



XXVI URSI GA
Commission J- Radio Astronomy

15-22 August 2026
Krakow, Poland

LOW- FREQUENCY RADIO ASTRONOMY IN UKRAINE **(70 YEARS HISTORY: 1956...2026)**

A. Konovalenko

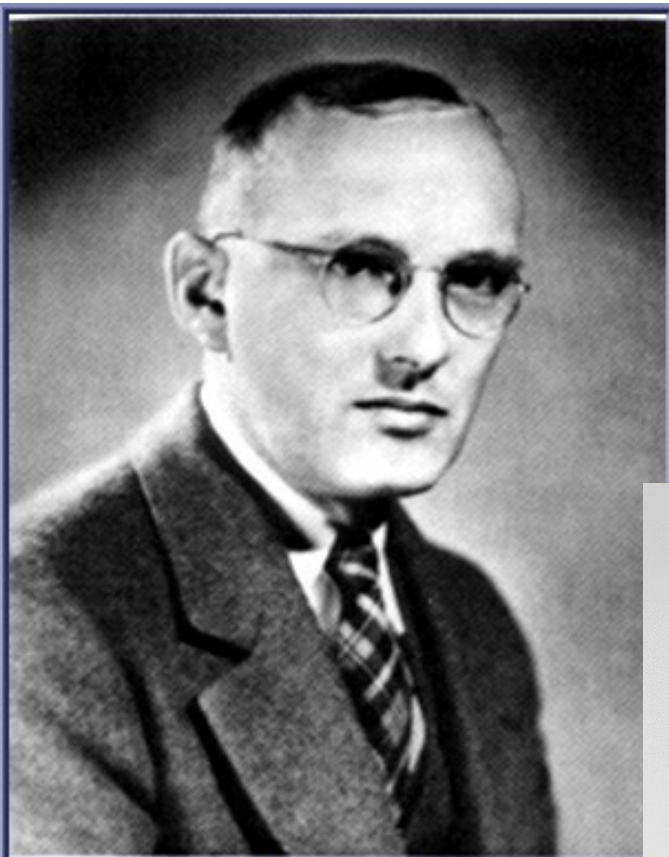


**Institute of Radio Astronomy of NAS of
Ukraine**

61002, Kharkiv, Mystetstv St. 4

akonovalenko194@gmail.com

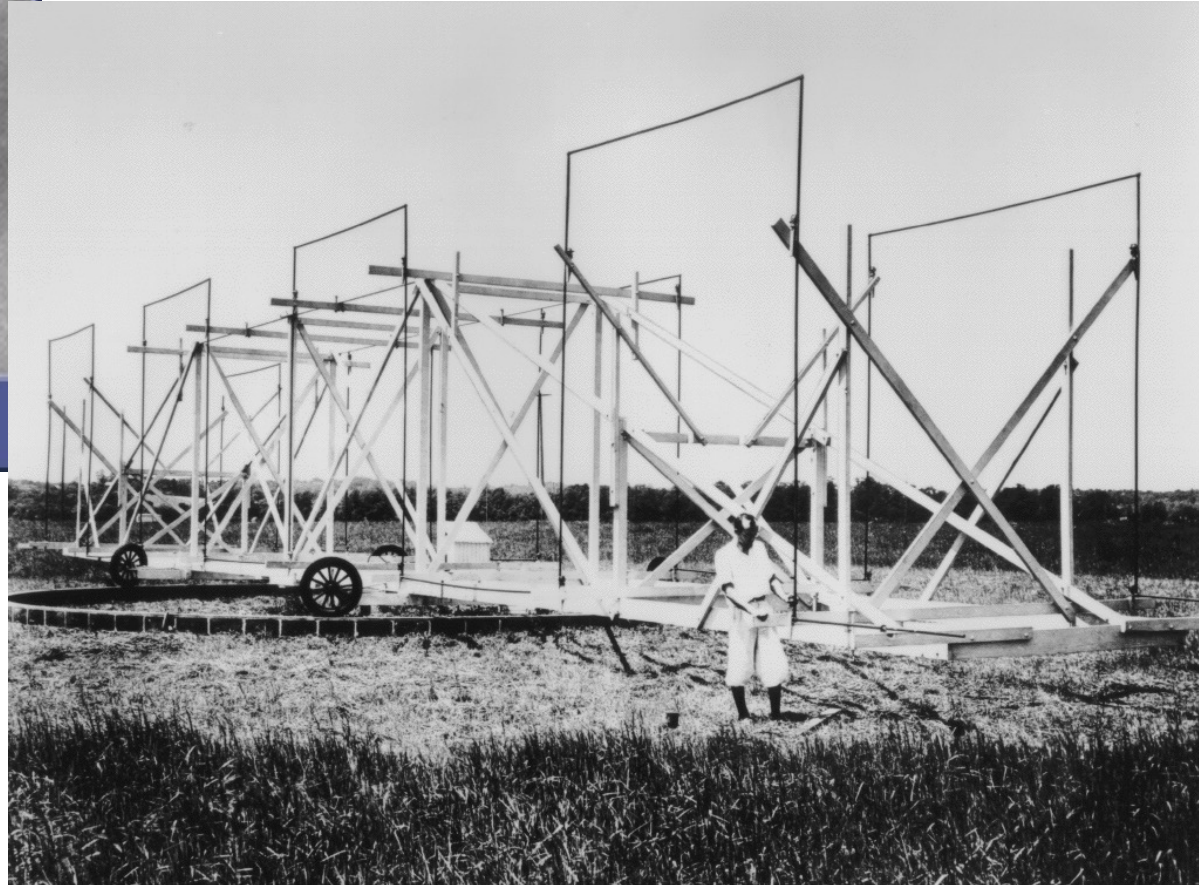




Karl Jansky
1905-1950

History of the low-frequency radio astronomy (decameter wavelengths, $f=3\text{-}30\text{ MHz}$)

Karl Jansky (1905-1950) –
American radio engineer , opened " radiowindow" in
the Universe (1933), it is at decameter waves
(at a frequency of about 20 MHz !)



$$\underline{1 \text{ Jy} = 10^{-26} \text{ W/M}^2 \text{ Hz}}$$

Difficulties of the decameter wavelengths radio astronomy

<i>Problems of low-frequency radio astronomy</i>	<i>Possible solution</i>
High temperature of the Galactic background	High effective area ($10^4 \dots 10^6 \text{ m}^2$) 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

Astrophysical significance of the decameter wavelength radio astronomy

Decameter wavelength radio astronomy (<30 MHz) has high astrophysical significance and evident background for the corresponding development in spite well-known technical and methodical difficulties. This radio astronomy gives unique information due to the following physical and astrophysical phenomena:

- strong interrelations between radio emission and space plasma;
- strong exceeding of non-thermal radio emission ($\sim f^{-2}$) over the thermal emission ($\sim f^2$);
- formation of the many kinds of non-thermal radio emission with very steep spectra (more intensive at low frequencies) as:
 - synchrotron radio emission (Galaxy, Supernova remnants, quasars, radio galaxies, galactic clusters, etc.);
 - coherent radio emission, in part, during the movement of the charged particles through magneto-active plasma (the Sun, Jupiter, Hot Jupiters, flare stars, pulsars, transients, etc.);
 - radio emission due to electrostatic discharges (the Earth, Saturn, etc.);
- strong variation of the spectral index of non-thermal radio emission at low frequencies due to various physical reasons;
- strong low-frequency stimulated radio emission for very excited interstellar atoms (radio recombination lines);
- evident cosmological effects due to synchrotron losses, diffusion, etc. for extragalactic radio sources and their count;
- evident cosmological effects for spectral lines of neutral hydrogen, RRL's, etc. with red shift of about 100 (dark ages, re-ionization, etc.);
- evident strong observable phenomena in space weather problems and corresponding prediction (all kinds of quiet and sporadic solar radio emission, interplanetary non-stationary phenomena from IPS tomography observations for all elongations and directions)

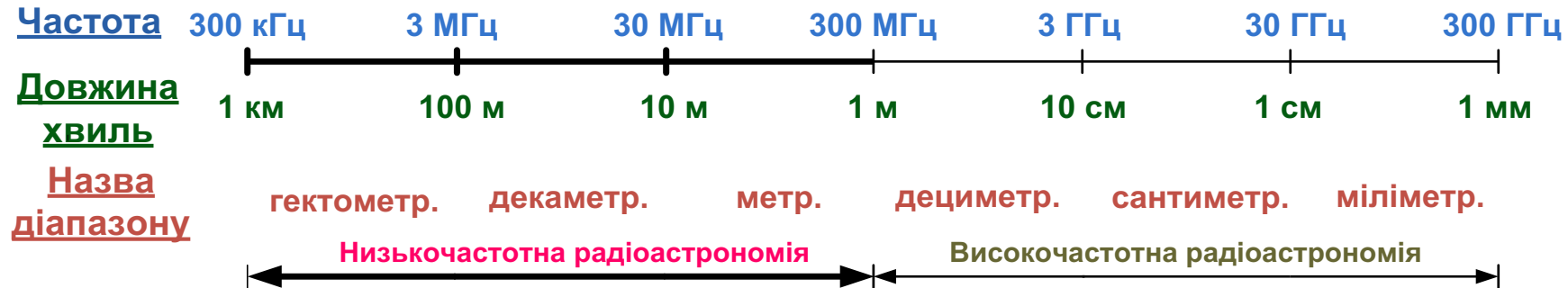
After K. Jansky it was created and used few tens of various LF radio telescopes in Russia, Ukraine, USA, Canada, Australia, Great Britain, France, Germany, India, Japan, Finland, Chili.

Some bright LF astrophysical results:

detection of the Jupiter sporadic radio emission (20MHz) (Burke, Franklin, 1955);

detection of pulsars radio emission (80 MHz) (Hewish, Bell, 1968)

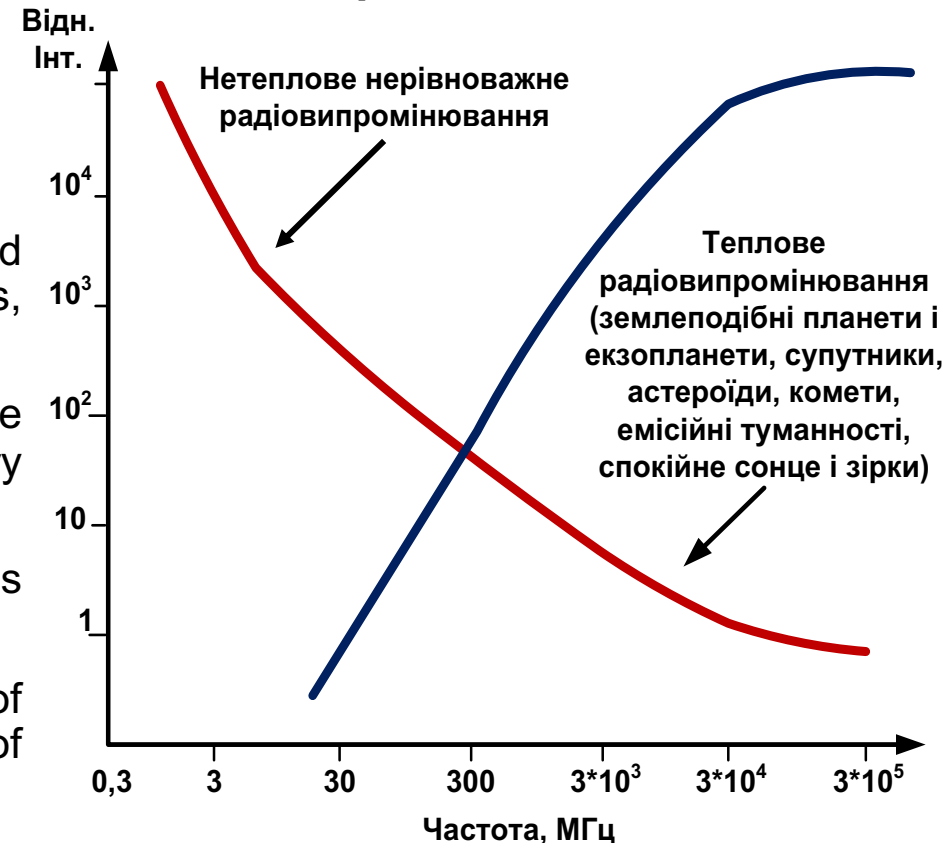
Frequency bands of radio astronomical studies



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



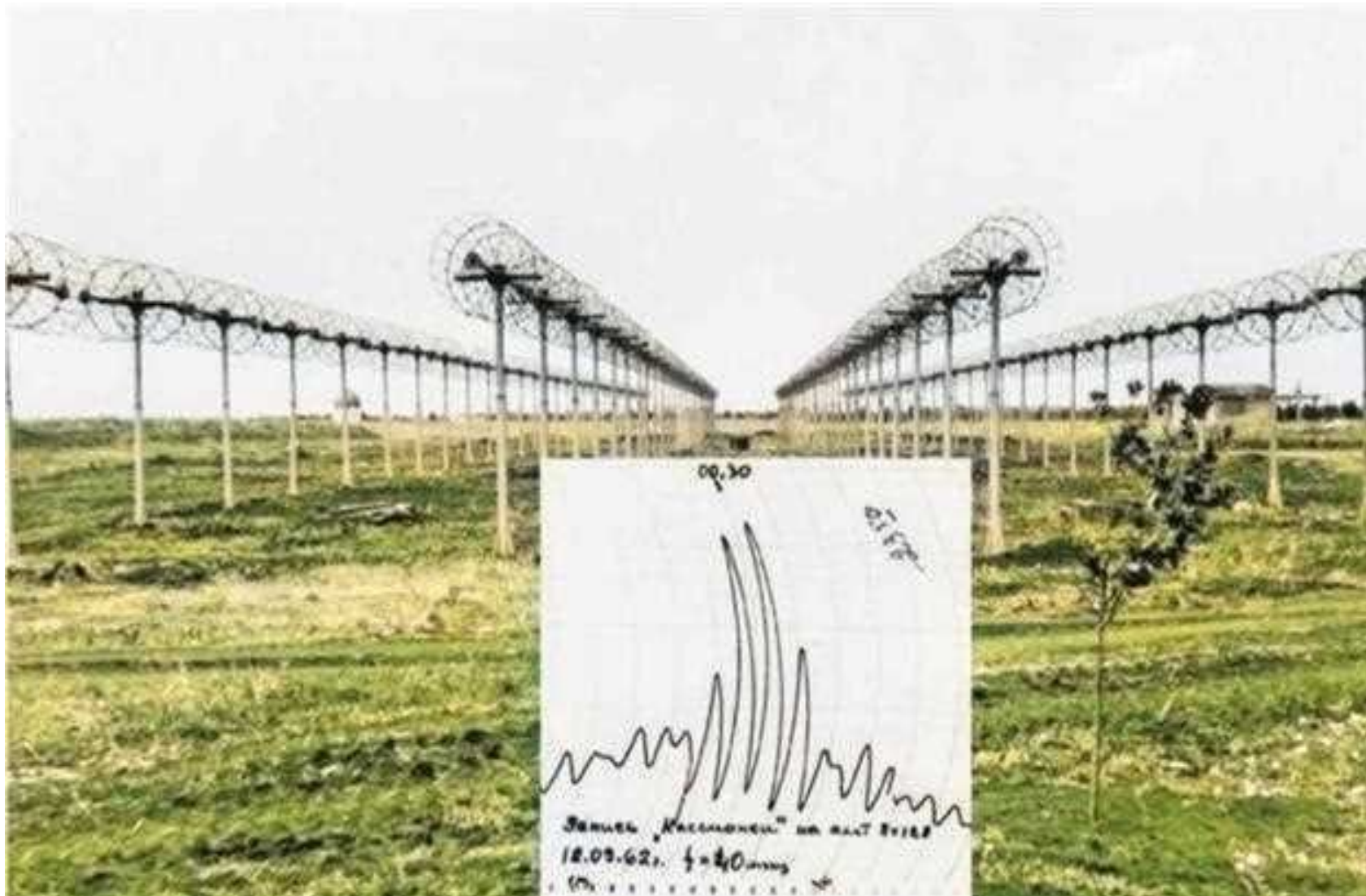
S.Ya.Braude
1911-2003

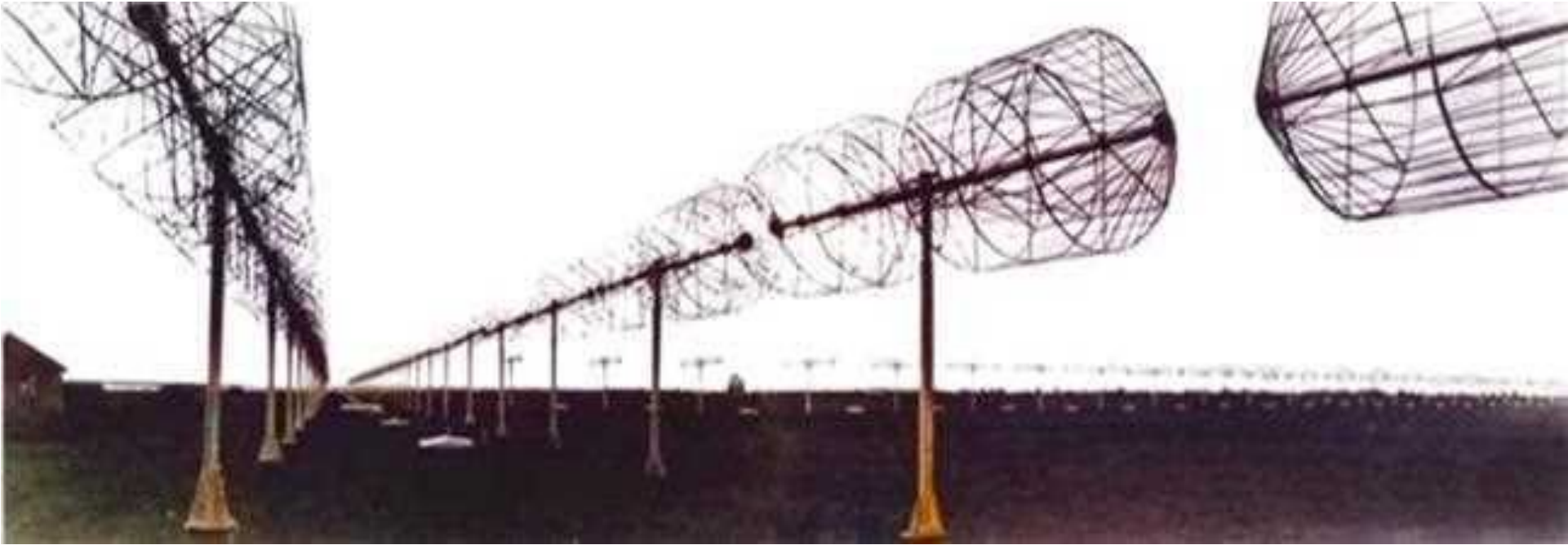


**2*24 elements interferometers ID-1 ID-2; First Ukrainian
decameter wavelength radio telescopes (10...25 MHz), 1958**



2*128 interferometer (20...40 MHz), 1962





UTR-1 radio telescope (10...25 MHz, 1 km*0,5 km), 1966



**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.**



East- West arm of UTR-2



4th June 1971: UTR-2 is open (S. Ya. Braude- 4 left, B. Ye. Paton- 5 left)

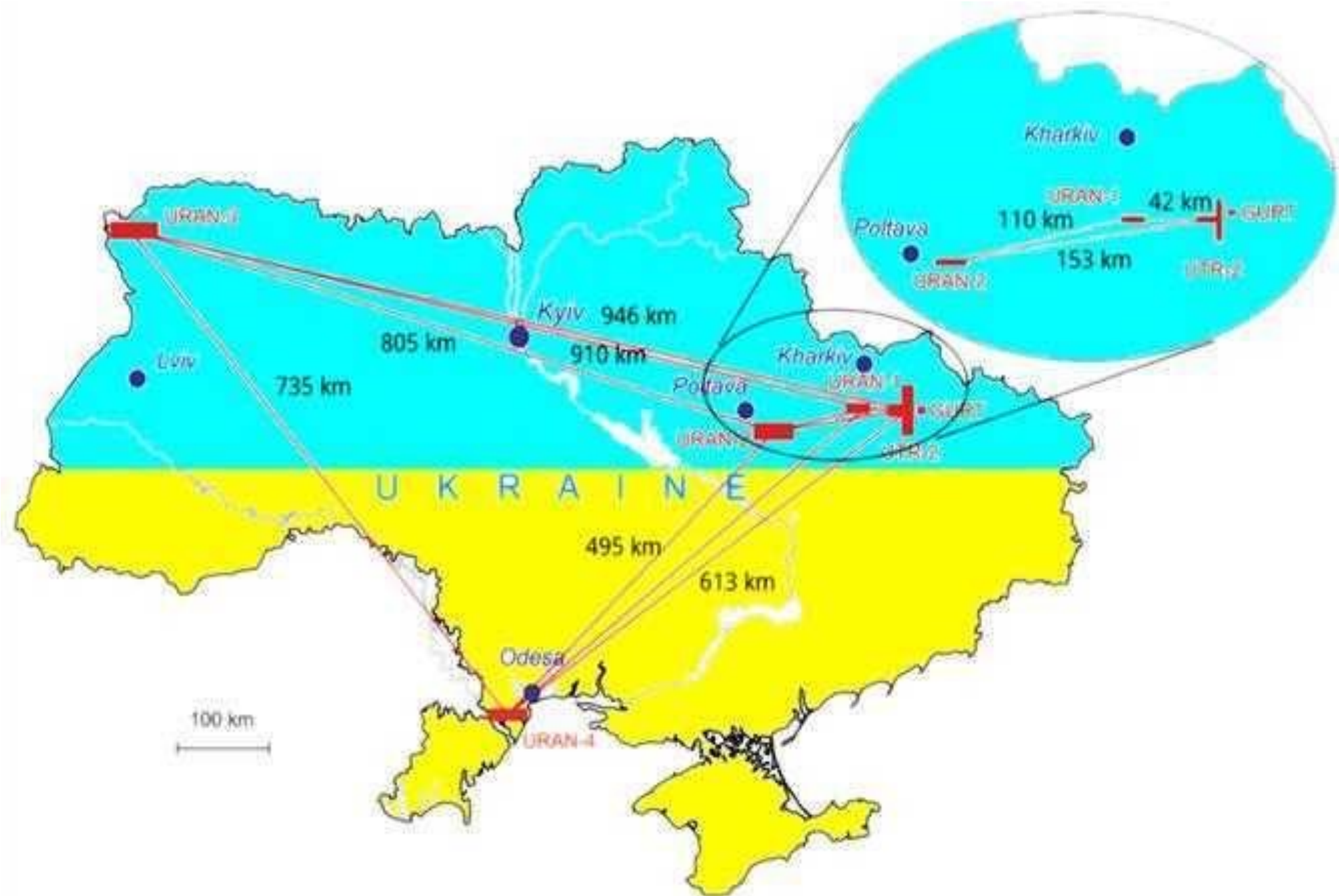


**B. Ye. Paton and S. Ya. Braude, 4th June 1971
(Observatory of UTR-2)**

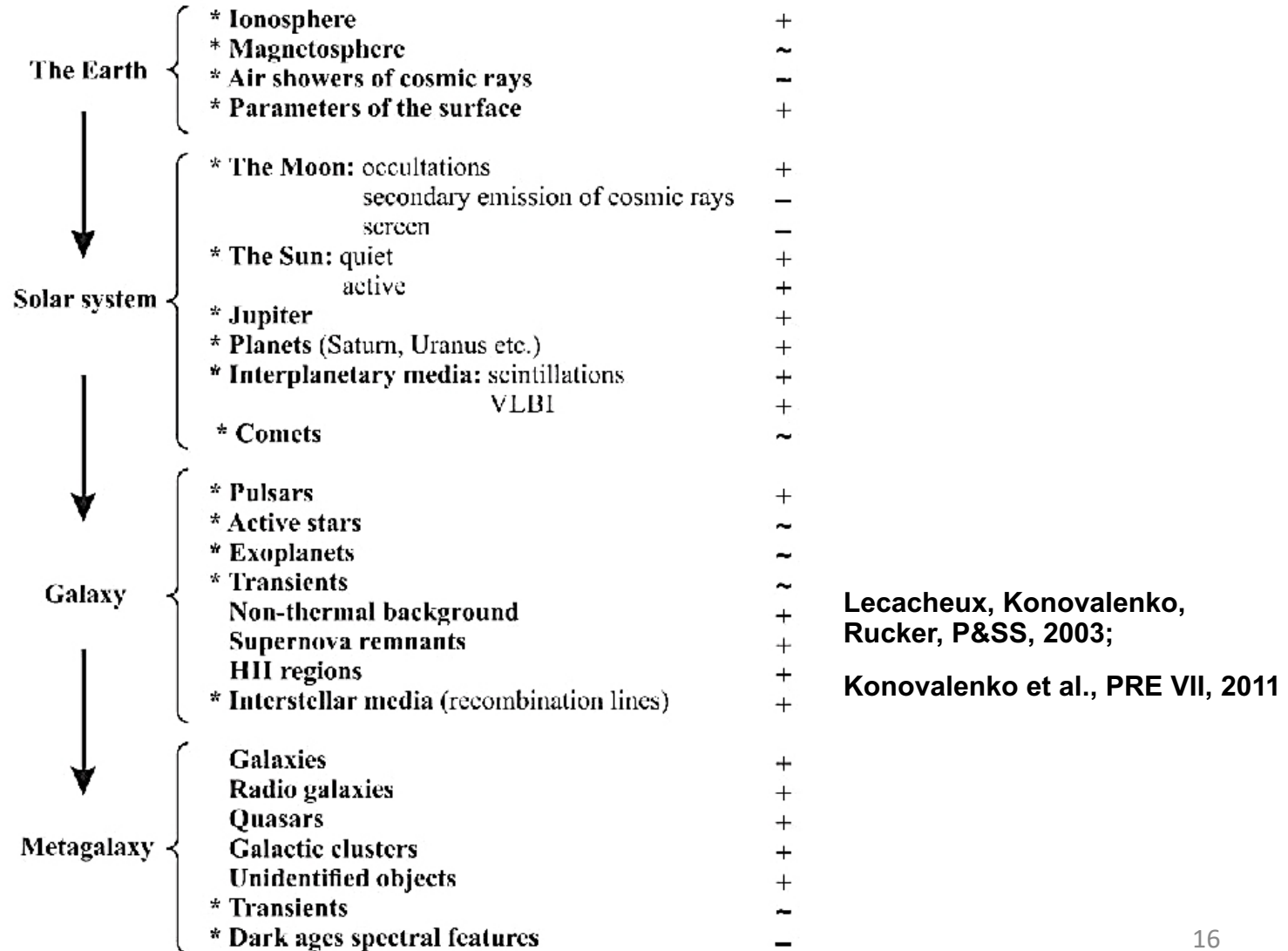


URAN-1...URAN-4 radio telescopes

$\Sigma N \text{ (URAN)} = 1000 \cdot 2$; $\Sigma N \text{ (total)} = 4040$; $A_{\text{eff}} \text{ (total)} = 200000 \text{ sq. m}$



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)



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



SYSTEM PARAMETERS AND REGIMES	OLD	NEW
<i>Antenna</i>		
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
<i>Back-end</i>		
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 $\pm 70^\circ$ for UTR-2 and $\pm 80^\circ$ for URAN and GURT

Radio telescope; institution; coordinates (longitude / latitude)	Frequency range, MHz	Dimensions, m; Max effective area, m ²	Number of elements ($l \times m = N$); 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)	–	$d_{NS} = 7.5$ 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

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

1. Informativeness 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_B / f_H . For low-frequency radioastronomy ($f = 8 \dots 80 \text{ Mhz}$) $f_B / f_H = 10$. (In an optics it equals only two). Thus the absolute band of frequencies folds only $F = f_B - f_H = 80 - 8 = 72 \text{ Mhz}$. 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 cryogenic 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.

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



New Generation Radio Telescope NenuFAR

(New Extension of Nancay Upgrading LOFAR), France, $f=8\ldots80$ 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., Capayrou 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., Griebmeier 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., Griebmeier 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

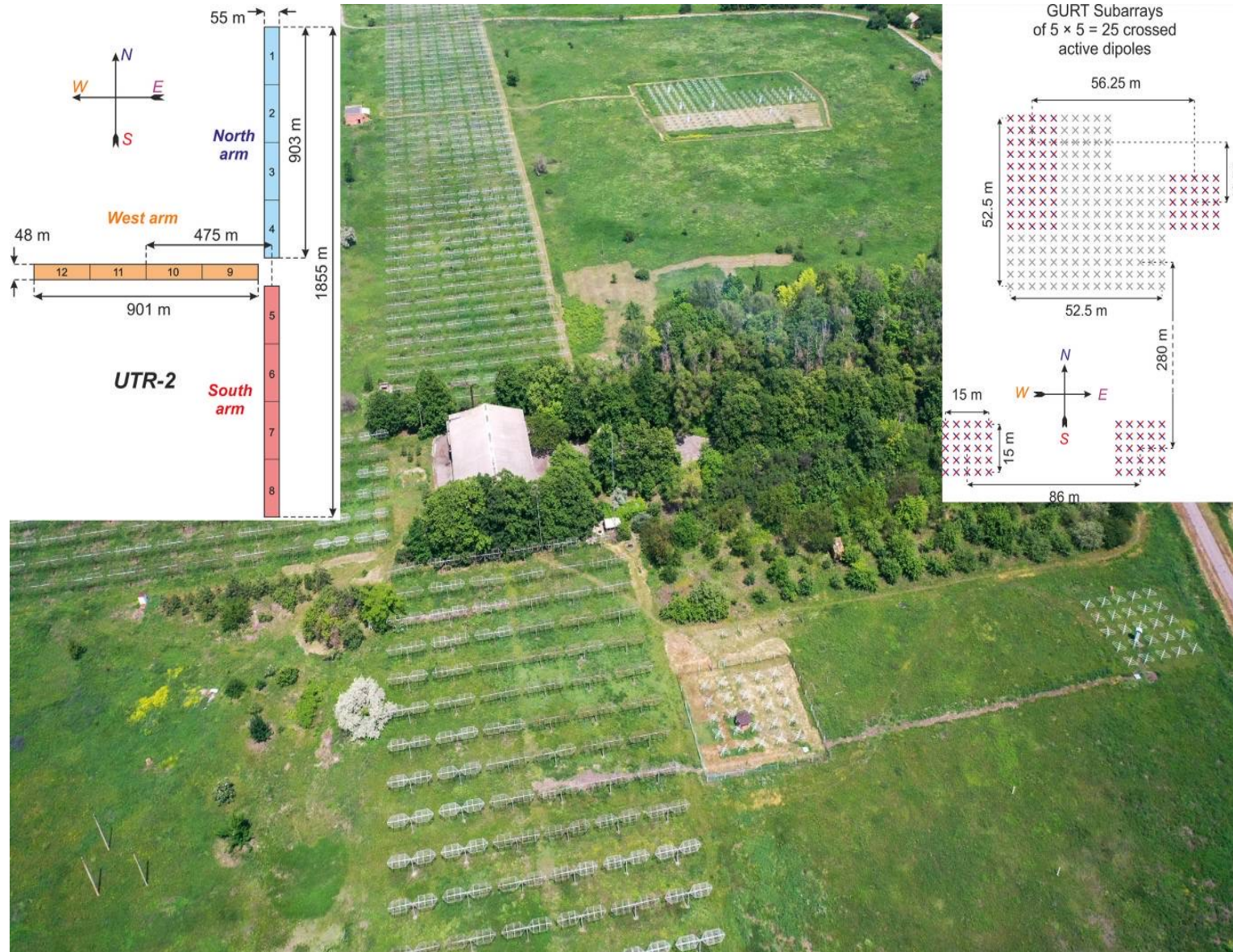


Additional New Generation GURT Radio Telescope with the UTR-2 Radio Telescope at the Observatory of the name S.Y. Braude

- ✓ 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!

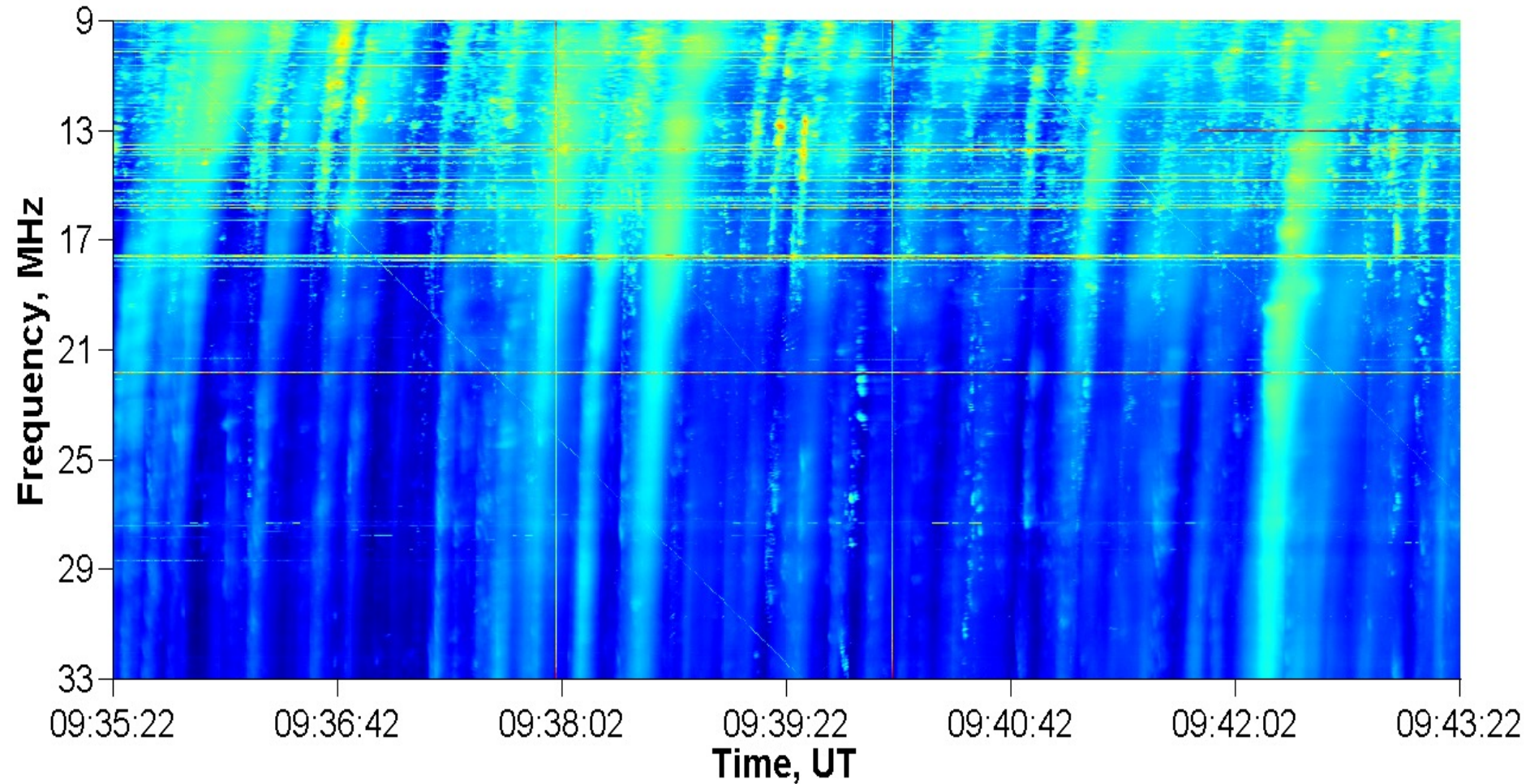


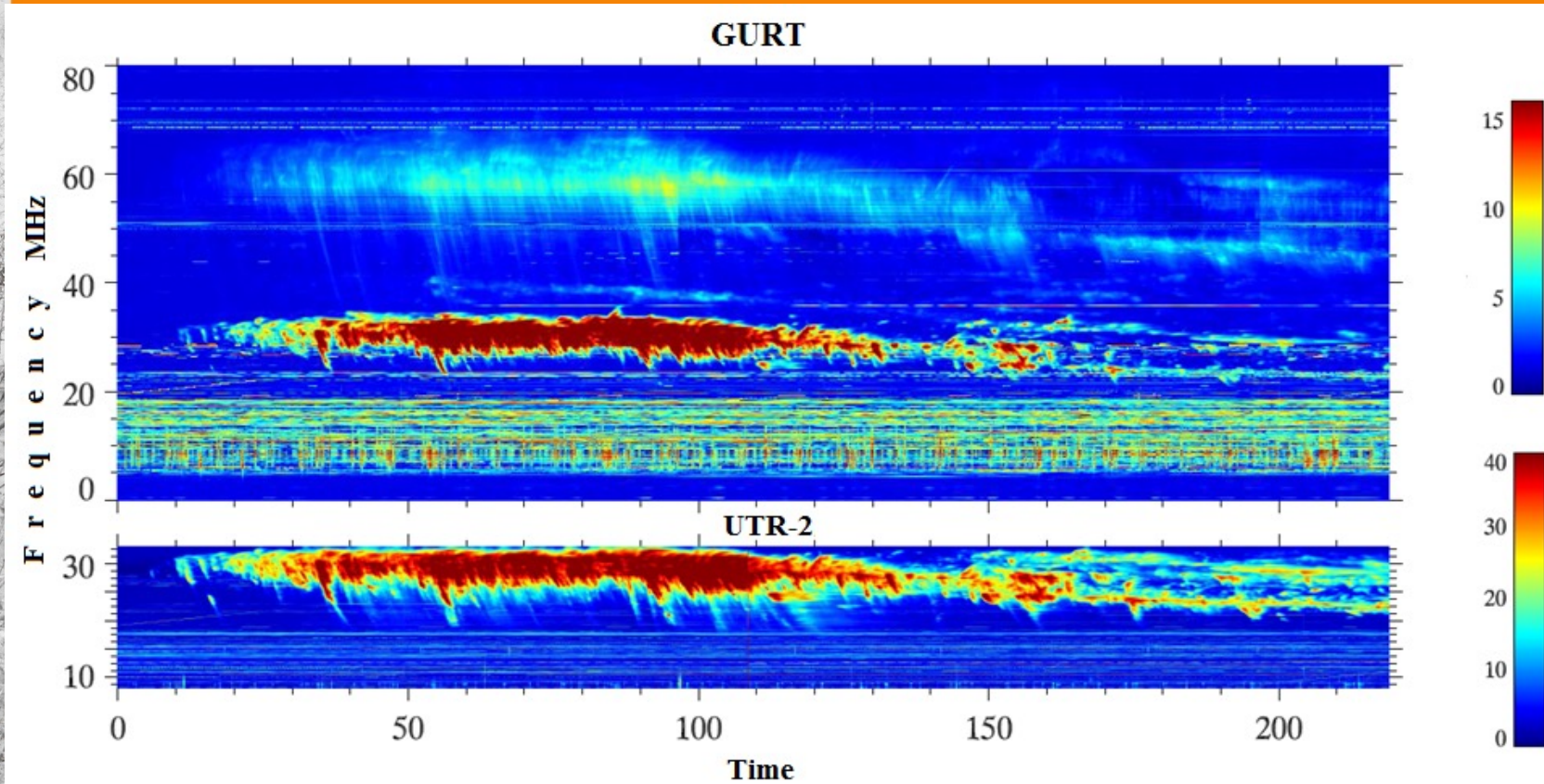
Radio telescopes UTR-2 and GURT and their structural schemes



Sporadic Solar radio emission detected by UTR-2, July 8, 2014

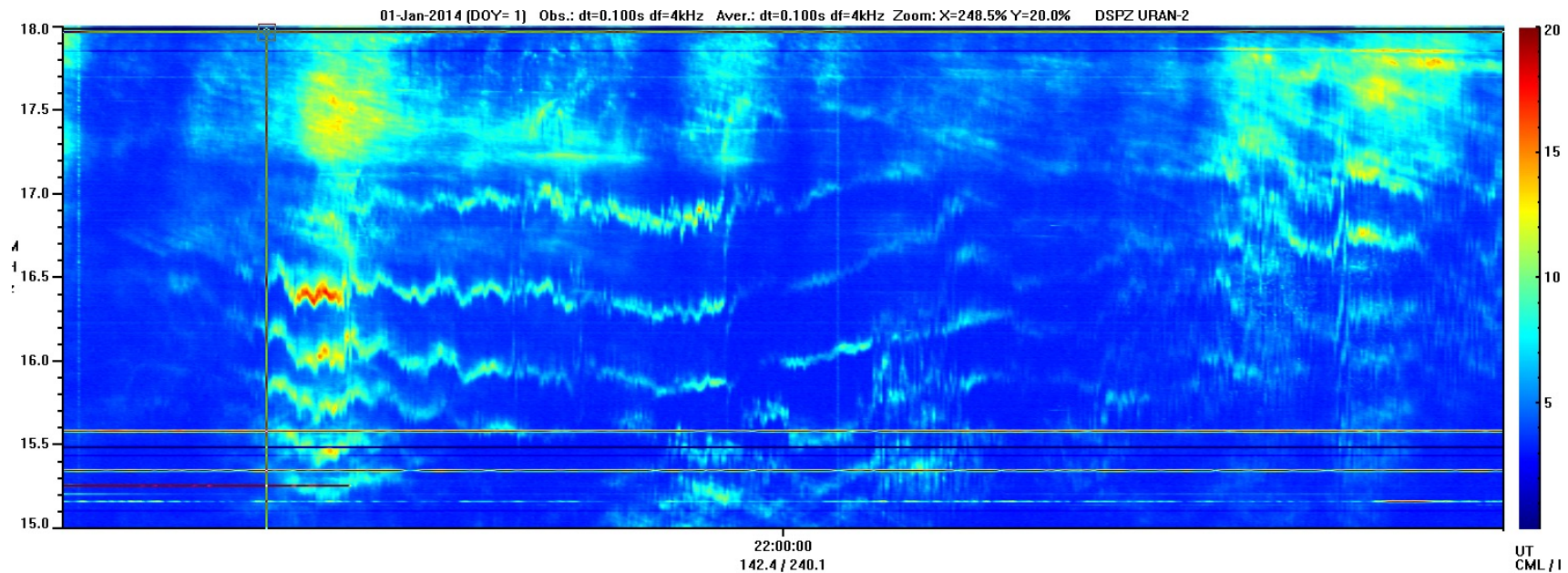
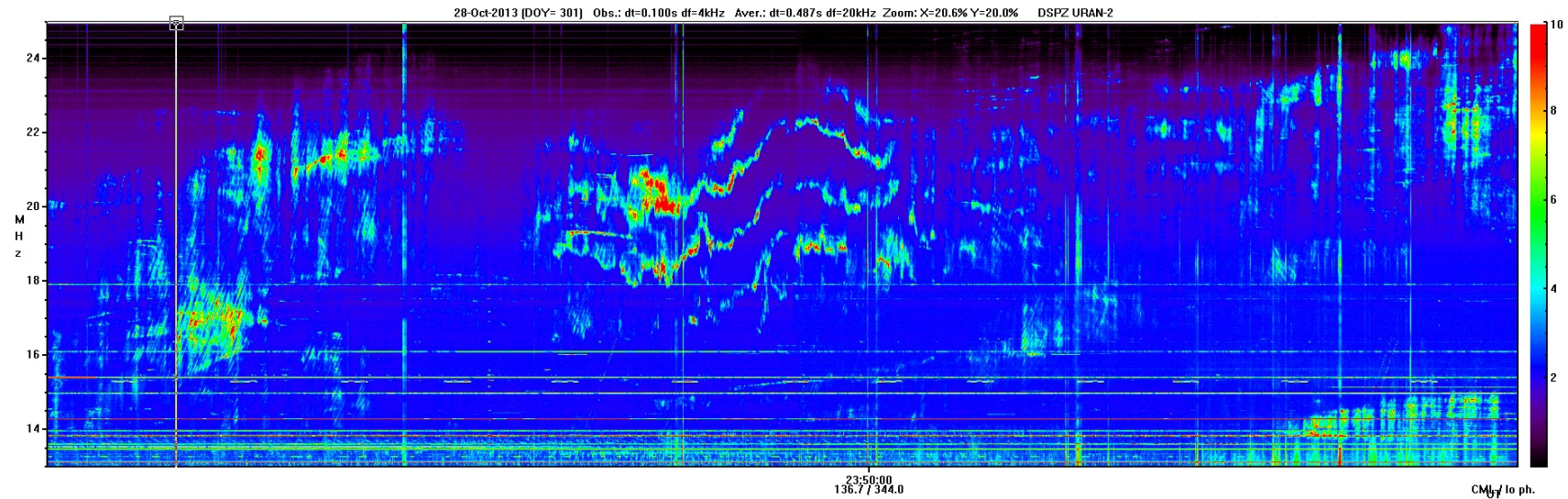
Due to high sensitivity and interference immunity of the UTR-2 ground-based observations are possible even at $f < 10$ MHz !

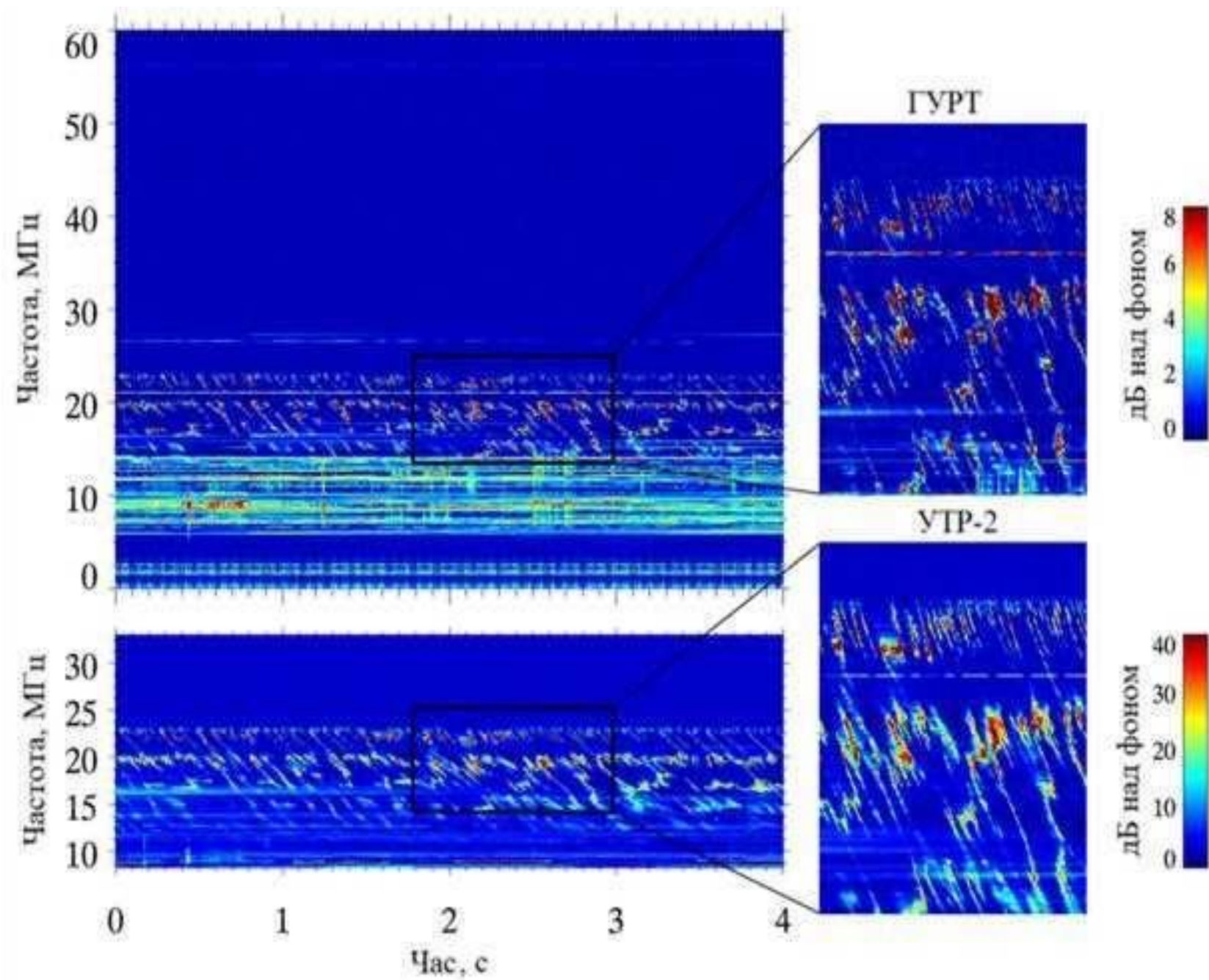


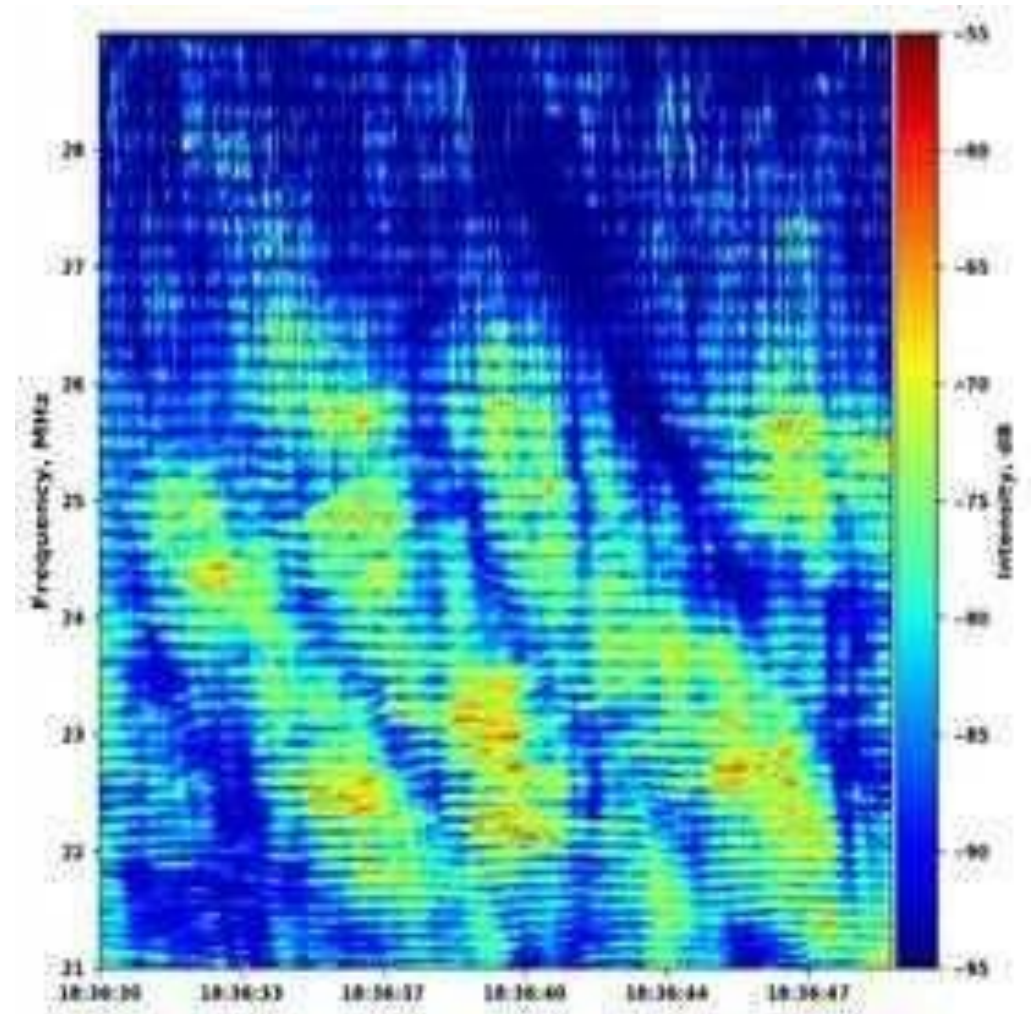
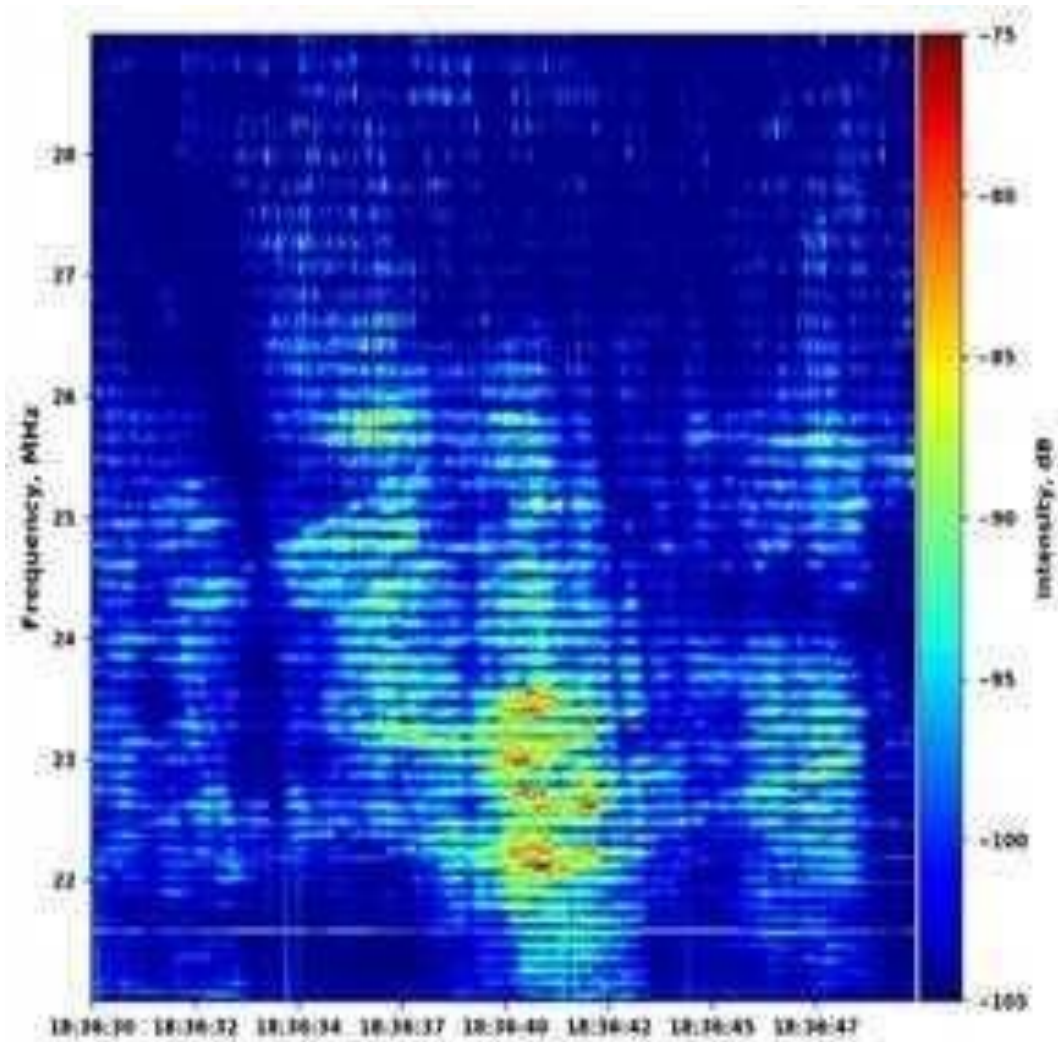


**Type II Solar bursts observed by GURT (top)
and UTR-2 (bottom) on 25.07.2014.
The start is 07:11:15 UT**

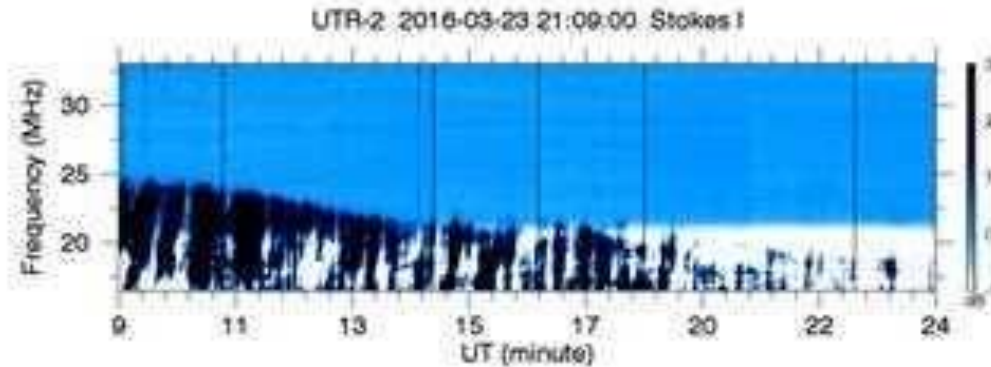
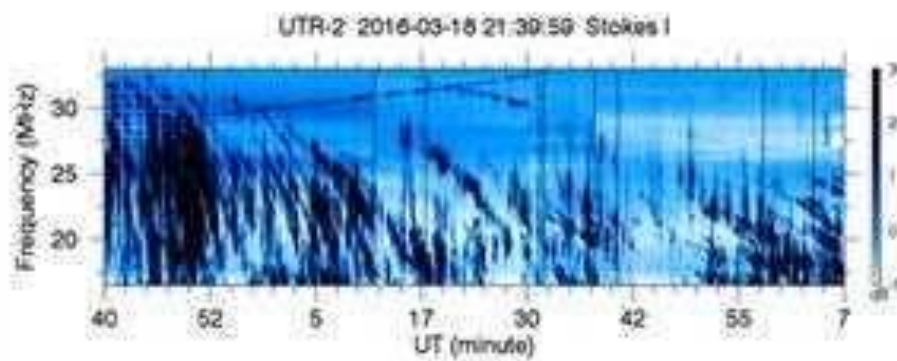
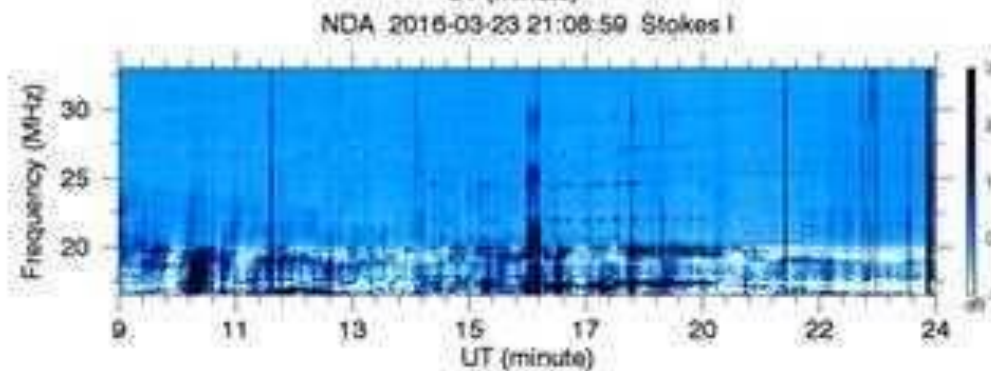
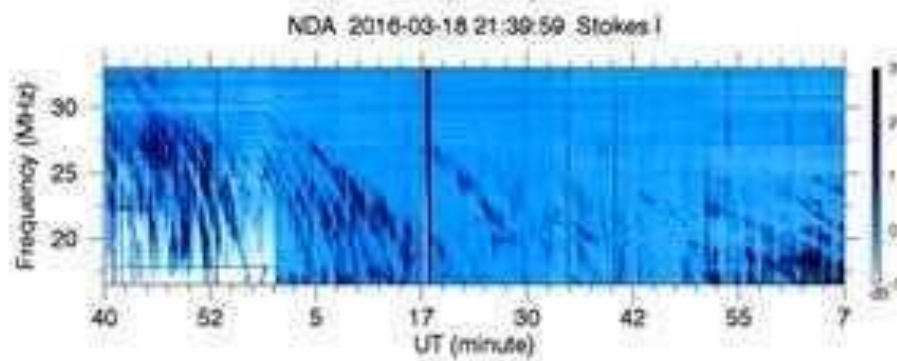
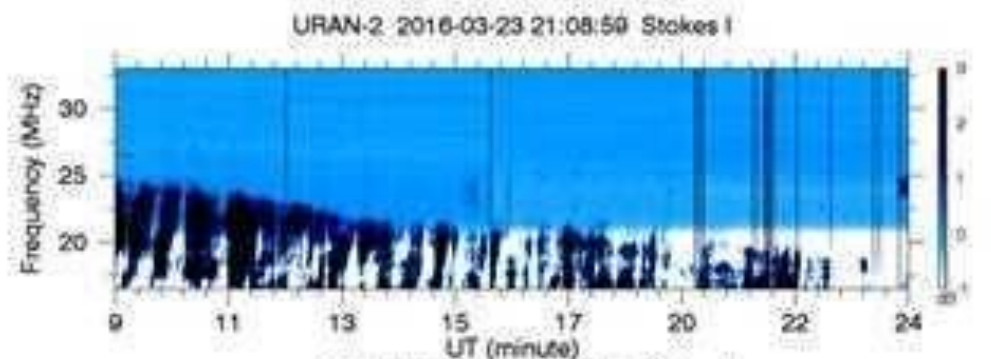
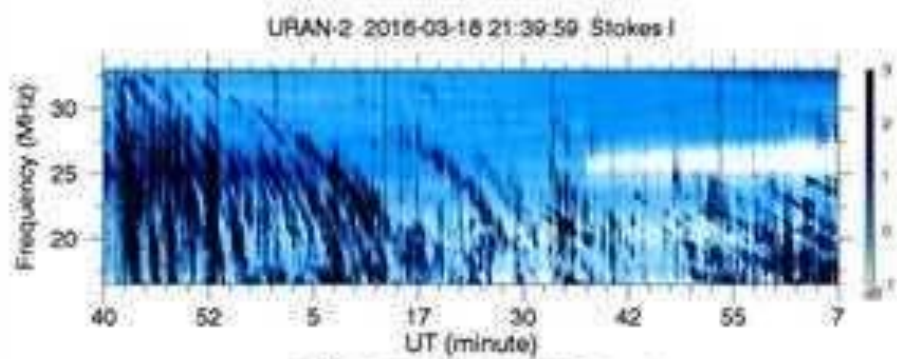
New “zebra” structures detection on Jupiter by UTR-2 and URAN-2, 2013-2015





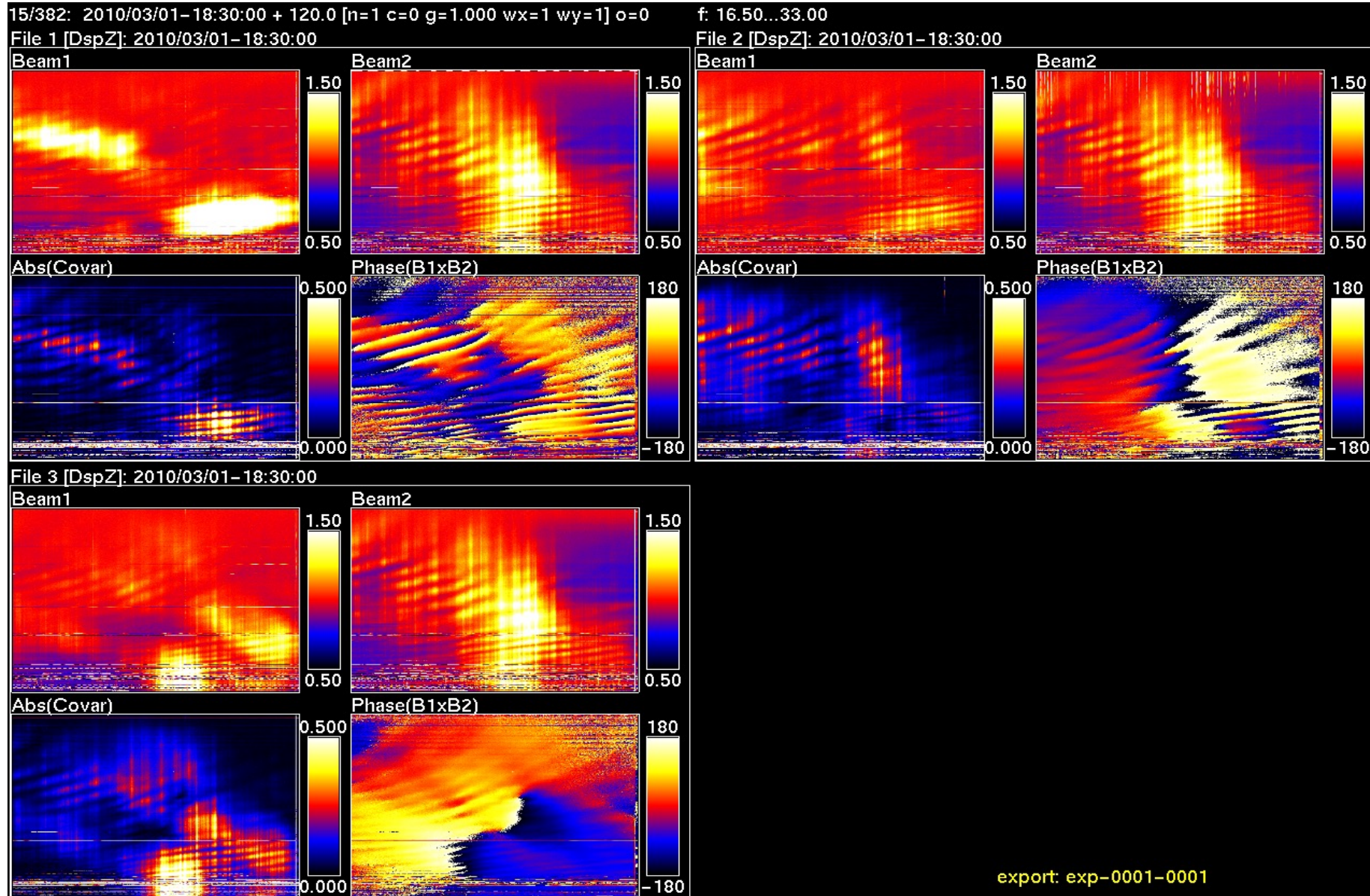


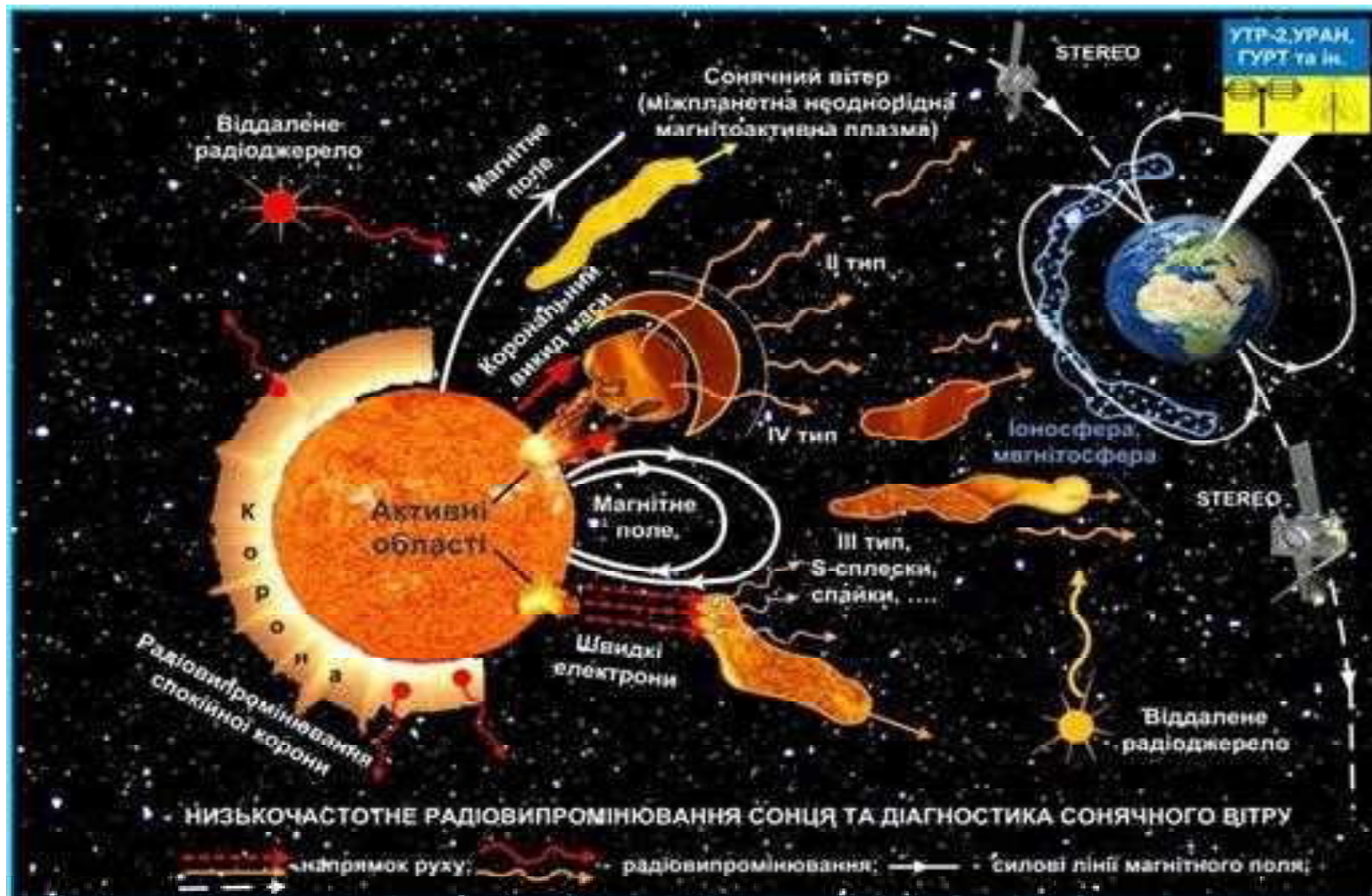
Faraday rotation of Jupiter radio emission observed by GURT polarimeter



Multi-antenna Jupiter observation by URAN-2 NDA, UTR-2

Typical IPS and non-typical ionospheric scintillations of 3C 144 in 3-beam operation mode of UTR-2



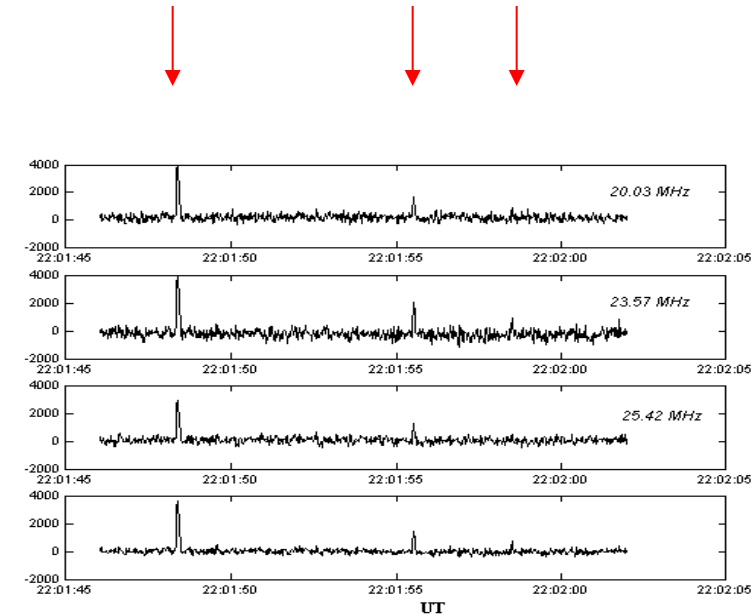


The studies of the Sun, planets, interplanetary medium by ground-based and space instruments at LF.

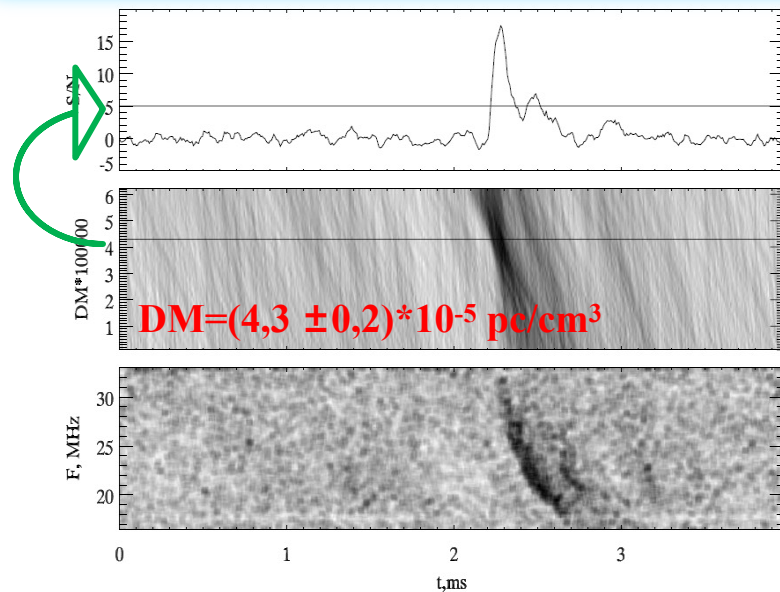
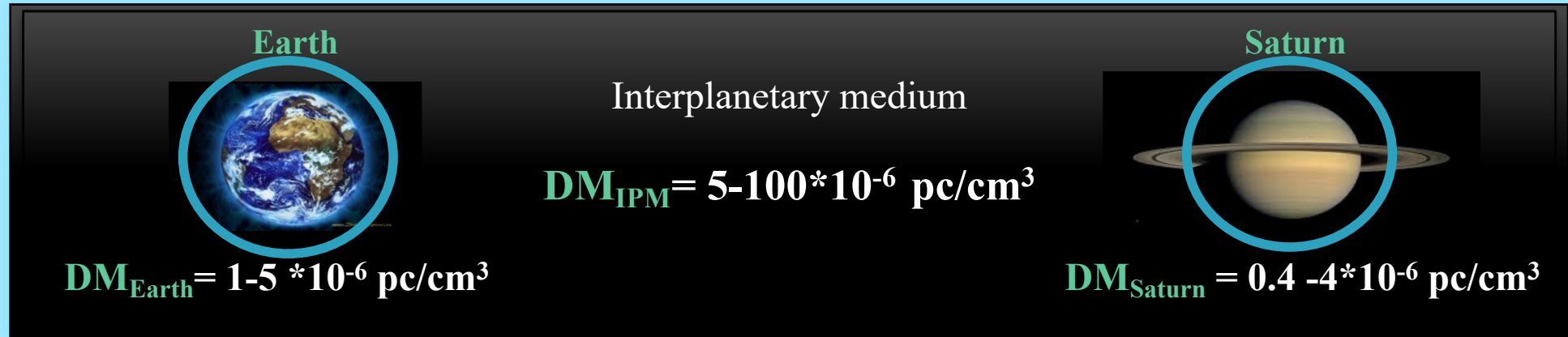
First detection of the Saturn Electrostatic Discharges (SED) by ground-based radio telescope (UTR-2) 2006 – 2008



Cassini Spacecraft near Saturn (ESA-NASA Project)



Dispersion of the SED signals during the propagation from Saturn to the Earth, $\Delta t = 7$ microsec



Time delay (dispersion) of the signals at different frequencies is

$$t(f_1) - t(f_2) = 4.5 \times 10^6 \text{ DM} (f_1^{-2} - f_2^{-2}),$$

with t in ms, f in MHz and $DM = N_e l$ is dispersion measure in pc cm^{-3} .

For $N_e = 1 \text{ cm}^{-3}$, $l = 9 \text{ AU}$

we have $DM \approx 5 \times 10^{-5} \text{ pc cm}^{-3}$.

It gives $t_1 - t_2 \approx 1.5 \text{ ms}$

between $f_1 = 10 \text{ MHz}$ and $f_2 = 20 \text{ MHz}$

$$DM_{Earth} = 1-5 \cdot 10^{-6} \text{ pc/cm}^3$$

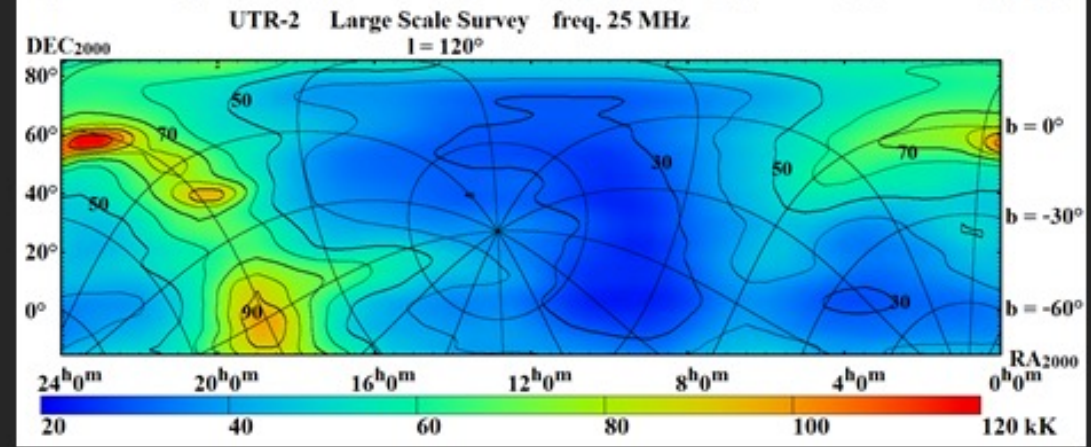
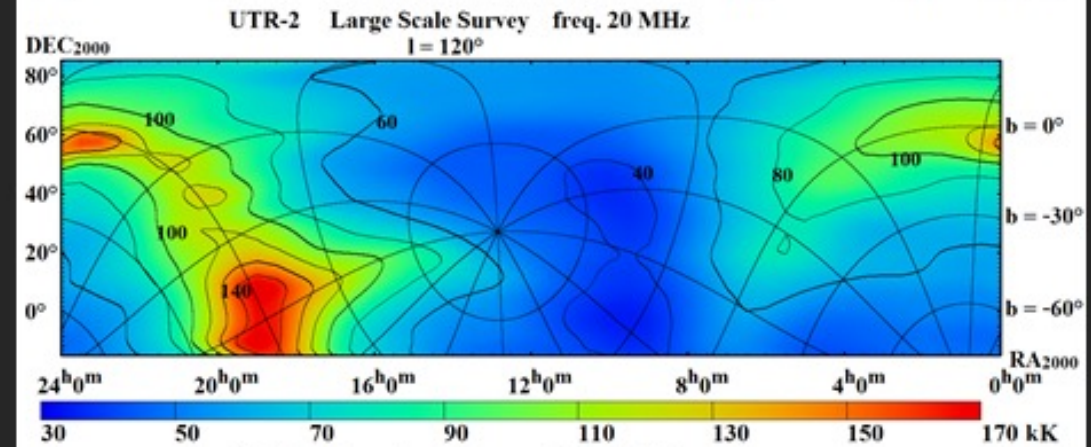
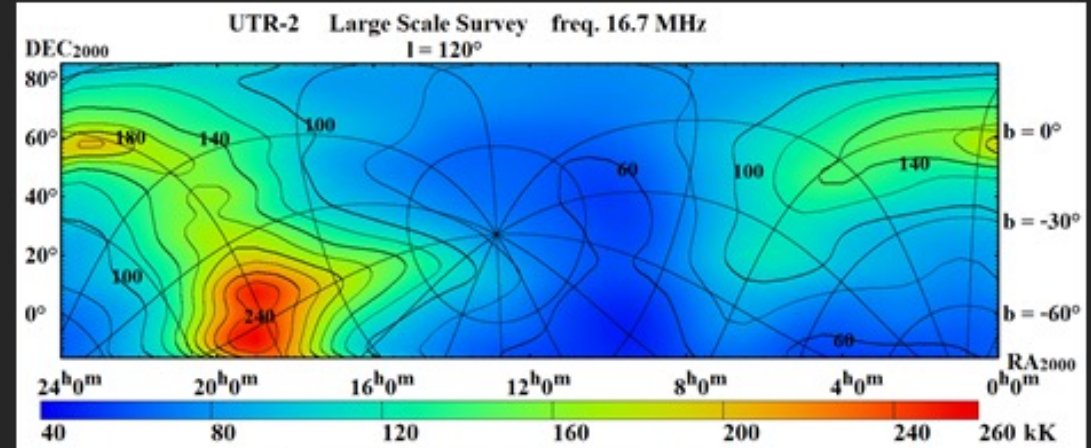
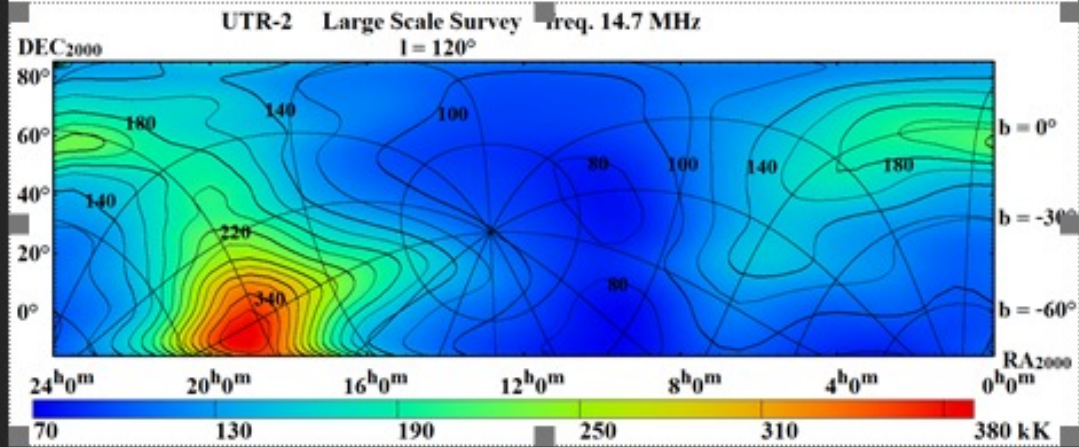
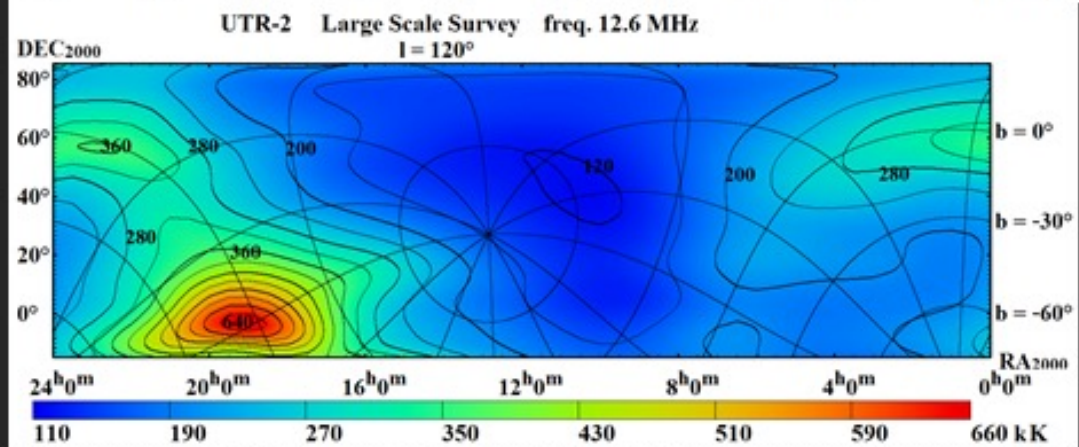
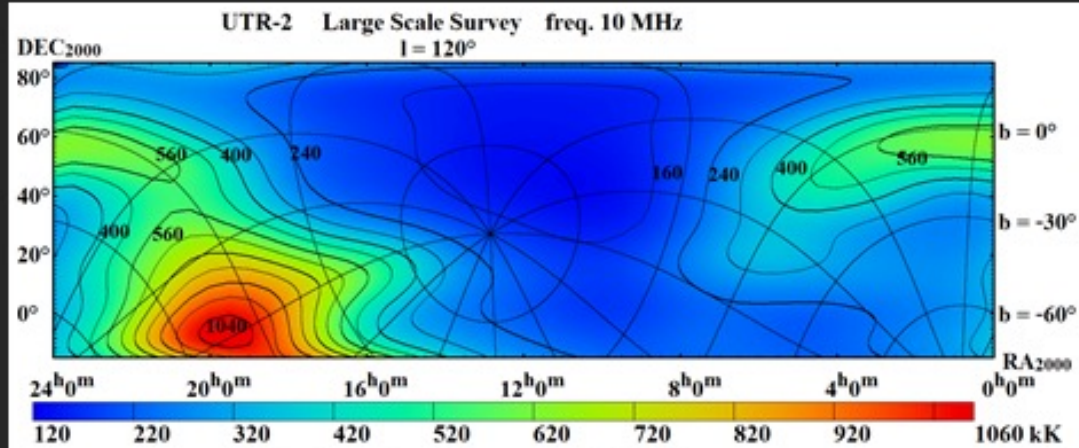
$$DM_{Saturn} = 0.4 - 4 \cdot 10^{-6} \text{ pc/cm}^3$$

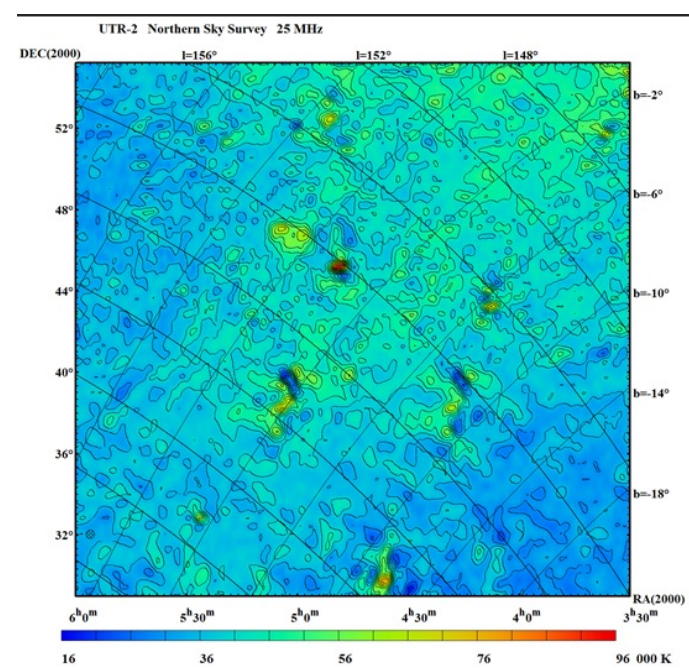
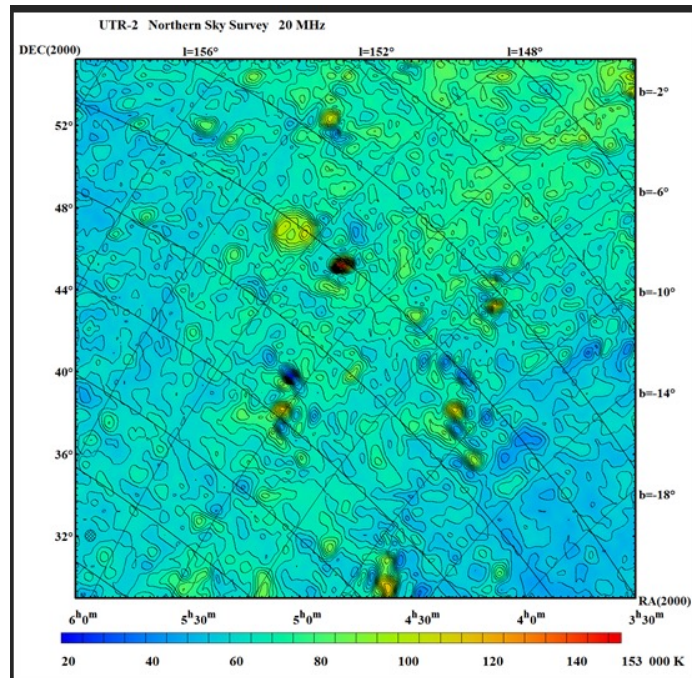
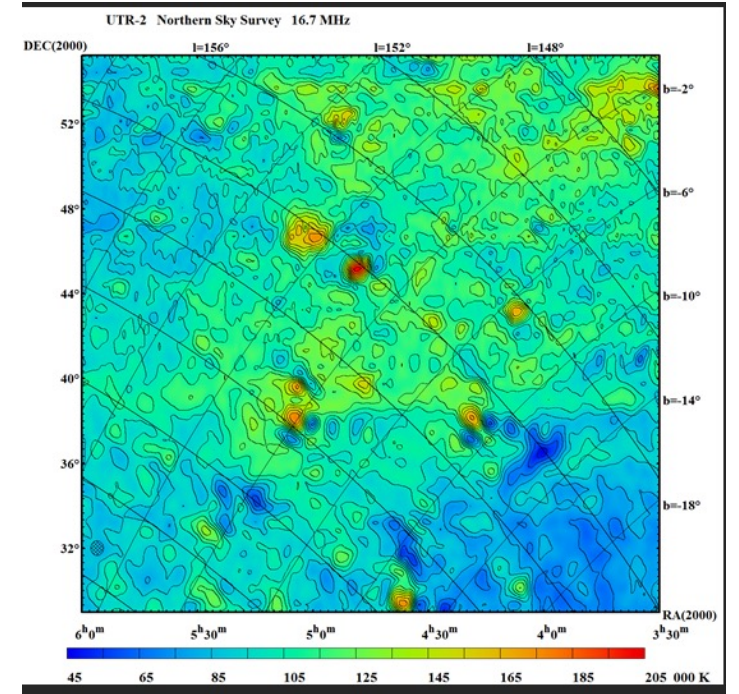
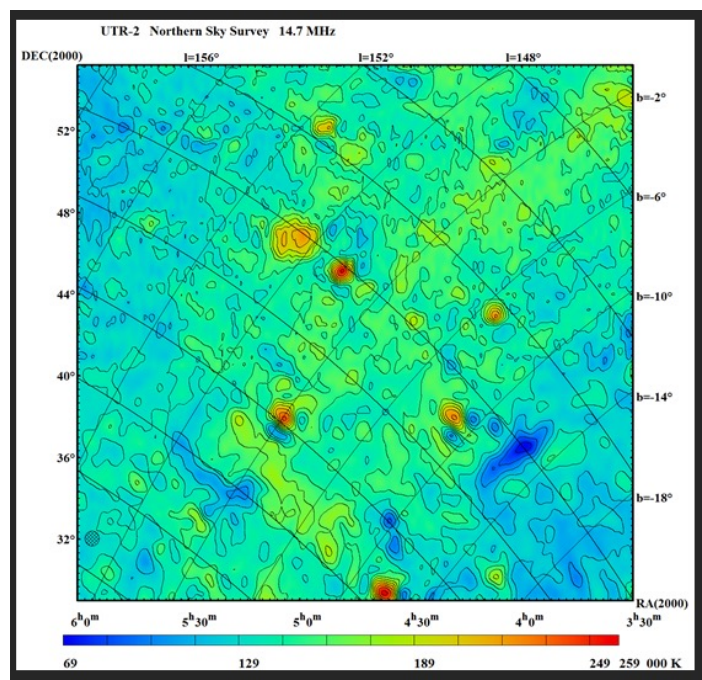
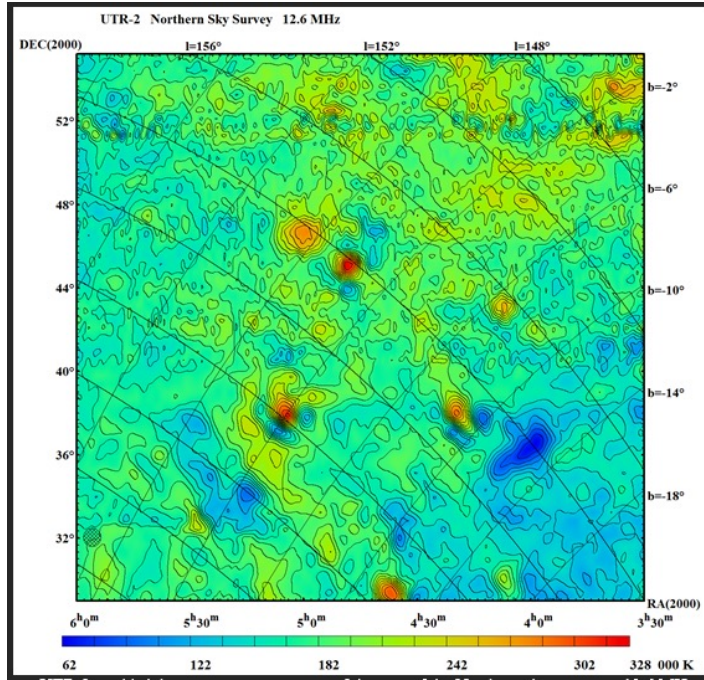
$$DM_{IPM} = 5 - 100 \cdot 10^{-6} \text{ pc/cm}^3$$

Konovalenko et al., Icarus, 2013

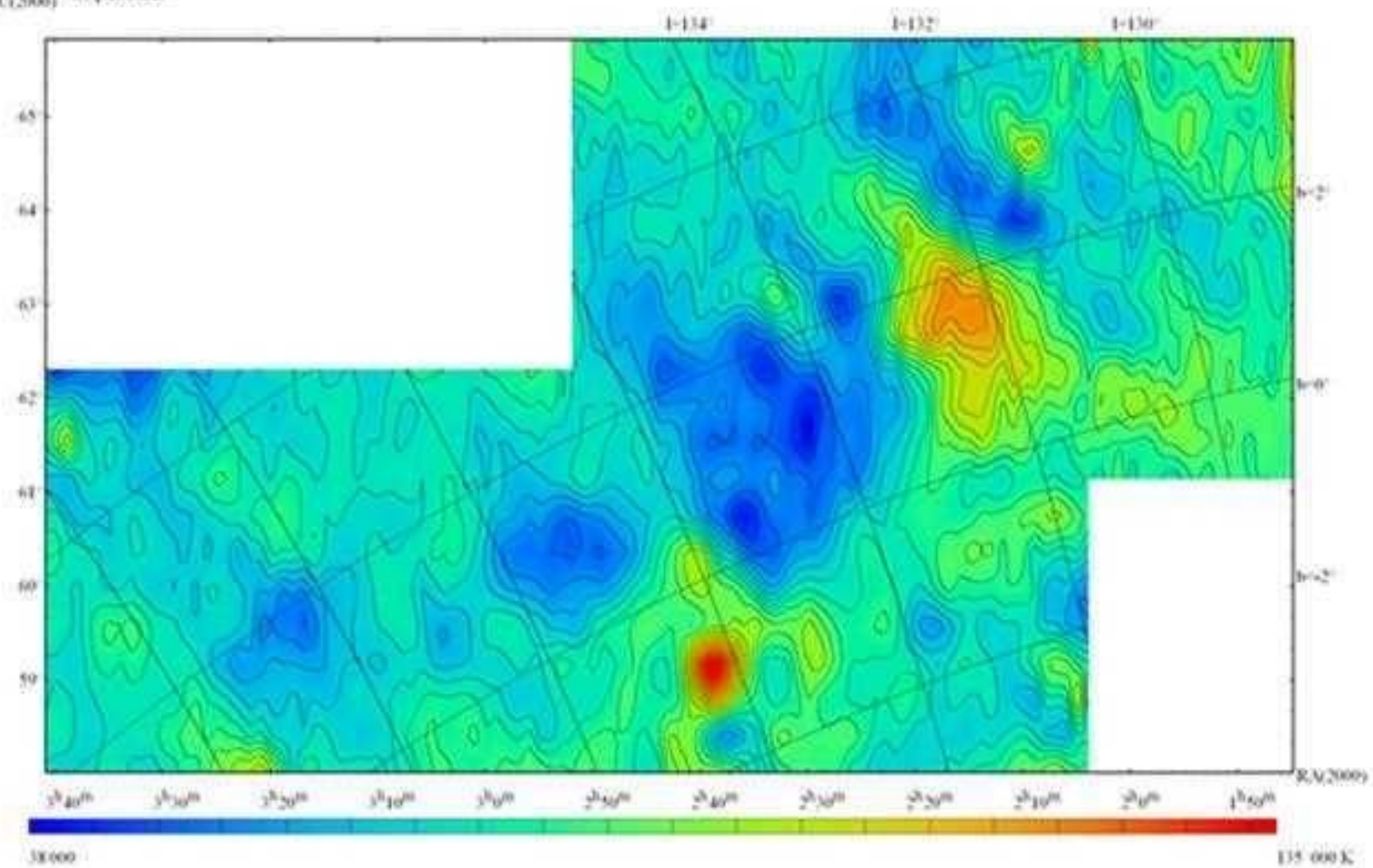
Zakharenko et al., P&SS, 2013;

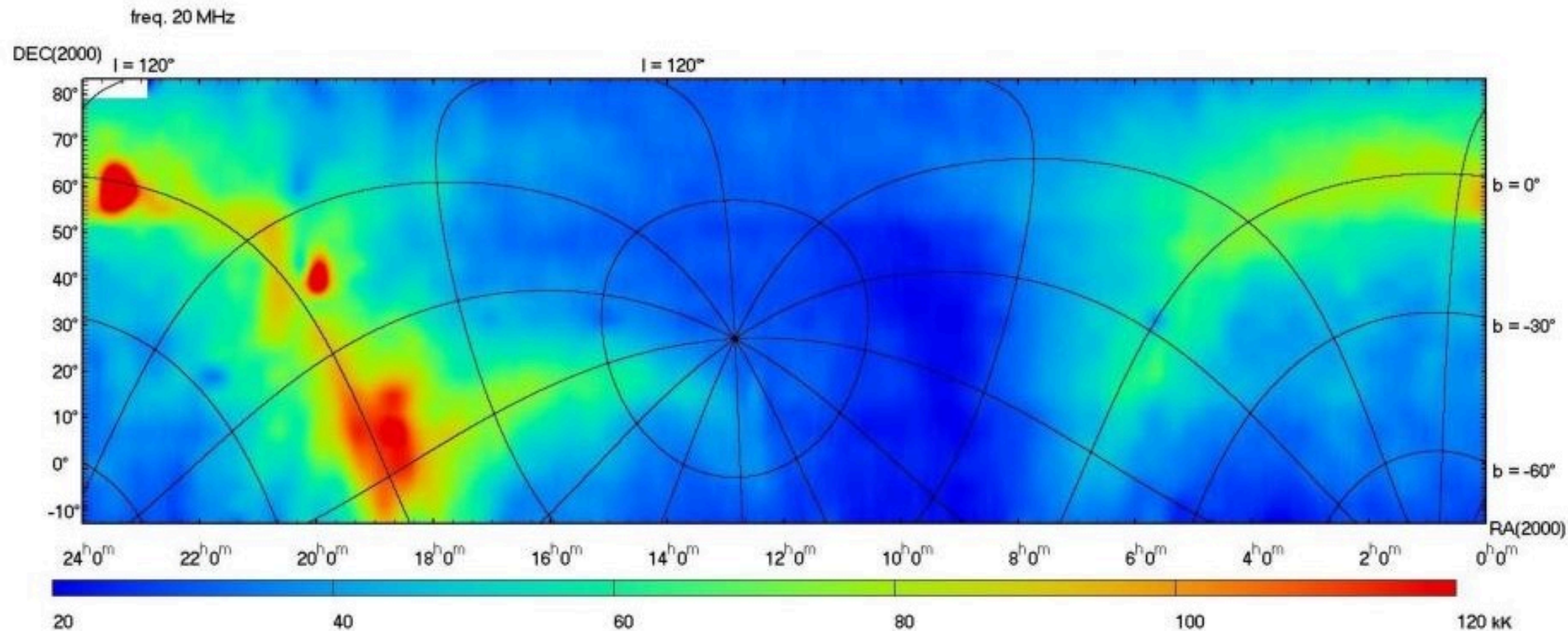
Zarka et al., Sp.Sci.Rev., 2007;





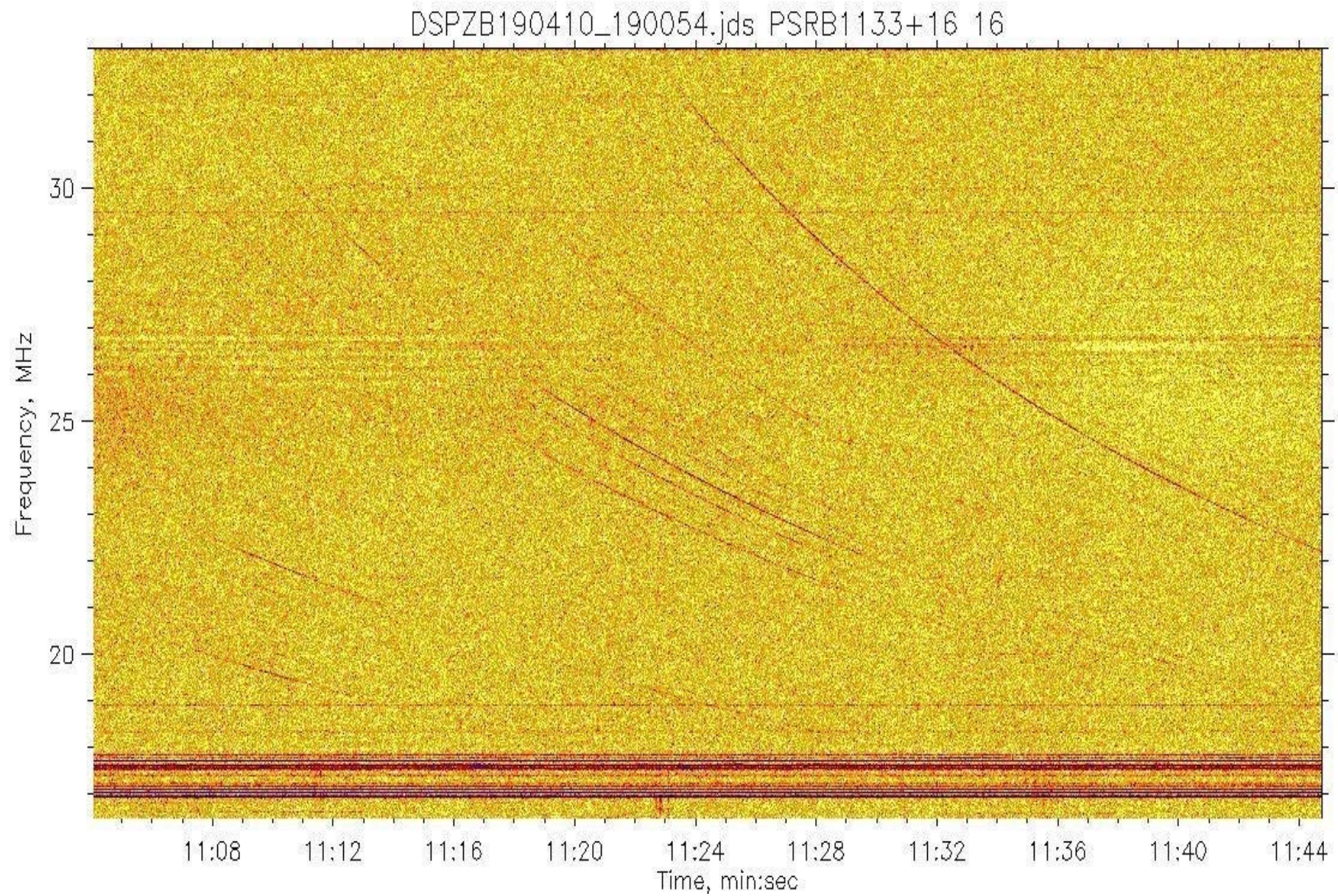
VTP-2 ID3 W3 W4 W5 S202
DEC(2000) freq. 50 MHz





The large-scale brightness temperature map of Northern sky brightness temperature map at 20 MHz. Map was produced with observations from one of the NS sections of UTR-2 and entire URAN-2 radio telescope. Half-power bandwidth($\alpha^\circ \times \delta^\circ$) was $\sim 11^\circ \times 7^\circ$ near the zenith direction of $\sim 50^\circ$. Map is represented in equatorial coordinates superimposed on galactic coordinates with angular step of 30°

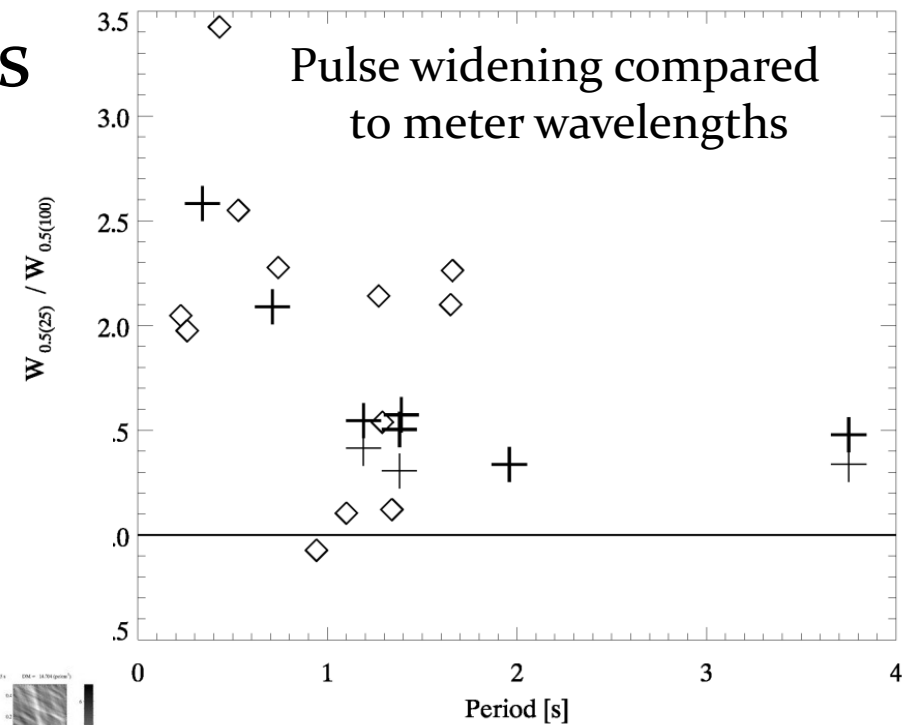
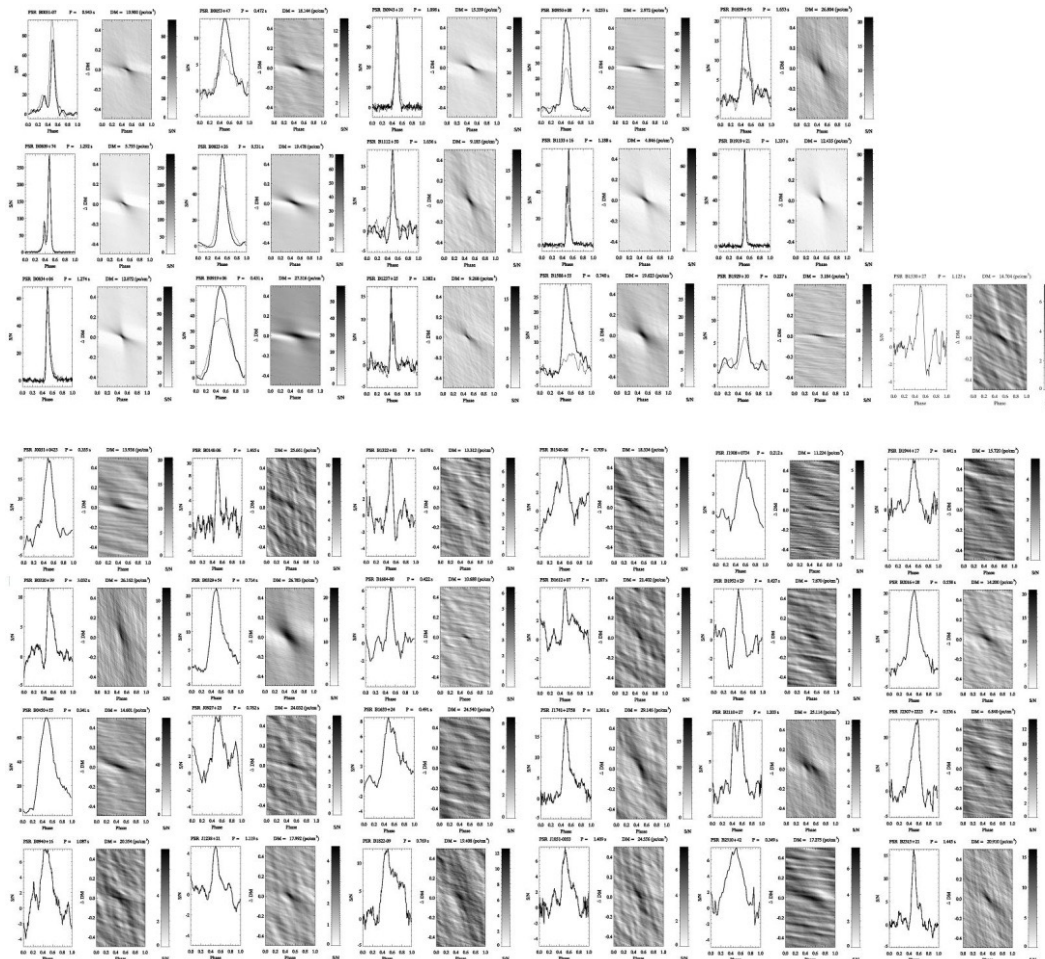
Dynamic spectra of PSRB1133+16



Decameter pulsar census with UTR-2:

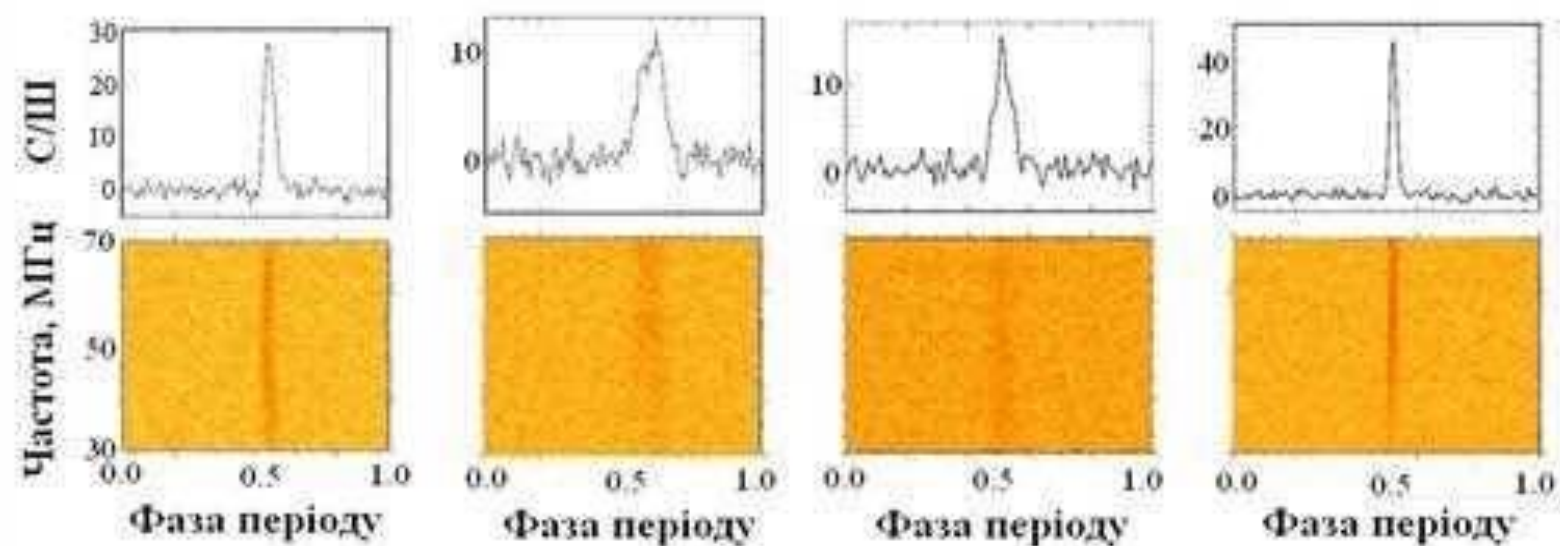
[Zakharenko et al., 2013, MNRAS, **431**, 3624]

- 74 pulsars observed
- 40 detected

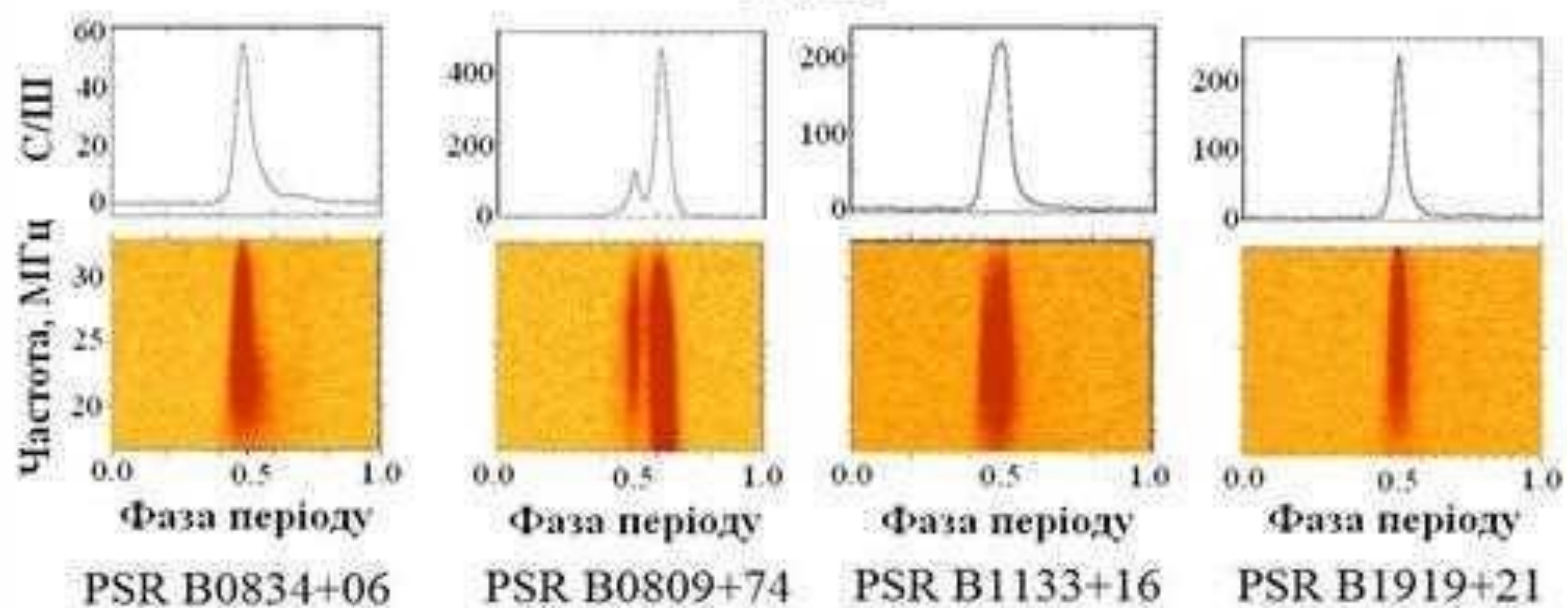


- Average pulse profiles derived
- Dispersion measures refined
- Pulse widths, scattering time constants and spectral indices determined
- Pulse widening compared to meter wavelengths observed

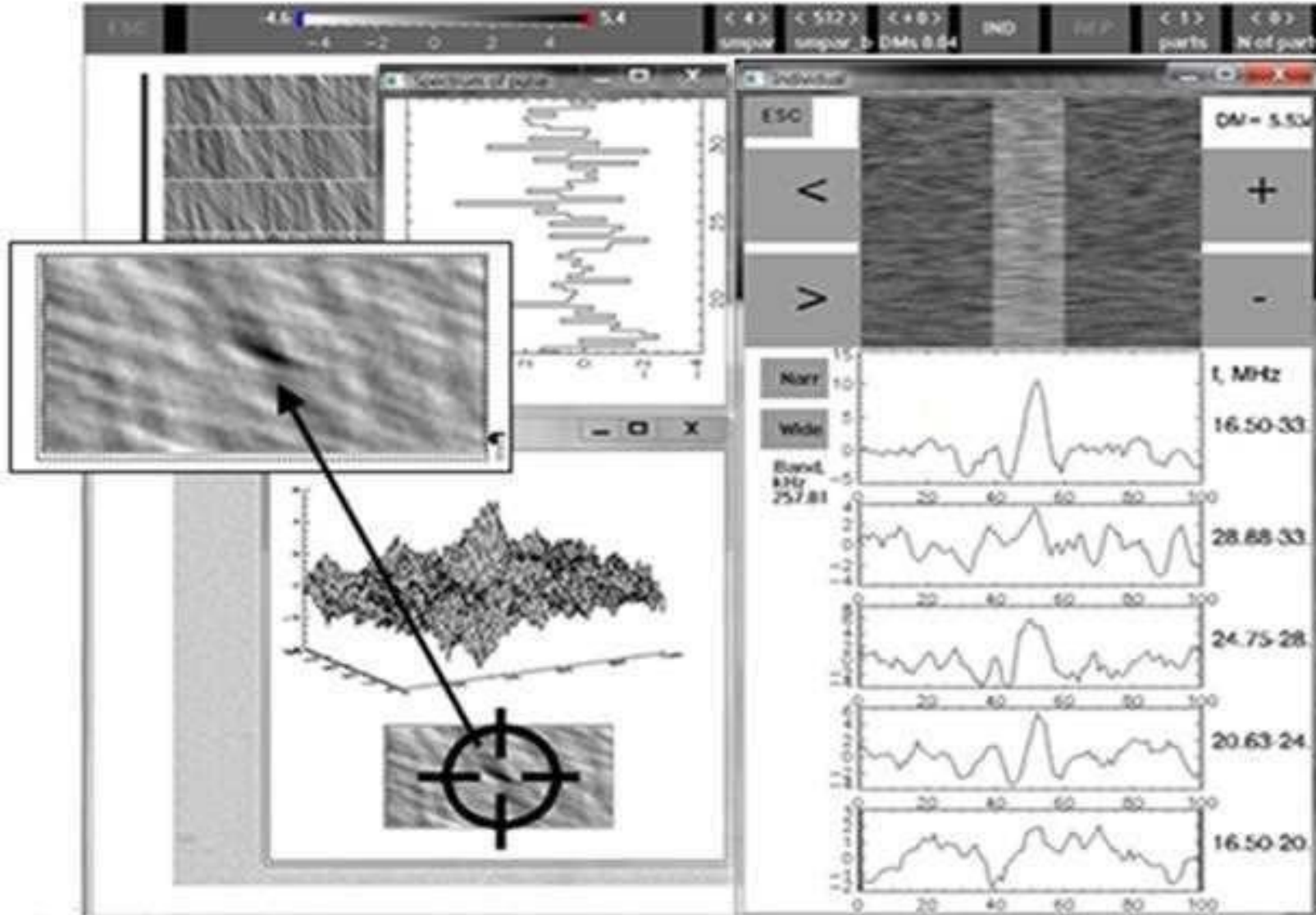
ГУРТ



УТР-2



Tranzients detection by UTR-2, V. Zakharenko et. al., A&A 2026



Detection of carbon RRL's at 26 MHz (n=631) by UTR-2

1981: The 26.13-MHz absorption line toward Cassiopeia A

A. A. Konovalenko and L. G. Sodin

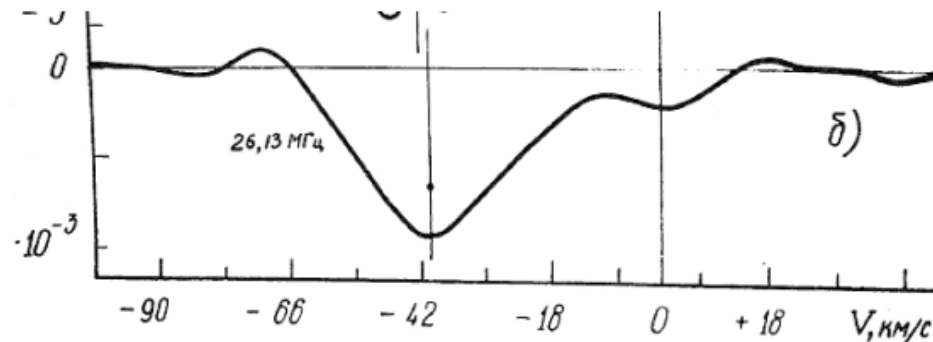
Institute of Radiophysics and Electronics, Ukrainian Academy of Sciences, Khar'kov

(Submitted April 1, 1981)

Pis'ma Astron. Zh. 7, 402-405 (July 1981)

New observations confirm that the 26.13-MHz absorption line previously detected in the direction toward the radio source Cas A represents a carbon recombination line, not a hyperfine-structure nitrogen line. Some relevant implications are discussed.

PACS numbers: 98.70.Dk, 98.40.Ct, 95.85.Dj

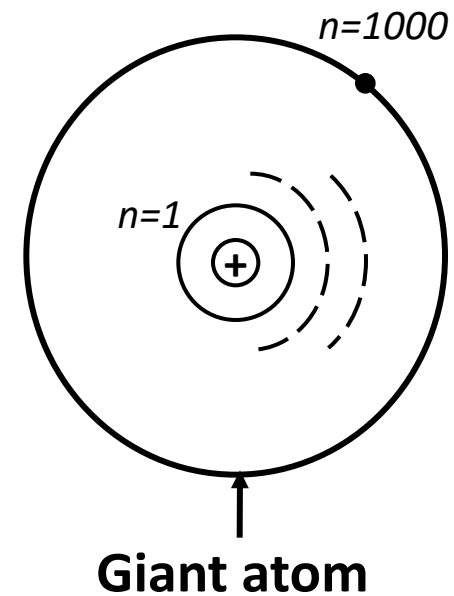
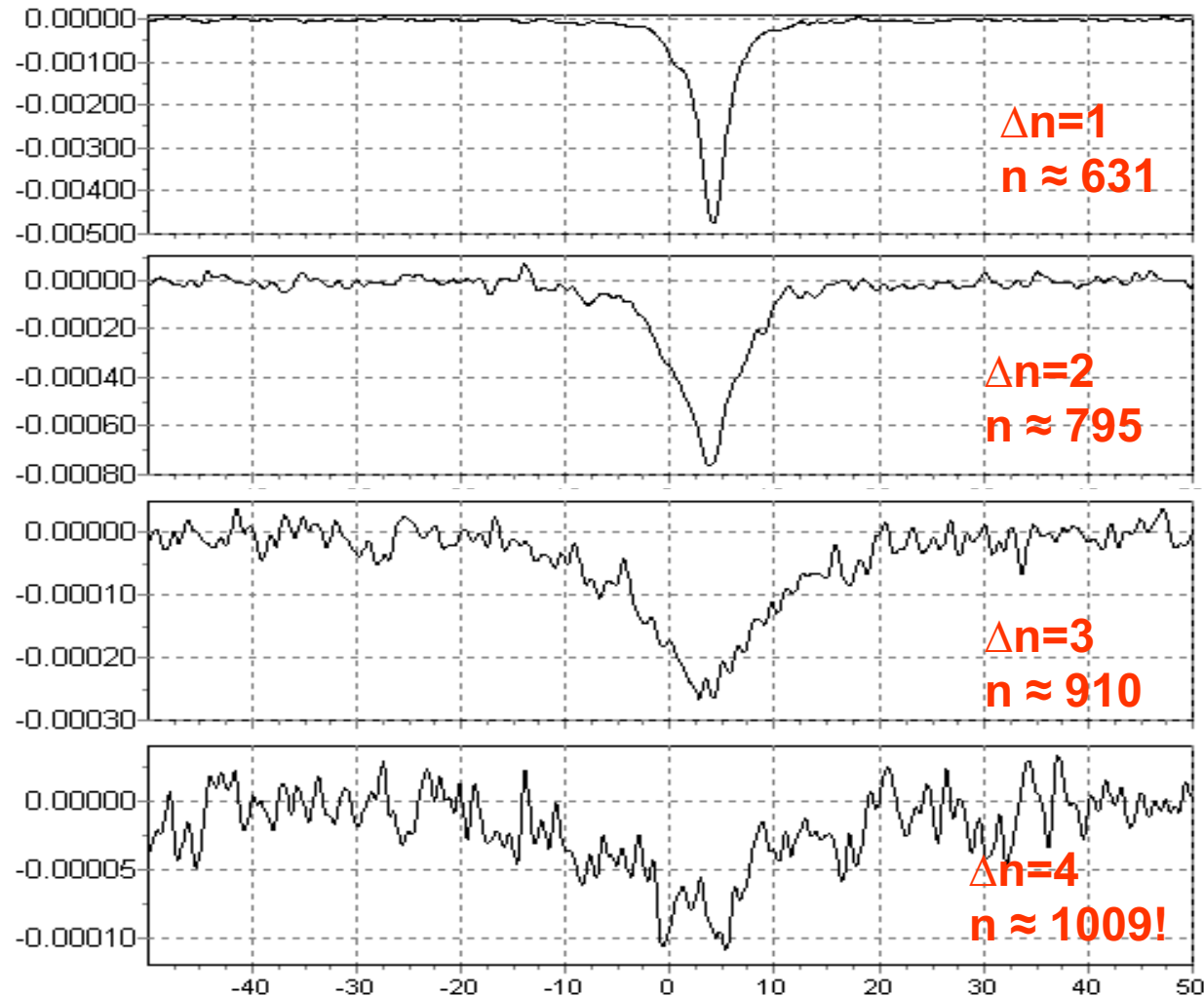


Konovalenko & Sodin, *Nature*, 1980
Blake, Crutcher & Watson, *Nature* 1980
Konovalenko & Sodin, *Nature*, 1981

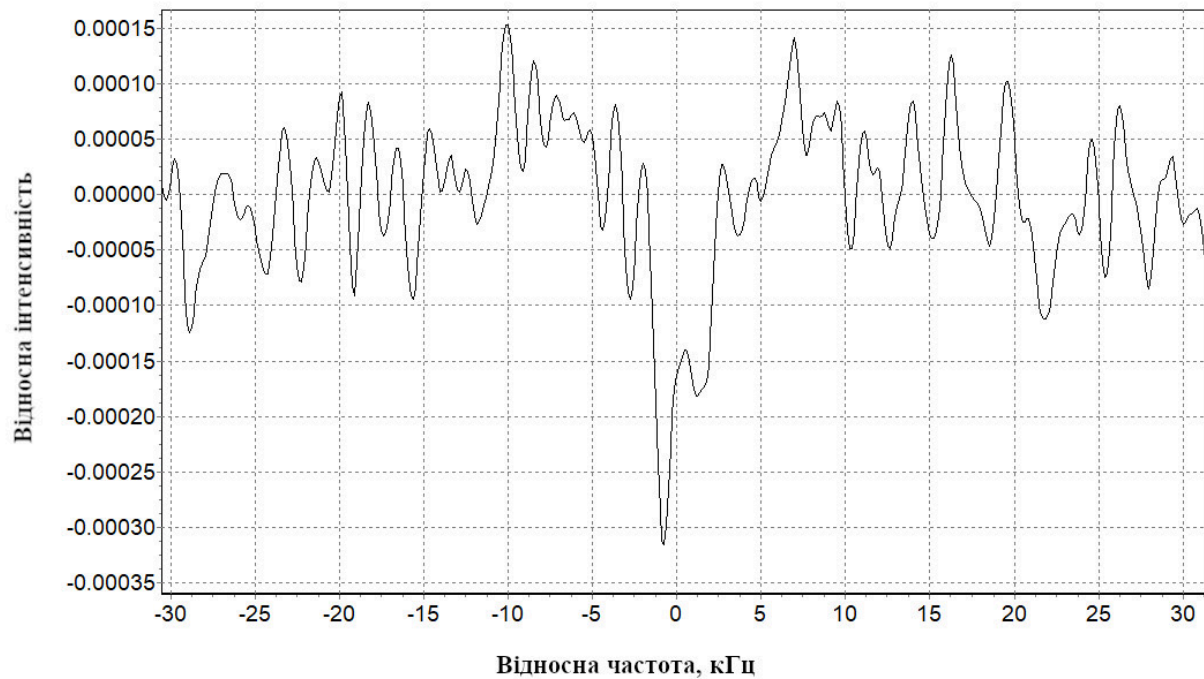
*A. Konovalenko & L. Sodin,
Nature 294, 135-136
(1981)*

Detection of the recordly high excited quantum states ($n > 1000$) on the interstellar atoms

(UTR-2, $\nu \approx 30$ MHz, $\Delta n = 1...4$, $n \approx 1009$) - 2007



$D \approx 0.1$ mm !



Carbon RRL's towards Syg A detected by UTR-2 during Apr-Jul 2014. $f \approx 25$ MHz; $n=644-653$; $\Delta f=1.1$ kHz; $\Delta t_e = \Delta t \cdot 10 = 360$ h

Furthermore:

UTR-2 (1983--2003):

NGC 2024; DR-21; S140; L1407;

M16; ρ Oph; PerOB2; etc.

(Konovalenko, Stepkin, 2003)

LOFAR:

Asgekar et al., 2013

Morabito et al., 2014

Oonk et al., 2017

Salgado et al., 2017

Salas et al., 2018;

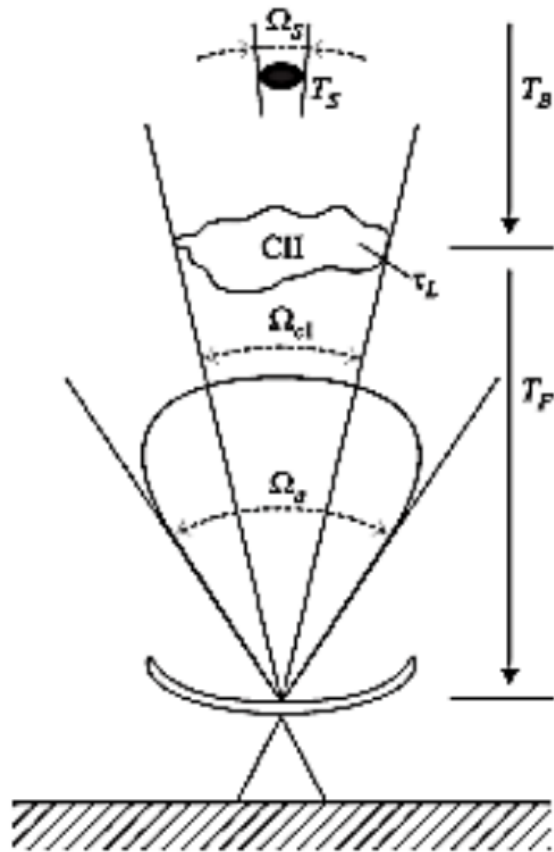
etc.

Nenu FAR:

Cros et al., 2023;

etc.

Structure of experiments for point background sources and distributed background



$$T_S \gg T_B:$$

$$\left(\frac{\Delta T_L}{T_C}\right)_{obs} = \left(\frac{\Delta T_L}{T_C}\right)_{real} = -\tau_L$$

$$T_S \ll T_B:$$

$$\left(\frac{\Delta T_L}{T_C}\right)_{obs} = \left(\frac{\Delta T_L}{T_C}\right)_{real} \frac{\Omega_{cloud}}{\Omega_a} \frac{T_B}{T_B + T_F}$$

$$T_B \gg T_F:$$

$$\left(\frac{\Delta T_L}{T_C}\right)_{real} = \left(\frac{\Delta T_L}{T_C}\right)_{obs} \left(\frac{T_{CasA} + T_B}{T_{CasA}}\right)$$

Ionized carbon in the ISM

Significance of CII ions:

- Most abundant element with $E < 13.6$ eV;
- Almost completely ionized outside the HII-regions;
- Cooling and thermostat in HI clouds due to $^2P_{3/2} \rightarrow ^2P_{1/2}$ transition;
- In interstellar molecules and gas-phase chemical reactions;
- Key role in physico-chemical processes and evolution.

Methods of CII observations:

UV $\rightarrow$ CI $\lambda = 1561 \text{ \AA}$
 $\rightarrow$ CII $\lambda = 1335 \text{ \AA}$

IR $\rightarrow$ CI $\lambda = 610 \text{ }\mu\text{m}$
 $\rightarrow$ CII $\lambda = 157 \text{ }\mu\text{m} *$

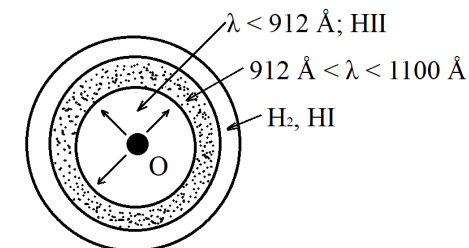
Radio $\rightarrow$ CII $\rightarrow$ Cn α $\rightarrow$ HF
 $\rightarrow$ LF *

in combination with HI, CO and plasma diagnostics with Hn α , τ_C , DM, etc.

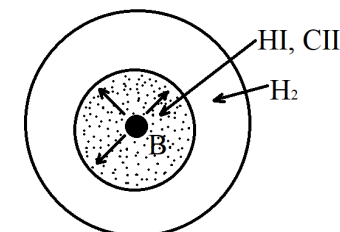
Radio ($\nu < 30$ MHz):
 UTR-2 (?); URAN -1...4; GURT;
 LOFAR LBA; NenuFAR; NDA;
 LWA

Possible ISM models with CII:

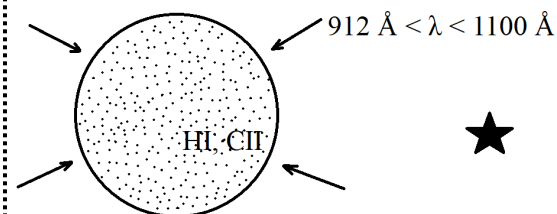
HII regions:



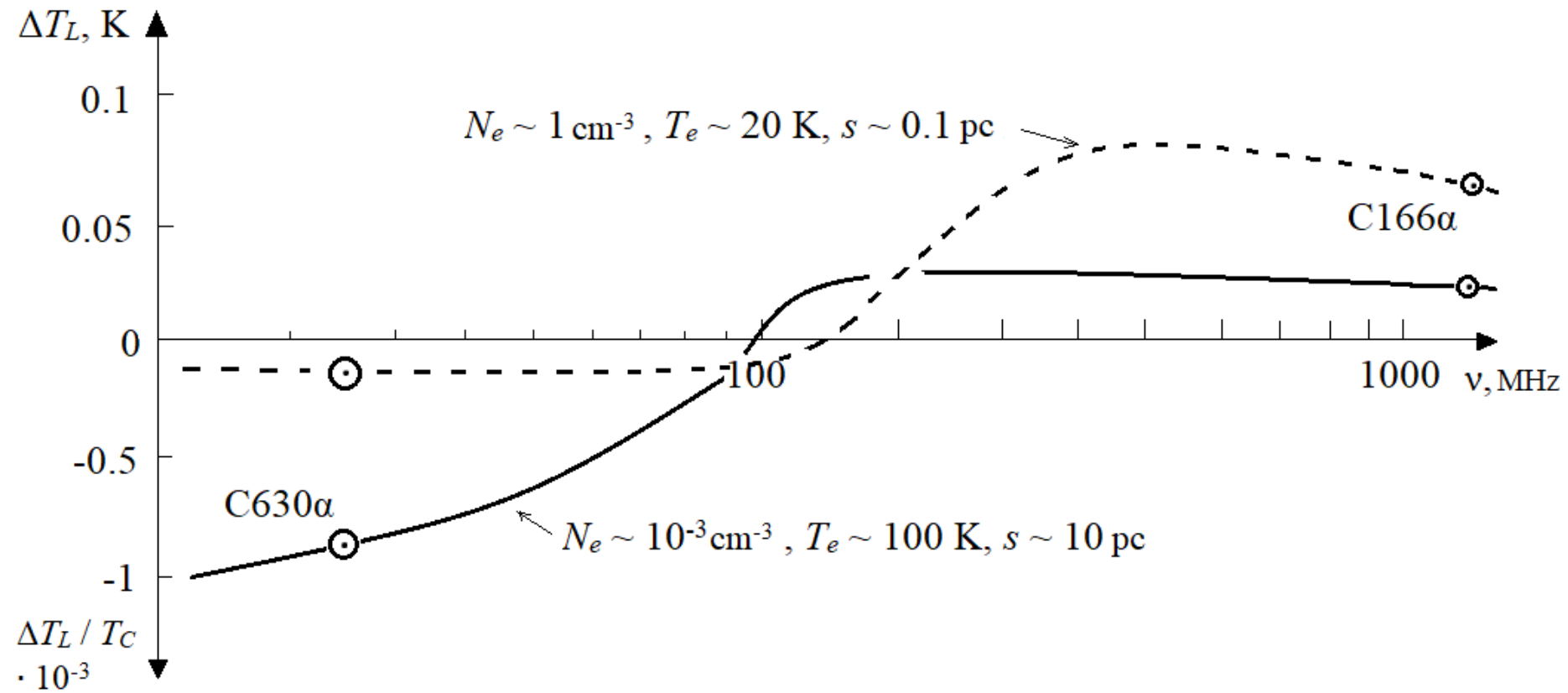
Dark dust clouds:

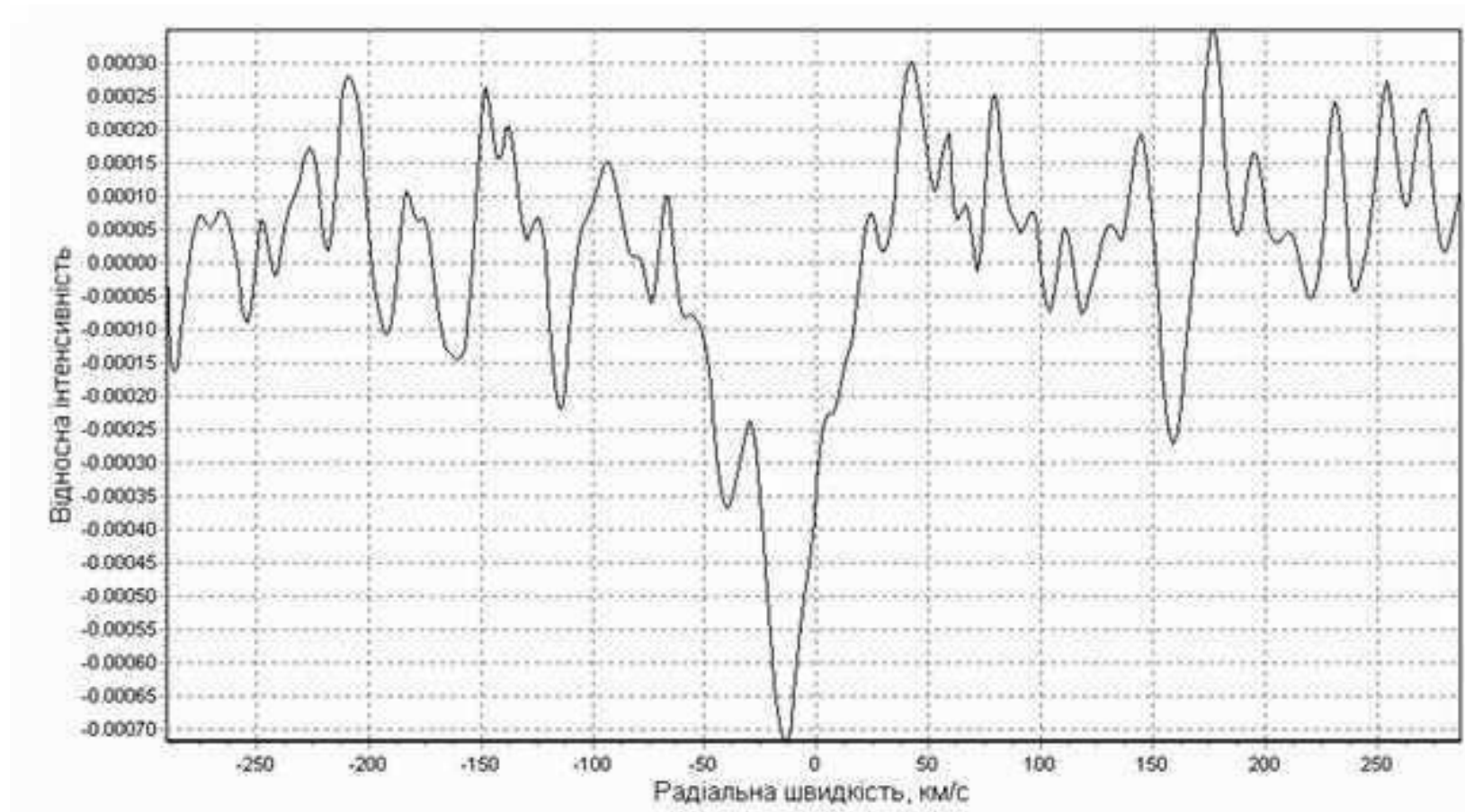


Diffuse clouds:

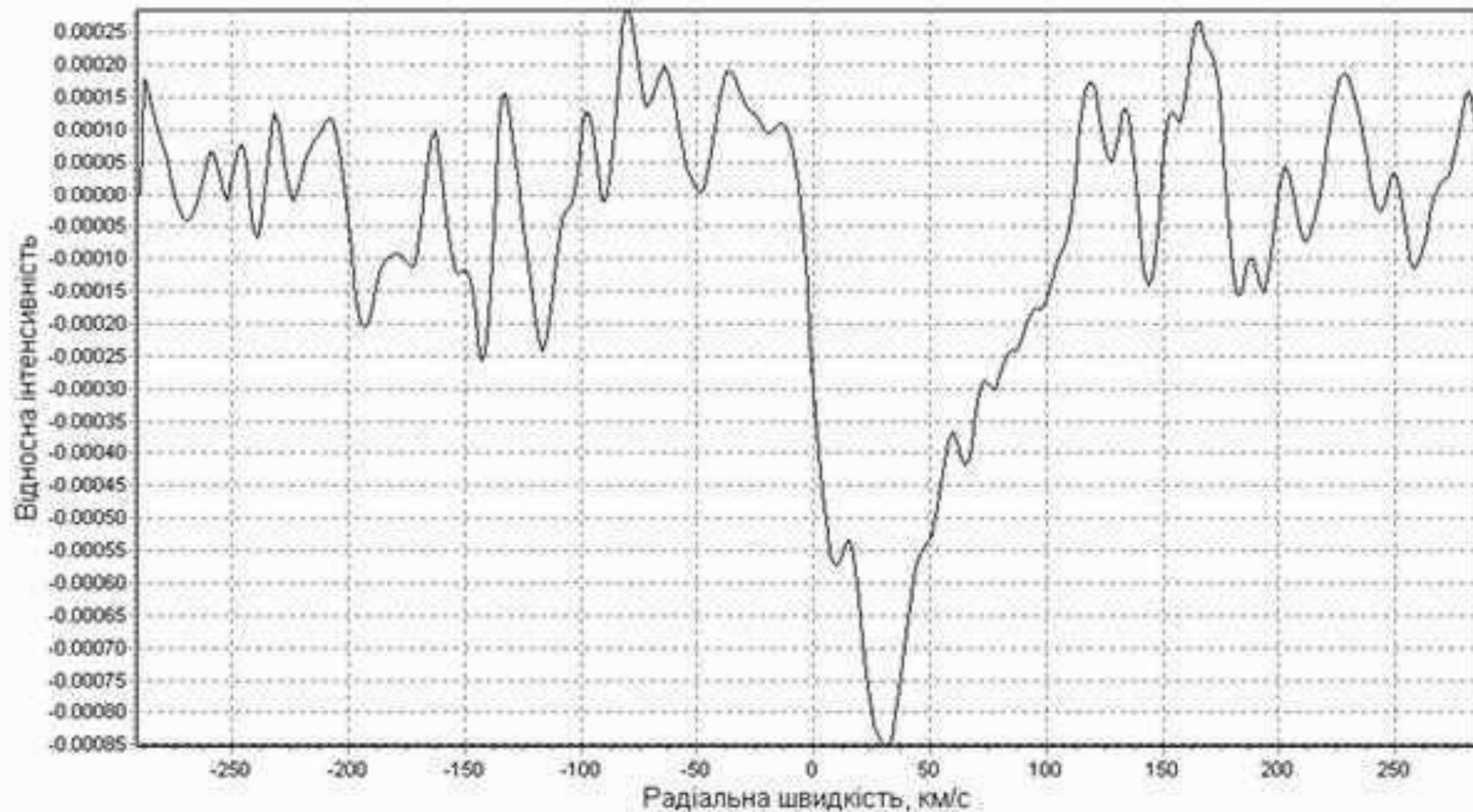


Frequency dependence of line intensities for RRLs, which have been formed in cold, high-density CII regions and in diffuse CII clouds, associated with HI





The average spectra of C627a-C636a lines measured in the direction of S 140

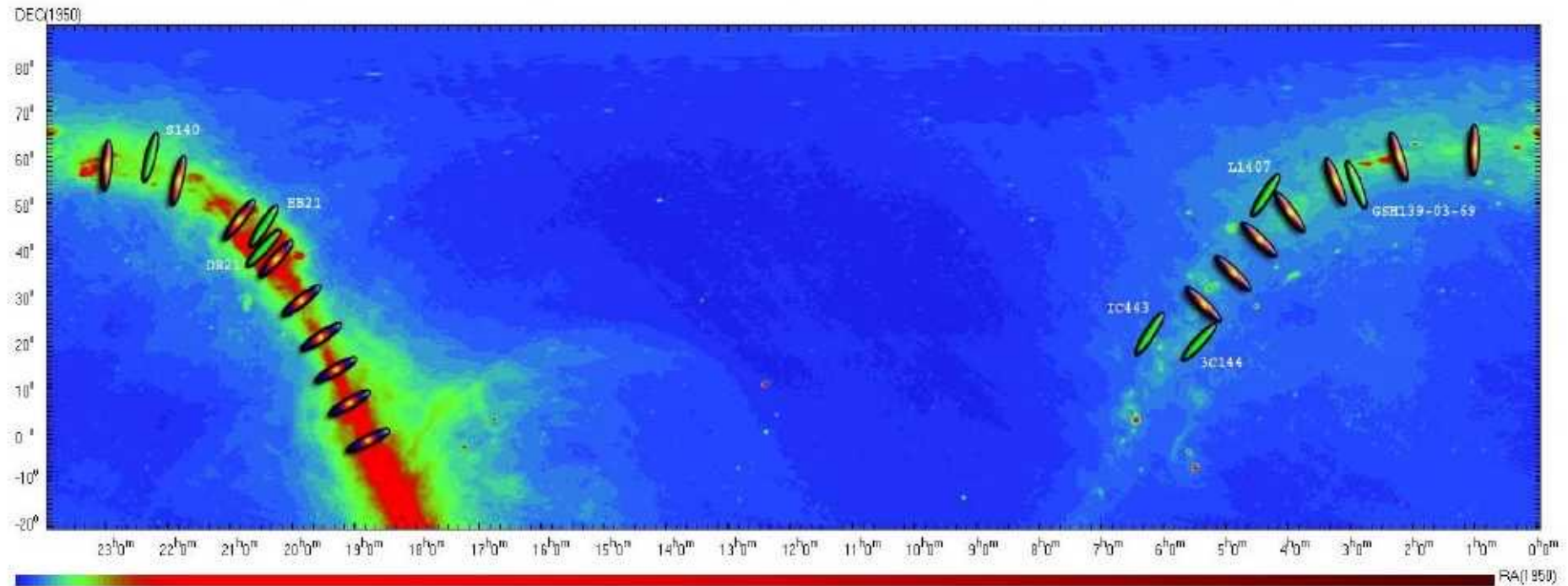


**Signus Loop decometer-range carbon
RRL's**

Galactic plane survey in the LF carbon RRL's (2006-2016)

$$\Theta_a \approx 0.5^\circ \times 12^\circ$$

(during beam steering $\Theta_a \approx 10^\circ \times 10^\circ$)



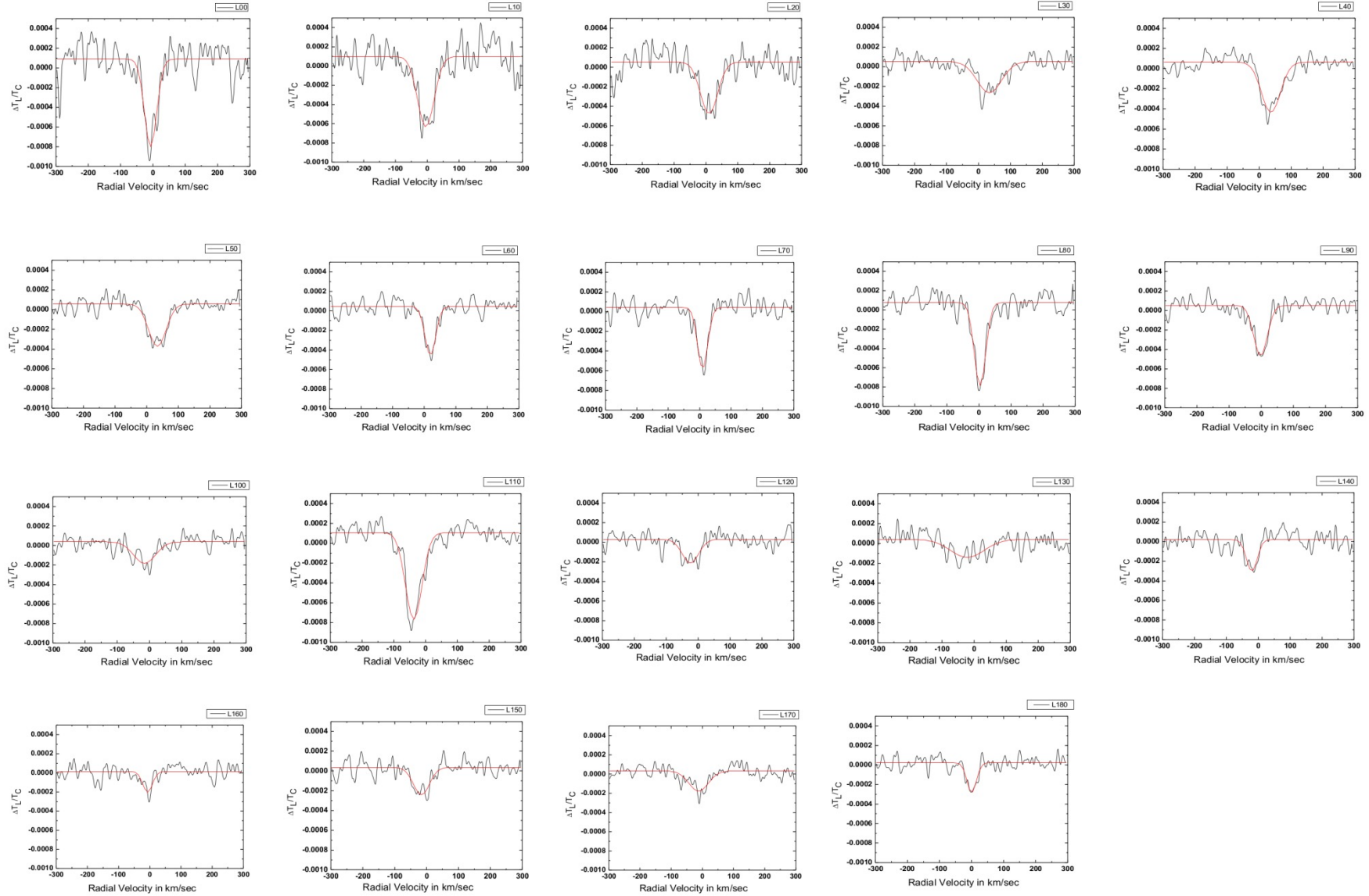
$b = 0^\circ (\pm 2^\circ, 4^\circ, \text{etc.})$

$n = 636-645, B \sim 1 \text{ MHz}, f \sim 25 \text{ MHz},$

$l = 0^\circ \dots 180^\circ$ with the step 10°

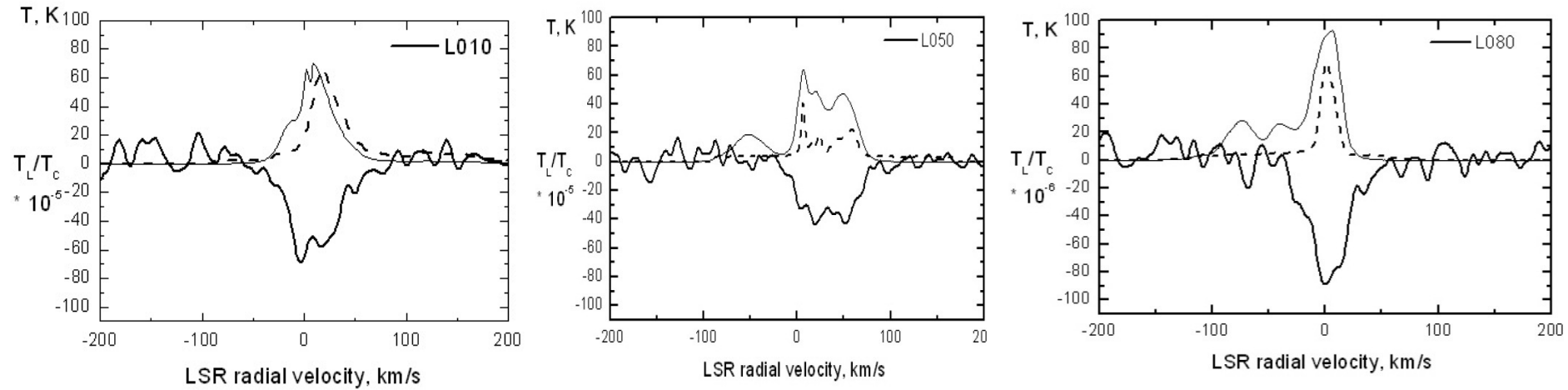
$t \sim 150 \dots 250 \text{ h}$ (for each point)

LF carbon RRL's detection near the Galactic plane by UTR-2



Detection of ionized carbon CII in a cold gas of the Galaxy and identification of areas of the global properties of neutral hydrogen HI

HI - ———; CII - ———; CO - - - - -



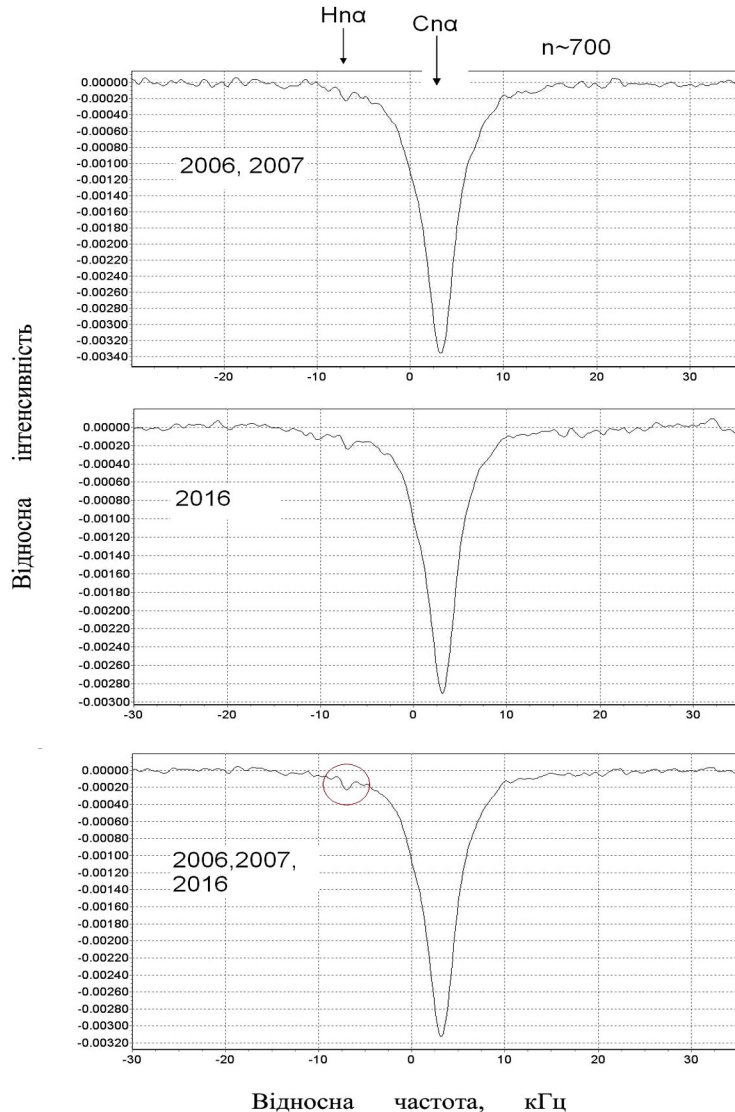
Hydrogen HI : (1) $N(H) = S \cdot n(H) = 3.88 \cdot 10^{17} \cdot T \int \tau(\nu) d\nu$

$T = 10 \dots 1000 \text{ K}$ $n(H) = 1 \dots 1000 \text{ cm}^{-3}$ $S = 0.1 \dots 100 \text{ kpc}$

Carbon CII: (2) $I = \int \tau(\nu) d\nu = 2 \cdot 10^6 \cdot n(e)^2 \cdot S \cdot b \cdot \theta / T^{2.5}$

(3) $\Delta V = K \cdot n(e) \cdot n^{5.2} / T^{0.1}$ $n(e) = 3 \cdot 10^{-4} n(H)$

Detection of Hnα for n~700 (f~20 MHz) towards Cas A by UTR-2 (Δt_e~1000h)



$$\text{Частота ліній: } \nu_n = cZ^2 R \left(1 - \frac{m_e}{M_a}\right) \left(\frac{1}{n^2} - \frac{1}{(n + \Delta n)^2}\right),$$

де c - швидкість світла, Z - ефективний заряд ядра,
 R - стала Ридберга, m_e и M_a - маси електрона та атома,
 n - головне квантове число.

Відносний вміст елементів: $C/H \approx 2 \cdot 10^{-4}$.

Потенціал іонізації: $C: E=11,2 \text{ eV}; H: E=13,6 \text{ eV}$.

Інтенсивність ліній:

$$I_C \approx \frac{S \cdot N(C^+) \cdot N_e(C) \cdot b_n \cdot \beta_n}{T^{5/2}} \quad (b_n \cdot \beta_n \approx 100),$$

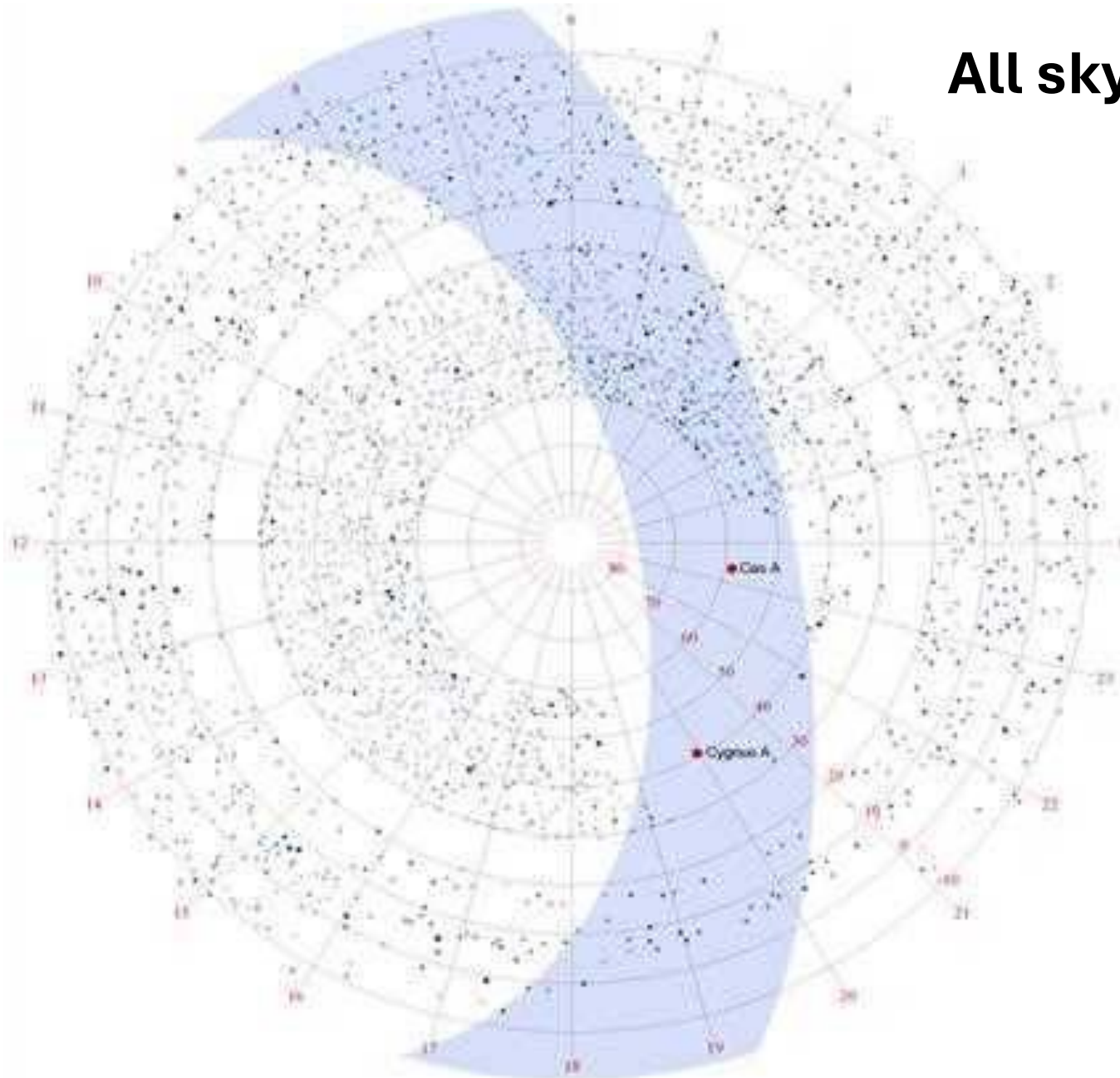
$$I_H \approx \frac{S \cdot N(H^+) \cdot (N_e(C) + N_e(H)) \cdot b_n \cdot \beta_n}{T^{5/2}} \quad (b_n \cdot \beta_n \approx 1).$$

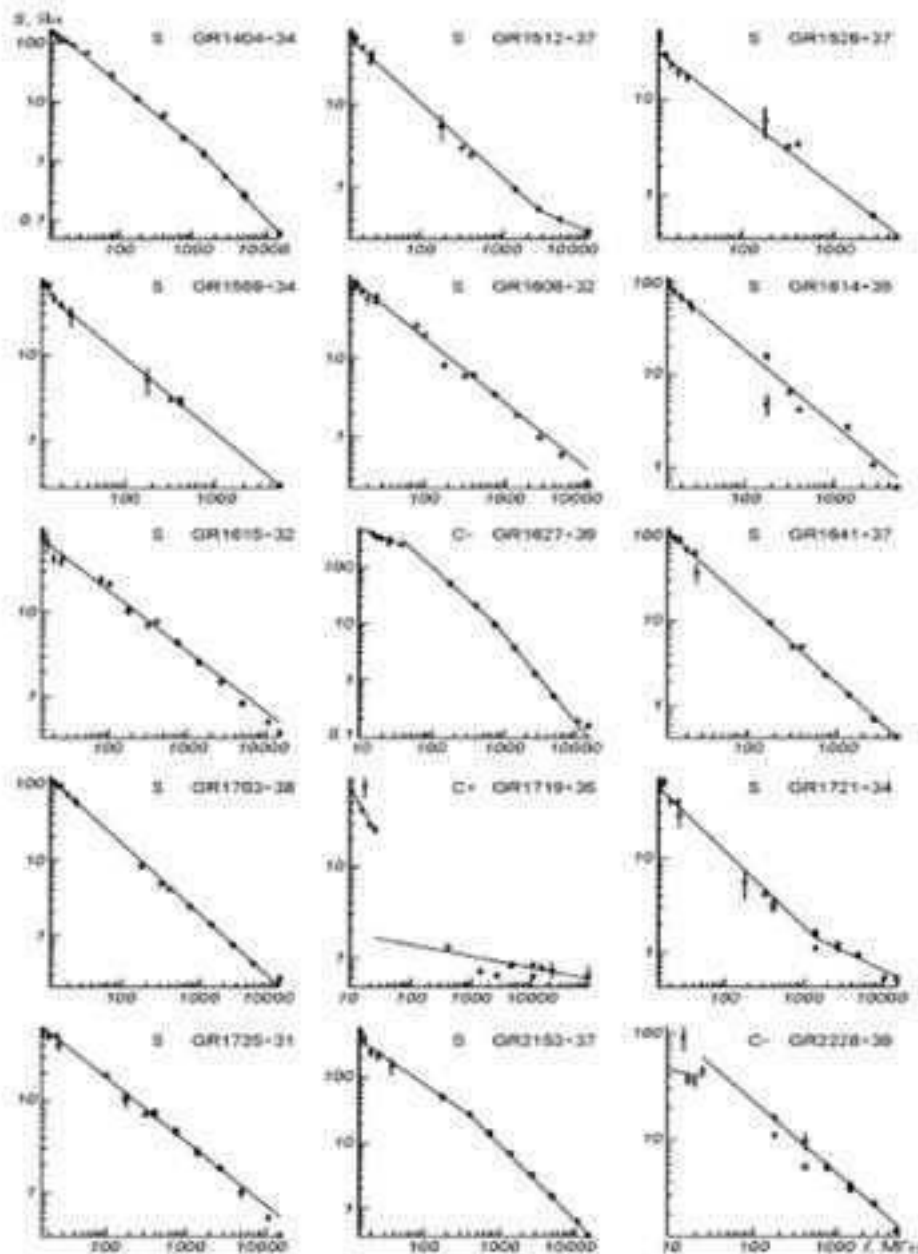
$$N_e(C) \gg N_e(H) \approx N(H^+).$$

С.В.Степкін, акад. О.О. Коноваленко

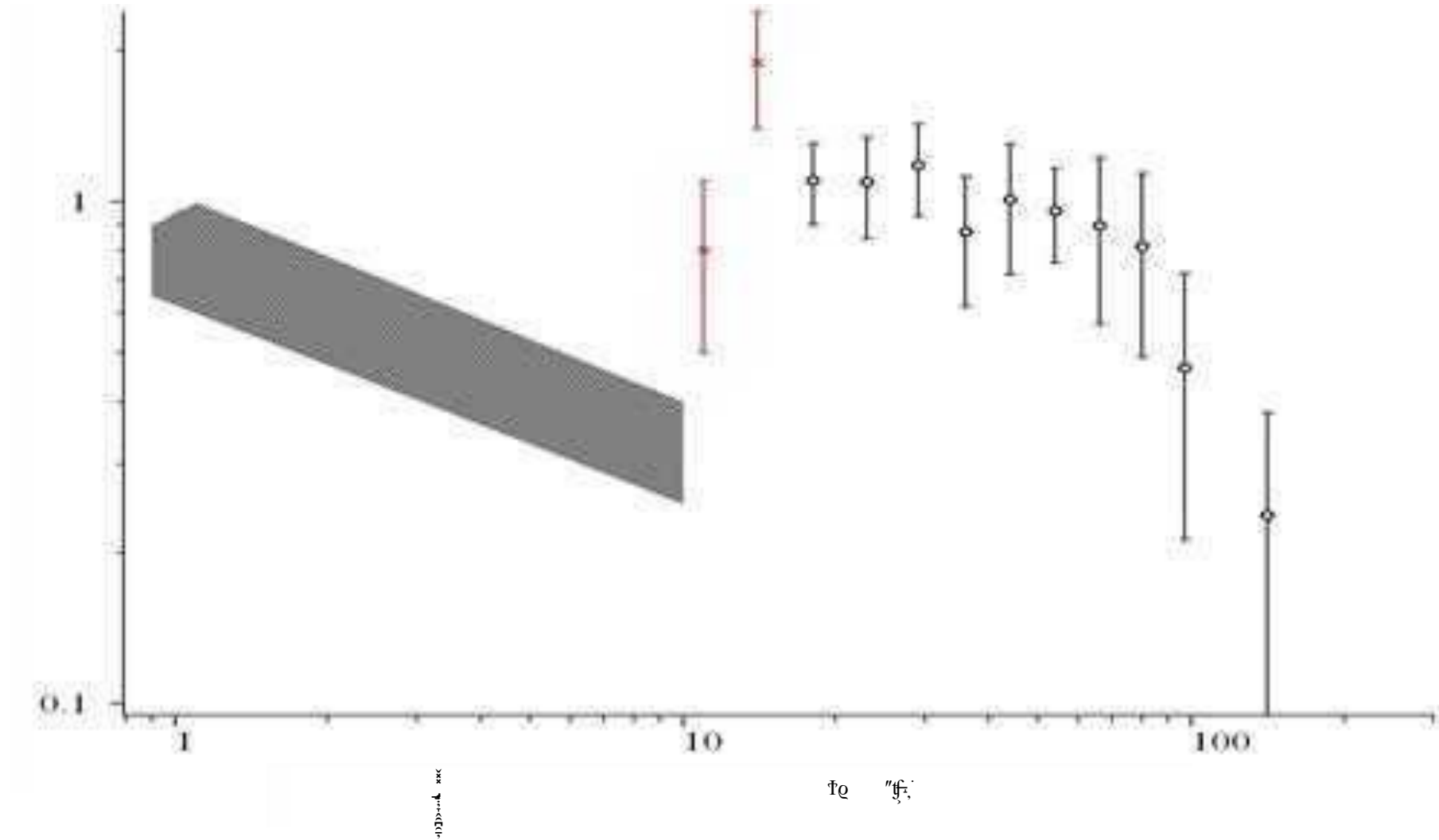
Запрошена доповідь на міжнародній конференції
 "Планетна, сонячна та геліосферна радіоемісія",
 Австрія, Грац, жовтень, 2016

All sky survey with UTR-2



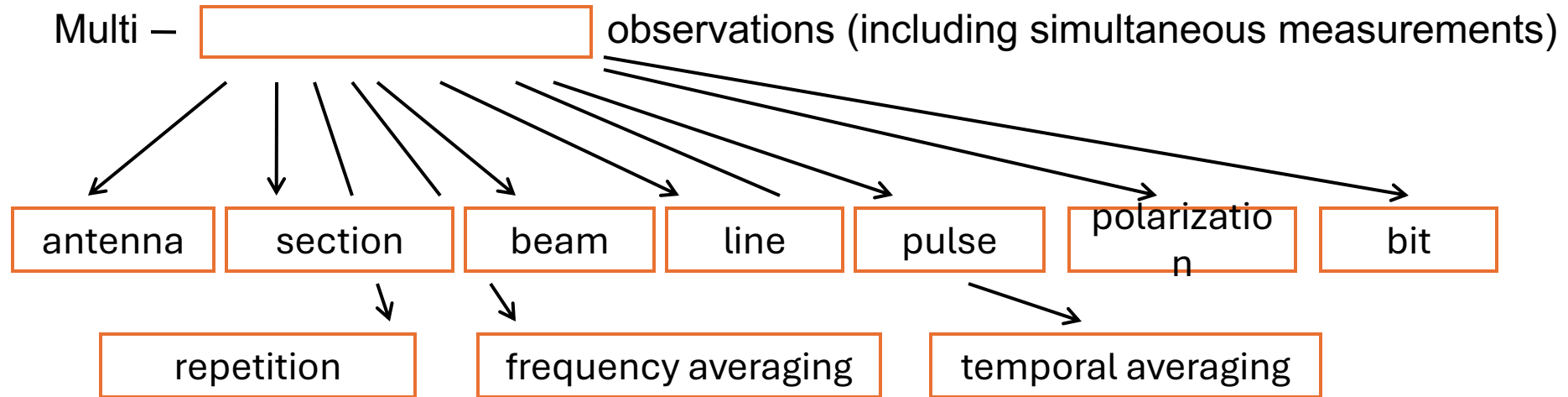


**Catalog (spectra) of radio sources
detected by UTR-2**



**Sources count at decameters (K.P.Sokokov,
Actronomy Reports,1985)**

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



Furthermore it should be:

- the decreasing of the side and diffractive lobes levels;
- optimal restoration of the low-frequency spatial 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.

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

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

1978 : detection of interstellar RRL at the decameter waves using UTR-2;

$\Delta t_{\text{ef}} = 4 \text{ год}$; $N_1=1, N_2=1, N_3=1, N_4=1$; $\Delta f=1\text{kГц}$; $B=20 \text{ kGz}$;

$(\Delta T_L / T_C)_{\min} = 4 \times 10^{-4}$; $(\Delta T_L / T_C)_{\text{det}} = 4 \times 10^{-3}$; $S/N \approx 10$

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 ($\Delta F = 3 f / n$)

$\Delta t_{\text{ef}} = 5 \times 4 \text{ год} = 20 \text{ hours}$; $N_1=5, N_2=1, N_3=1, N_4=1$; $\Delta f=1\text{kГц}$; $B=20 \text{ kGz} \times 5$;

$(\Delta T_L / T_C)_{\min} = 1,8 \times 10^{-4}$; $(\Delta T_L / T_C)_{\text{det}} \approx 1,5 \times 10^{-3}$; $S/N \approx 10$

1992-2005 : detection of the recordly high excited states ($n \sim 1000$);

$\Delta t_{\text{ef}} = 10 \times 4 \text{ год} = 40 \text{ hours}$; $N_1=10, N_2=1, N_3=1, N_4=1$; $\Delta f=1\text{kГц}$; $B=1,5 \text{ МГц}$;

$(\Delta T_L / T_C)_{\min} = 1 \times 10^{-4}$; $(\Delta T_L / T_C)_{\text{det}} = 1 \times 10^{-3}$; $S/N \approx 10$

2005-2018 : simultaneous observations of many RRL ($\Delta n \sim 100 \dots 400$);

$\Delta t_{\text{ef}} = 400 \times 4 \text{ hours} = 1600 \text{ hours}$; $N_1=400, N_2=1, N_3=1, N_4=1$; $\Delta f=1\text{kГц}$; $B=12 \dots 24 \text{ MHz}$;

$(\Delta T_L / T_C)_{\min} = 2 \times 10^{-5}$; $(\Delta T_L / T_C)_{\text{det}} = 1 \times 10^{-4}$; $S/N \approx 5$

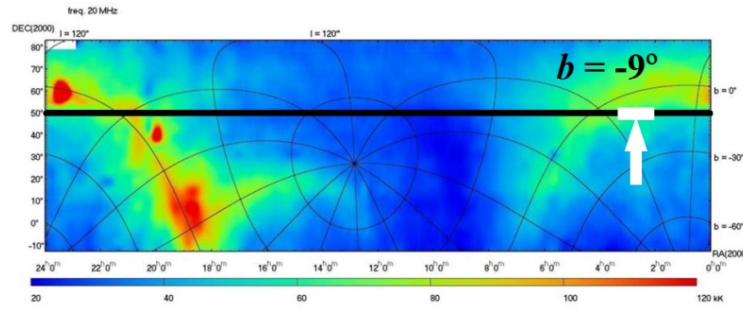
2019: simultaneous multilinear ($N_1=400$), multi-section ($N_2=100$), multi-antenna ($N_3=3$),
bipolarization ($N_4=2$), many bits ($N_5=2$) insensitive searches RRL;

! $\Delta t_{\text{ef}} = 400 \times 100 \times 3 \times 2 \times 4 \text{ hours} = 480\,000 \text{ hours} \leftarrow 100 \text{ years} !$

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

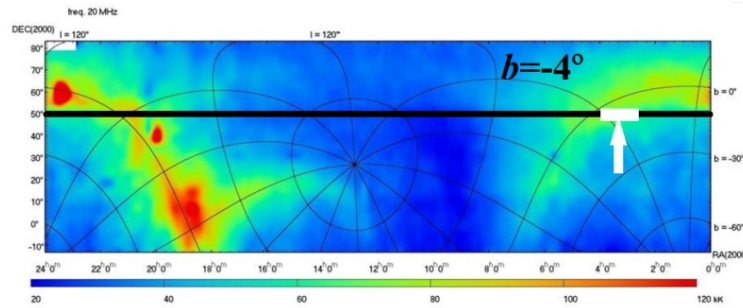
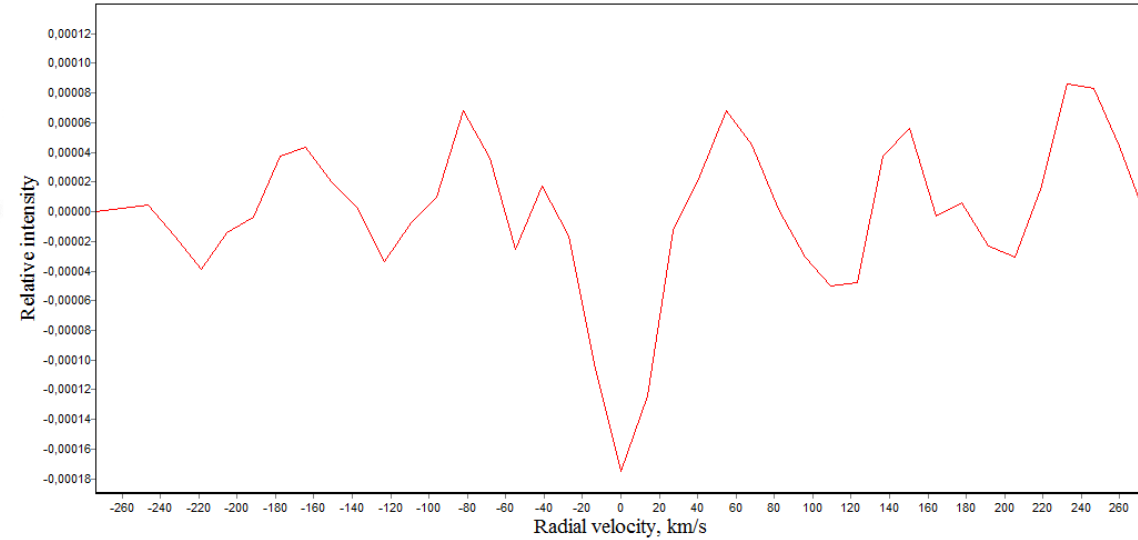
Detection of LF carbon RRLs in medium across the Galactic plane

$N = 40, \Delta F = 20...24 \text{ MHz}$



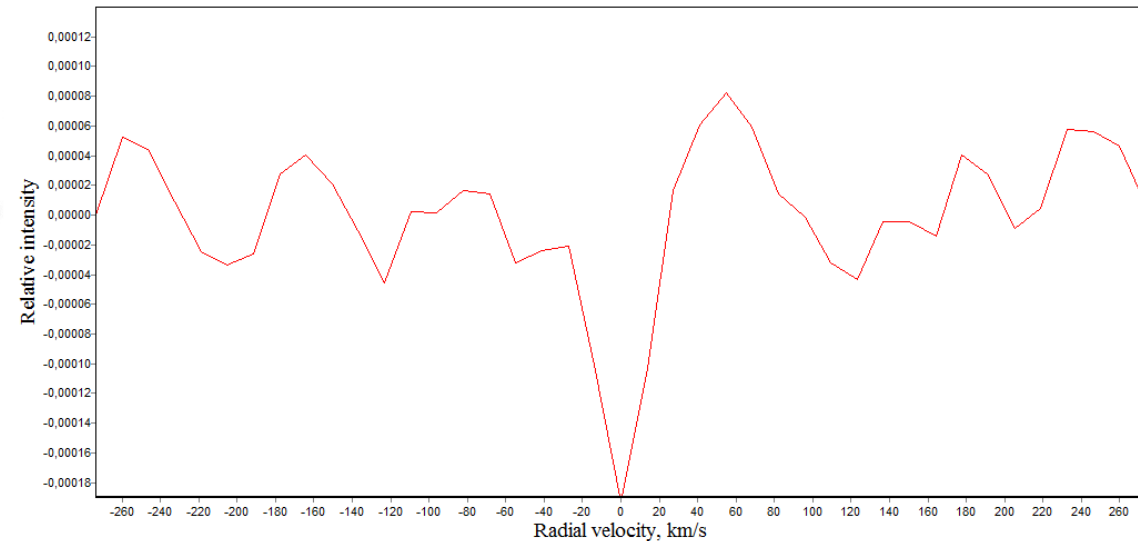
$\Delta\alpha = 2\text{h}...3\text{h}, \delta \sim +50^\circ$

$\Delta T = 40 \times 8.2\text{h} = 328\text{h}$

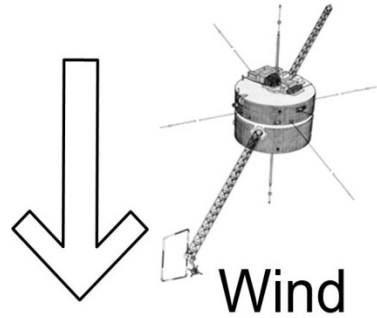


$\Delta\alpha = 3\text{h}...4\text{h}, \delta \sim +50^\circ$

$\Delta T = 40 \times 10.7\text{h} = 428\text{h}$



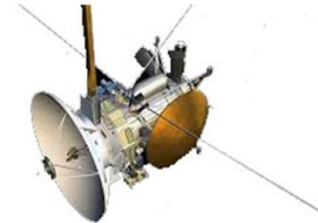
Complementary character of space and ground-based low-frequency radio astronomy systems



Wind



Stereo



Cassini



Juno

SPACE:

$f < 10 \text{ MHz}$ (NOT IONOSPHERIC LIMIT):

$f=0,1 - 30 \text{ MHz}$; $\Delta F=100 \text{ kHz}$; $\Delta T=100 \text{ ms}$

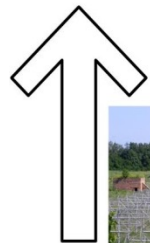
$N \approx 1$; $A_{\text{eff}} \approx 100 \text{ m}^2$ (!)

$$\Delta S_{\text{min}} = 2kT / A_{\text{eff}} \sqrt{\Delta f \Delta T} ; \quad A_{\text{eff}} \approx NA_1 \approx N \lambda^2 / 4$$

GROUND: (UTR-2, URAN1.....URAN4,GURT); $F \geq 10 \text{ MHz}$ (IONOSPHERIC LIMIT):

$f=8-32 \text{ MHz}$ (8-80 MHz); $\Delta F=1\text{kHz}$; $\Delta T=1 \mu\text{s}$

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



UTR-2



URAN-1



URAN-2



URAN-3



URAN-4



GURT

Huge Solar system – scale low-frequency radio telescope

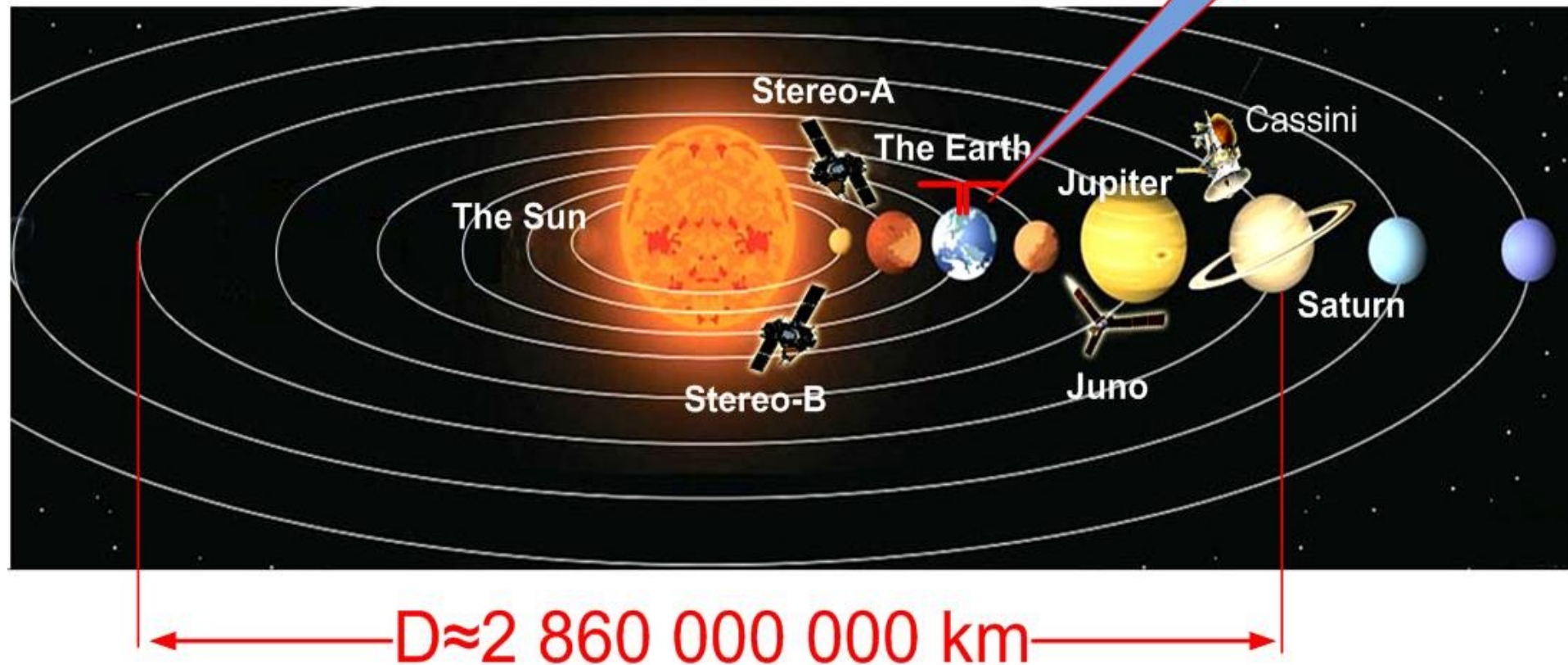
(It is in principal, it is a joke 🤓):

$f \approx 0.1 \dots 100$ MHz !

$N \approx 20000$ elements !

$D \approx 2\,860\,000\,000$ km !!!

Ground-based
LF radio
telescopes





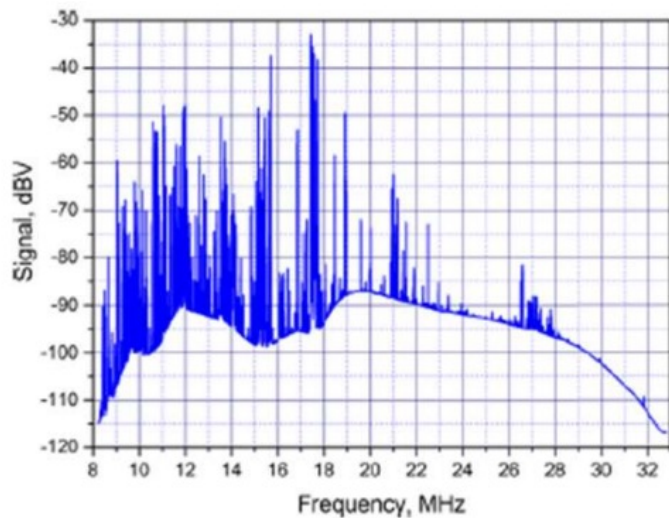
Low-frequency radio telescopes in Europe (**UTR-2, URAN-1, URAN-2, URAN-3, URAN-4, GURT, LOFAR, E-LOFAR, Nenu FAR, NDA**)

LF: 10...30 MHz (dkm); 30...300 MHz (m)

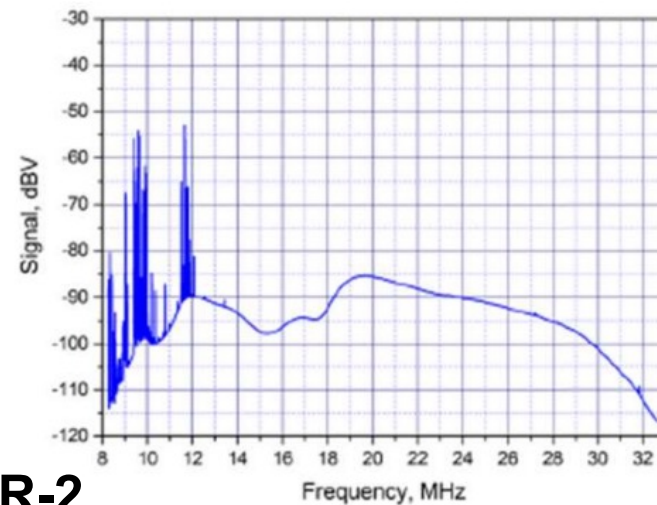
Advantages of the multi-telescope (ground-ground, ground-space) radio astronomy observations at low-frequencies (the distances between telescopes are from ~ 1 km up to ~ 3 000 km)

1. Improvement of the sensitivity (summarization of the effective areas in coherent mode).
2. Improvement of the angular resolution (VLBI mode).
3. Mutual positive complementarity (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 diffrational lobes influence.
- *12. Considerable improvement of the effectivity and realibility of the low-frequency radio astronomy investigation in general

Day

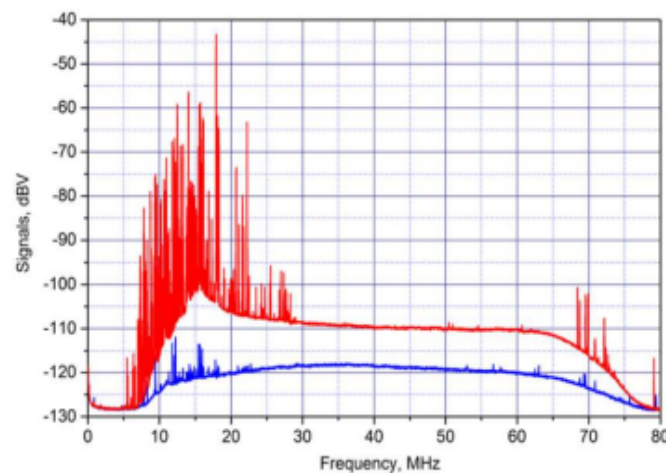


UTR-2

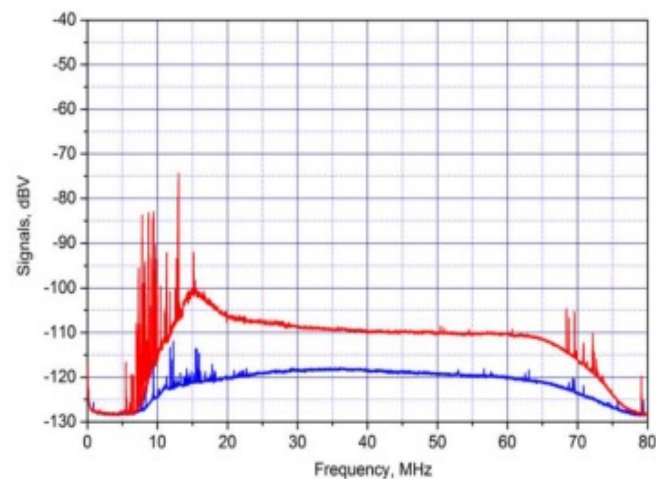


Night

Day

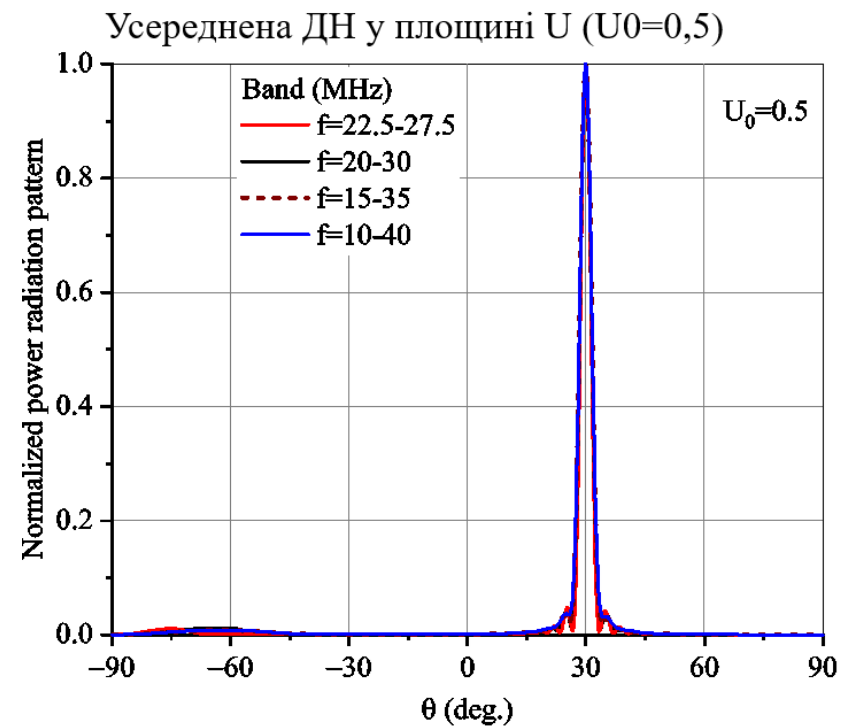
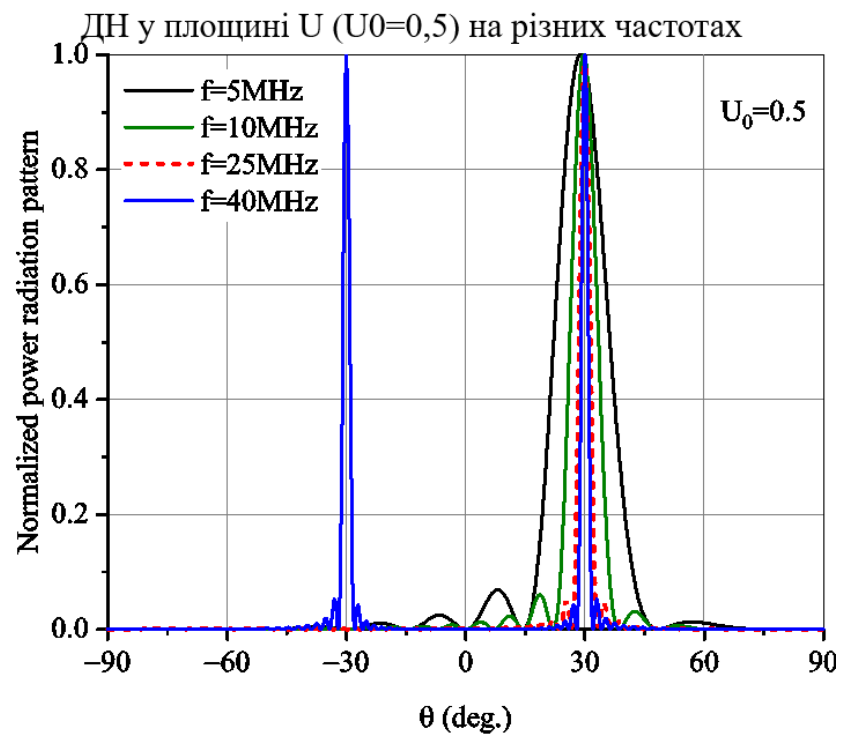


GURT

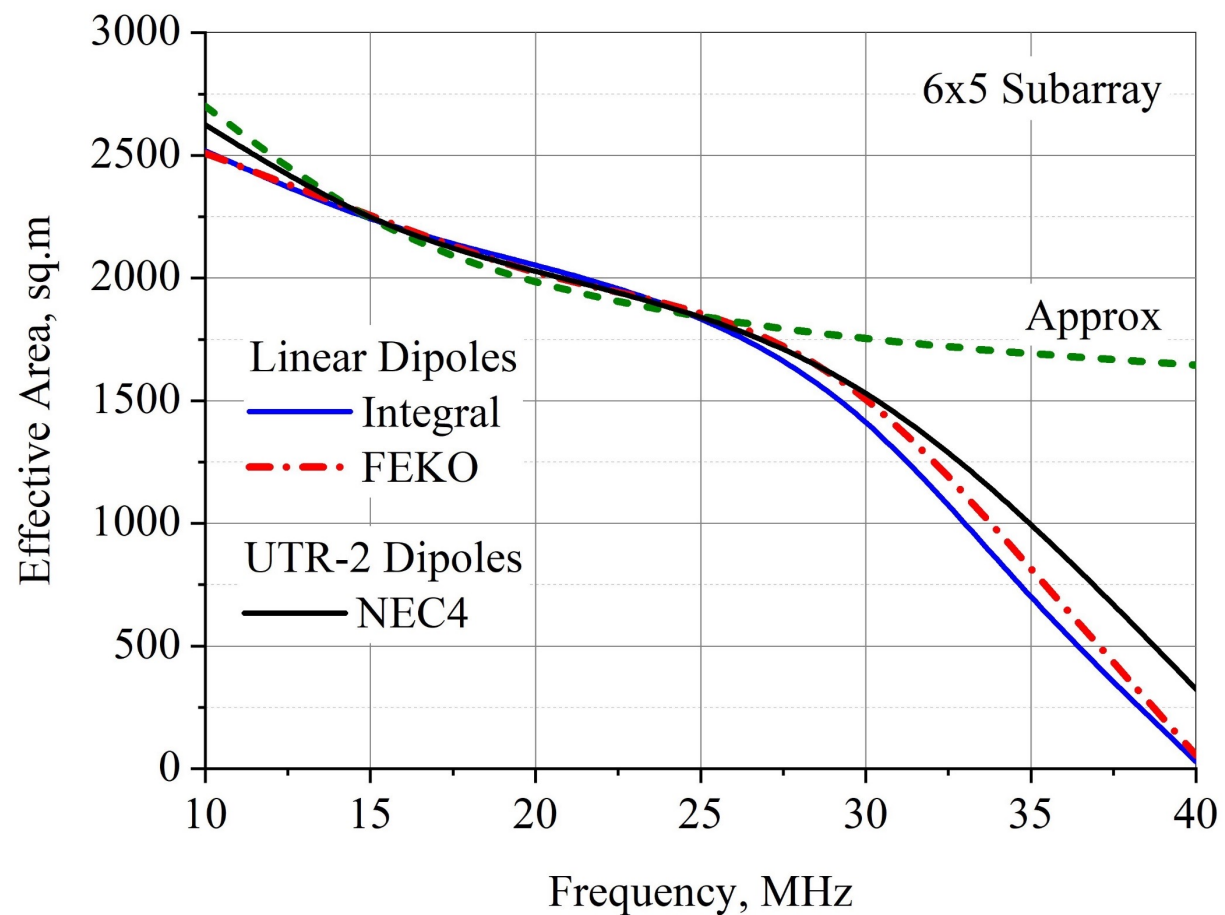


Night

**Broad-band Frequency
responses of UTR-2 and GURT**

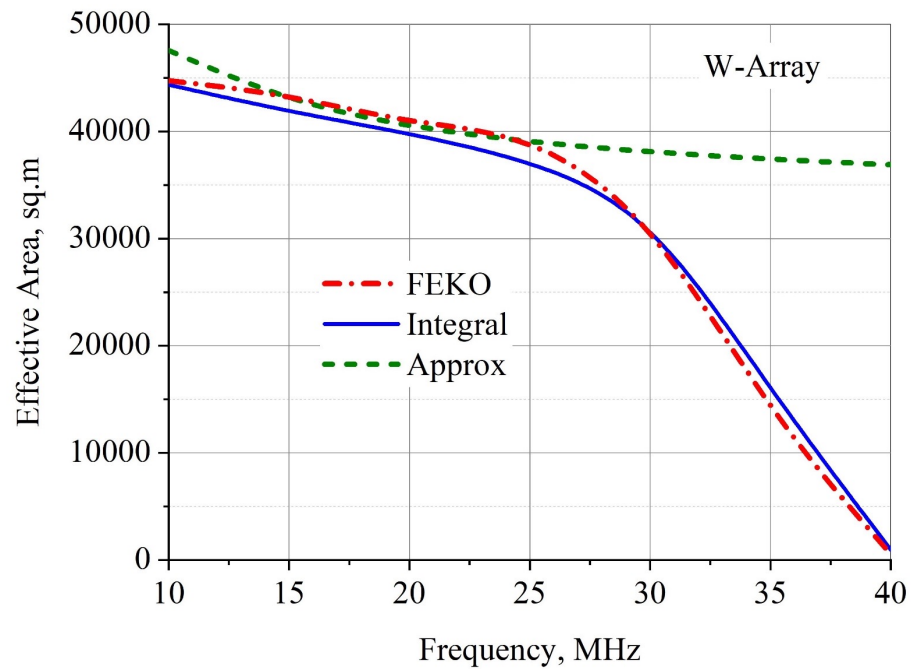


**New calculations of LF antenna arrays parameters
(URAN-2)**

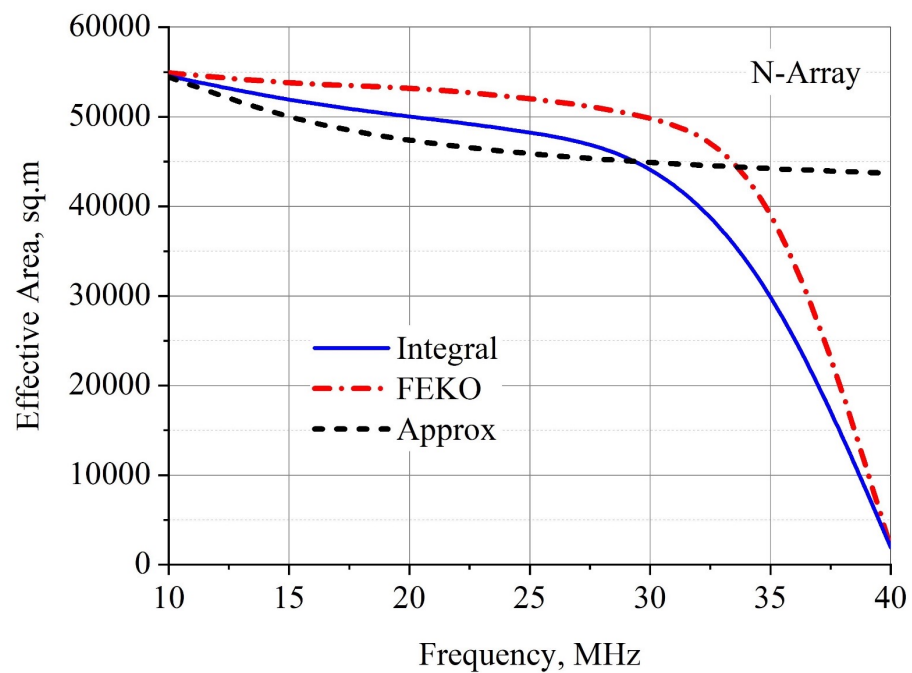


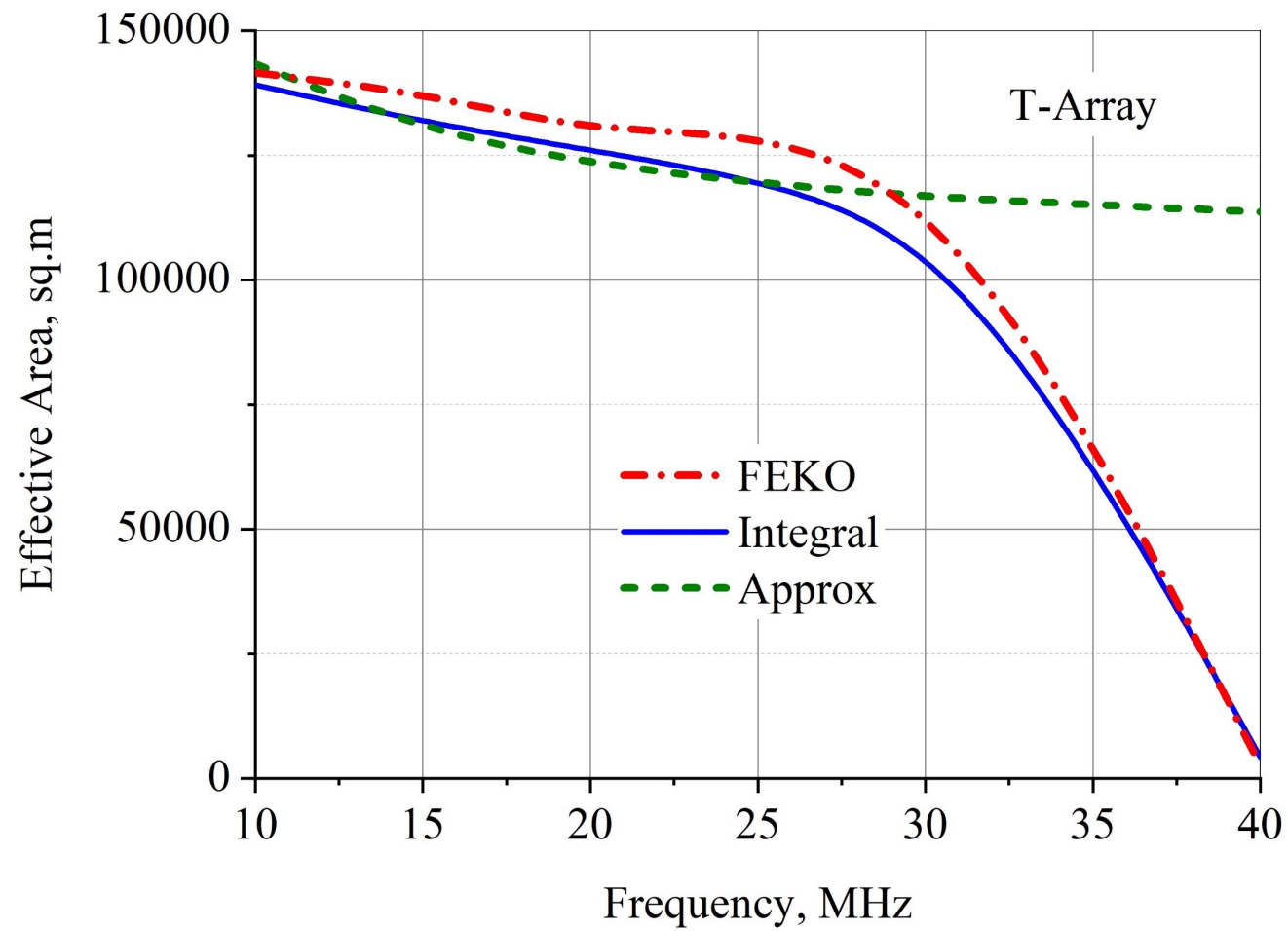
New calculations of 30-elements subarrays from UTR-2.

**Recovery plan of UTR-2. 68 subarrays* 30 elements= 2040 elements in
T-shape UTR-2 configuration**



Effective area of West and North arrays of UTR-2

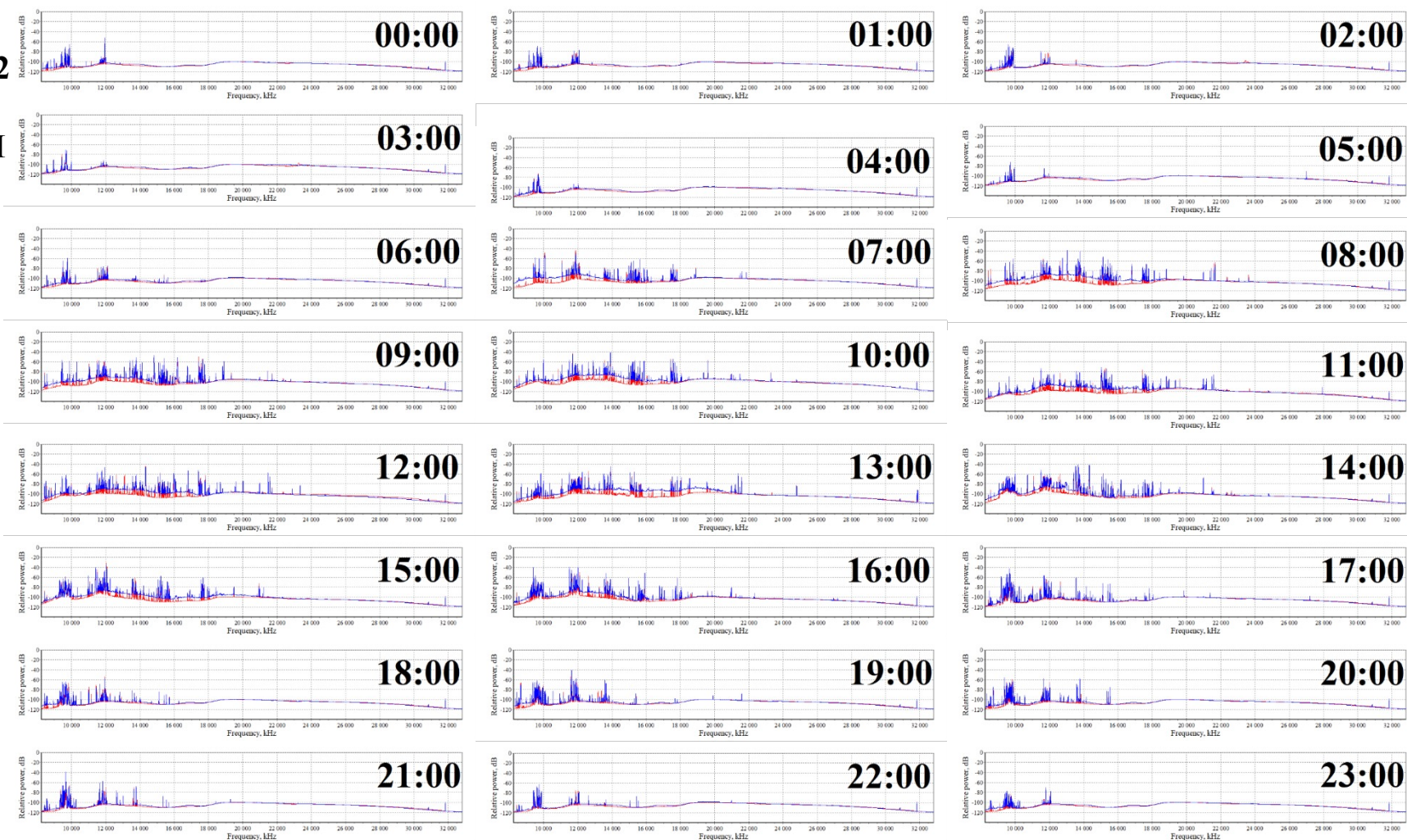




Effective area of T-array (full radio telescope)

**UTR-2,
21.01.2022**

**Daily RFI
spectra,
celestial
sphere
scanning
at
Dec = 0°**



Recent experiments for the illustration of some specialties of ground based extremely low-frequency radio astronomy.

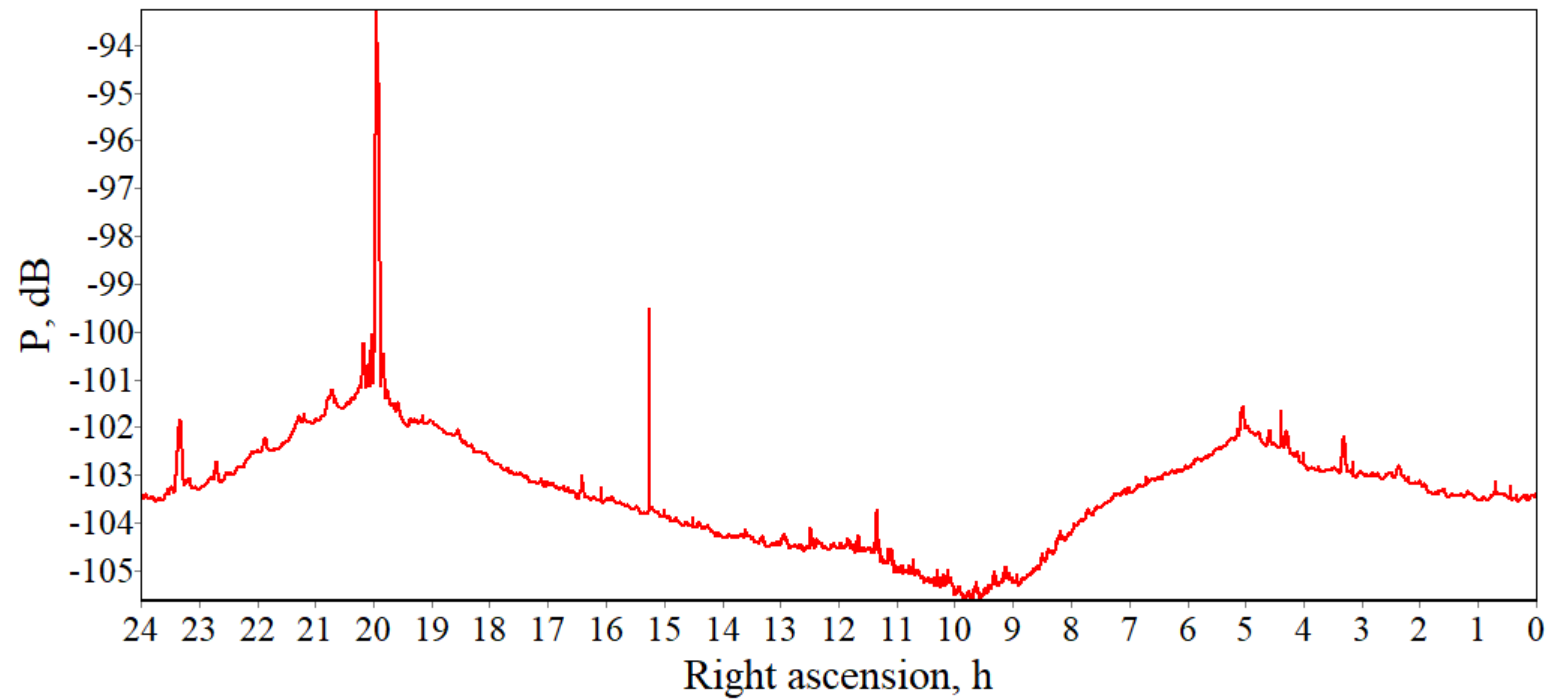
Daily RFI distribution with UTR-2. Together with Dutch radio astronomers.

SURVEY AT UTR-2. TRANSIT RELATIVELY Dec = +41° (u = 0, v = 143), DIURNAL SCAN

Central frequency 25 MHz (analysis band 24.5 – 25.5 MHz)

$\Delta F = 1$ MHz, $\Delta t = 10$ s

“East - West” arm of UTR-2, March 17-18, 2021



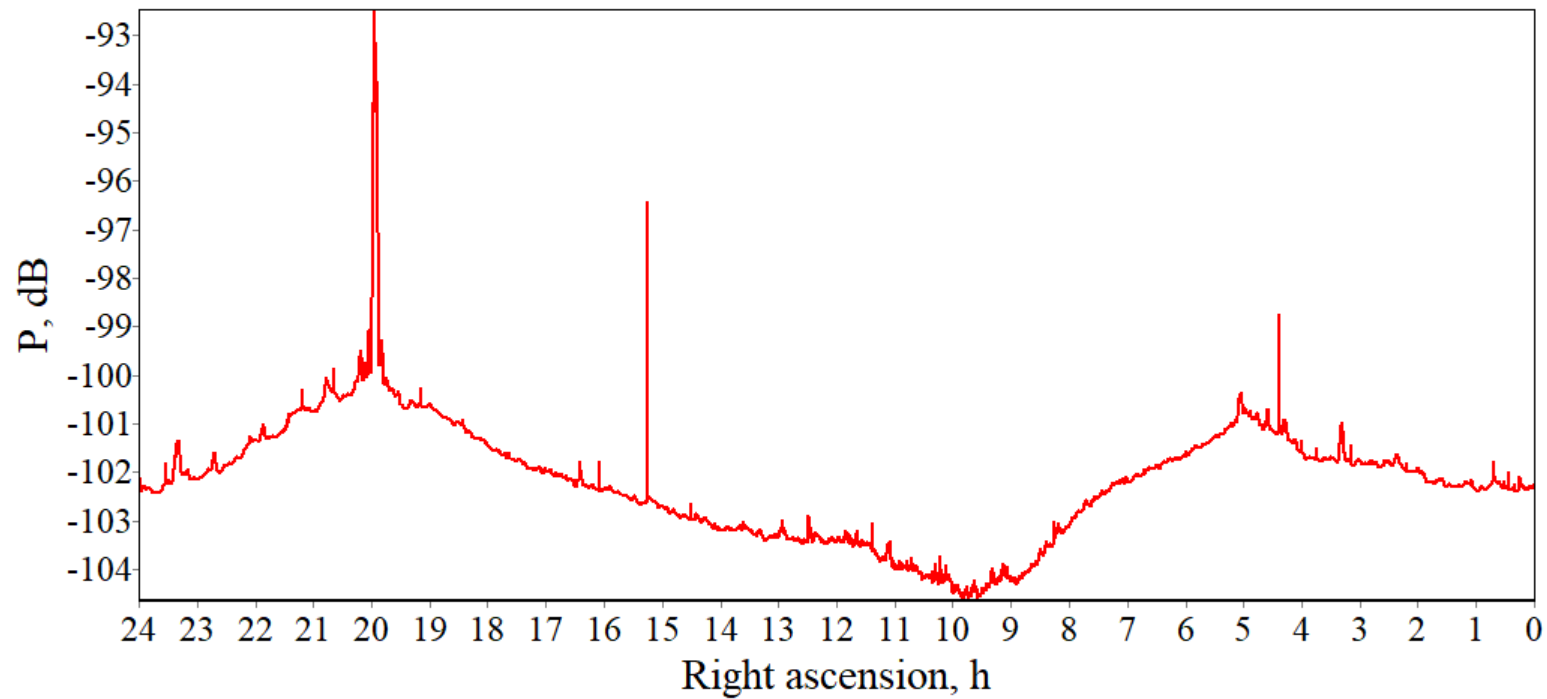
**The beginning of all-sky survey at 5...40 MHz with UTR-2,
URAN-1...4, GURT. (25 MHz)**

**SURVEY AT UTR-2. TRANSIT RELATIVELY Dec = +41° (u = 0, v = 143),
DIURNAL SCAN**

Central frequency 23 MHz (analysis band 22.5 – 23.5 MHz)

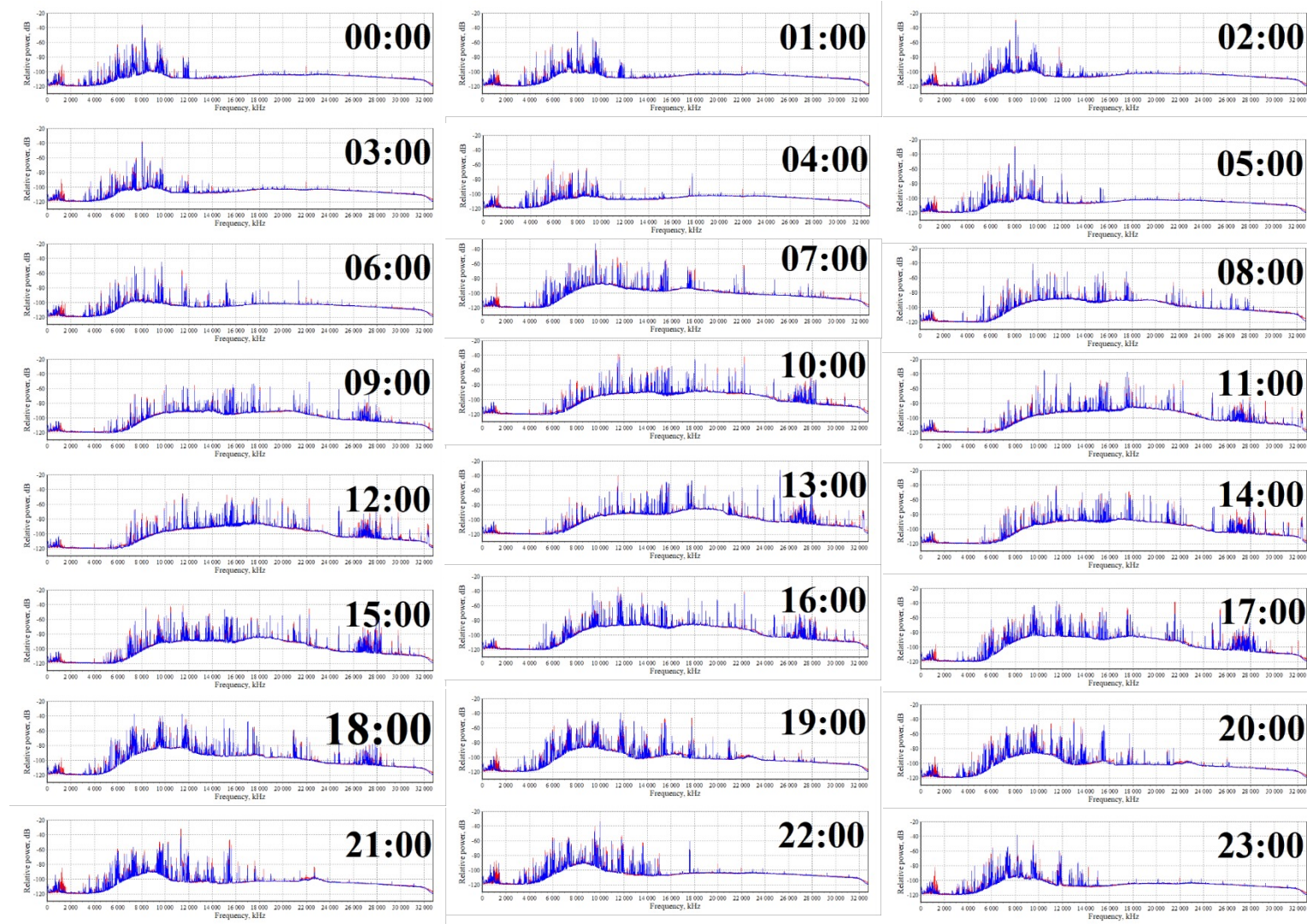
$\Delta F = 1$ MHz, $\Delta t = 10$ s

“East - West” arm of UTR-2, March 17-18, 2021



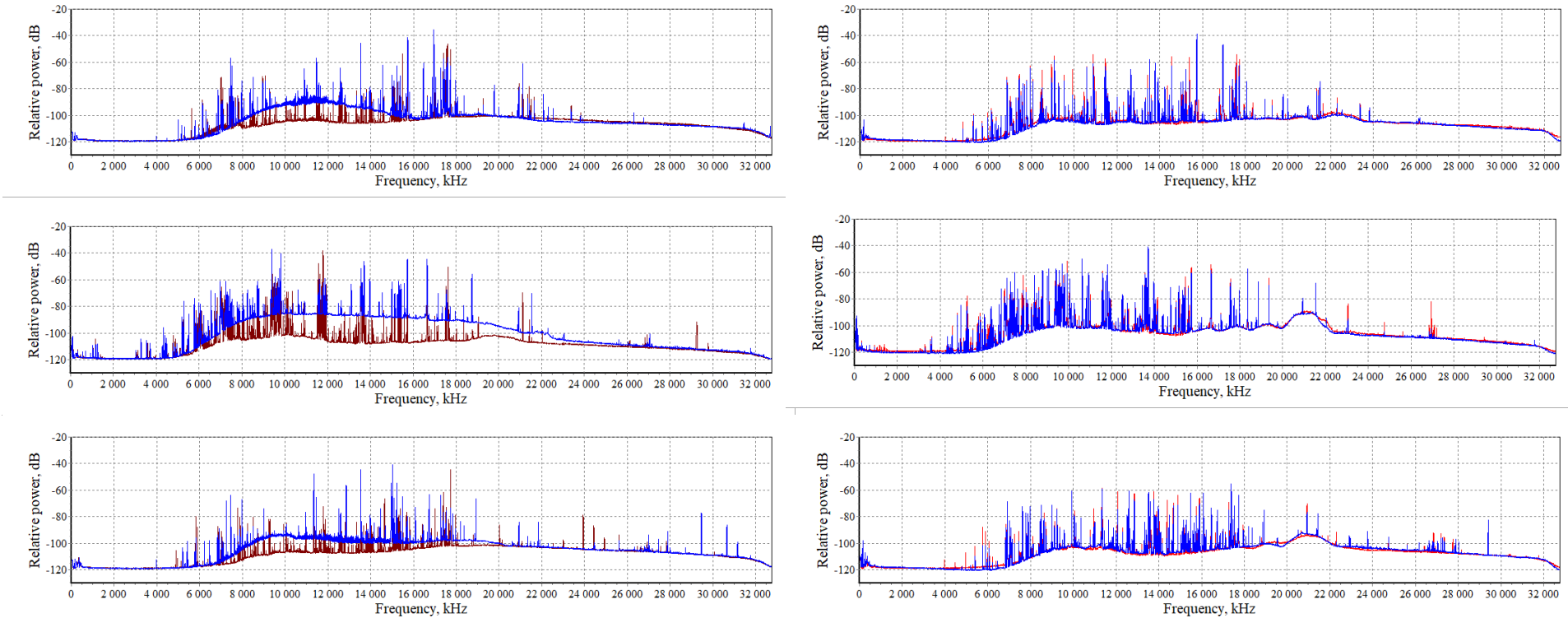
(23 MHz)

**URAN-2,
22.02.2025.
Daily RFI
spectra,
celestial sphere
scanning at
Dec = 0°**



Daily RFI distribution with URAN-2 (22.02.2025) and ionospheric cut-off demonstration.

Spectra, obtained at URAN-2 radio telescope. Left column: *red* – zenith beam orientation, *blue* – elevation angle 30° toward SOUTH; Right column: elevation angle 30° toward NORTH. Spectra were obtained during or after sunset. *Top row* – April 19, 2025; *Middle row* – June 16, 2025; *Bottom row* – August 11, 2025.



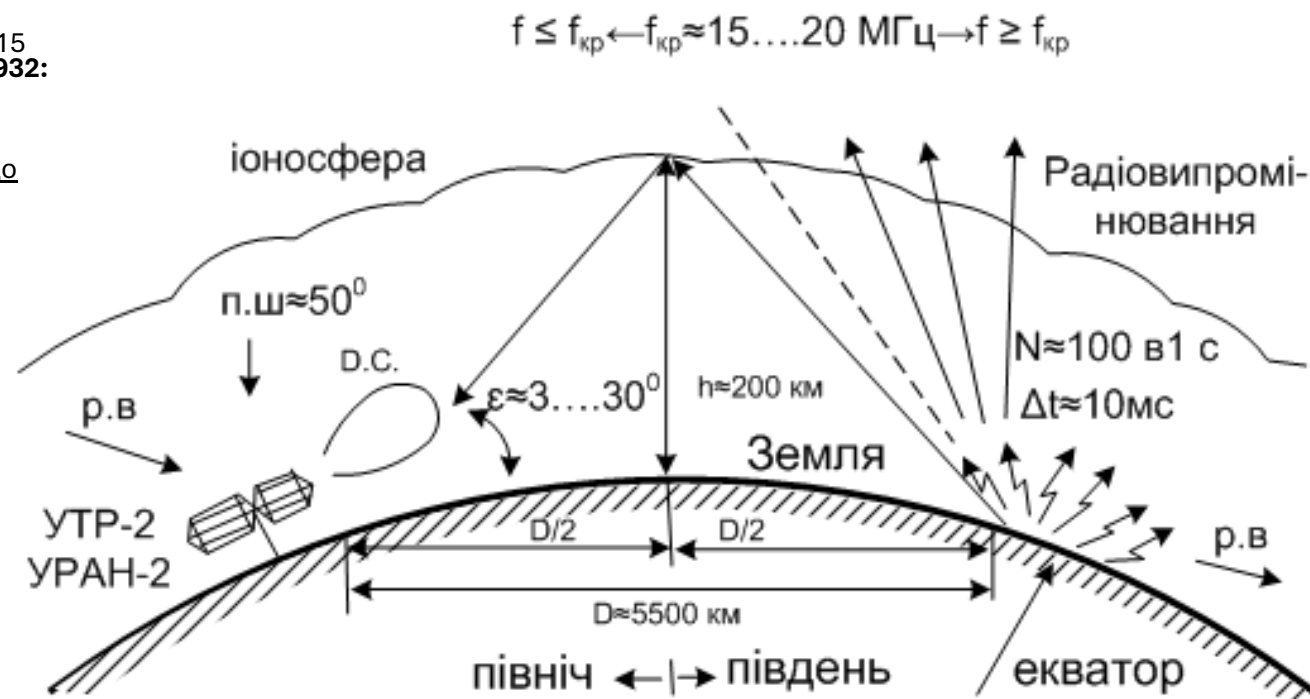
Broad band quasi-continuum LF radio emission from the lightnings in tropical latitudes.

Низькочастотне випромінювання блискавок в тропічних широтах

Дж. Краус, “Радіоастрономія”, 1973, с.15
Посилання на відкриття К. Янського, 1932:

“Він виявив три типи завад:

- 1) місцеві грозові розряди,
- 2) завади від далеких грозових розрядів, що приходять головним чином з південних напрямків,
- 3)постійне шипіння невідомого походження”.



D. Xiao, X. Zhang, O. Yang, J. Li
Improved Main Lobe Cancellation
Method for Suppression Direction
Noise in HFSWR System
„Remote Sensing”, 2024, 16, 254

Geometry of tropical lightnings LF radio emission

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)





Australian radio astronomers in UTR-2 observatory, 1975



Prof. O. B. Slee (Australia) near URAN-1 radio telescope, 1977



**Director of Raman Research Institute, Bangalor, India
V. Radhakrishnan near UTR-2, 1983**



**Leaders of the world LF radio astronomy B. Erickson and
S. Braude in UTR-2 observatory, 1994**



K. van't Klooster, ESTEC, The Netherlands and P. Rodriguez, NRL, USA during the observations on UTR-2, 1997



**H. Rucker and M. Bodiada (Austria) for Jupiter
observations on UTR-2, 1998**



**M. Leitner (Austria), A. Lecacheux, C. Rosalen (France)
in the UTR-2 laboratory, 1999**



**N. Kantharia (India) in UTR-2 observatory,
2002**



**Ukraine- France- Austria- Japan experiment for the search of
exo-planets radio emission, 2007**



Prof. B. Thide (Sweden) in Ukraine, 2004



French radio astronomers near first GURT subarray, 2006



More than 30-years fruitful collaboration between France (team leader Ph. Zarka) and Ukraine (team leader A. Konovalenko) in the field of LF radio astronomy, 2009

The Nature of the Observatory, Forge steppe (June, 2016)

