SEARCH OF NON-THERMAL RADIO EMISSION FROM PLANETS AND STARS AT DECAMETER WAVELENGTH

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Abstract

The search and study of decameter non-thermal sporadic radio emission of magnetized objects inside and outside an solar system is an important task for modern radio astronomy and especially for the future giant instruments of a new generation which will work in the low frequency range (LOFAR). The implementation of the largest existing radio telescopes UTR2, URAN, NDA with new high efficiency backends allowed to perform deep high sensitivity investigations of known objects (the Sun, Jupiter, pulsars) as well as to start the search of similar emission from other objects — flare stars, white dwarfs, red dwarfs, exoplanets, Saturn (SED – Saturn Electrostatic Discharge). New possibilities of the ground-based SED search emerged not only due to new broad-band equipment with high dynamic range, time and frequency resolutions, but due to simultaneous observations with distant largest separate antennas: UTR-2 ($A_{\max} \sim 150\,000\ m^2$) and URAN-2 ($A_{\max} \sim 2 \times 30\,000\ m^2$) and, especially, due to SED monitoring data of Cassini.

1 Introduction

The search and study of sporadic non-thermal decameter radio emission of magnetized objects is one of the most important tasks of low-frequency (decameter) radio astronomy. Radio emissions (including coherent emissions) generated by moving beams of particles in magneto-active plasma mostly have shown rather steep spectra. On lowest frequencies this radiation is most prominent.

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Table 1: Sources of sporadic non-thermal decameter radio emission

Origin	Source	Ground-based detection
Solar system	Earth magnetosphere	+
	Solar corona	+
	Jupiter	+
	Planets	-
Galaxy, Metagalaxy	Active stars	+
	Exoplanets	-
	Pulsars	+
	Other transient phenomena (Supernova explosions, Gamma-ray bursts, microquasars, etc.)	-

The list of objects that radiate sporadic non-thermal decameter radio emission is well known as shown in Table 1.

It is well known, that decameter radio emission from several classes of objects is already detected by ground-based instruments - mark '+' on the rightmost side of the diagram. But mostly the problem is still not solved - mark '-'.

2 Requirements and instrumentation

This type of radio emission is often characterized by sporadic (pulse) or variable intensity and very complex time-frequency structure. It also must be noted that intensities of radio emissions from objects not belonging outside an Solar system are very weak. These facts lead to a very strong demand of radio telescopes and back-end facilities:

Table 2: Requirements for ground-based instruments

Frequency range	ΔF = 10...40 MHz
Effective area	$A_{\rm eff} \geq 10^4$ m^2
Time resolution	$\tau \leq 1$ ms
Frequency resolution	$\Delta\nu \leq 10$ kHz
Frequency analysis band	$B \geq 10$ MHz
Dynamic range	$D \geq 70$ dB
Lowest detectable flux density	$\Delta S_{\rm min} \leq 1$ Jy
Source tracking time	$t \geq 1^{\rm h}$

It is necessary to note that sensitivity is in fact not restricted by confusion noise for such kind of observations. Thus it is more important to have a radio telescope of maximum effective area rather than high angular resolution. In the near future LOFAR will have the most suitable parameters for this kind of investigation: $f = 10 \ldots 200$ MHz, $A_{\text{eff}} \approx 10^6$ m^2. The investigation of these phenomena is an important task in its scientific program.

However there are good possibilities for handle such tasks in the present time: using the largest existing decameter radio telescopes with modern back-end facilities. Currently the approach of using world's largest decameter radio telescopes for testing and developing the LOFAR concept is being carried outin the frame of international cooperation of France, Austria, Ukraine, Russia, India and Sweden [Lecacheux, et al, 2004].

The following instruments are used in the program:

Table 3: Instruments used in the joint program

Instrument	Frequency band, MHz	Effective area, m^2	Steering
UTR-2, Ukraine	8...35	150 000	Electrical
URAN-2, Ukraine	8...35	$2 \times 30\ 000$	Electrical
NDA, France	8...70	$2 \times 8\ 000$	Electrical
GEE.TEE, India	35	30 000	No
GMRT, India	30...70	30 000	Yes

The main instruments are equipped with new back-end facilities (first of all, an DSP [Lecacheux, et al, 1998]) with following parameters: f = 10...0 MHz, B = 12.5 MHz, τ = 1 ms, $\Delta\nu$ = 10 kHz, D = 70 dB

One can see that the requirements are met.

Minimum detectable flux density is given by:

$$\Delta S_{\text{min}} = \frac{k \cdot T_{\text{sys}}}{A_{\text{eff}} \sqrt{\Delta\nu \cdot \tau}} \tag{1}$$

for UTR-2 at 25 MHz and $T_{\text{sys}} = T_b = 30000\ K, \Delta\nu = 10$ kHz$, \tau = 1$ ms$, S_{\text{min}} = 87$ Jy.

If the radio emission being registered is wide-banded or has a known frequency drift we can perform integration over frequency. For $\tau = 1$ ms and $\Delta\nu = B = 12.5$ MHz we obtain rather high sensitivity: $S_{\text{min}} = 2.5$ Jy.

Combining high efficiency of existing radio telescopes and back-end facilities allowed high quality observations of non-thermal radio emission from known objects and the search for sporadic decameter radio emission not detected previously. The main results of these investigations are presented here. Jupiter and Sun observations were presented separately in this proceedings.

3 Saturn (SED) investigations (Cassini and ground-based instruments)

One must definitely use giant antennas for the tasks described below. As it is known, the Sun and Jupiter are the only objects in the solar system which can be observed by ground-based radiotelescopes at decameter wavelengths. There were a few unsuccessful attempts to detect Saturn radio emission, mainly SEDs. But due to the existence of high efficiency largest decameter arrays (UTR-2, URAN, NDA) and high performance new generation back-end facilities it is interesting to organize new experiments for SED search even by simultaneous use of distant antennas (UTR-2 and URAN). It is especially important due to the success of Cassini mission, including positive observation of many SED events. The recalculation to the ground-based conditions gives a flux density up to 300 Jy. So we can calculate the sensitivity of the largest ground-based radio telescopes (UTR-2 and URAN) taking into account the broad-band behavior of SEDs (without frequency drift). For back-ends like DSP ($B_{\rm max} = 12.5$ kHz) we will have the following values of minimum detectable flux density (σ-level). For UTR-2 in correspondance with equation 1 ($A_{\rm eff}$ towards Saturn is around 7×10^4 m^2): $T_{\rm sys} = T_{\rm background}(20$ MHz$) \approx 5 \times 10^4$ K; B = 12.5 MHz; $\tau = 10$ ms; $\Delta S_{\rm minUTR-2} \approx 3$ Jy or URAN-2 ($A_{\rm eff}$ towards Saturn is around 1.5×10^4 m^2): $\Delta S_{\rm min,URAN} \approx 15$ Jy.

During 7 – 15 February 2005 new experiments for SED search were carried out. We used few sets of filter bank analyzers with different frequency bands and numbers of channels. A Block-diagram of UTR-2 is shown in figure 1. Figure 2 demonstrates the positive possibilities of the method: sensitivity, recognition of interferences and artifacts. According to these experiments we could not detect SEDs for this period with intensity more than 10–100 Jy. As follows from Cassini data the SED activity was absent for this time. So, the experiments prove that we can obtain the sensitivity and interference-immunity needed for successful SED detection with existing back-ends and especially with the DSP. In the case of strong SED activity as was detected by Cassini during last autumn, the detection of SED by ground-based stations was possible. It is important not only as the study of new Solar system phenomena, but also as methodological development of the transient events search in the Universe at decameter wavelengths with the existing instruments and with the future LOFAR system.

4 Radio emission from objects outside Solar system

4.1 Pulsars

It is interesting to search for sporadic (pulse) non-thermal radio emissions from objects outside an Solar system. The example is radio emission from pulsars. Earlier, at decameter wavelength their radiation was observed only with use of accumulation of huge amounts of pulses [Bruck; 1987]. As a rule, it is possible to observe individual pulsar pulses at higher frequencies [Kuzmin et al; 1978].

The high sensitivity of the UTR-2 radio telescope together with a high efficiency back-end (DSP) allowed decameter wavelength detection of individual pulses for a set of pulsars: PSR 0809+74, 0834+06, 0950+08, 0943+10 and 1133+16. An example for pulse detection is shown in figure 3 for PSR 0809+74 (with integration over 10 MHz frequency band. Dispersion is taken into account). In all cases there are strong intensity variations of individual pulses. The intensity of some pulses exceed the mean intensity value by a factor of ten. Very likely, such strong variations of intensity are due to physical processes taking place in the pulsar's magnetosphere.

Filter bank analyzer: Frequency range from 20 to 25 MHz, total bandwidth = 50–100 kHz and 3 MHz, time resolution = 25 ms.

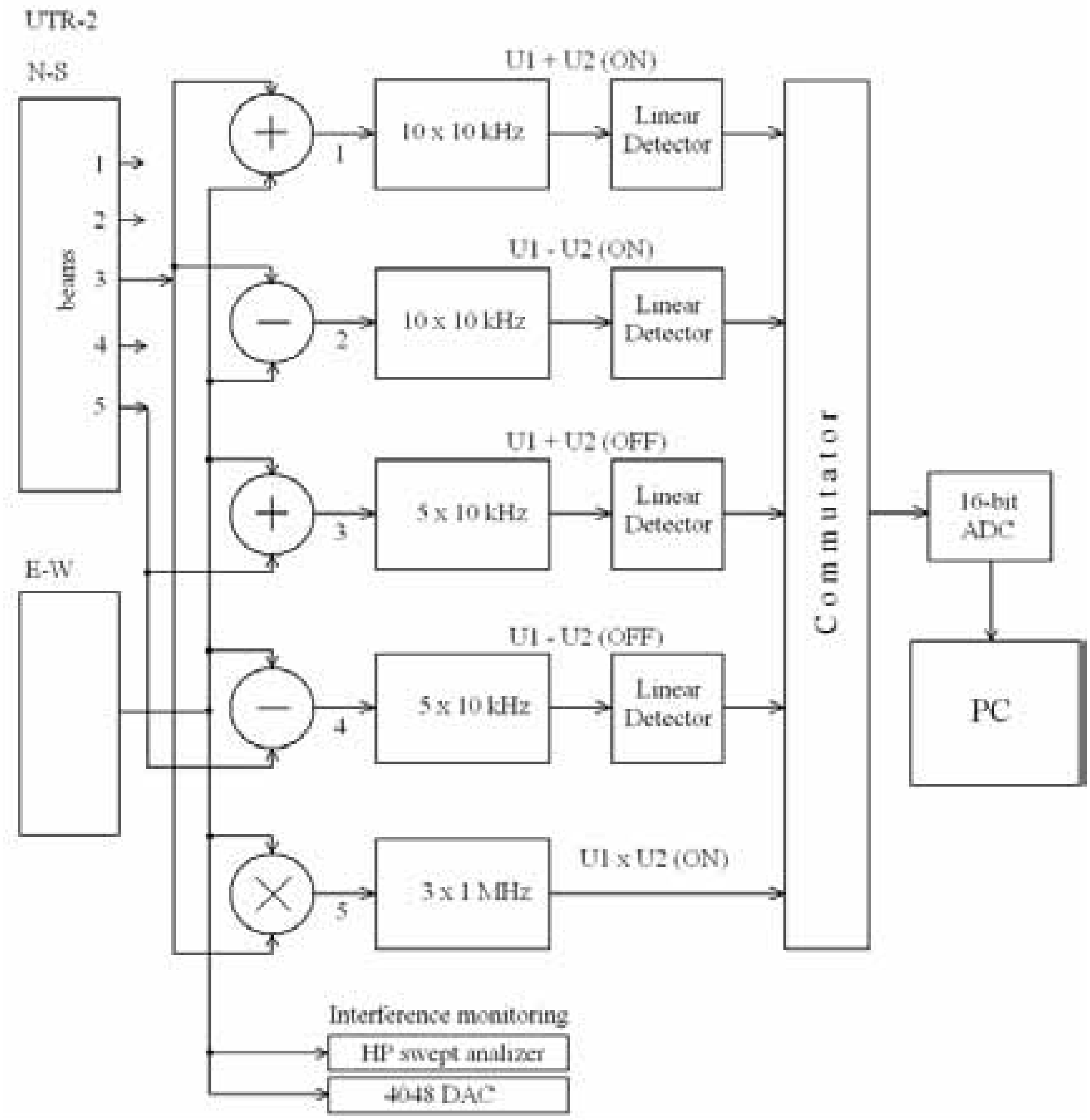

Figure 1: Diagramm of SED search on UTR-2 radio telescope

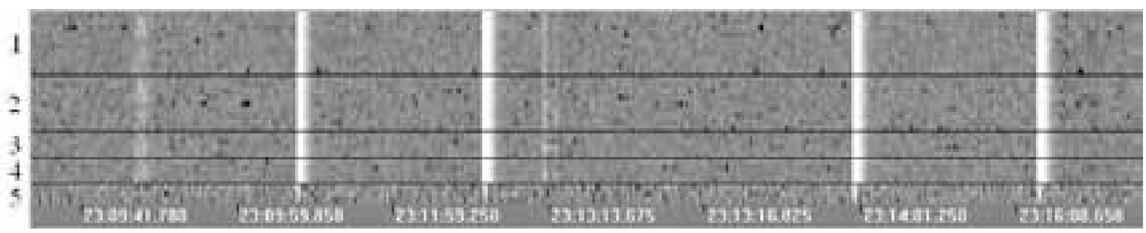

Figure 2: Filterbank dynamic spectrum of SED experiment fragment

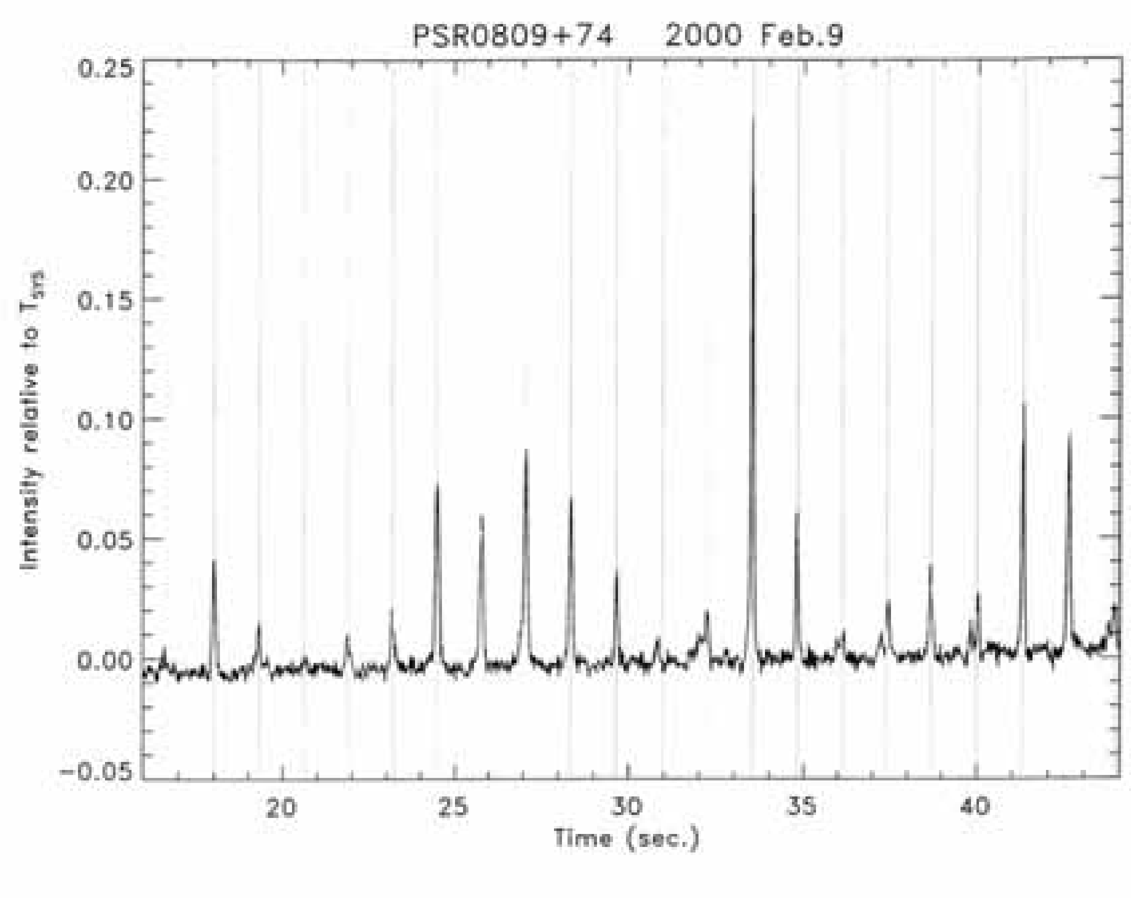

Figure 3: Detection of single pulsar pulses using UTR-2 with DSP

4.2 Active stars

Observations of these flaring stars shown in Table 4 were conducted using the UTR-2 radio telescope. During an observational campaign during the years 1990–2000 [Abranin et al., 2001] we detected 4 bursts which are very likely of stellar nature with high probability (for EV Lac).

In 4–8 November 2002 we searched for sporadic decameter radio emission from white dwarfs. The object of investigation was white dwarf Grw+70 8247 which is 11.5 light years apart from Earth. It has the following coordinates: right ascension J2000: $19^h00^m10.3^s$, declination: $+70°39'$. No emission was detected.

4.3 Exoplanets

During an observational campaign at the UTR-2 radio telescope in 2000 [Zarka et al., 1997] the search for planetary decameter radio emission was carried out. The list of objects is presented in Figure 4. The radio emission from exoplanets is not detected yet.

Table 4: The list of observed active stars

Star	α_{1950}	δ_{1950}	Distance, pc	Date of observation
YY Gen	7^h 31.4^m	$31°58.8'$	14.7	28.11-02.12.1992
YZ Cmi	7^h 42.1^m	$3°40.8'$	6	02.12-06.12.1994
				21.12-22.12.1994
AD Leo	10^h 16.9^m	$20°7.3'$	4.8	21.01-24.01.1993
				11.01-15.01.1995
CN Leo	15^h 54.1^m	$7°19.2'$	2.3	01.03-04.03.1993
				01.02-05.02.1995
Wolf 461	12^h 58.1^m	$5°57.1'$	8.3	01.03-05.03.1995
CD Dra	16^h 16^m	$55°23.8'$	20.8	01.03-04.03.1993
EV Lac	22^h 44.7^m	$44°4.6'$	5.1	1986-1998

Target Name	Spectral type	Distance (pc)	Coordinates α h m s	(1950/2000) δ ° '	number of acquisition sequences	Acquisition duration (minutes)	Time resolution (seconds per spectrum)
Wolf 359	dM8e	2.4	10 54 06	+07 19	4	20	0.5
ε Eri	K2V	3.3	03 30 36	-09 38	2	20	0.5
Ross 128	dM5	3.3	11 45 06	+01 06	1	20	0.5
Ross 614	dM7e	4.1	06 26 48	-02 46	2	20	0.5
Barnard	M5V	1.8	17 55 24	+04 33	1	15 - 30	0.25 - 0.5
BD +36°2147	M2V	2.5	11 00 36	+36 18	2	15 - 30	0.25 - 0.5
Ross 248	dM6e	3.2	23 39 24	+43 55	1	15 - 30	0.25 - 0.5
BD +50°1725	K7V	4.5	10 08 18	+49 42	3	15 - 30	0.25 - 0.5
BD +68°946	M3.5V	4.7	17 36 42	+68 23	4	15 - 30	0.25 - 0.5
BD +43°4305	dM5e	5	22 44 42	+44 05	5	15 - 30	0.25 - 0.5
Altair	A7IV,V	5.1	19 48 18	+08 44	2	15 - 30	0.25 - 0.5
BD +15°2620	M4V	5.2	13 43 12	+15 10	8	15 - 30	0.25 - 0.5
Gliese 229	M1/M2V	6	06 10 35	-21 51	3	45	0.27
51 Peg	G2IV	14.7	22 57 27	+20 46	14	45	0.27
Gliese 9245	G8V	19	07 52 03	-01 17	7	45	0.27
47 UMa	G0v	13.3	10 59 29	+40 26	5	43	0.26
Gliese 229	M1/M2V	6	06 10 35	-21 51	9	45	0.27
51 Peg	G2IV	14.7	22 57 27	+20 46	30	23 - 45	0.14 - 0.27

Figure 4: List of objects used for exoplanet radiation search.

5 Conclusion

It is necessary to continue investigation of known objects and search for new ones using existing largest instruments (UTR-2 and the like). Without doubt the progress in this investigation will continue with emerging newer and larger radio telescopes like LOFAR.

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