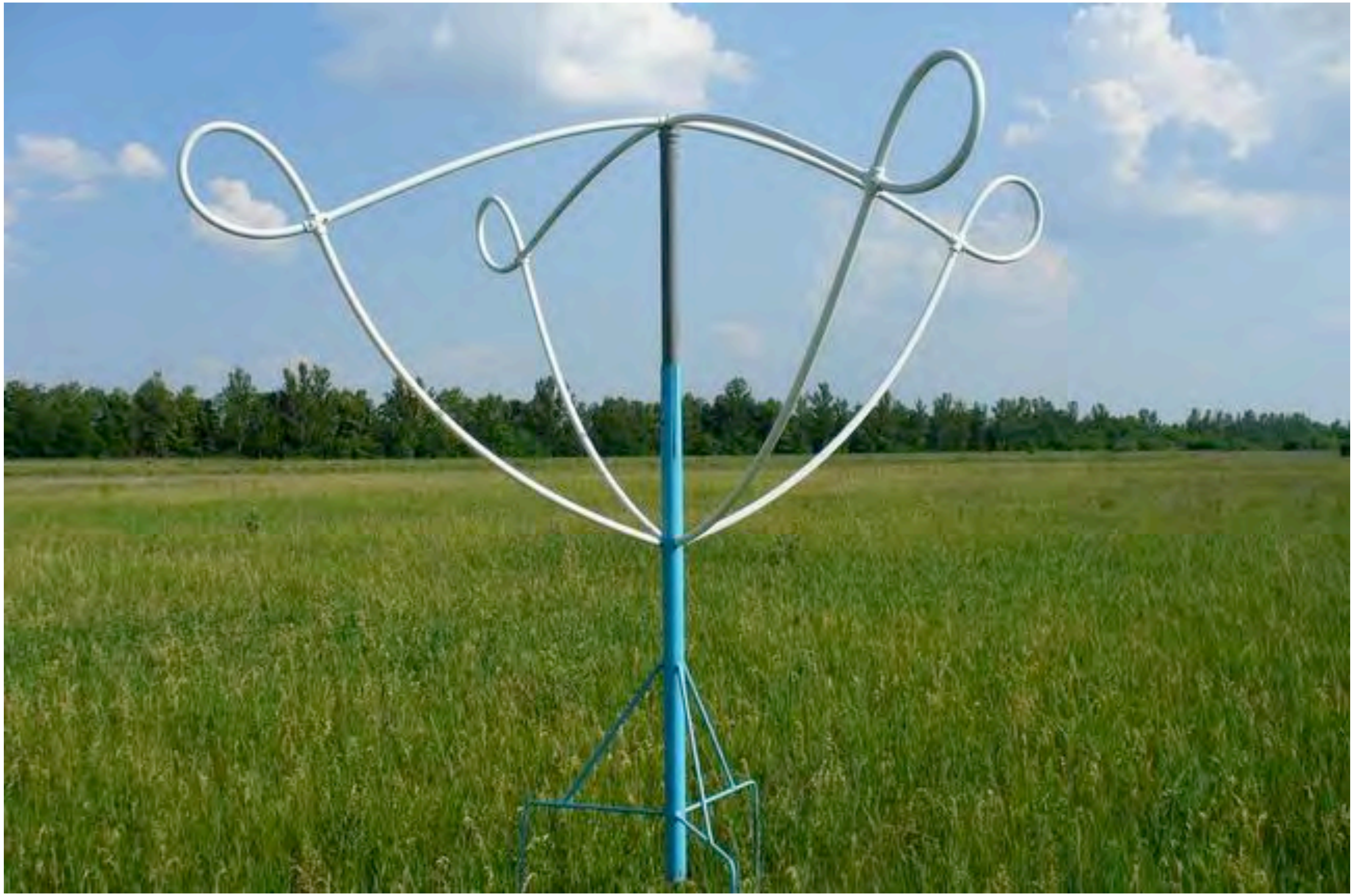
f = 10…70 MHz

New 25-elements test array, 2006 year

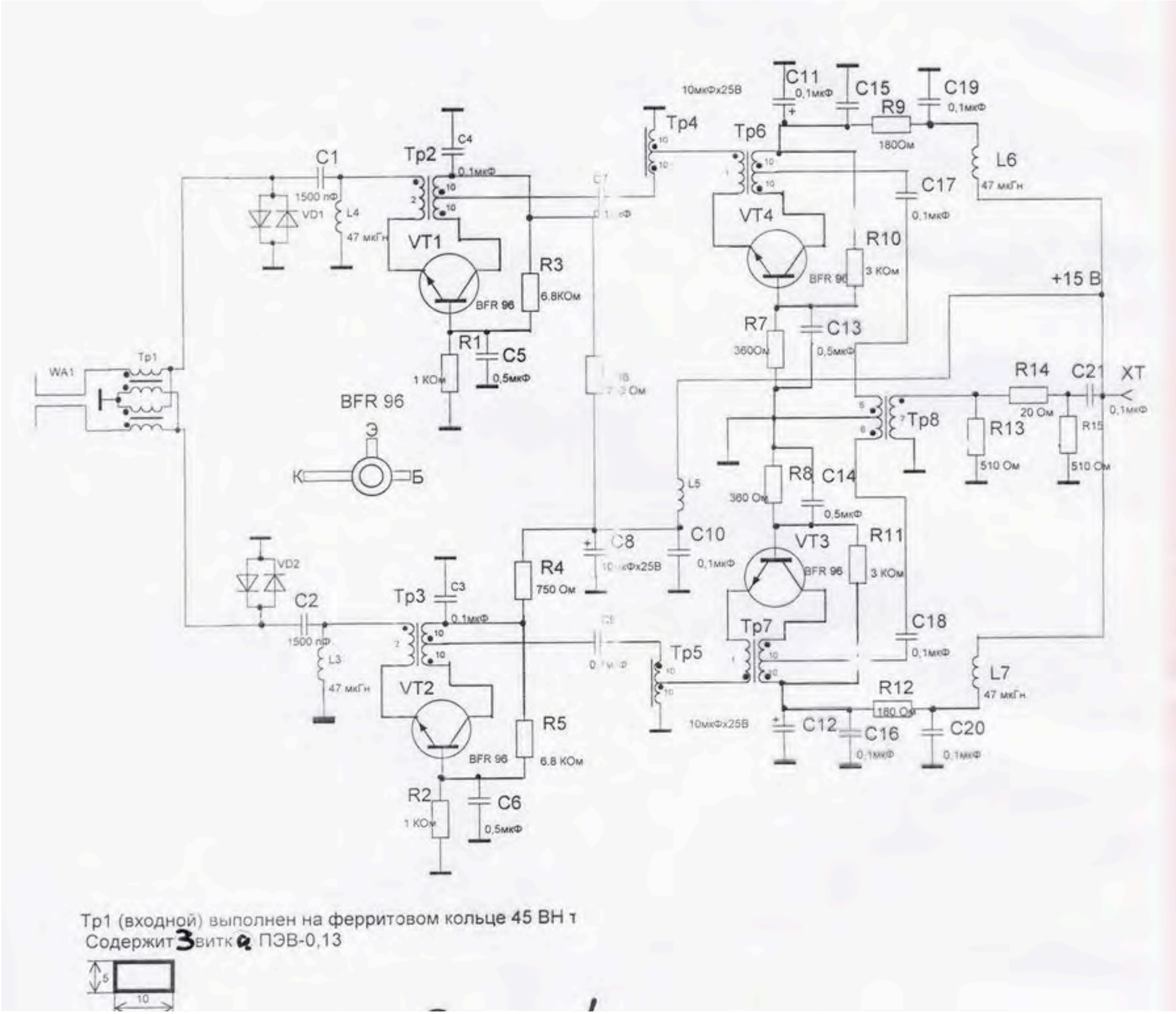




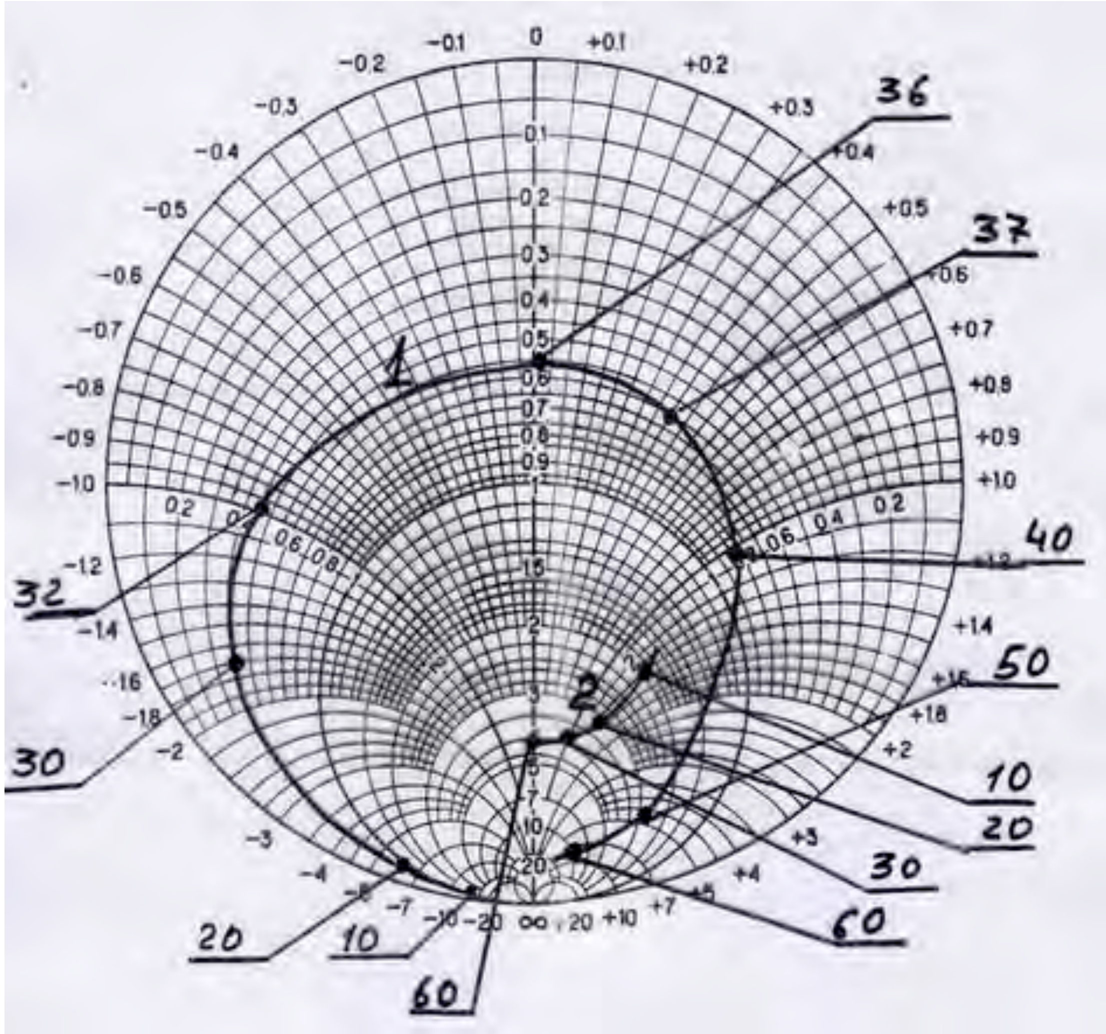
Antenna patterns of 25-elements sub-array



New active antenna element (10-60 MHz, k=3…10 dB)

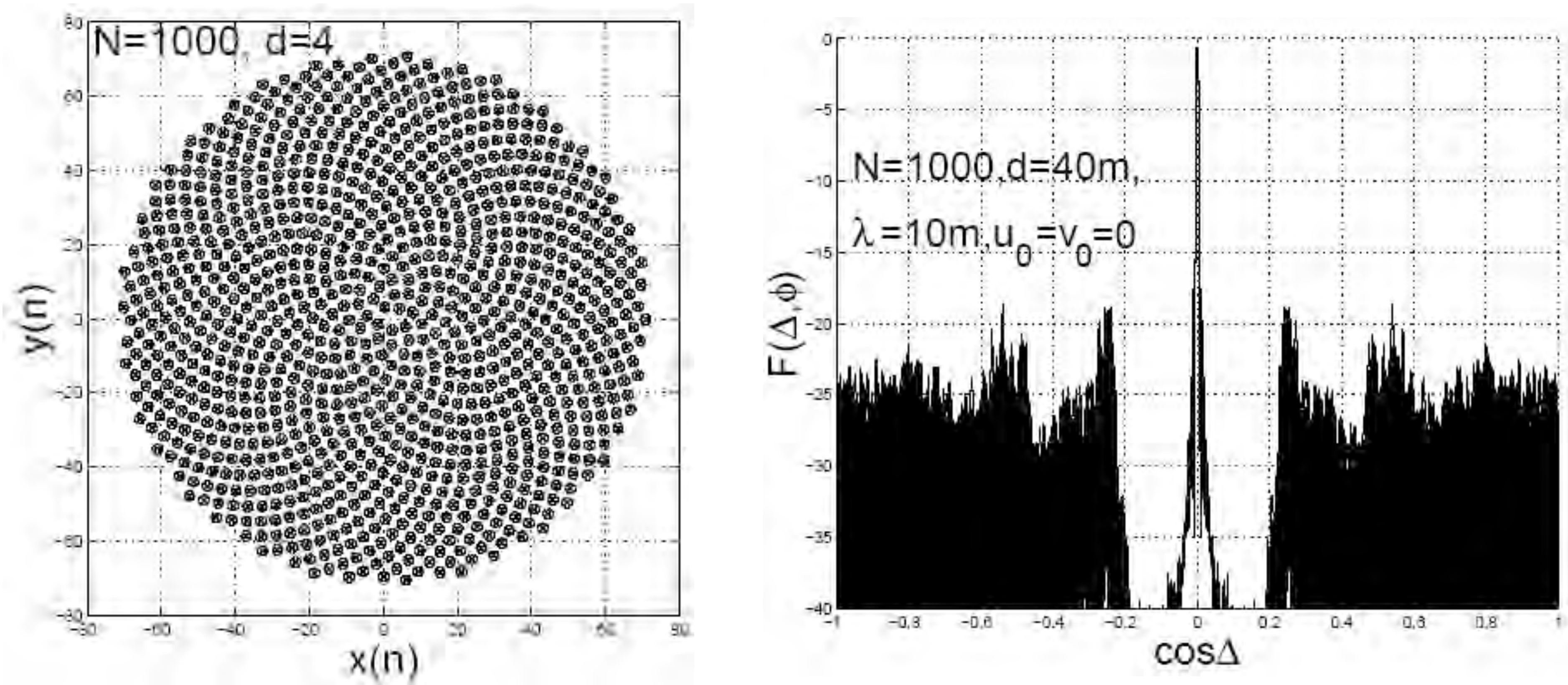


Preamplifier of active antenna element

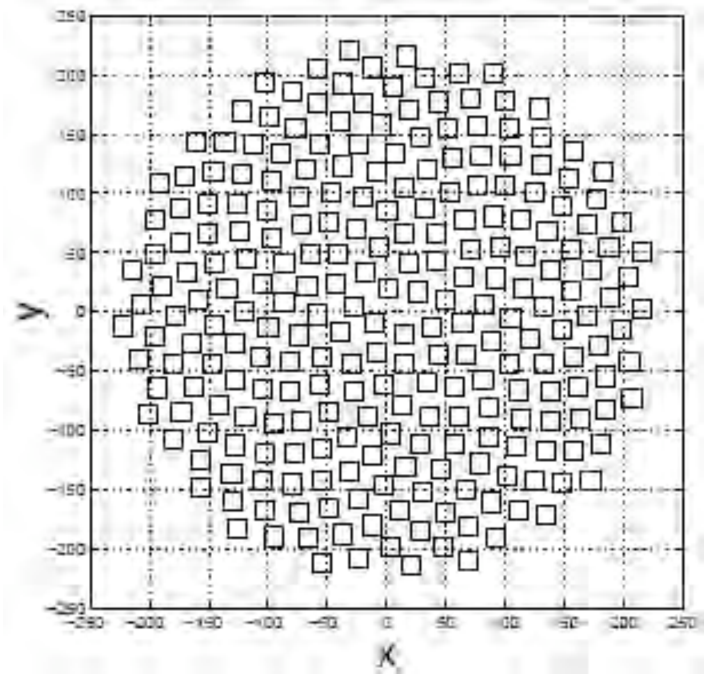


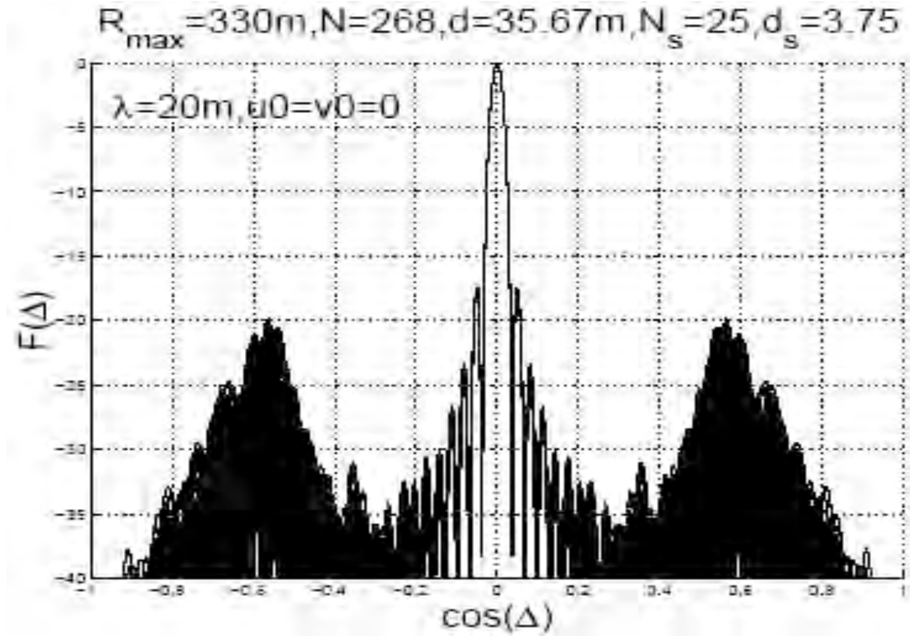
Impedances of antenna element and preamplifier

Exeeding of the antenna temperature over the noise temperature

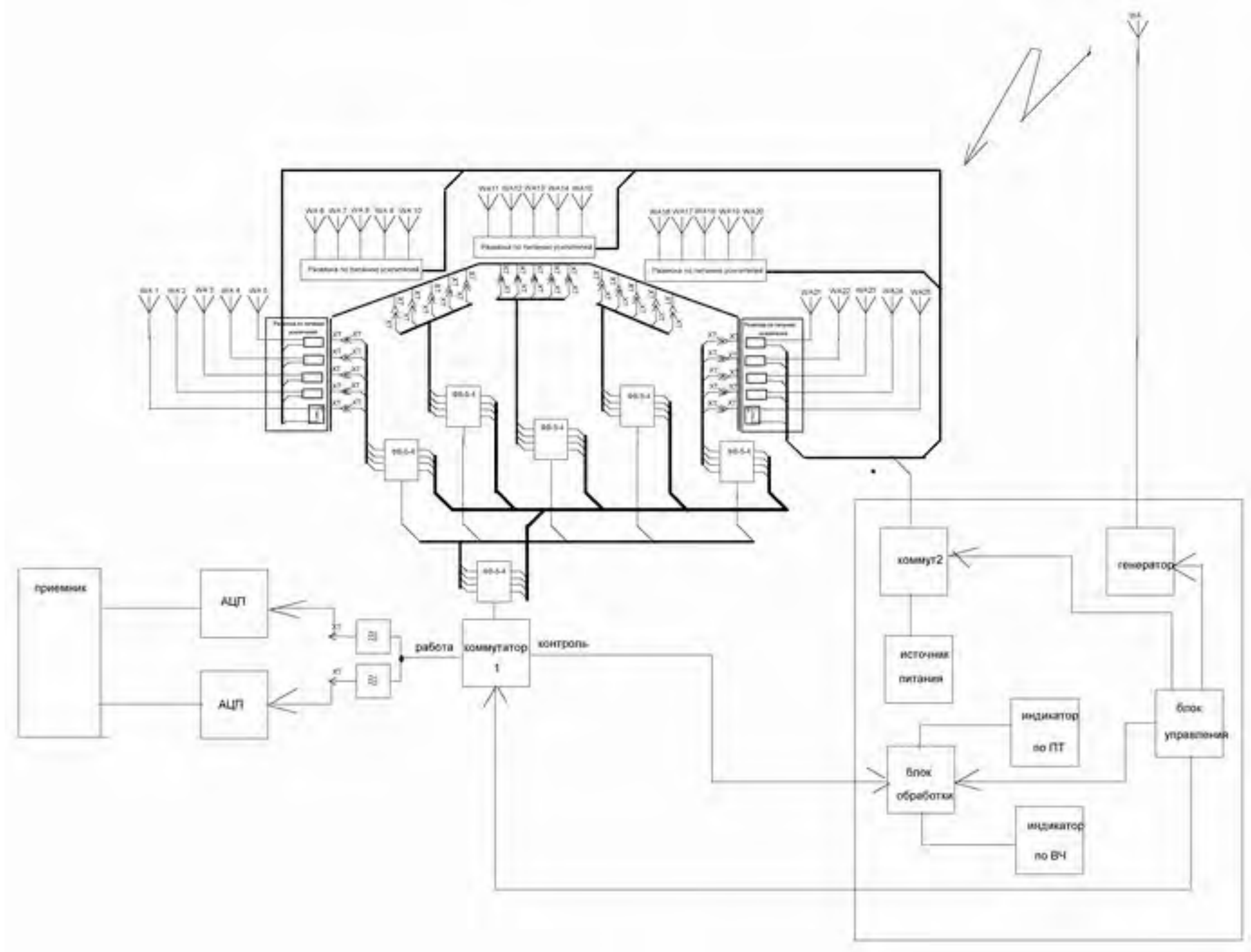


The structure and antenna pattern of compact array





Possible distribution of sub-arrays



Block diagramme of 25-elements array

The steps of sub-array building (August, 2007)

Second 25-elements sub-array (December, 2007)

CONCLUSION.

The existing world largest decameter wavelength instruments are the good precursors for the investigations with the future new generation low-frequency radio telescopes from astrophysucal, methodical and technical point of view. The high astrophysical importance of low-frequency radio astronomy is evident. The creation of new giant meter-decameter wavelength radio telescopes is very actual and in time. They will give a huge amount of new astrophysical results.