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New Frontiers in the Low-frequency Radio Astronomy. Part 2

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New Opportunities of Ukrainian and World Low Frequency Radio Astronomy

Part 1: Super sensitive low-frequency radio astronomy
Part 2: New astrophysical tasks and capabilities

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Abstract

There is a rapid progression of low-frequency radio astronomy (8-80 MHz band) around the world. Giant new generation instruments LOFAR, NenuFAR, LWA, MWA, SKA are being built and used. But for half a century, Ukraine has remained the world leader in this current field of fundamental and applied science, thanks to the creation and use of the world's largest UTR-2, URAN, GURT radio telescopes. Recently, a careful analysis has shown that the reserves of these unique tools and related research have not yet been exhausted. This concerns the further development and modernization of experimental means and observation methods that will radically increase the sensitivity of measurements, resolution, noise immunity. The integration of Ukrainian radio astronomy potential and related facilities into the worldwide network of radio research of the Universe is also an additional opportunity for progress.

Low-frequency radio telescopes on the map of Ukraine

The world's largest UTR-2 radio telescope (N-S arm, 1.9 km x 60 m)
Frequency range - 8… 32 MHz; number of elements - 2040;
effective area - 150,000 square meters.

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




URAN-1…URAN-4 radio telescopes

Σ N (URAN) = 1000*2;   Σ N (total) = 4040;   Aeff (total) = 200000 sq. m

Upgrade of the UTR-2 radio telescope during 2006-2016

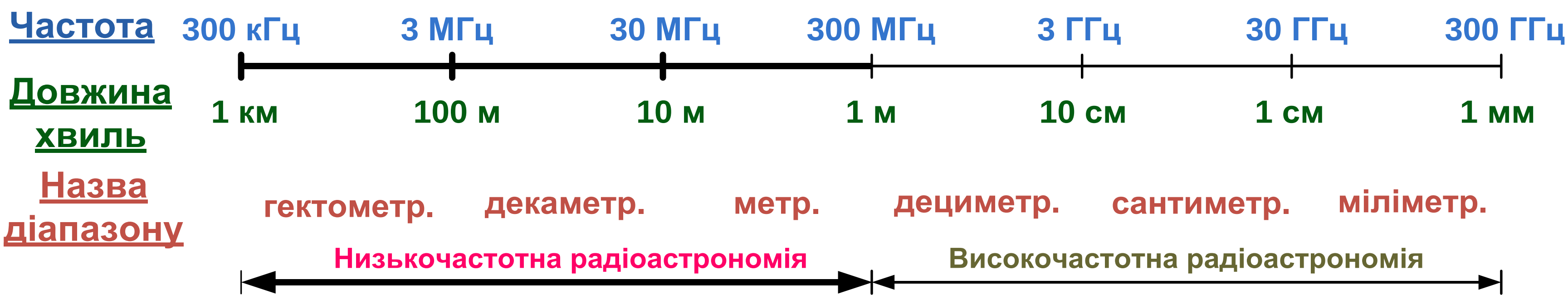
SYSTEM PARAMETERS AND REGIMES	OLD	NEW
Antenna		
Frequency range	10-25 MHz	8 – 32 (40) MHz
Frequency band	6 x 1 MHz = 6 MHz	24 (32) MHz
Calibration, check-in, control, hardware, software	~	high - performance
Back-end		
Number of channels	5 beams x 12 rec. = 60 ch.	5 x 2 x 8192 = 81920 ch.
Frequency band	10 kHz x 60 = 600 kHz	24(32) MHZ
Time resolution	20 ms	0,25 ms (up to 1 mcs)
Frequency resolution	10 kHz	4 kHz (up to 0,1 kHz)
Dynamic range	40 dB	90 dB
Sensitivity	10 Jy	10mJy
Regimes of measurements	Power spectra; post detector registration	Power spectra; complex cross-spectra; real-time Fourier transform; wave-form

Main parameters of Ukrainian low-frequency radio telescopes

Sky Noise Dominance for UTR-2 and URAN system is 4-8 dB, for GURT – 10 dB.
Main beam scan sector from zenith along both coordinates is ± 70° for UTR-2 and ± 80° for URAN and GURT

Radio telescope; institution; coordinates (longitude / latitude)	Frequency range, MHz	Dimensions, m; Max effective area, m^2	Number of elements (l × m = N); polarization	Beamwidth at 25 MHz	Distance to UTR-2 (LOFAR), km	VLBI resolution at 25 MHz (UTR-2 – URAN)	Array spacing (d), suspension above ground (h)
UTR-2; IRA NASU (49° 39′ / 36° 56′)	8 – 32 (40)	1800 × 900 m 140 000 m^2	2040 1 linear	0.4° × 0.4°	0 (~2000)	–	*dNS* = 7.5 m *dW* = 9 m, *h* = 3.5 m
UTR-2 North-South arm	8 – 32 (40)	1800 × 53 m 105 000 m^2	6 × 240 = 1440 1 linear	0.3° × 12°	0 (~2000)	–	---//---
UTR-2 West arm	8 – 32 (40)	900 × 45 m 40 000 m^2	6 × 100 = 600 1 linear	0.6° × 12°	0 (~2000)	–	---//---
URAN-1; IRA NASU (49° 40′ / 36° 21′)	8 – 32 (40)	200 × 29 m 5 500 m^2	4 × 24 = 96 2 linear	5° × 30°	42 (~1950)	59″	*d* = 7.5 m *h* = 3.5 m
URAN-2; PGO NASU (49° 38′ / 34° 50′)	8 – 32 (40)	238 × 116 m 28 000 m^2	16 × 32 = 512 2 linear	3.5° × 7.5°	150 (~1850)	16″	*d* = 7.5 m *h* = 3.5 m
URAN-3; PMI NASU (51° 29′ / 23° 50′)	8 – 32 (40)	238 × 58 m 14 000 m^2	8 × 32 = 256 2 linear	3.5° × 15°	946 (~1100)	2.6″	*d* = 7.5 m *h* = 3.5 m
URAN-4; IRA NASU (46° 24′ / 30° 16′)	8 – 32 (40)	238 × 29 m 7 000 m^2	4 × 32 = 128 2 linear	3.5° × 30°	613 (~1500)	4″	*d* = 7.5 m *h* = 3.5 m
GURT (single subarray); IRA NASU (49° 39′ / 36° 56′)	8 – 70 (80)	18 × 18 m 650 m^2 (at 10 MHz)	5 × 5 = 25 2 linear	30° × 30°	~1 (~2000)	–	*d* = 3.75 m *h* = 1.6 m

Frequency bands of radio astronomical studies



Non-thermal non-thermal radio emission mechanisms important for low-frequency radio astronomy

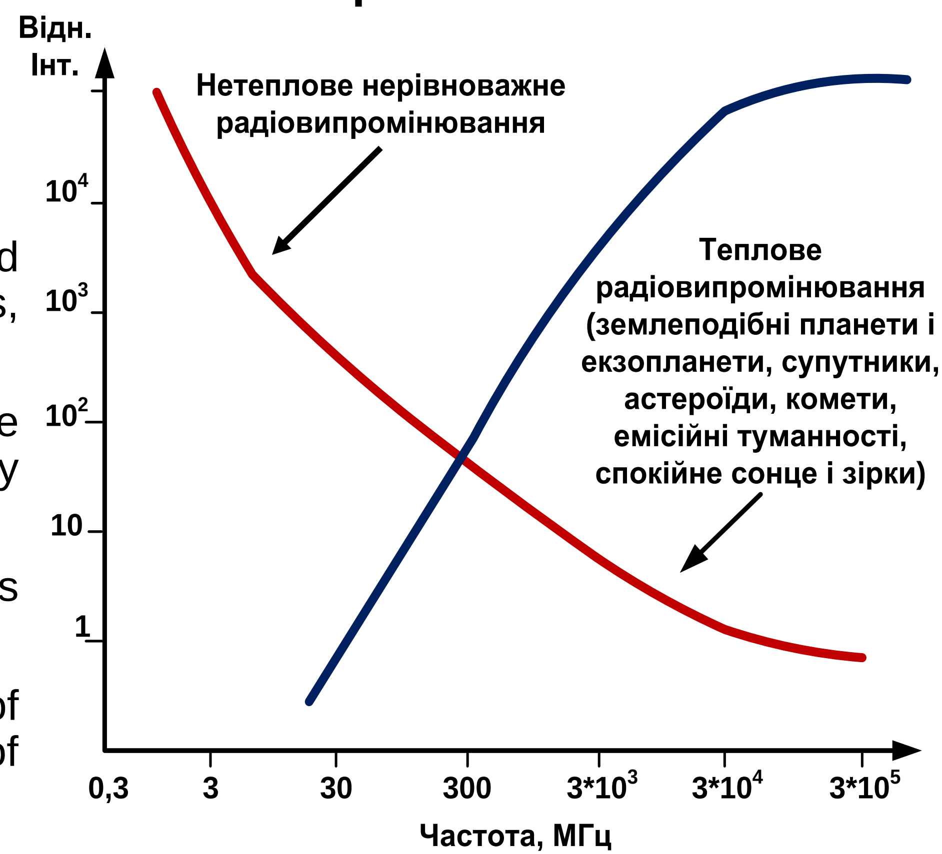
•Synchrotron radio emission (galactic and extragalactic background, radio galaxies, quasars);

•Coherent radioemission in magnetoactive plasma (active Sun and stars, pulsars, planetary giants and giant exoplanets);

•Radio emission of electrostatic discharges (lightning in planets and exoplanets);

•Monochromatic stimulated radioemission of highly excited atoms (recombination lines of interstellar atoms).

Possible spectra of radio emission



Equipment-methodical advantages of the low-frequency radio-astronomy

1. Informativenees of the astronomical observations in the certain range of spectrum rises with the increase of relative width of this spectrum that is determined as $f_в$ / $f_н$. For low-frequency radioastronomy (f= 8 ...80 Mhz) $f_в / f_н$ = 10. (In an optics it equals only two). Thus the absolute band of frequencies folds only F = of fв - fн = of 80 - 8 = 72 Mhz. Up-to-date digital technique such band it can be simply digitised "straight".

2. As a noise temperature of low-frequency of radio telescopes is determined by the temperature of the galactic background, then there is not a necessity to use criogenic entrance receiver.

3. The number of required antenna elements (at a given effective area) decreases inversely in proportion to the square of the wavelength, so the price of the LF radio telescope is significantly reduced.

4. For low-frequency radio telescopes are built as antenna arrays in which it is possible to achieve simultaneously unlimited field of view, multi-beam and multi-section signal reception, flexibility in changing the configuration of the radio telescope.

5. Phased array antennas do not have mechanically moving parts, which increases the reliability and longevity of radio telescopes.

6. Low-frequency radio telescopes are scientific-capacitive, but not technologically-capacitive, so they are not very expensive.

Difficulties of the decameter wavelengths radio astronomy

Problems of low-frequency radio astronomy	*Possible solution*
High temperature of the Galactic background	High effective are (10^4 … 10^6 m^2). The increasing of the integration time, frequency band, observational statistics. **Multi-telescope observations.**
Ground-based interferences (natural, artificial, narrow-band, broad-band)	High dynamic range of the front-end. High dynamic range and resolutions back-end. Broad-band antenna. High directivity, low side lobes of antenna. Special processing (clean). **Space-borne instruments.** **Multi-telescope observations.**
Ionosphere influence (refraction, scintillations, absorption)	Large field of view (multi-beams). Adaptive antenna. Special processing (clean). **Space-borne instruments.** **Multi-telescope observations.**
Low angular resolution in single-dish mode (low D/λ ratio)	VLBI (ground-ground; ground-space). It is **Multi-telescope observations.**

Low-frequency radio telescopes on the map of Ukraine

First part of LOFAR core

LBA: 30...80 MHz; HBA: 110...240 MHz

The Netherlands, Exloo, 2010

Quenn Beatrix at the inauguration of the first part of LOFAR, Exloo, 2010

New LF radio telescope LWA (Long Wavelength Array, USA, New Mexico)f = 20...80 MHz

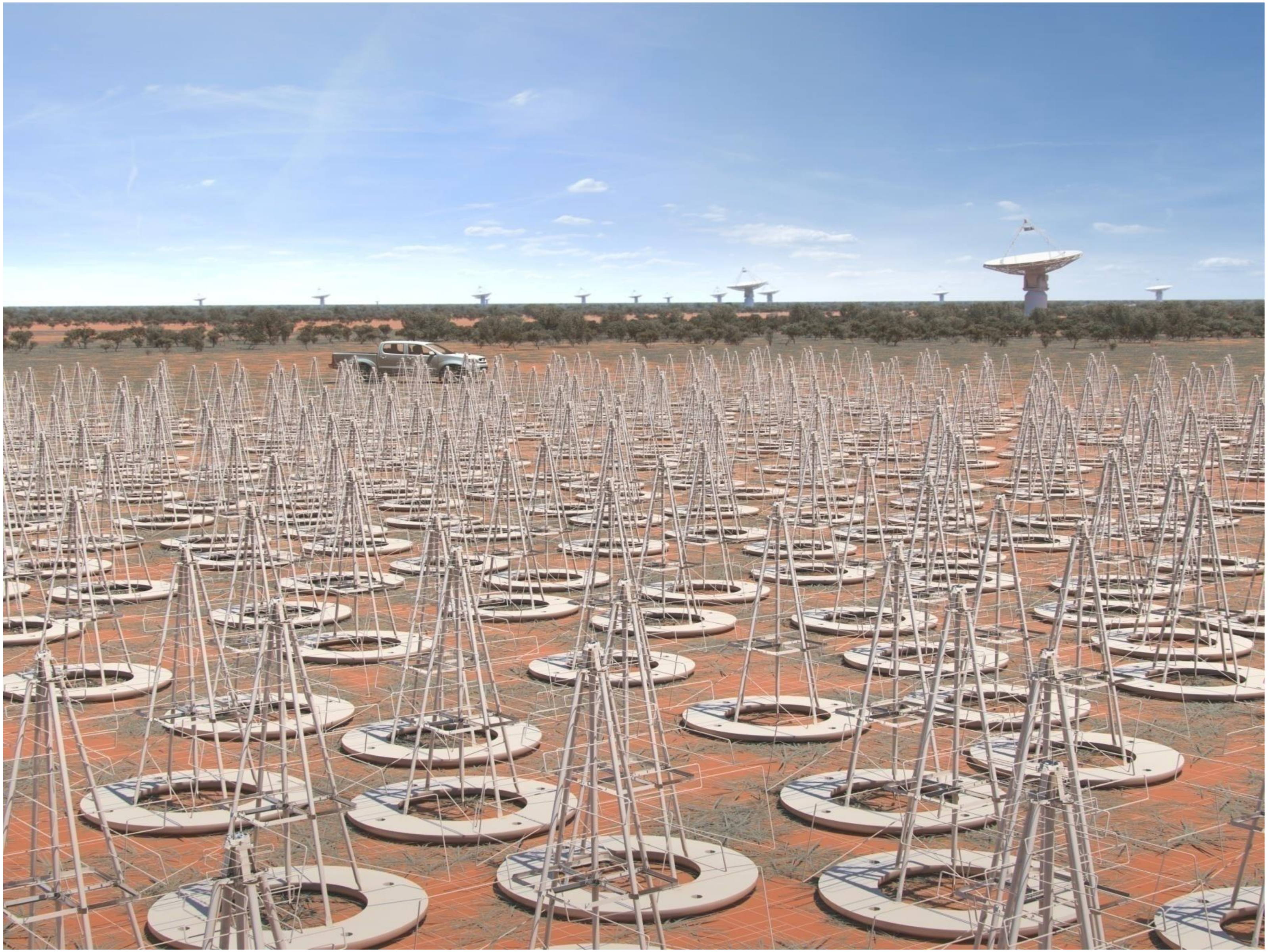
США, LWA: f=30-80 МГц; N=256; B=16 МГц; D=85 дБ; ΔТ=6 дБ ; b= 12 біт; Σ_1 = 400 USD

Європа, LOFAR: f=30-80 МГц; N=96х10; B=16 МГц; D=80 дБ; ΔТ= 4дБ ; b= 12 біт; Σ_1 = 350 USD

Україна, GURT: f=10-80 МГц; N=275; B=70 МГц; D=95 дБ; ΔТ= 9дБ ; b= 16 біт; Σ_1 = 150 USD

Radio Telescope MWA, 50-300 MHz, Australia

Radio Telescope SKA, 200-1000 MHz, International

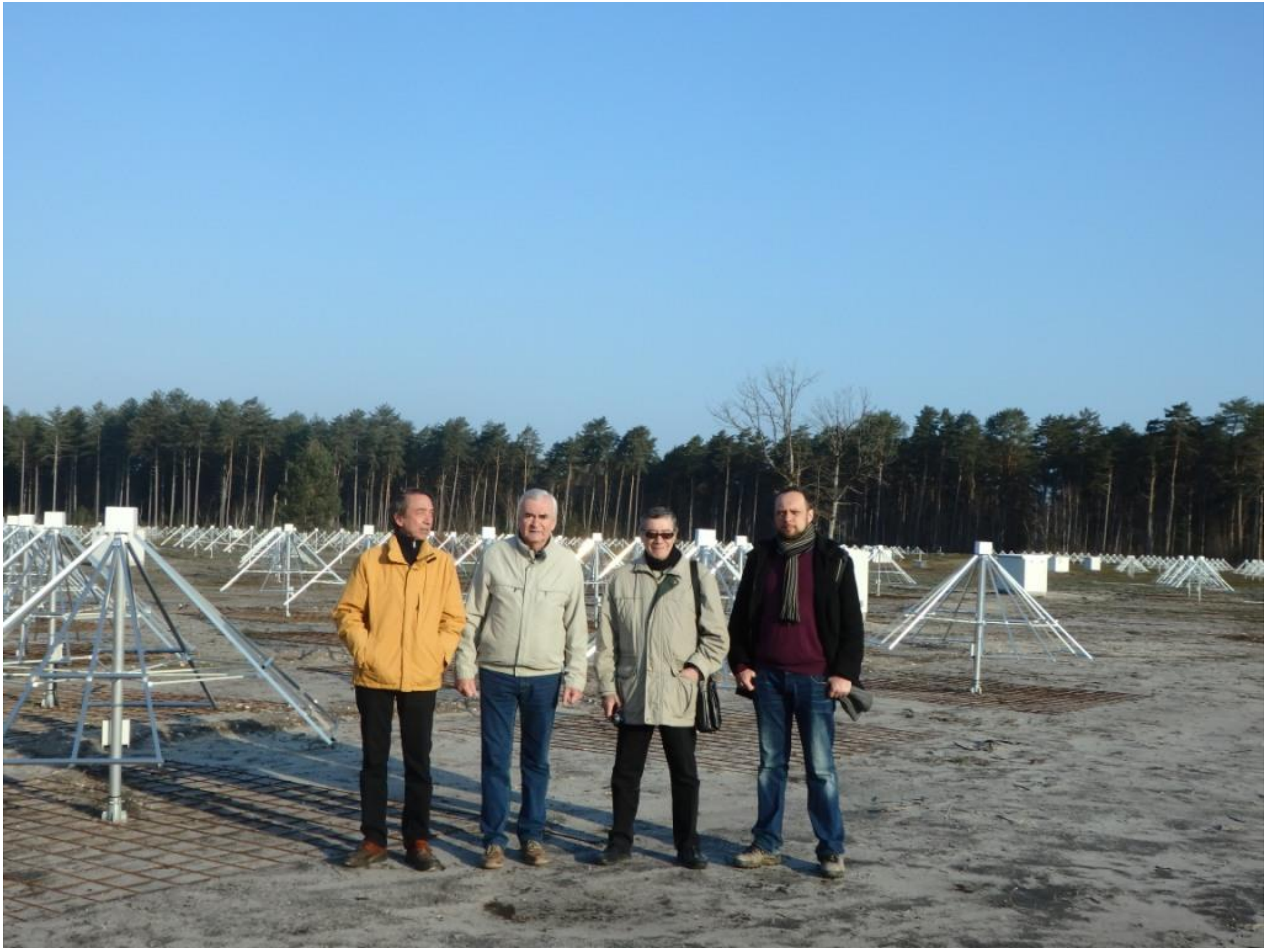


NANCAY Decameter Array (NDA), France (10-80 MHz)

New Generation Radio Telescope NenuFAR

(New Extention of Nancay Upgrading LOFAR), France, f= 8…80 MHz

Radio telescope NenuFAR sub-arrays



The Contribution of Ukrainian Radio Astronomers to the development of the NenuFAR Radio Telescope, Nancay Observatory, France

1. Girard J.N., Zarka P., Tagger M., Denis L., Charries D., **Konovalenko A.**, Boone F. Antenna design and distribution of the LOFAR superstation.// Comptes Rendus Physique. – 2012. – V.13 – P. 33-37.

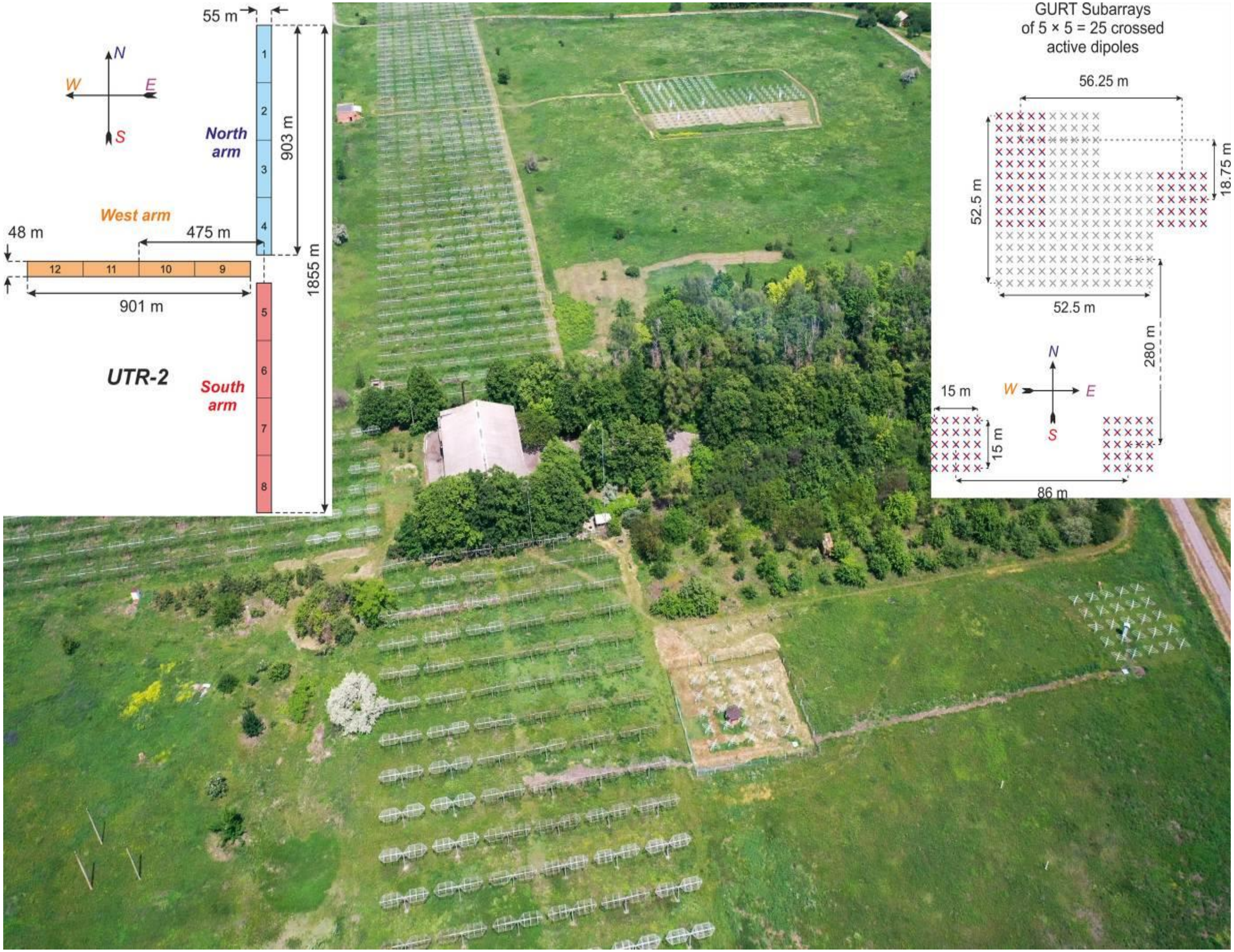
2. Zarka P., Girard J. N., Tagger M., Denis L., Aghanim N., Alsac L., Arnaud M., Barth S., Boone F., Bosse S., Capay-rou D., Capdessus C., Cecconi B., Charrier D., Coffre A., Cognard I., Combes F., Corbel S., Cornilleau-Wehrlin N., Cottet P., Dole H., Dumez-Viou C., **Falkovych I.**, Ferrari C., Floquet F., Garnier S., Georges G., Gond B., Grespier N., Grießmeier J.-M., Joly S., **Konovalenko A.**, Lamy L., Leh-nert M., Pommier M., Rucker H., Sandré P., Semelin B., Taffoureau C., Tasse C., Thétas E., Theureau G., **Tokarsky P.**, Van Driel W., Vimon J.-B., and Weber R.: LSS/ NenuFAR: The LOFAR Super Station project in Nançay //S. Boissier, P. de Laverny, N. Nardetto, R. Samadi, D. Valls-Gabaud, and H. Wozniak, eds. SF2A 2012: Proc. of the Annual meeting of the French Society of Astronomy and Astrophysics. – 2012. – P. 687–694.

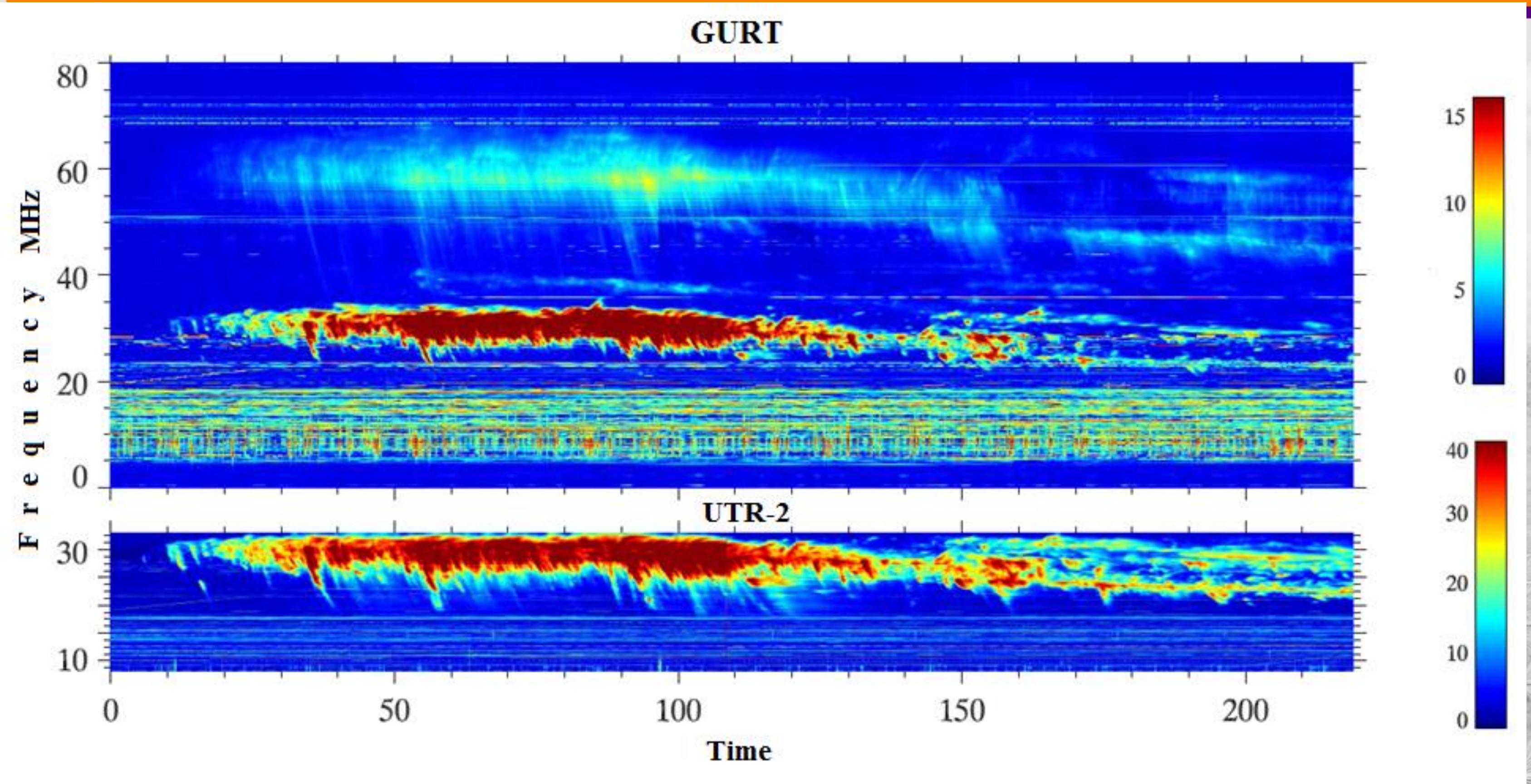
3. Zarka P., Tagger M., Denis L., Girard J. N., **Konovalenko A.**, Atemkeng M., Arnaud M., Azarian S., Barsuglia M., Bonafede A., Boone F., Bosma A., Boyer R., Branchesi M., Briand C., Cecconi B., Célestin S., Charrier D., Chassande-Mottin E., Coffre A., Cognard I., Combes F., Corbel S., Courte C., Dabbech A., Daiboo S., Dallier R., DumezViou C., El Korso M. N., Falgarone E., **Falkovych I.**, Ferrari A., Ferrari C., Ferrière K., Fevotte C., Fialkov A., Fullekrug M., Gérard E., Grießmeier J.-M., Guiderdoni B., Guillemot L., Hessels J., Koopmans L., Kondratiev V., Lamy L., Lanz T., Larzabal P., Lehnert M., Levrier F., Loh A., Macario G., Maintoux J.-J., Martin L., Mary D., Masson S., Miville-Deschenes M.-A., Oberoi D., Panchenko M., Pandey-Pommier M., Petiteau A., Pinçon J.-L., Revenu B., Ri-ble F., Richard C., Rucker H. O., Salomé P., Semelin B., Serylak M., **Sidorchuk M.**, Smirnov O., Stappers B., Taffoureau C., Tasse C., Theureau G., **Tokarsky P.**, Torchinsky S., **Ulyanov O.**, van Driel W., **Vasylieva I.**, Vaubaillon J., Vazza F., Vergani S., Was M., Weber R., and **Zakharenko V.** NenuFAR: Instrument description and science case // International Conference on Antenna Theory and Tech-niques (ICATT): Proc. conf. – Kharkiv, Ukraine. – 2015. – P. 1–6. DOI: 10.1109/ICATT.2015.7136773

Additional New Generation GURT Radio Telescope with the UTR-2 Radio Telescope at the Observatory of the name S.Y. Braude

- ✓ **Frequency range – 8…80 МГц;**
- ✓ **Number of crossed elements in the subarray– 25;**
- ✓ **The total number of elements installed – 550;**
- ✓ **Potential number of elements - up to 10,000, which can provide an area of up to 1 sq. km!**

Radio telescopes UTR-2 and GURT and their structural schemes





Type II Solar bursts observed by GURT (top) and UTR-2 (bottom) on 25.07.2014. The start is 07:11:15 UT

High quality astrophysical studies by using of small size low-frequency new generation radio telescopes

1. Advantages of new generation sub-array GURT (25 active antenna elements)

- broad band;
- high sensitivity for brightness temperature;
- high time and frequency resolution;
- high dynamic range and interference immunity;
- electronic beam steering;
- polarimetric capabilities;
- high filling factor of antenna elements;
- continuous operation in automatic mode;
- optimal combination of analog and digital equipment;
- low costs of the development and maintenance;
- simple checking and repairing.

2. Astrophysical possibilities and tasks

- The Sun and interplanetary medium;
- Earth ionosphere;
- Jupiter;
- Saturn electrostatic discharges;
- pulsars;
- galactic and extragalactic background;
- interstellar medium and radio recombination lines;
- cosmological spectral lines;
- secular decreasing of CasA flux density.

The world's best low frequency radio telescopes (f ≤ 300 MHz)

*(Existing modernized *, New generation**, Future***),* **$K = T_N / (T_N + T_{sys})$**

1.* **UTR-2 :** f = 8 … 32(40)MHz; **A_{ef} ≈ 150 000 sq.m** (K≈0,8) – Ukraine

2.* **URAN-1…URAN-4**: f = 8… 32(40)MHz; **∑A_{ef} ≈ 50 000 sq.m** (K≈0,8) – Ukraine

3.** **GURT**: f=8 … 80 MHz; **A_{ef} ≈ 400 sq.m** (1 субрешітка) (K≈0,9) – Ukraine

4.* **NDA:** f=(10)20 … 80MHz; **A_{ef} ≈ 14 000 sq.m** (K≈0,7) – France

5.** **NenuFAR**: f=(8)20 … 80MHz; **A_{ef} ≈ 20 000 (40 000) sq.m** (K≈0,9) – France

6.** **LOFAR (LBA)**: f=(10)30 … 80MHz; **A_{ef} ≈ 50 000 sq.m** (K≈0,3) – Europe
LOFAR (HBA): f=110 … 240MHz; **A_{ef} ≈ 10 000 sq.m** (K≈0,5) – Europe

7.** **LWA**: f=(10)20 … 80MHz; **A_{ef} ≈ 7 000 sq.m** (K≈0,7) – USA

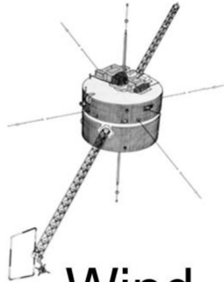
8.** **MWA**: f=50 … 300MHz; **A_{ef} ≈10 000 sq.m** (K≈0,7) – Australia

9.*** **SKA** (Low-band): f=200 … 1000MHz; **A_{ef} ≈ 10^6 sq.m** (K≈0,7) – South. Africa

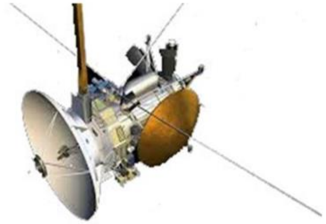
Low-frequency radio telescopes in Europe (UTR-2, URAN-1, URAN-2, URAN-3, URAN-4, GURT, LOFAR, E-LOFAR, Nenu FAR, NDA)

LF: 10…30 MHz (dkm); 30…300 MHz (m)

Complementary character of space and ground-based low-frequency radio astronomy systems


Wind


Stereo


Cassini


Juno

SPACE: f < 10 MHz (NOT IONOSPHERIC LIMIT):

f=0,1 – 30 MHz; ΔF=100 kHz; ΔT=100 ms

$N \approx 1$; $A_{eff} \approx 100\ m^2$ **(!)**

$$\Delta S_{min} = 2kT / A_{eff}\sqrt{\Delta f \Delta \tau}\ ; \quad A_{eff} \approx N A_1 \approx N \lambda^2/4$$

GROUND: (UTR-2, URAN1…..URAN4,GURT); F ≥ 10 MHz (IONOSPHERIC LIMIT):

f=8-32 MHz (8-80 MHz); ΔF=1kHz; ΔT=1 μs

N=2040 (UTR-2); N_Σ=4500; A_{eff} (UTR-2)= 140 000 m^2 ; $A_{eff\Sigma} \approx$ 300 000 m^2 **(!)**


UTR-2


URAN-1


URAN-2


URAN-3


URAN-4


GURT

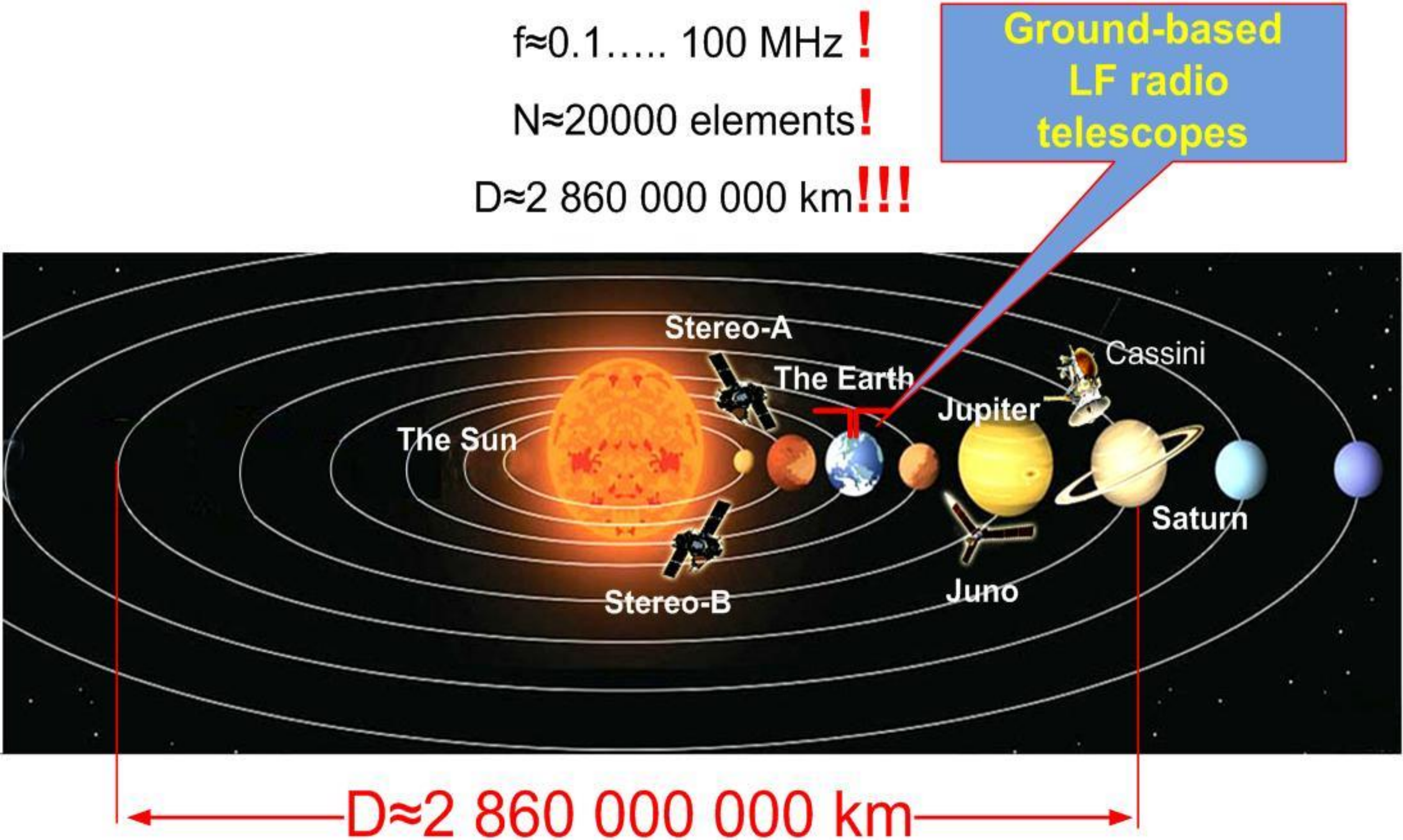
Huge Solar system – scale low-frequency radio telescope

(It is in principal, it is a joke):

f≈0.1….. 100 MHz !

N≈20000 elements!

D≈2 860 000 000 km!!!



Advantages of the multi-telescope (ground-ground, ground-space) radio astronomy observations at low-frequencies

(the distances between telescopes are from ~ 1 km up to ~ 3 000 km)

1. Improvement of the sensitivity (summarization of the effective areas in coherent mode).

2. Improvement of the angular resolution (VLBI mode).

3. Mutual positive complementarily (low effective area, sensitivity and resolutions, but broad frequency range + high effective area, sensitivity and resolutions but moderate frequency range).

*4. Reducing and/or identification of the interferences (inner, external, natural, artificial, broad-band, narrow-band) influences.

*5. Reducing and/or identification of the ionospheric influences.

6. Reducing and/or identification of the interplanetary medium influence.

7. In the frame of the previous point it is interesting to measure of the delay in the interplanetary inhomogeneous movements across of line-of-sigh.

8. Measurements of the directivity of the source pulse radio emission.

9. Improvement of the sporadic radio emission identification.

10. Identification of the negative instrumental effects.

11. Identification of the observational arte-facts what produced by the telescope side-lobes and difractional lobes influence.

*12. Considerable improvement of the effectivity and realibility of the low-frequency radio astronomy investigation in general

The sensitivity of the radio astronomy investigations

$$\Delta S_{min} = 2\, kT_{sys} / A_{ef} \sqrt{\Delta f \Delta t}$$

$k = 1{,}38 \times 10^{-23}$ – Boltzmann constant;
T_{sys} – the noise temperature of the receiving system of the radio telescope; (cryogenic input amplifier);
Δf, Δt – registration band (frequency resolution) and accumulation time (temporal resolution)

For high frequency radio astronomy (f >300 MHz): T_{sys} ~ 10 K; A_{ef} ~ 3000 sq.m.

$2k\, T_{sys} / A_{ef}$ = S E F D ~ 1 Jy (System Equivalent Flux Density)

For low frequency radio astronomy (f <300 MHz):

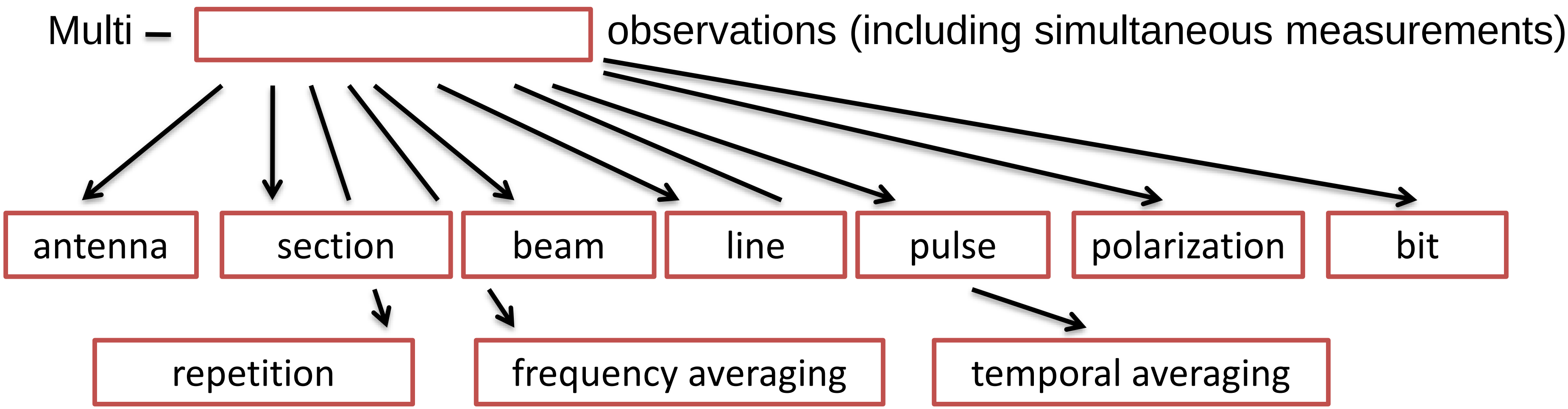
$$\Delta S_{min} = 2\, kT_{sys} / A_{ef} (T_N / (T_{sys} + T_N)) \sqrt{\Delta f \Delta t}\ ;$$

T_{sys} = 1000 - 1 000 000 K! (temperature of the galactic background);
T_N ~ 100 K (noise temperature of the input antenna amplifier);
A_{ef} ~ 1000 – 1000000 sq.m.

New low frequency radio telescope quality parameter introduced by Ukrainian radio astronomers:

$A_{ef} (T_N / (T_{sys} + T_N))$ = S E E A ~ 100 000 sq.m. (System Equivalent Effective Area)

New methods for the strong improvements of the low frequency measurements sensitivity



Furthermore it should be:

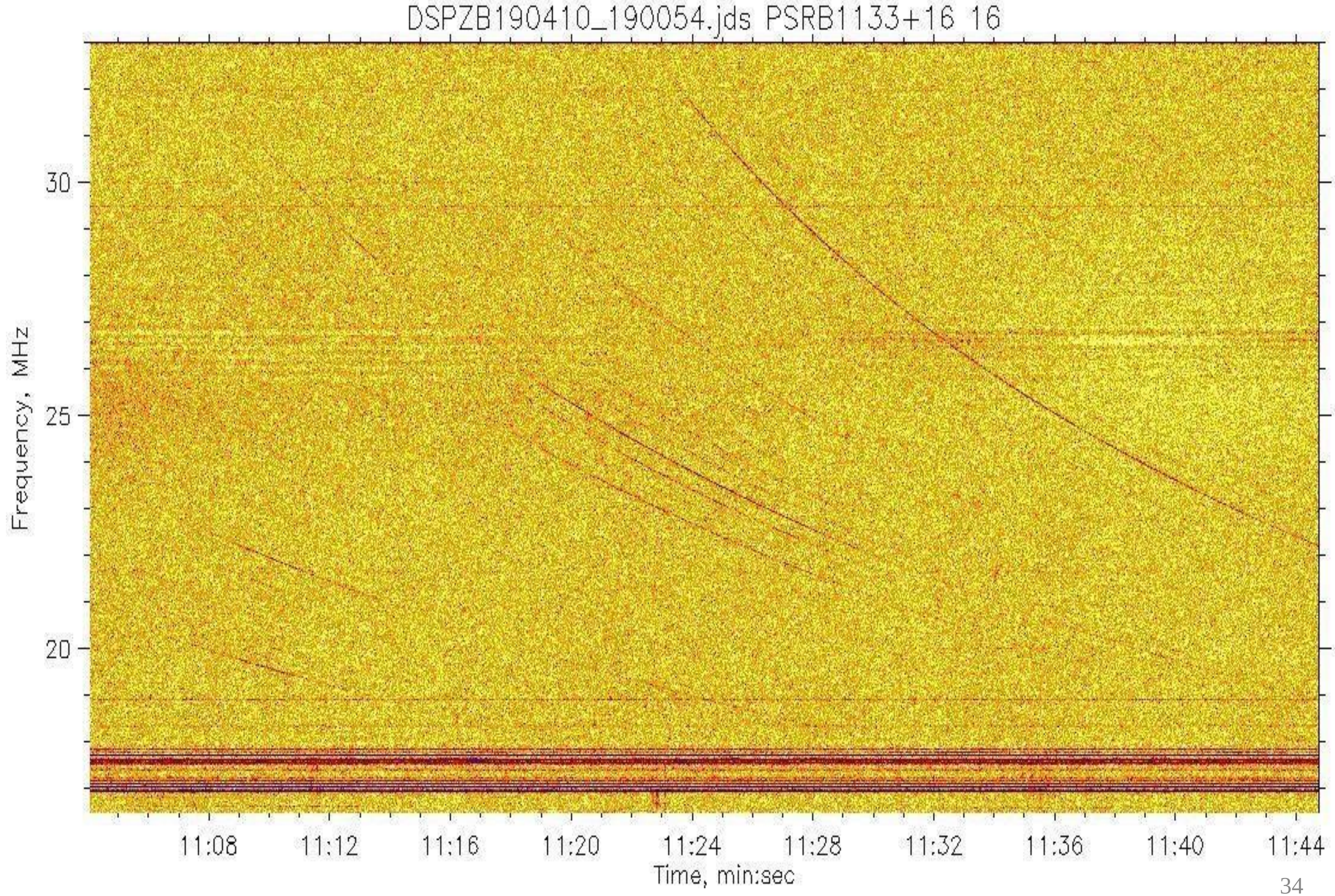
- the decreasing of the side and difractional lobes levels;
- optimal restoration of the low-frequency spacial harmonics;
- optimal implementation of the time and frequency resolution during the observations;
- optimal implementation of the averaging parameters during the processing;
- optimal choosing of signals levels in the systems for the maximum dynamic range;
- combination of the absolute and relative measurements;
- optimization of the calibration procedures;
- maximization of the fluctuation and “confusion” sensitivities.

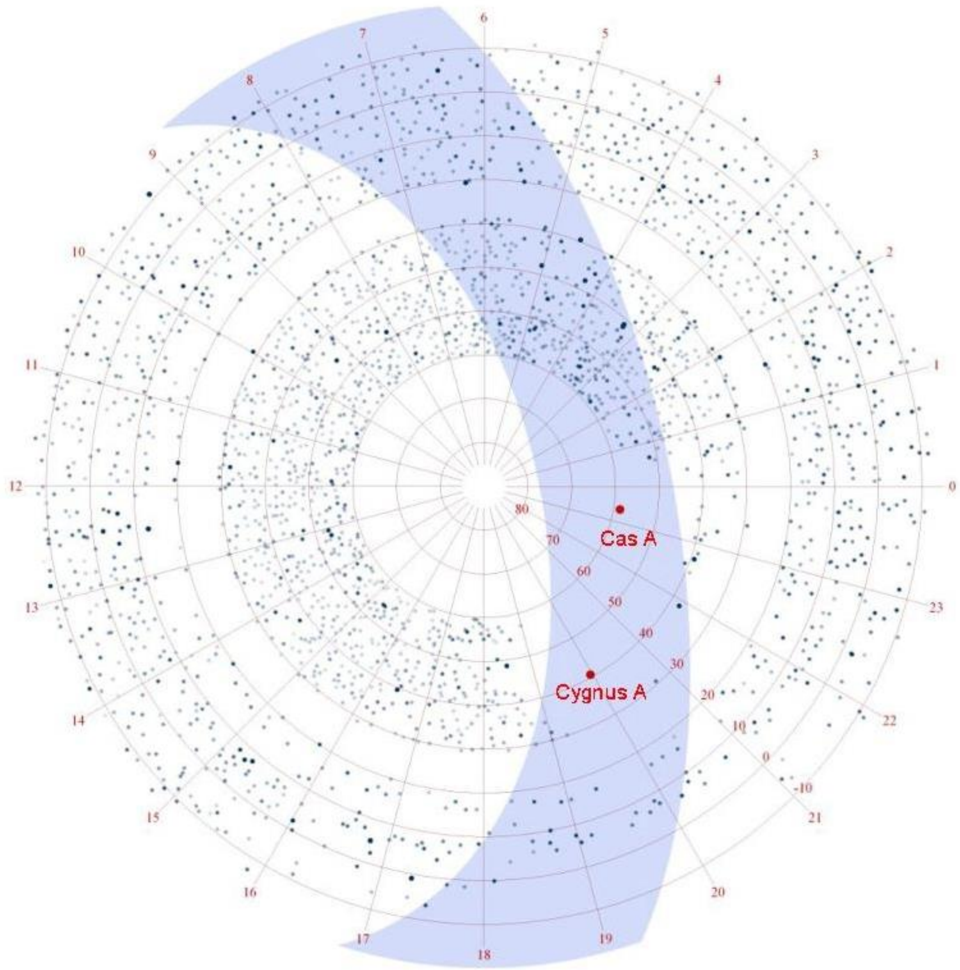
New Frontiers in the Low-frequency Radio Astronomy

Part 2: New astrophysical tasks and capabilities

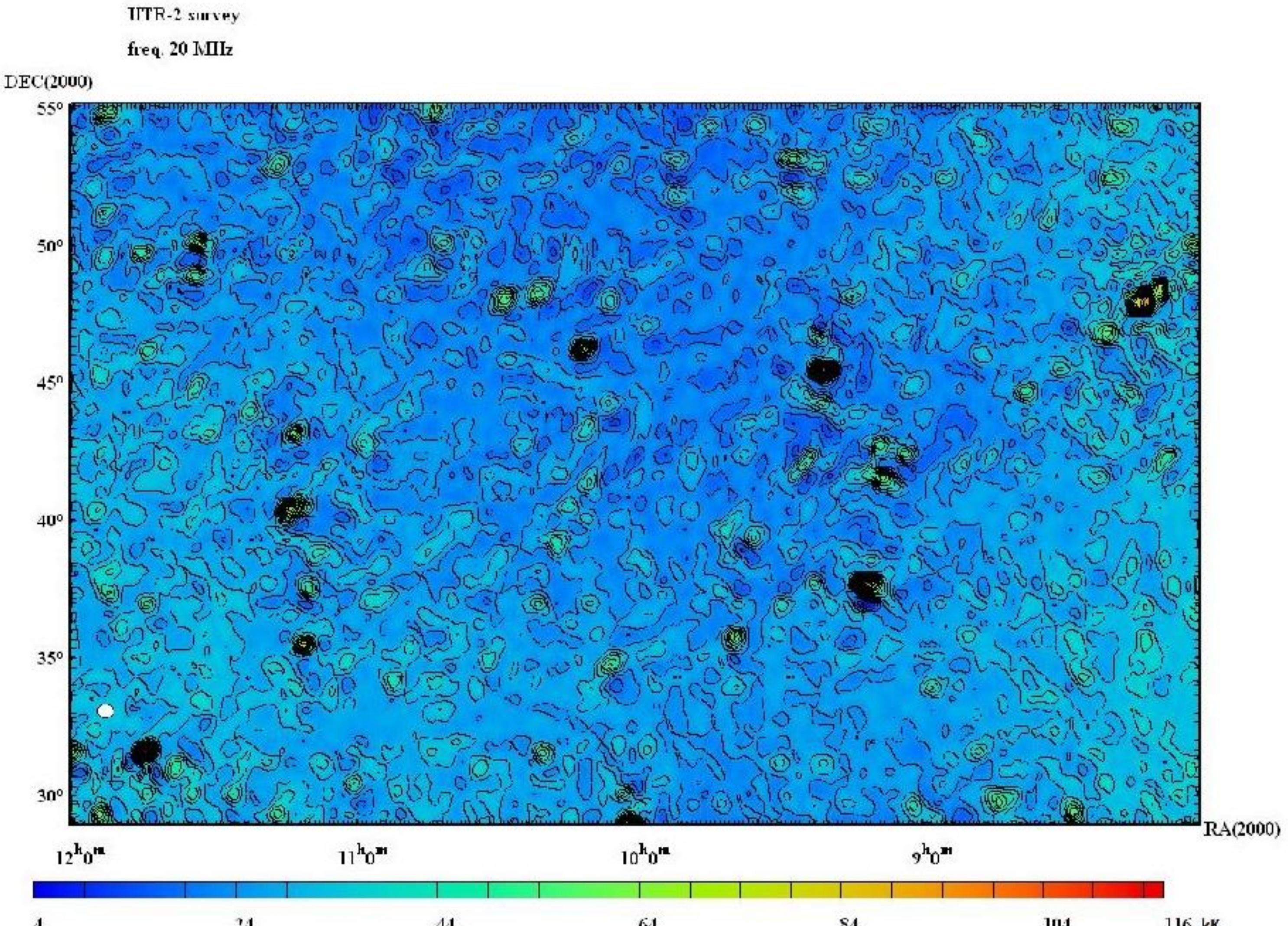
New low-frequency radio astronomy Programme is prepared in IRA NASU, Kharkiv. It includes the implementation of the mentioned above methodology for the resolving of the actual astrophysical tasks by simultaneous observations of many objects for various types of cosmic radioemission (continuum, monochromatic, pulse, sporadic, polarized). So, there is concept “Ten in the ones” and it includes the studies of: **1**. Discrete radiosourses (radio galaxies, quasars, H II regions, supernova remnants); **2**. galactic background; **3**. extragalactic background; **4**. pulsars; **5**. transients; **6**. recombination lines; **7**. cosmological spectral specialties; **8**. the Sun, planets and exoplanets; **9**. interplanetary and ionospheric scintillations; **10**. lighting activity.

Dynamic spectra of PSRB1133+16



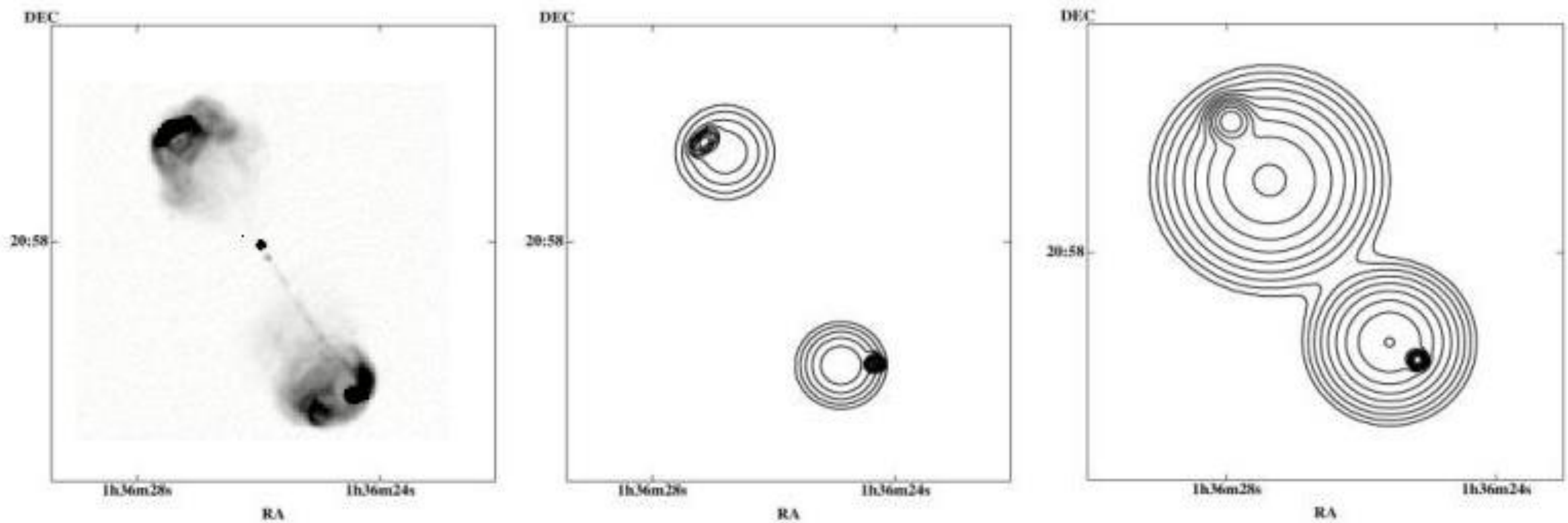


UTR-2 catalogue coverage of the Northern sky. Color intensities of individual point sources represent their flux densities. Shaded region is the Galactic disk: |b| < 15º



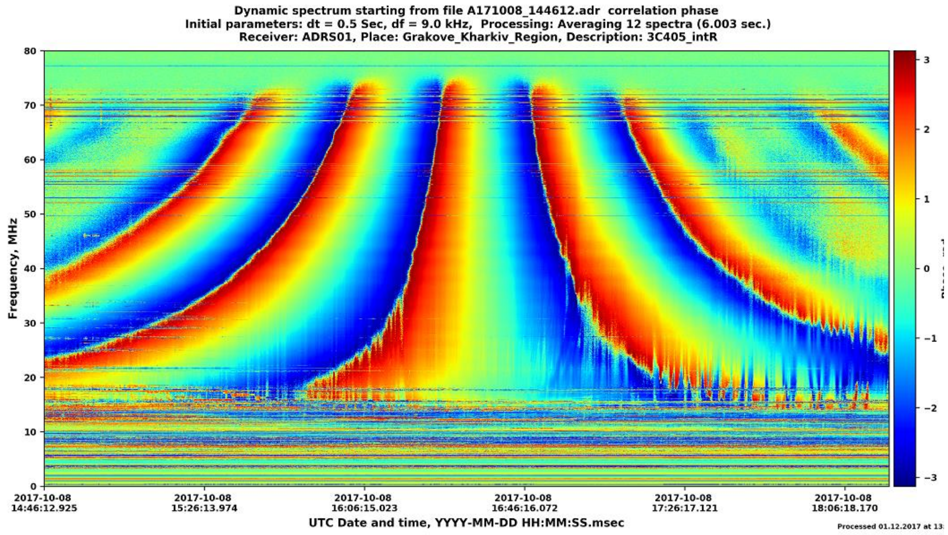
UTR-2 full resolution image (half-power bandwidth is ~ 34´×38´) describing the brightness temperature map of Northern sky part at 20 MHz. The contour map starts at level of 5 x 10^3 K and runs in steps of 5 x 10^3 K

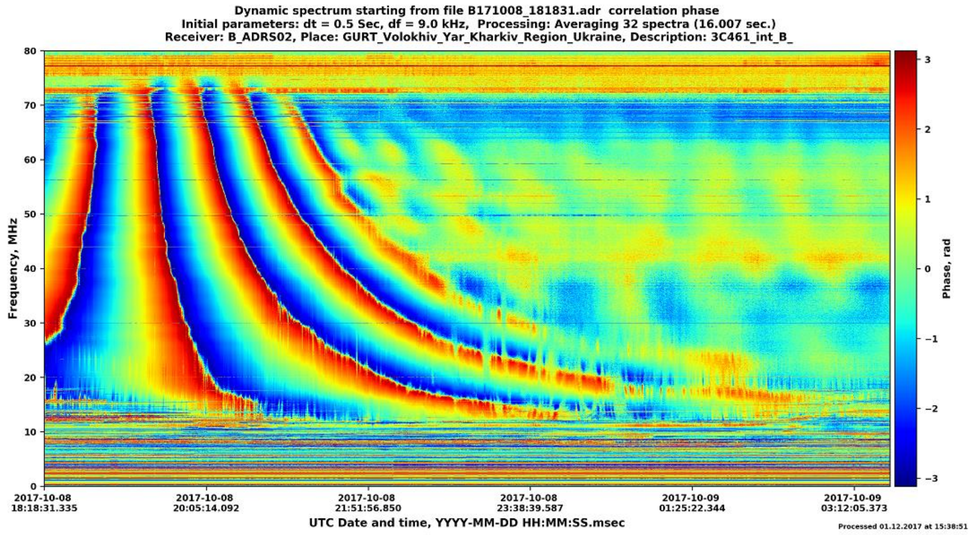
Krymkin, Sidorchuk, A&A, 1988

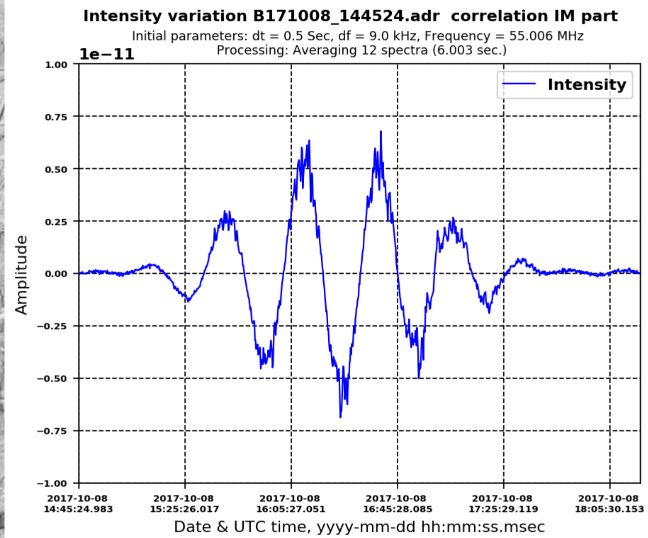


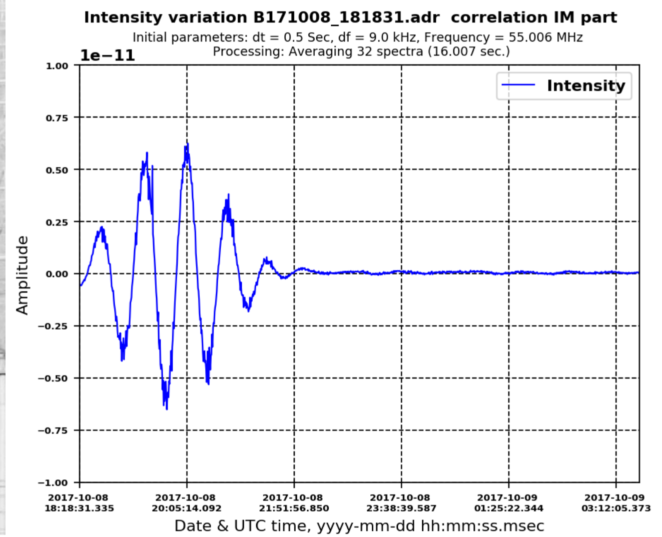
The VLA map of the 3C47quasar at the frequency 1,65 GHz (left). In the middle panel one can see a simplified model of the source which was computed taking into consideration the URAN resolution. On the right panel a model of low frequency structure of the 3C47 obtained with URAN interferometers is presented at 25 MHz at the same scale as those in pictures to the left of it

Interferometric observations 3C405 and 3C461 (Oct, 2017)



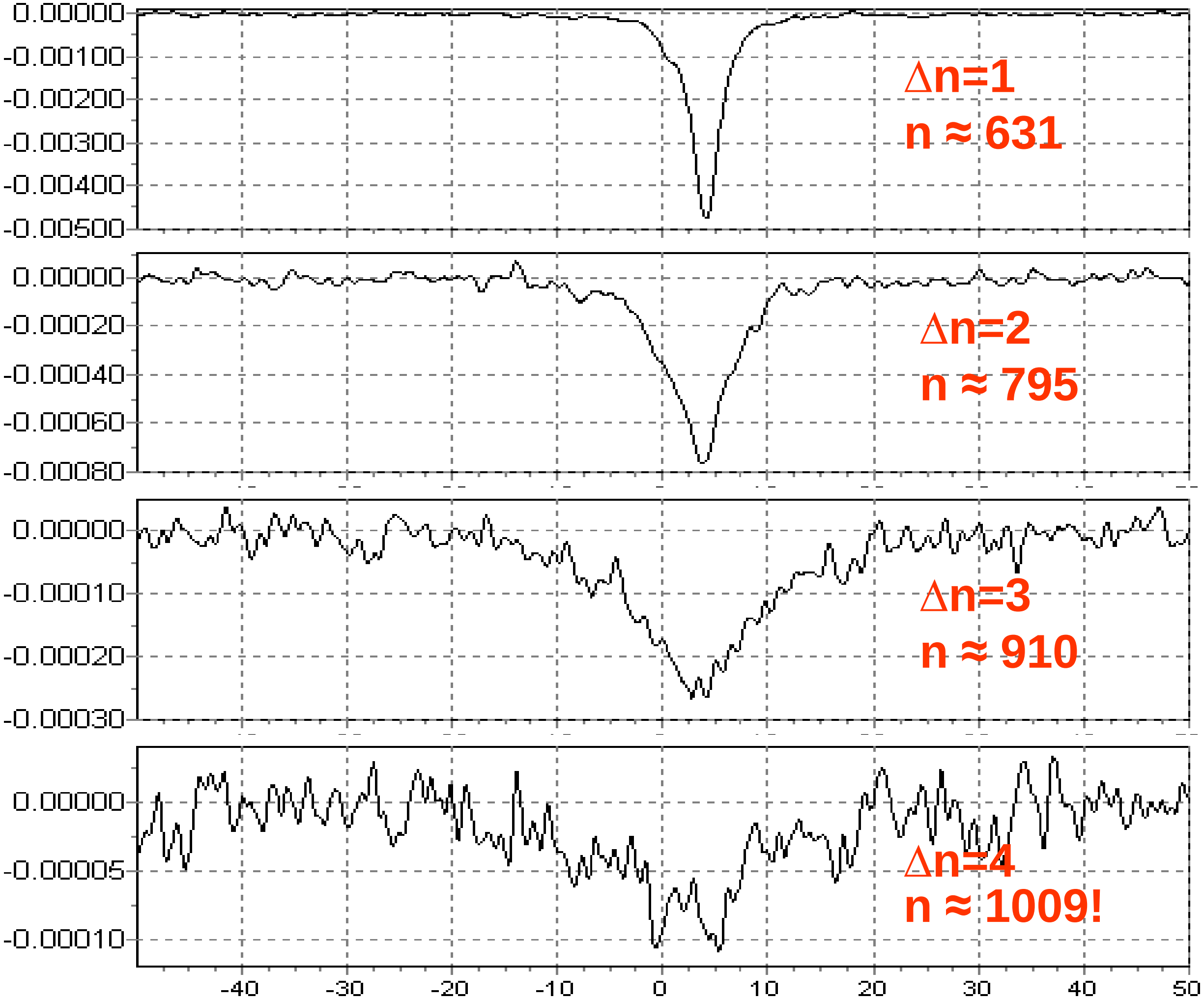


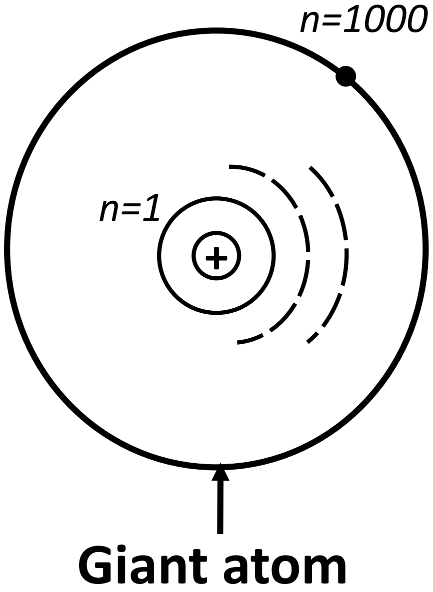




Interferometric responses when observing 3C405 and 3C461 sources
on the interferometer of two GURT sub-arrays with a base of 56 m.
The upper panel is the signal correlation phase, the lower panel is the imaginary part of the correlation

Detection of the recordly high excited quantum states (n > 1000) on the interstellar atoms
(UTR-2, *ν* ≈ 30 MHz, *Δn* = 1...4, *n* ≈ 1009) - 2007

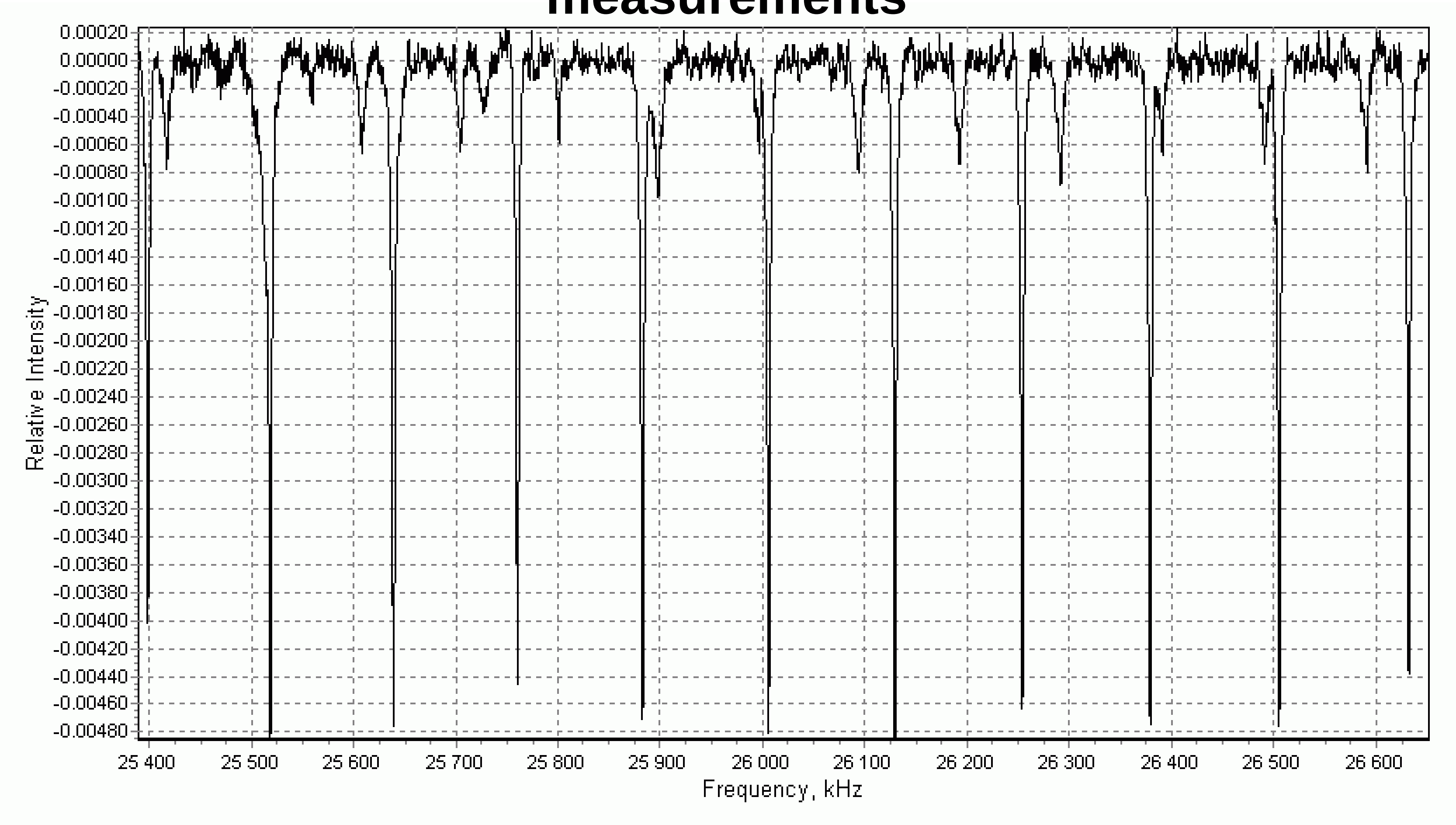




D ≈ 0.1 мм !

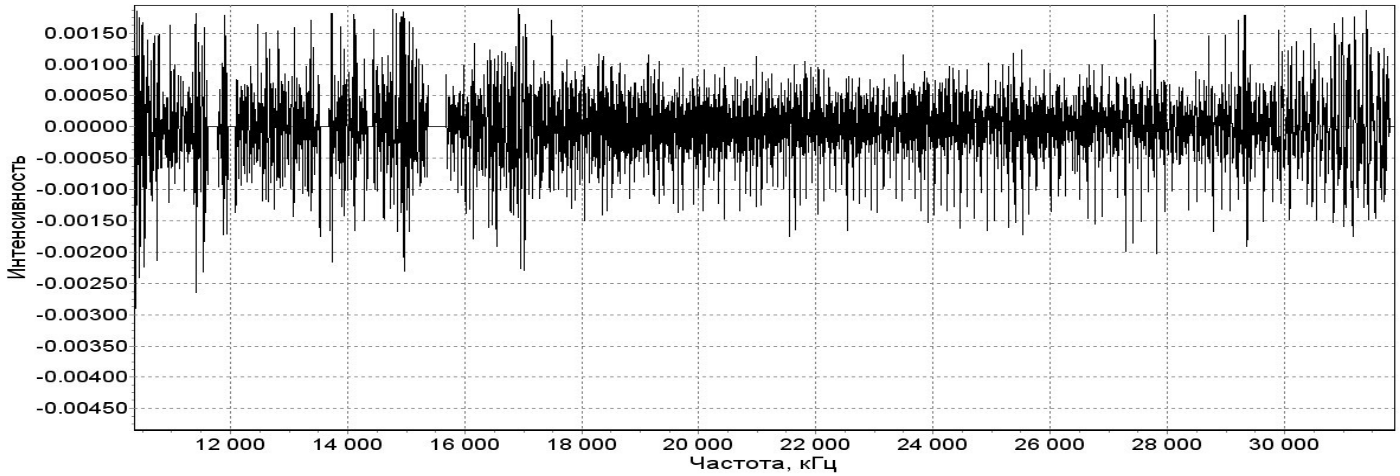
Konovalenko, Sodin, Nature, 1981; Stepkin et al., MNRAS, 2007

Radio recombination lines towards Cas A detected by UTR-2 with broad-band (B> 1 MHz) and multi – channel (N=4096) measurements

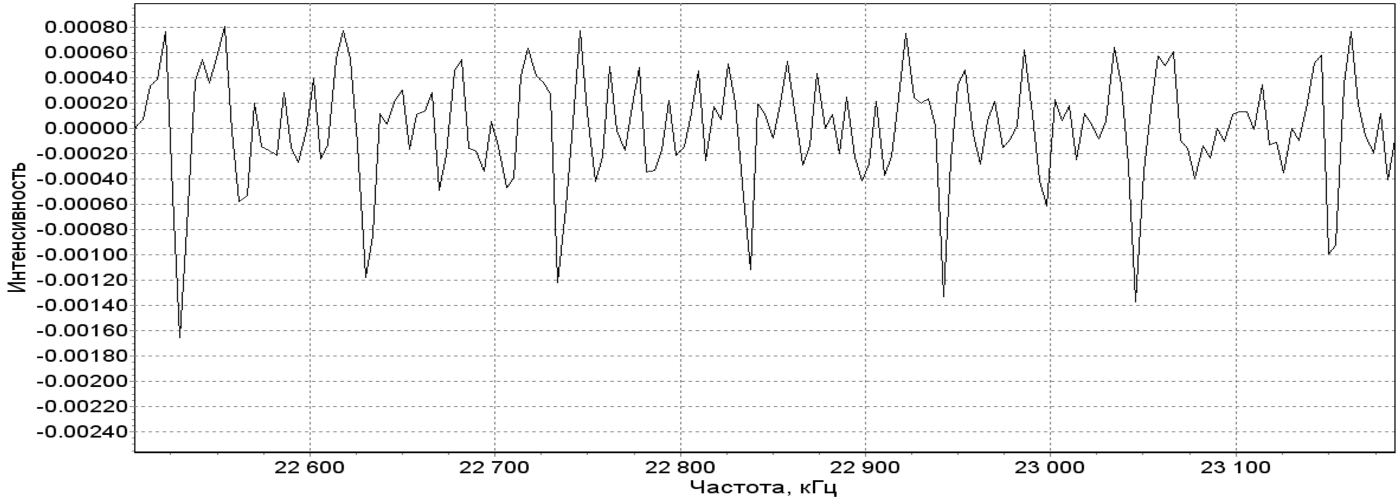


S.V. Stepkin, A.A. Konovalenko. Radio recombination lines from the largest atoms in space. **Monthly Notices of Royal Astronomical Society**, 2007, January, v. 374, issue 3, pp. 852-856.

First simultaneous registration
a large number of recombination lines (~ 250) at UTR-2, Oct., 2017



Normalized spectrum in the direction of Cassiopeia A containing a series of RRL carbon. C854α ... C596α lines fall in the range from 10.5 MHz to 31 MHz. The accumulation time was 55 minutes



A part of the spectrum with lines C663α ... C657α

A New Method of Sensitive Search and Studies of the Low Frequency Radio Recombination Lines

$$(\Delta T_L / T_C)_{min} = \pi / 2\sqrt{\Delta f_{ef} \Delta t}\ N_1\ N_2\ N_3\ N_4\ N_5$$

1978 : detection of interstellar RRL at the decameter waves using UTR-2;
Δt_{ef}= 4 год ; **N_1 =1**, N_2=1, N_3=1, N_4=1; Δf=1kГц; B=20 kGz;
$(\Delta T_L / T_C)_{min}$ = 4 x 10^{-4} ; $(\Delta T_L / T_C)_{det}$ = 4x10^{-3}; S/N ≈10

1978-1992 : detection of the low-frequency RRL in selected galactic objects;
it is shown that the distance between the lines is significantly reduced at LF (ΔF= 3 f / n)
Δt_{ef} = 5 x 4год = 20 hours; N_1 =5, N_2=1, N_3=1, N_4=1; Δf=1kГц; B=20 kGz x 5;
$(\Delta T_L / T_C)_{min}$ = 1,8 x 10^{-4} ; $(\Delta T_L / T_C)_{det}$ ≈ 1,5x10^{-3}; S/N ≈10

1992-2005 : detection of the recordly high excited states (n ~ 1000);
Δt_{ef} = 10 x 4год = 40 hours ; N_1 =10, N_2=1, N_3=1, N_4=1; Δf=1kГц; B=1,5 МГц;
$(\Delta T_L / T_C)_{min}$ = 1 x 10^{-4} ; $(\Delta T_L / T_C)_{det}$ = 1x10^{-3}; S/N ≈10

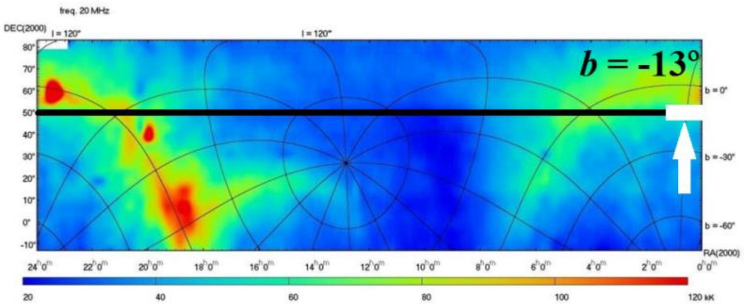
2005-2018 : simultaneous observations of many RRL (Δn ~ 100…400);
Δt_{ef} = 400 x 4 hours = 1600 hours ; N_1 =400, N_2=1, N_3=1, N_4=1; Δf=1kГц; B=12…24 MHz;
$(\Delta T_L / T_C)_{min}$ = 2 x 10^{-5} ; $(\Delta T_L / T_C)_{det}$ = 1x10^{-4}; S/N ≈5

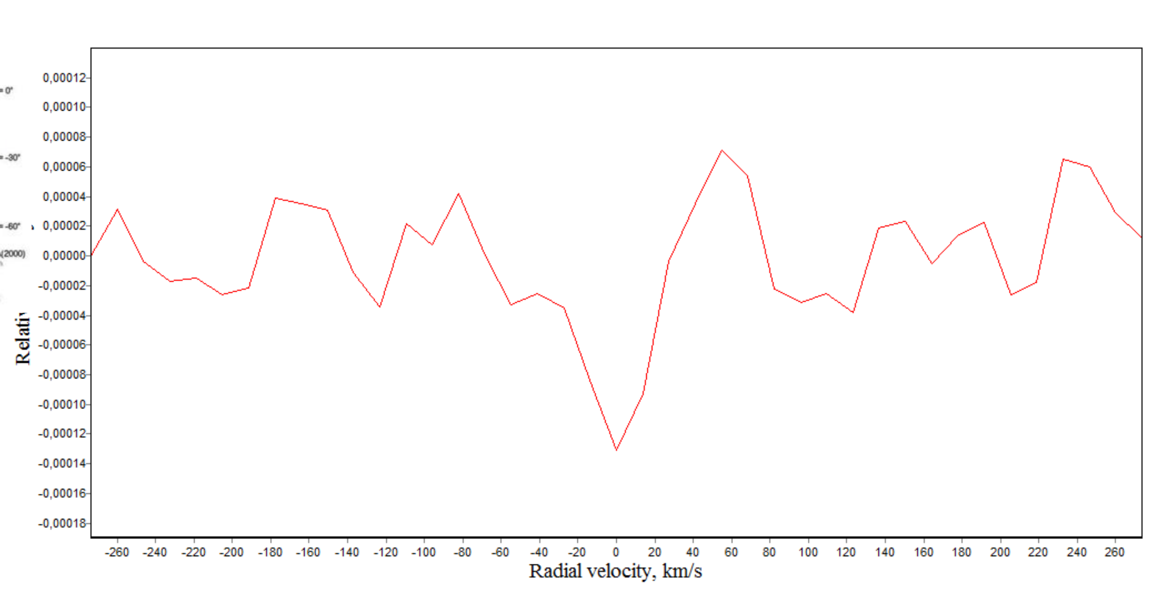
2019: simultaneous multilinear **(N_1 =400**), multi-section **(N_2 =100),** multi-antenna (**N_3 =3**), bipolarization **(N_4=2),** many bits **(N_5=2)** insensitive searches RRL;

! Δt_{ef} = 400 x 100 x 3 x 2 x 4 hours = 480 000 hours ← 100 years !

! $(\Delta T_L / T_C)_{min}$ = 6 x 10^{-7}

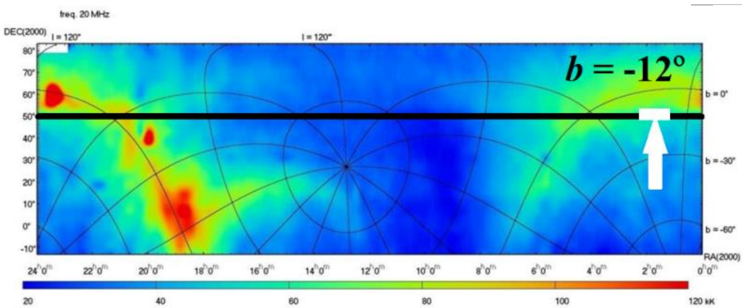
Detection of LF carbon RRLs in medium across the Galactic plane
N = 40, ΔF = 20…24 MHz

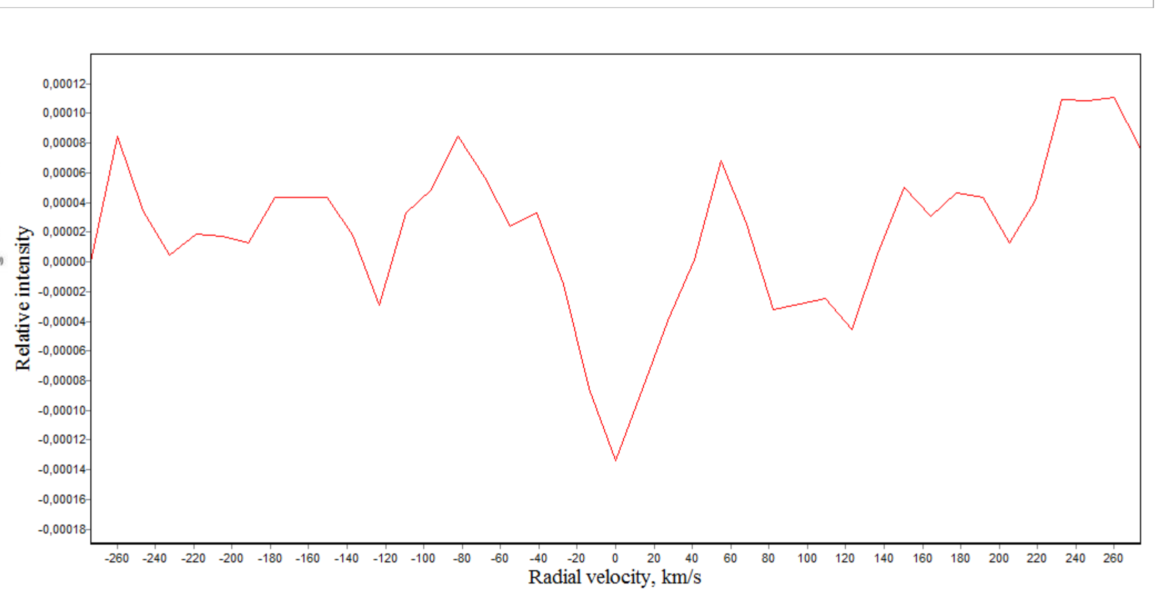




Δα = 0h…1h, δ ~+50°

ΔT=40×8.7h=348h

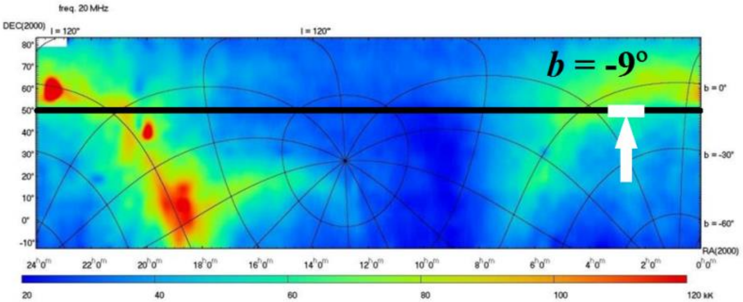




Δα = 1h…2h, δ ~+50°

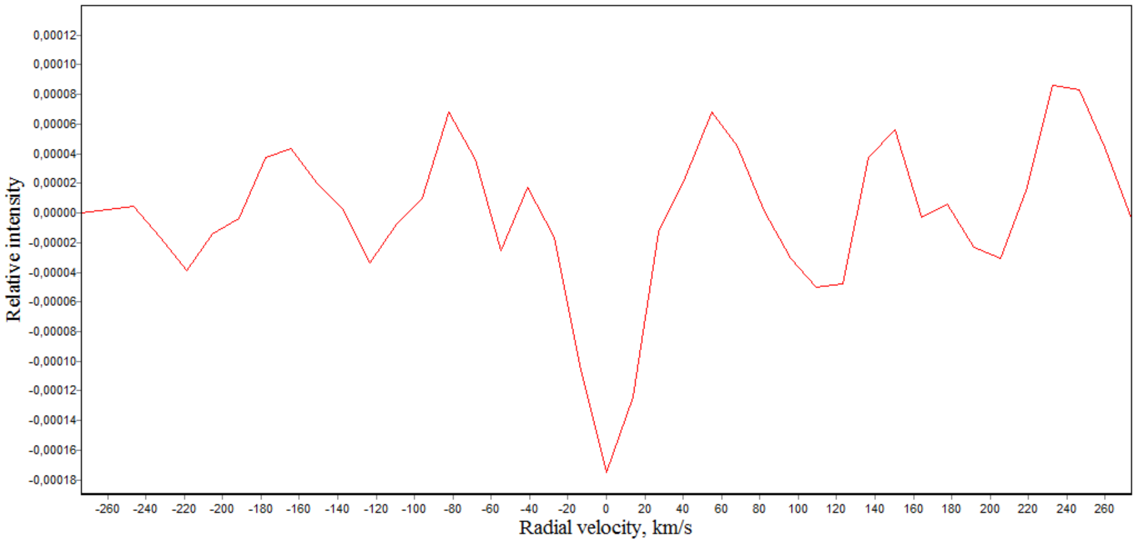
ΔT=40×7.2h=288h

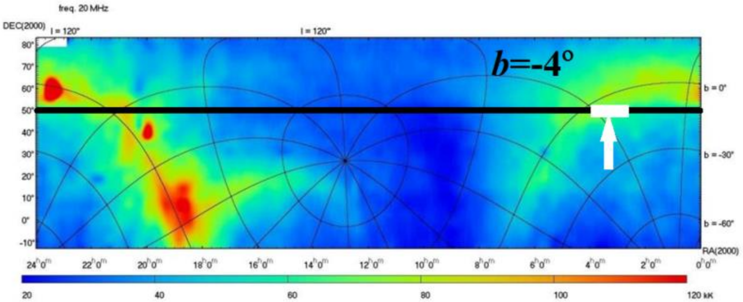
Detection of LF carbon RRLs in medium across the Galactic plane
N = 40, ΔF = 20…24 MHz



Δα = 2h…3h, δ ~+50°

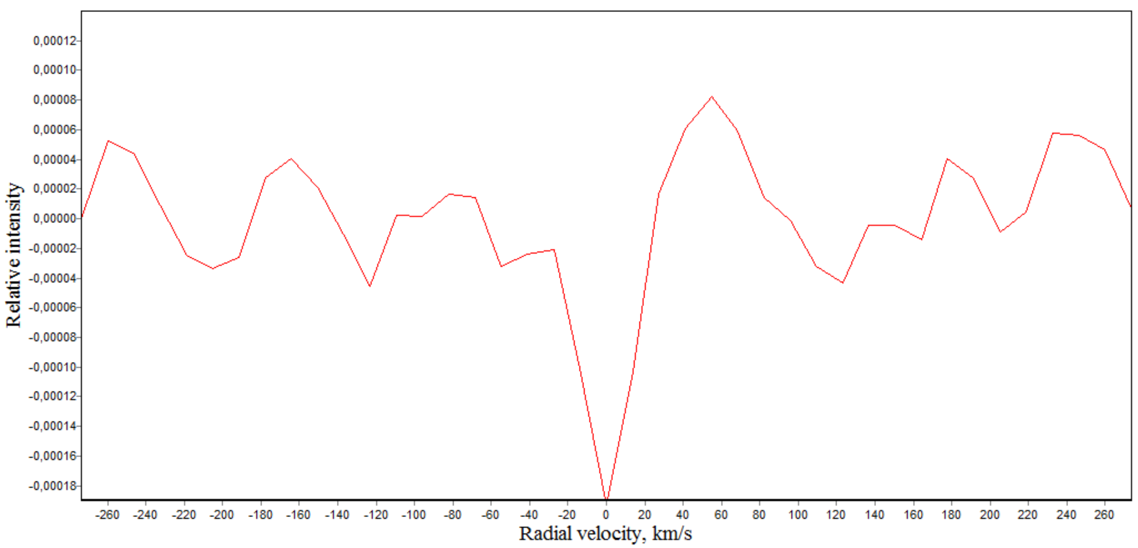
ΔT=40×8.2h=328h





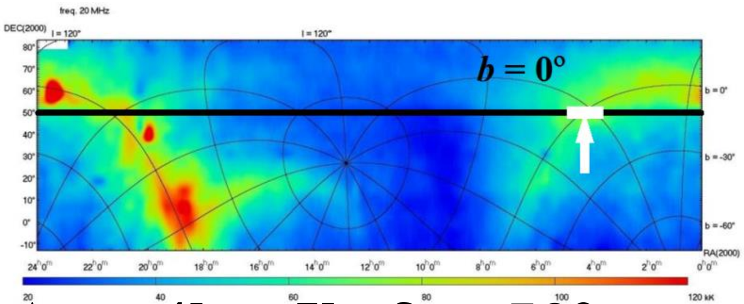
Δα = 3h…4h, δ ~+50°

ΔT=40×10.7h=428h



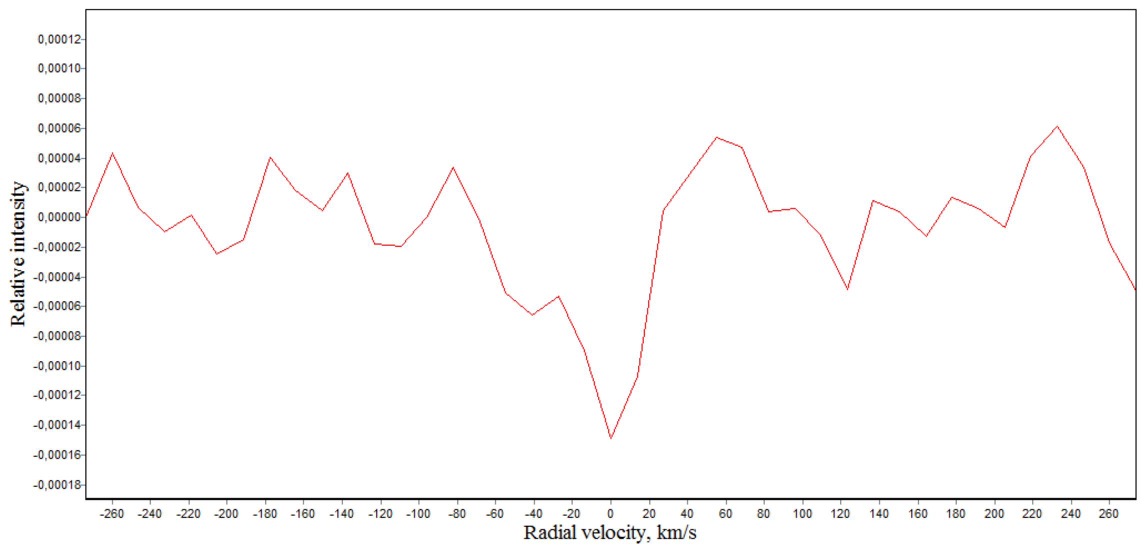
Detection of LF carbon RRLs in medium across the Galactic plane

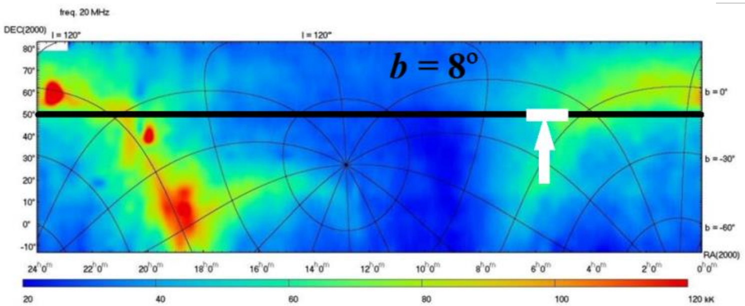
N = 40, ΔF = 20…24 MHz



$\Delta\alpha = 4h…5h, \delta \sim +50°$

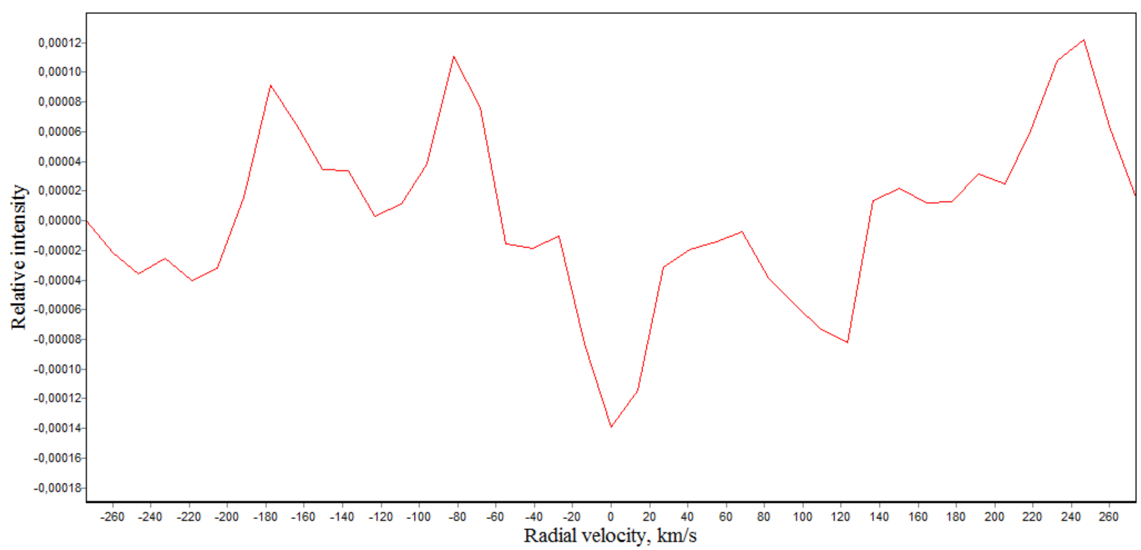
$\Delta T = 40 \times 10.5h = 420h$



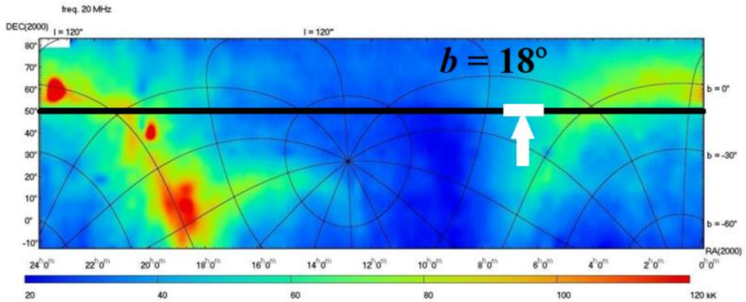


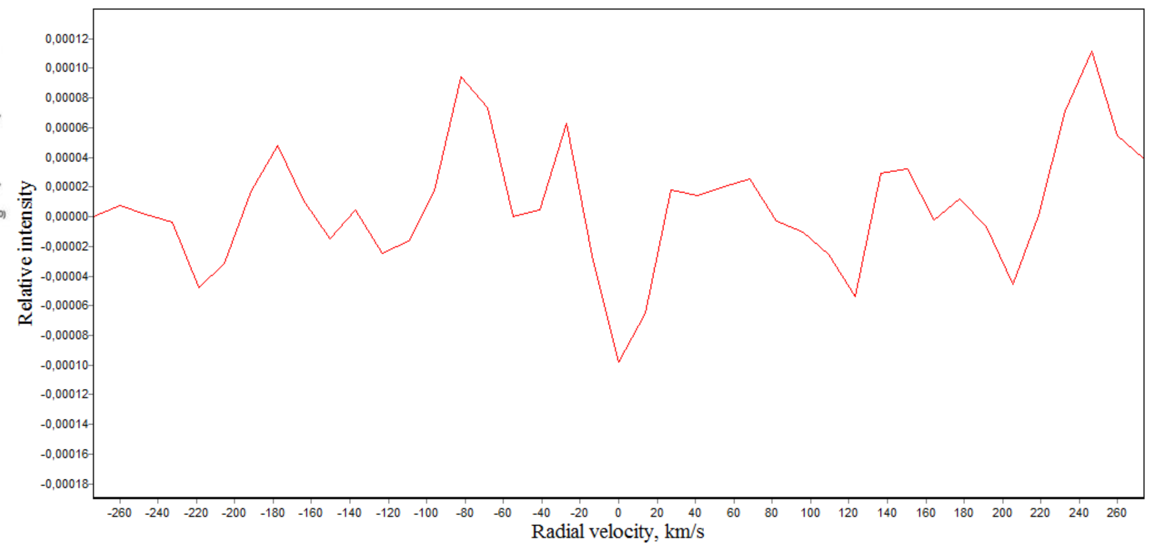
$\Delta\alpha = 5h…6h, \delta \sim +50°$

$\Delta T = 40 \times 11.3h = 452h$



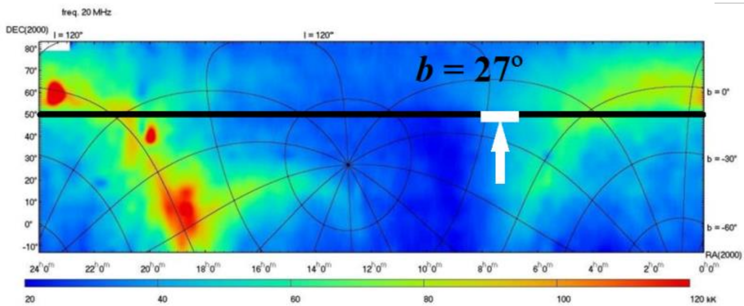
Detection of LF carbon RRLs in medium across the Galactic plane
N = 40, ΔF = 20…24 MHz

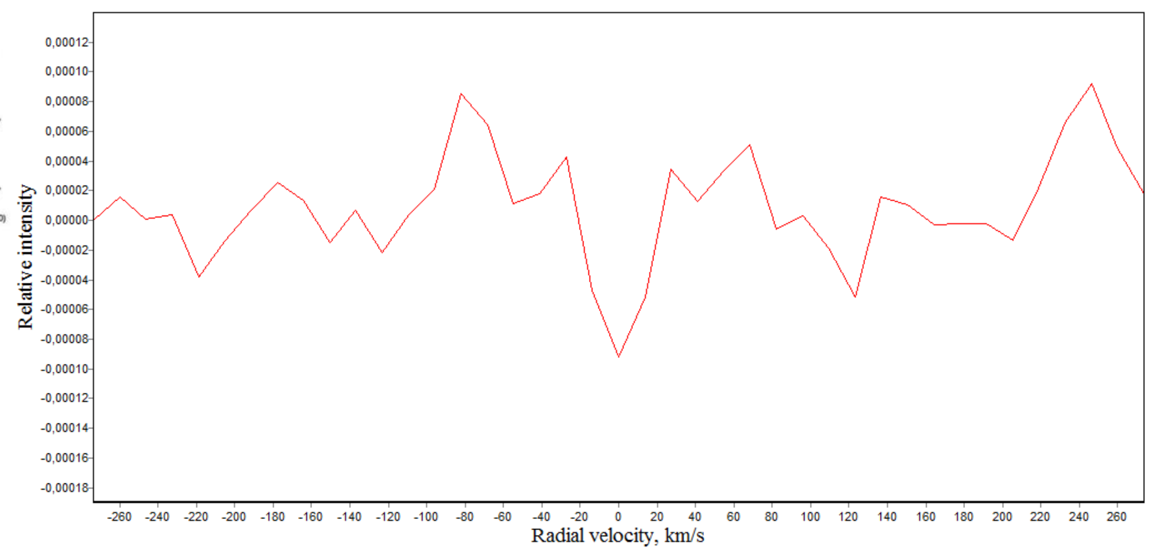




$\Delta\alpha$ = 6h…7h, δ ~+50°

$\Delta T = 40 \times 11.1h = 444h$

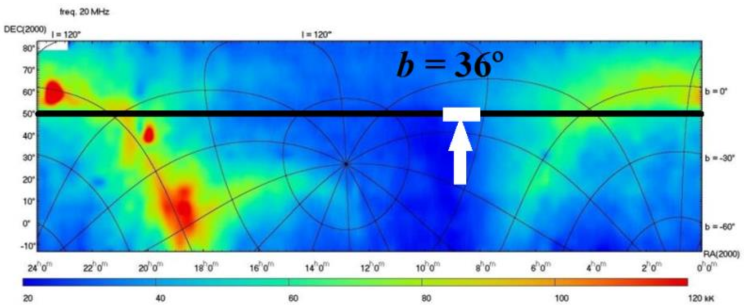


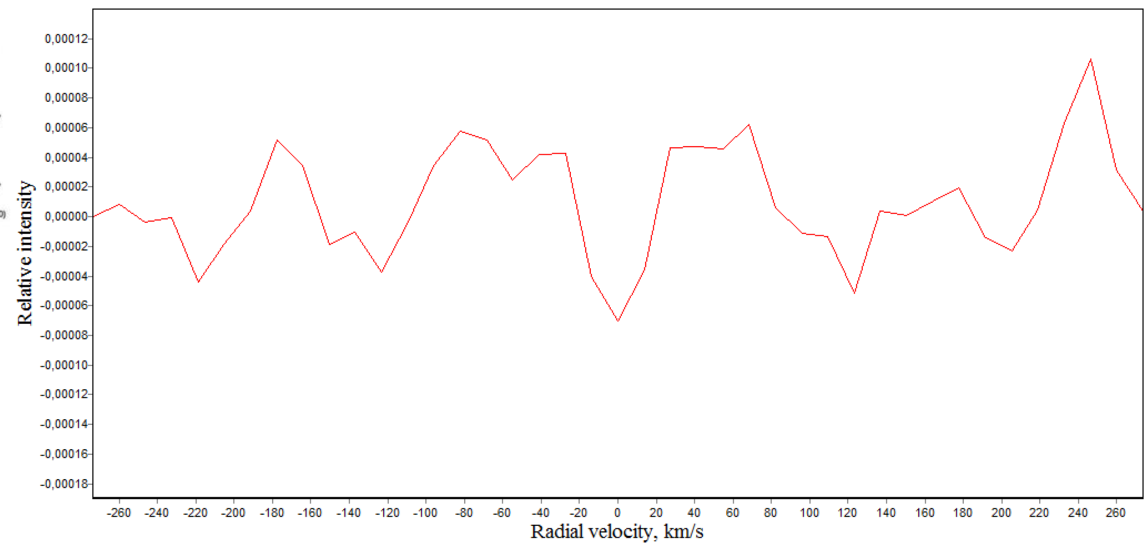


$\Delta\alpha$ = 7h…8h, δ ~+50°

$\Delta T = 40 \times 12.3h = 492h$

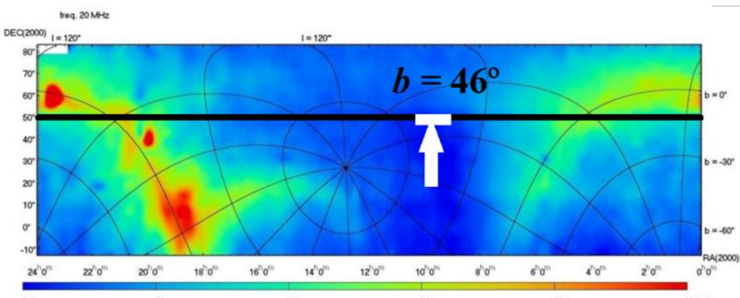
Detection of LF carbon RRLs in medium across the Galactic plane
N = 40, ΔF = 20…24 MHz

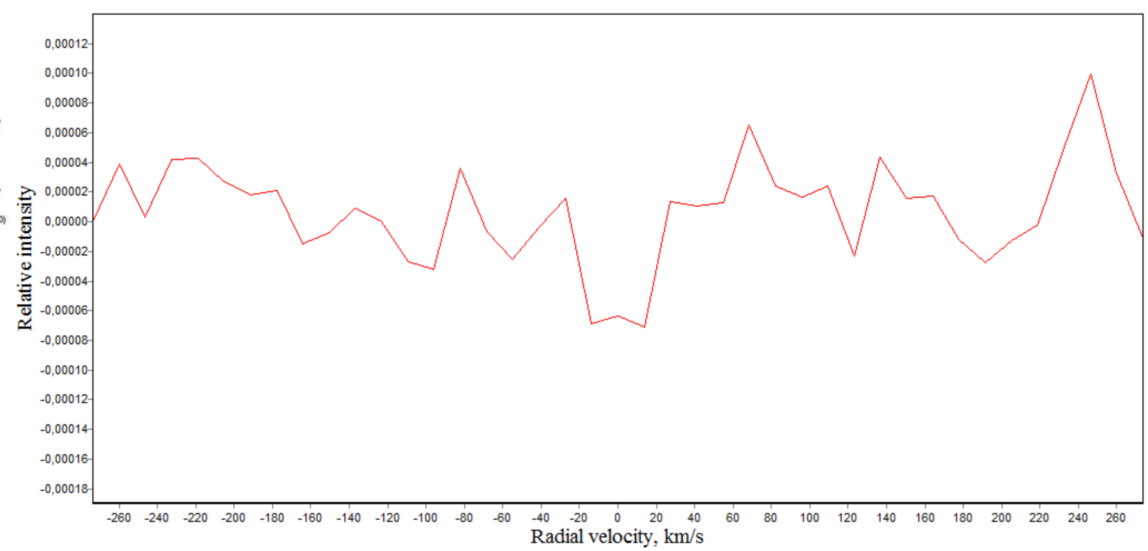




Δα = 8h…9h, δ ~+50°

ΔT=40×9.8h=392h





Δα = 9h…10h, δ ~+50°

ΔT=40×10.8h=432h

The tasks of the ground-based (and space-born) low frequency radio astronomy in the solar system, galactic and metagalactic sciences

(including UTR-2 and URAN observations)

The Earth	* **Ionosphere**	+
	* **Magnetosphere**	~
	* **Air showers of cosmic rays**	–
	* **Parameters of the surface**	+
Solar system	* **The Moon:** occultations	+
	secondary emission of cosmic rays	–
	screen	–
	* **The Sun:** quiet	+
	active	+
	* **Jupiter**	+
	* **Planets** (Saturn, Uranus etc.)	+
	* **Interplanetary media:** scintillations	+
	VLBI	+
	* **Comets**	~
Galaxy	* **Pulsars**	+
	* **Active stars**	~
	* **Exoplanets**	~
	* **Transients**	~
	Non-thermal background	+
	Supernova remnants	+
	HII regions	+
	* **Interstellar media** (recombination lines)	+
Metagalaxy	**Galaxies**	+
	Radio galaxies	+
	Quasars	+
	Galactic clusters	+
	Unidentified objects	+
	* **Transients**	~
	* **Dark ages spectral features**	–

Lecacheux, Konovalenko, Rucker, P&SS, 2003;

Konovalenko et al., PRE VII, 2011

The State Prize of Ukraine in the Field of Science and Technology for 2018:

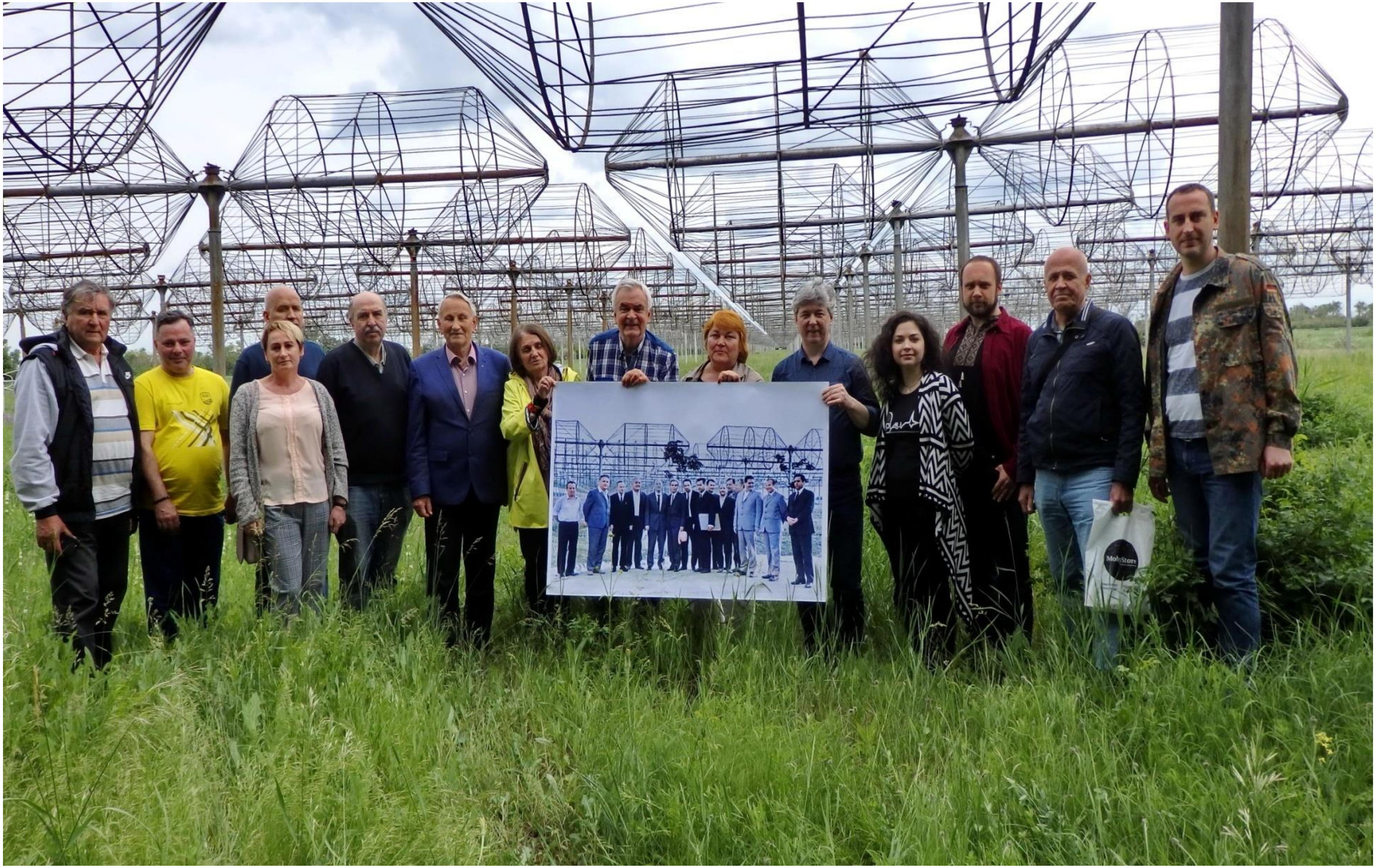
"The Universe Radio Emission at Decameter Wavelength"

Konovalenko A.A., Zakharenko V.V., Kalinichenko N.N., Melnik V.N., Sidorchuk M.A., Stanislavsky A.A., Stepkin S.V., Ulyanov O.M., (IRA NASU, Kharkiv)

Solemn meeting at the National Academy of Sciences of Ukraine (NASU),
June 5, 2019

President of the NASU B. Paton with Academic of the NASU S.Braude at the meeting of the Presidium of the Ukraine Academy of Sciences during the inauguration of the UTR-2 Radio Telescope (June, 1971).

Honorary meeting dedicated to 50-years of inauguration of UTR-2
(4 June 2021)



The Nature of the Observatory, Forge steppe