# NEW FRONTIERS IN DECAMETER RADIO ASTRONOMY

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**Abstract**

The international EU–INTAS project "New Frontiers in Decametric Radio Astronomy" (97–1964) comprises the cooperation of four European nations under the lead of the Observatoire de Paris–Meudon: France–Austria–Ukraine–Russia. Main objectives of this cooperation is 1) the development of new techniques and methods for high sensitive and interference–robust radio astronomical observations in the decameter wavelength regime, 2) the performance of joint and new observations by using a European radio telescope network, and 3) working out scientific and technical rationales for the establishment of a large ground–based decameter radio telescope for the 21st century.

In the course of this project, starting in December 1998, a series of decameter wavelength observations have been performed by the large decameter array at Kharkov (Ukraine) and by the Nançay Reseau Decametrique (France), comprising Jupiter DAM, Solar burst and pulsar observations. A number of "Firsts" yielded remarkable scientific results, specifically obtained during observation campaigns under summer and winter terrestrial ionospheric conditions. This paper gives an overview of the overall structure of the project, the involved telescopes and receivers, the measurement and methods, and future perspectives.

## 1 Introduction

The 3 years European Research Project 97–1964 is based on the availability in Europe of several of the most powerful decameter antennas in the world, as there are UTR–2 and URAN (Ukraine), SURA (Russia) and Nançay Decameter Array (France), and on the newly available type of wide band, waveform digital receivers (developed in Austria and France), which will allow unprecedented accuracy, resolution, sensitivity and dynamic range (at least 70 dB) for measurements at decameter wavelengths.

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This EU–INTAS project, having started in November 1998, comprises 4 European nations, France, Austria, Ukraine, and Russia. The main objectives of the project are to develop and validate new concepts and methods for high–sensitive and radio frequency interference robust measurements, to improve performances of existing radio telescopes by increasing their sensitivity and reception capabilities, and to obtain new information on several kinds of astrophysical objects and the experimental proof of the significance of the decameter wavelengths domain [Lecacheux, 2001].

As outlined in Figure 1 the EU–INTAS project 97–1964 is subdivided into 7 different working units comprising Management, Astrophysics, Instrumentation, Radio Frequency Interference, Propagation Effects, Multi–Telescope Effects, and finally the Feasibility Study of a new generation radio telescope in the decameter range. Among the many topics addressed by these working units some aspects should be described in detail which are of specific interest with regard to planetary and Solar radio emissions. In section 2 special attention is focused on the terrestrial ionospheric effects, its daily and seasonal dependence as well as the local variations in latitude and longitude. This terrestrial magnetoplasma is the only part along the propagation path of external decametric radiation where the conditions of transition are known in more detail. In section 3 Jovian DAM emission, in particular millisecond radiation is analyzed under the aspect of simultaneous measurements at Kharkov (Ukraine) and Nançay (France), section 4 describes new observational waveform reception techniques and corresponding results, and section 5 finalizes with an overview of the past and future measurement campaigns including the organization of data archiving.

## 2 The influence of the terrestrial ionosphere

Propagation effects on radio waves entering the terrestrial ionosphere are due to the Faraday effect (i.e. the rotation of the signal polarization) and scintillation, irregular fluctuations of signal parameters. Thus, ground–based radio observations are strongly influenced by the terrestrial ionosphere which also exhibits seasonal variations. The "INTAS Simultaneous Observation Campaigns", Campaign number 1, thereafter called C1 (May through August 1999), and C2 (February through April 2000) performed observations under summer and winter conditions, respectively. Ionospheric models (COST 251, COSTTEC, Leitinger, University Graz) provide an estimate on the ionospheric electron content in dependence of latitude, longitude and time. Thus it is of great importance to quantify the ionospheric influence on decametric radio waves, to know the ionospheric temporal and spatial dependence and, by searching and defining any new observing grounds, to minimize this influence.

As can be seen in Figure 2, there is a different longitude/latitude electron content pattern as modeled for winter (a) and summer (b) conditions. Taking into account the longitude positions of the radio station Nançay (Reseau Decametrique, Nançay, France) at around 0° Eastern longitude and the UTR–2 radio station Kharkov (Ukraine) at around 37° E., both at approx. 47° Northern latitude, we can estimate some general behaviour of the ionospheric conditions influencing both telescope sites, in particular in the case of simultaneous radio burst observations.

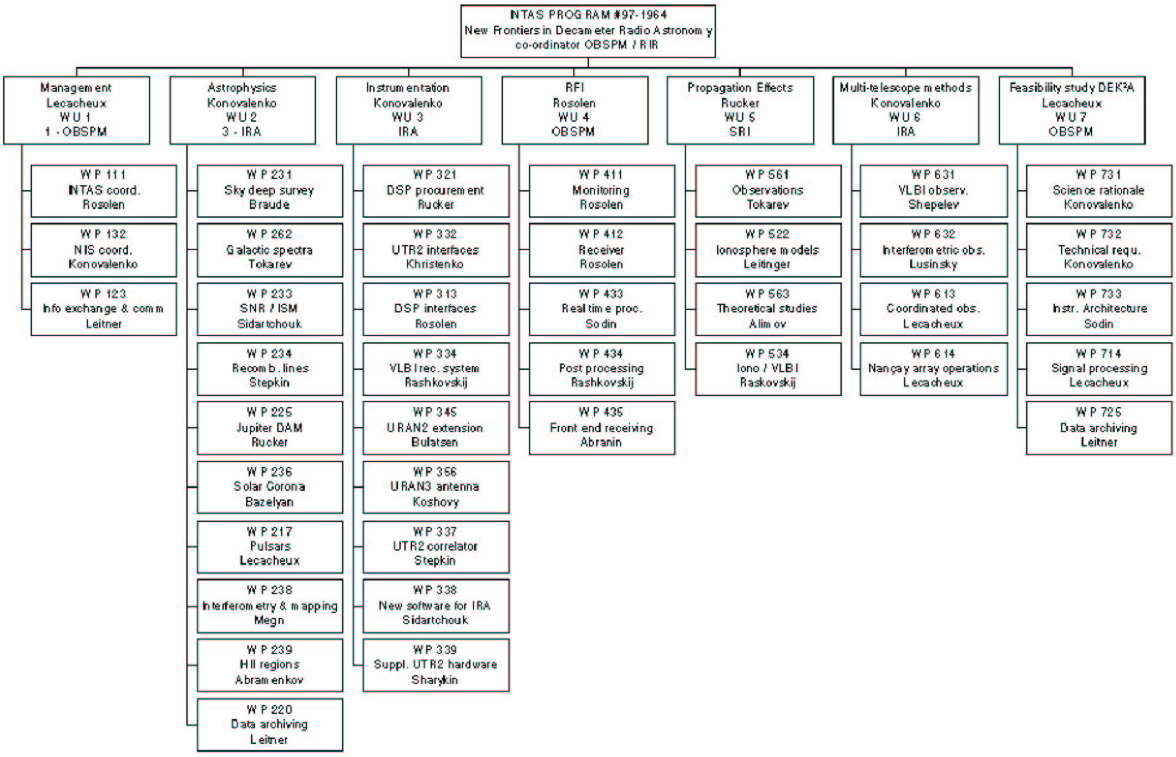


*Figure 1: Working units of the EU–INTAS Project 97–1964.*

Under winter conditions (January) the change of the local electron content above Nançay from 00:00 UT ($35 \cdot 10^{15}\ e\ m^{-2}$) to 04:00 UT ($27 \cdot 10^{15}\ e\ m^{-2}$) is approx. -20%, whereas for Kharkov within the same time is approximately +10%. Under summer conditions (July) the change in electron content above Nançay from 00:00 UT to 04:00 UT is -30%, for Kharkov +50%. These changes have important implications on the terrestrial ionospheric cutoff frequency when performing simultaneous burst observations. It is interesting to note that for both seasons the modeled value of the electron content for Kharkov at 00:00 UT corresponds to Nançay at 04:00 UT. Figure 2b additionally shows for 04:00 UT that there is a strong longitudinal gradient of the electron content. This distinct East–West "stratification" of the electron content may also be responsible for higher ionospheric turbulence influencing radio burst propagation.

## 3 Nançay and Kharkov simultaneous Jupiter S–bursts observations

During the "INTAS Simultaneous Observation Campaign 1", called C1, which comprised the period from May through August 1999, among Solar and pulsar radio observations a number of high resolution Jupiter millisecond radio burst observations have been obtained [Rucker et al., 2000], for the first time being simultaneously performed by two almost

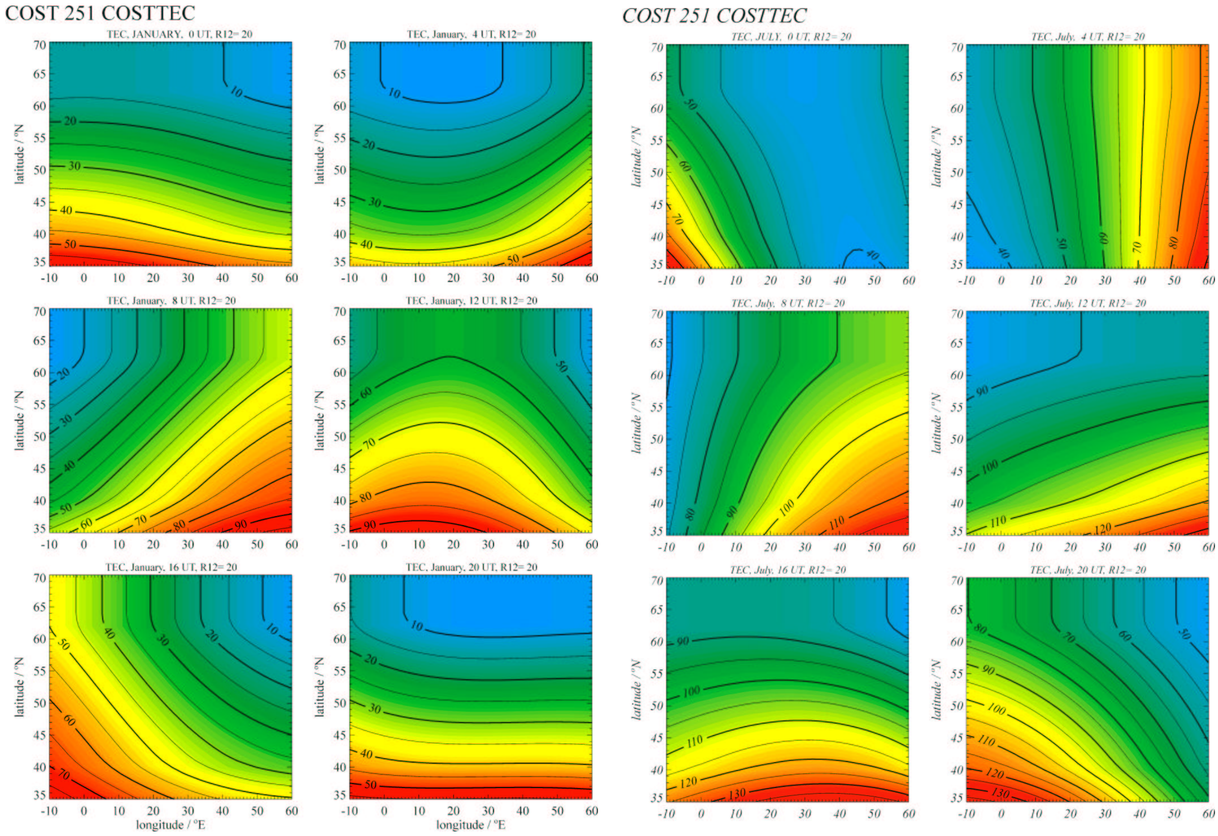


*Figure 2: (a) The schematics exhibit modeled electron contents ($10^{15}$ e $m^{-2}$) over Europe ($10°$ west. long. to $60°$ east. long., $35°$ to $70°$ north. lat.) under winter conditions (January), in dependence of various times of the day (00:00 UT, 04:00 UT etc.). (b) Same as (a), but under summer conditions (July).*

identical digital spectropolarimeters (DSPs) which have been developed and built by the Austrian – French cooperation [Kleewein, 1997]. The DSP provides the ultimate spectral analysis capability performing real time digital signal processing techniques.

As an example of the high quality spectra a Reseau Decametrique (Nançay) and UTR–2 (Kharkov) spectrum is combined in Figure 3. With a time resolution of 6 ms single Jupiter millisecond radio bursts during an Io–AC event have been recorded. The similarity in both spectra is striking, but unfortunately an overall synchronized time normal could not yet been established during C1 and incorporated into the spectra. (Time synchronization was a "First" then being introduced in Campaign 2.)

The INTAS C2 winter campaign provided another valuable data collection period on pulsar, sun, and Jupiter radio observations, under different ionospheric conditions with regard to C1. Using a modulated GPS clock signal which was mixed into the dynamic spectrum producing a possible deviation of about 1 ms, synchronization has been established in the radio burst measurements from both radio telescopes Nançay and Kharkov. As can be seen in Figure 4, simultaneous Jupiter DAM emission is visible in the spectra from March 30, 2000, exhibiting a continuous frequency decrease within the chosen

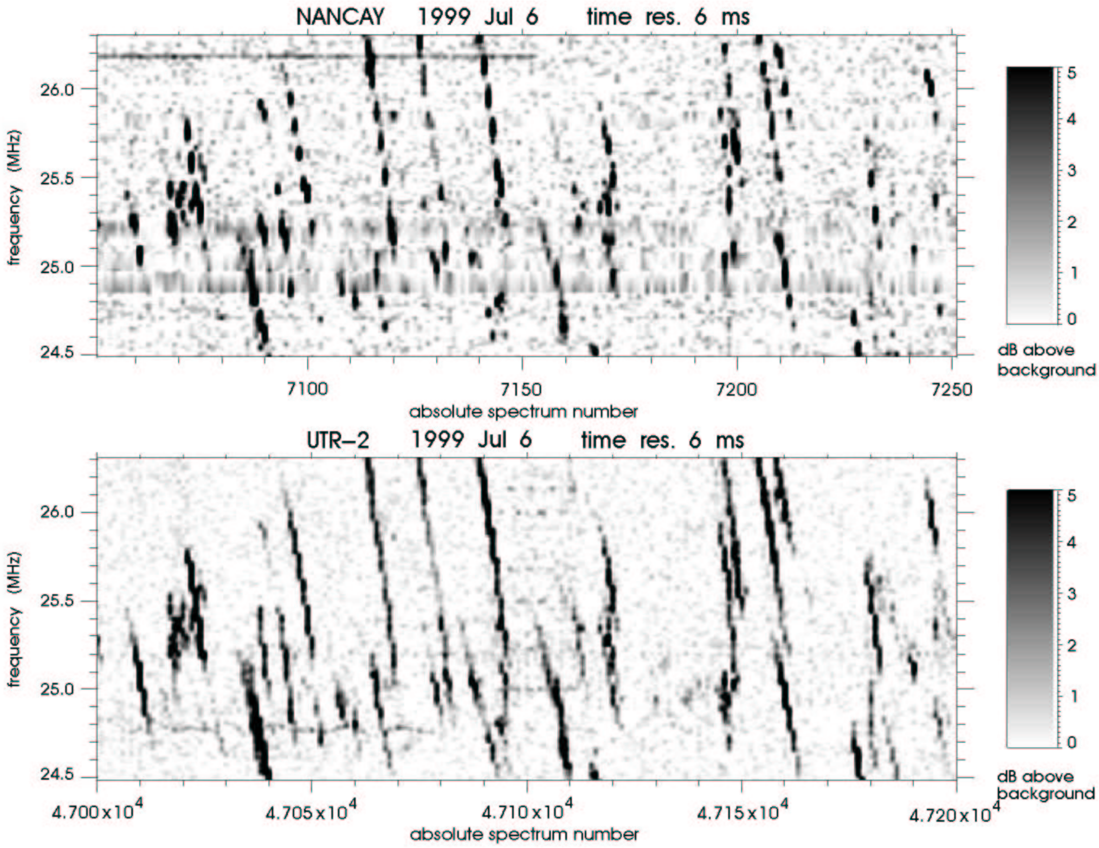


*Figure 3: Non–synchronized DPS measurements of single Io–AC S–bursts during C1. Frequency and time resolution is 12 kHz and 6 ms, respectively. The apparent similarity in both spectra enables simple comparison, the higher gain at UTR–2 is visible in the bottom spectrum. The time axis comprises 1.2 s, the shown frequency range is 1.8 MHz.*

part of observations. Since time synchronization is applied, a correlation of both spectra might reveal some deviations of identical radio reception from both telescope sites. The overall time resolution for this specific period was 100 ms for both recordings. The correlation (Figure 5) exhibits a clear maximum for all shown frequencies at a delay time $\delta$t = ±100 ms, an obvious consequence of the spectral time resolution and well above the inaccuracy of the GPS clocks.

As already pointed out, the digital spectropolarimeter (DSP) [Kleewein, 1997] enables radio observation in the decameter wavelength regime with at present unsurpassed receiver characteristics using realtime digital signal processing techniques. Within the frame of the INTAS campaign C2 two almost identical DSPs installed at Nançay and Kharkov performed recordings of Jovian DAM emission during defined periods of time with the highest available time and frequency resolution. As shown in Figure 6 Nançay and Kharkov observations on February 27, 2000, have yielded Io–B S–burst observations at a time resolution of 6 ms and 2 ms, respectively. The DSP in connection with the huge UTR–2 antenna array [Konovalenko et al., 2001] is able to observe single S–bursts even on daytime. Peak

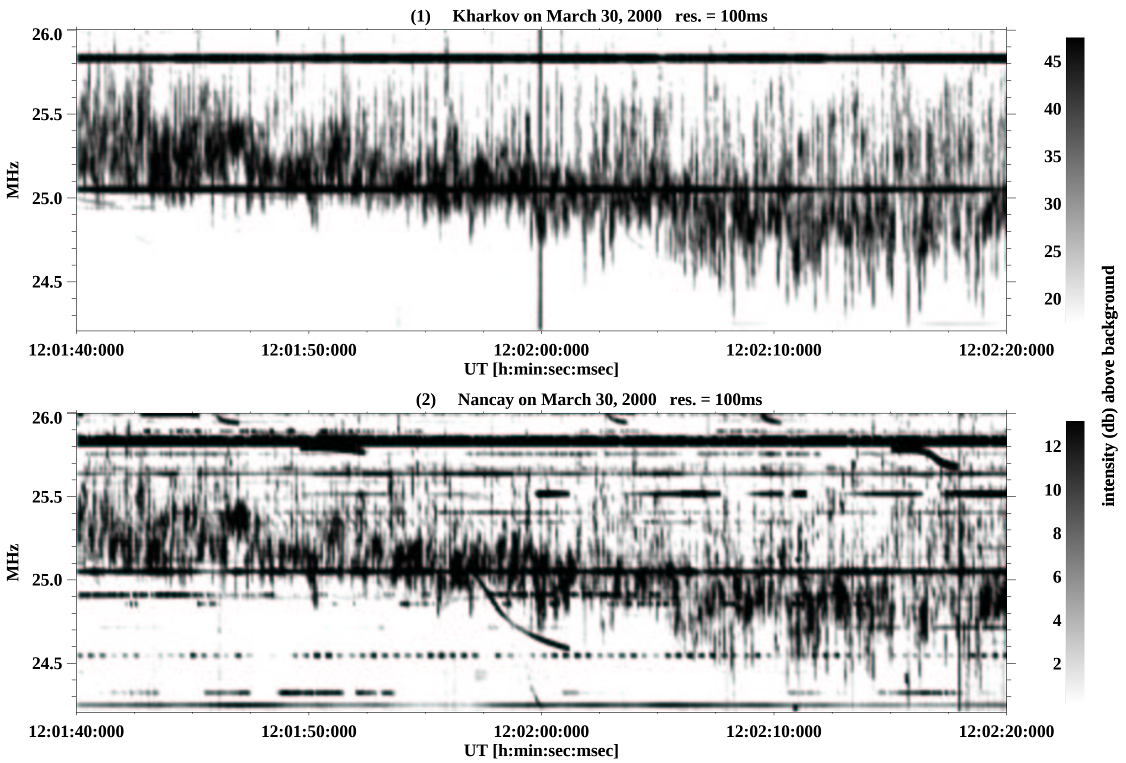


*Figure 4: Synchronized data of Jupiter Io–B using GPS clocks as obtained during the C2 observation campaign.*

intensities are clearly visible in the Nançay spectrum, complete burst structures however are very faint.

Simultaneous measurements from different observing sites, with a time resolution in the range of a few milliseconds, are necessary to answer the question on how radio emission, in particular leaving the source region, the geometry of the emission cone, its beaming and eventual change in the course of propagation, gets influenced just within the time when radio emission first hits the antenna array of Kharkov before being detected at Nançay, due to the rotation of Jupiter. This time difference is in the order of milliseconds.

A correlation coefficient spectrum of both spectra of Figure 6 is shown in Figure 7. Time resolution of the Kharkov spectrum is - by averaging - artificially worsened to 6 ms in order to correlate with the Nançay spectrum. Thus the peak correlation cannot be resolved better than 6 ms. Interestingly, shades of secondary correlation peaks may just reveal the repetition rates (±40 to 60 ms) of the S–bursts in the spectra of Figure 6.

Finally, Jupiter DAM recordings have provided further surprises regarding internal structures as can be seen in Figure 8. Within the same period of observations as demonstrated in Figure 4 (March 30, 2000), emission appears as a result of various effects superposing each other. Primarily, radiation varies in intensity in different "directions" within the frame of the dynamic spectrum: Almost vertical "strokes" may be the result of intensity

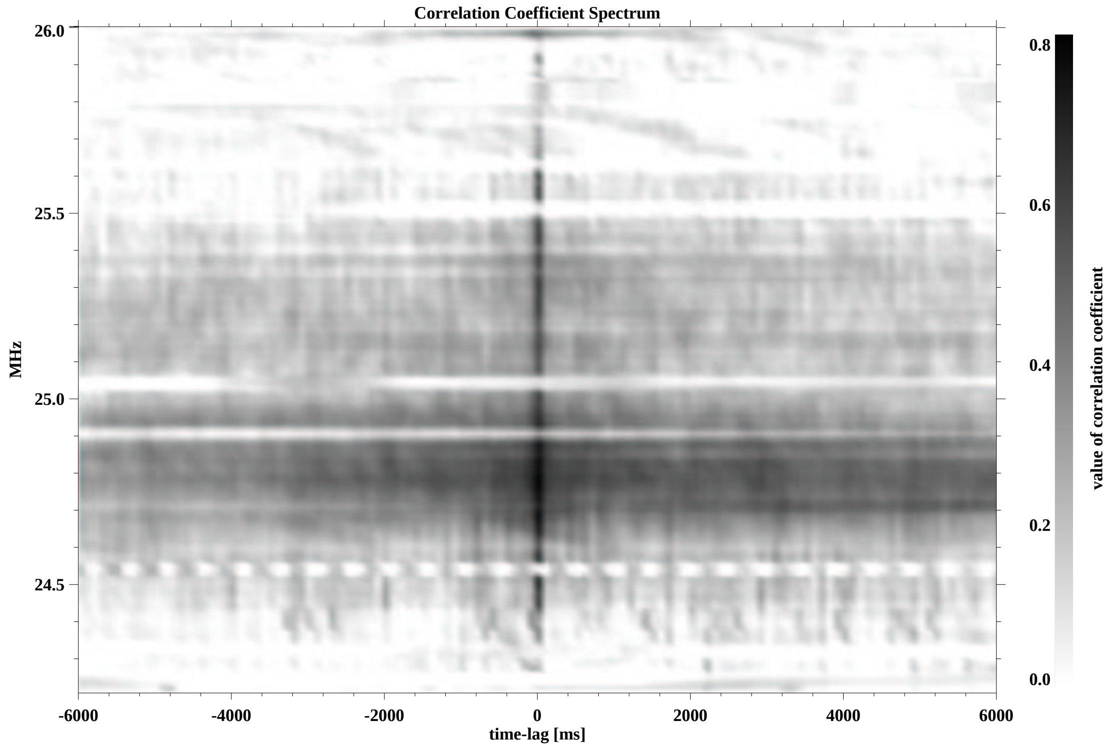


*Figure 5: Correlation coefficient spectrum of Figure 4. Both spectra Kharkov and Nançay as displayed in Figure 4 are correlated for each single frequency and shifted in time up to the maximum shift of 6 s. Obviously, correlation is stronger in the burst frequency "core" region, and weaker in higher as well as lower frequency parts. Common interferences are intentionally masked in order to prevent false maximum correlation values.*

variations on a time scale of about 370 to 400 ms for all frequencies shown, which is well resolved with a time resolution of 100 ms (effect due to interplanetary scintillation). Superposed on these structures are lanes with a positive drift of approx. 0.13 MHz/s and with a negative drift of approx. -0.08 MHz/s. The overall composition of these structures is by no means only related to the observations at Kharkov: Figure 8 shows in the bottom panel the time synchronized Nançay dynamic spectrum, parts of it surprisingly similar in structure to the top panel. Even in this case of a still puzzling and unresolved problem, the value of synchronized observations is well demonstrated.

## 4 Waveform observations

Within the frame of a doctoral thesis [Leitner, 2001] a digital waveform receiver (WFR) has been designed and developed which - in connection with the digital spectropolarimeter (DSP) - can perform broadband high time and frequency resolution recordings of the complete wave signal information. This WFR is the first broadband receiving device reaching a frequency–time product of 1 which means that the maximum theoretically

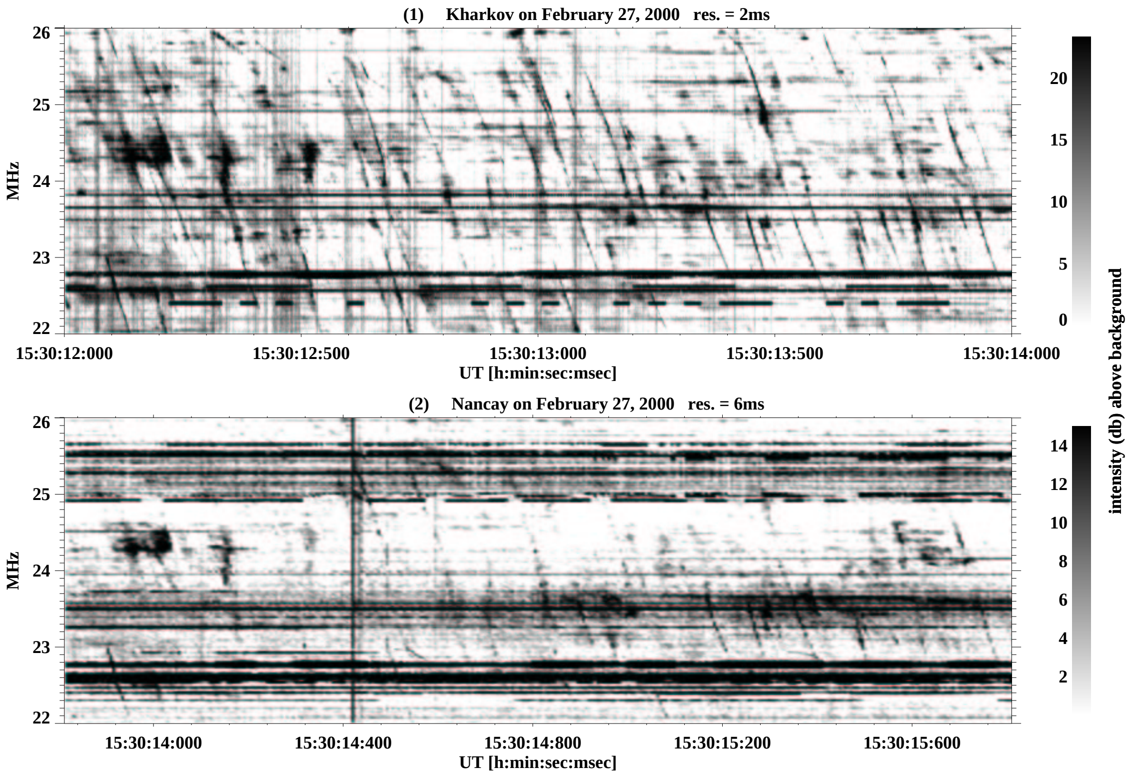


*Figure 6: During the INTAS observation campaign C2 Jupiter Io–B was observed in February 27, 2000, exhibiting single burst structures. Even with different radio station timing visible along the time axes, the time normal impulse fed into one channel enables synchronization. Apparently the Kharkov spectrum shows more details, here also at a higher time resolution of 2 ms.*

possible time and frequency resolution (i.e. the Heisenberg uncertainty relation) is now reached. With a dynamical range of about 70 dB and a bandwidth of 25 MHz, the WFR is at the optimum for observations of radio phenomena in the decametric wavelength range. Nevertheless the only parameter of the WFR necessary to be improved is the low acquisition duration (at present about 6 seconds). This limit however is only valid for observations at high time and frequency resolutions (producing about 100 MB of data per second).

The essential advantage, by capturing the original signal of the emission without any data manipulation, is that post processing methods allow various methods of detailed signal substructure analysis. Especially the wavelet transformation turns out to be very effective when dealing with intrinsic signal information.

Waveform observations have been carried out at Kharkov and Nançay with this newly developed digital Waveform receiver [Leitner and Rucker, 2001; Rucker et al., 2001a], specifically during the INTAS measurement campaign C2. The ability to observe a bandwidth of up to 25 MHz and directly save waveform data for several seconds enables to perform Jovian millisecond (S-) burst substructure analysis. Figure 9 shows a dynamic

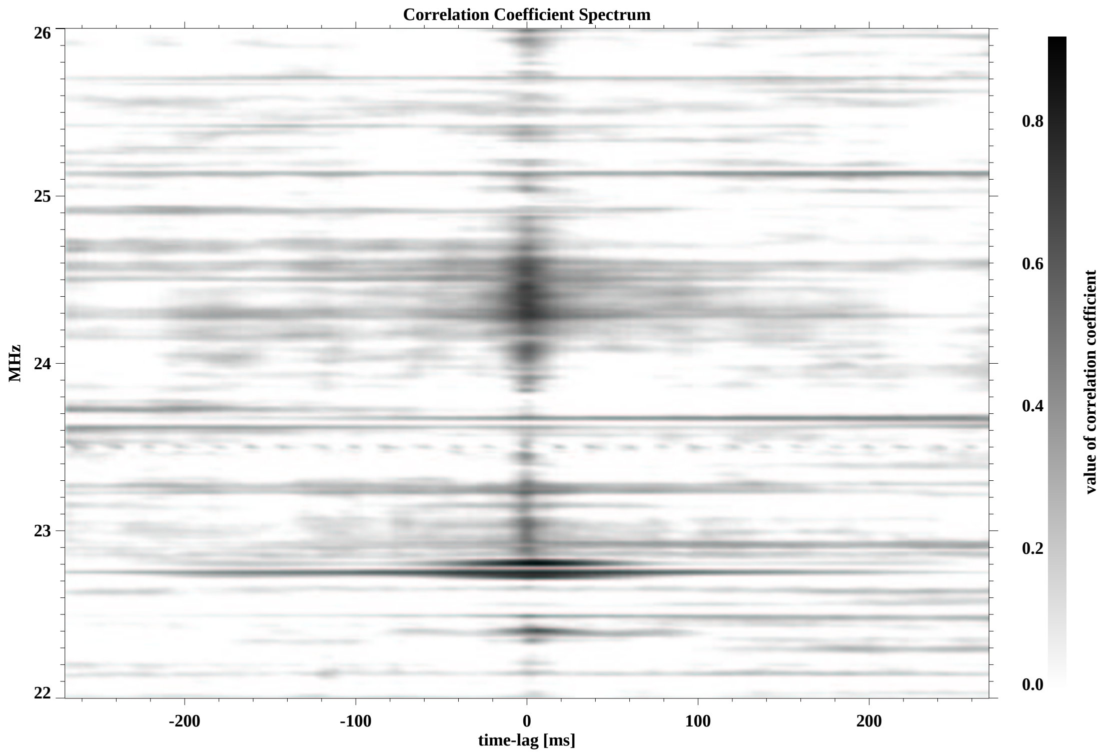


*Figure 7: Correlation coefficient spectrum of Figure 6. The broadening of maximum correlation around zero delay time is very likely due to the different spectral recordings of both stations, whereas slightly enhanced correlation at multiples of* $\pm$(40–*60 ms) off the zero delay time mirrors the repetition rates of the shown S–bursts.*

spectrum of an S–burst at millisecond resolution and a wavelet scalogram of part of the burst in the microsecond time domain (indicated by an arrow). The scalogram reveals in a very high time resolution that the S–burst apparently consists of several signal trains as short as 10 microseconds in time. This series is separated and exhibits phase discontinuities inbetween. As a consequence, this picture does not coincide with a model of continuous emission within an S–burst, but rather with a sequence of subbursts separated by phase changes. The true implications have yet to be analyzed.

## 5 Conclusions

The international EU–INTAS project "New Frontiers in Decametric Radio Astronomy", even still running until the end of 2001, turned out to be a highly successful project addressing a number of topics (deep sky survey on selected fields, observations on supernovae remnants, microstructures in the millisecond and sub–millisecond time domain of Solar system radio objects, i.e. Jupiter and the Solar corona, and of pulsars), introducing several "Firsts" and developing new methods as there are: Multi–telescope observing techniques, time synchronization, interference monitoring, investigation of non–linear ef-

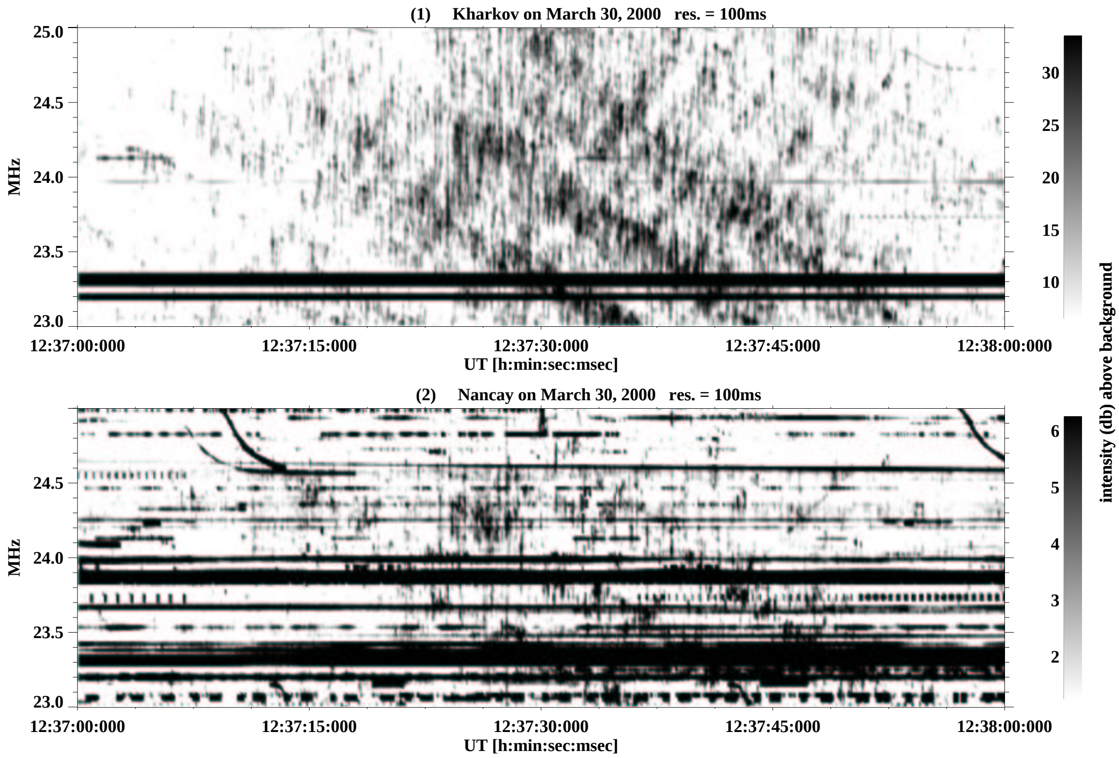


*Figure 8: Dynamic spectra obtained by UTR–2 (Kharkov) and the Reseau Decametrique (Nançay), on March 30, 2000, slightly more than half an hour after the observations as shown in Figure 4. The almost vertical "strokes" in the spectrum of Kharkov are superposed by a pattern of lanes with positive as well as negative frequency drifts.*

fects in the receiving chain (intermodulation, interferences) and broad–band waveform reception.

During spring 2001, the INTAS observation campaign C3 has been performed, among other topics also devoted to the Kharkov - Nançay time synchronous observation of Solar bursts, which still needs to be analyzed in detail. As a natural consequence, development of an efficient data storage system is of essential importance. The central data storage system of the INTAS project is installed at the Space Research Institute, Graz. The data are stored on a 550 GB RAID (Redundant Array of Inexpensive Discs) system in a hierarchical directory structure defined by the number of observation campaign, observation site, and date. Communication and information exchange among the participants involved in the project is made possible via the website http://www.iwf.oeaw.ac.at/intas/.

The rationale for future astrophysical programs at very low frequencies comprises investigations on technical requirements for large, low frequency radio telescopes, the determination of an optimal instrument architecture as well as the analysis on the requirements for receiving, amplification, transforming and data acquisition systems. In this direction non–thermal planetary and Solar radio emission investigations and studies will increasingly benefit to a high degree.

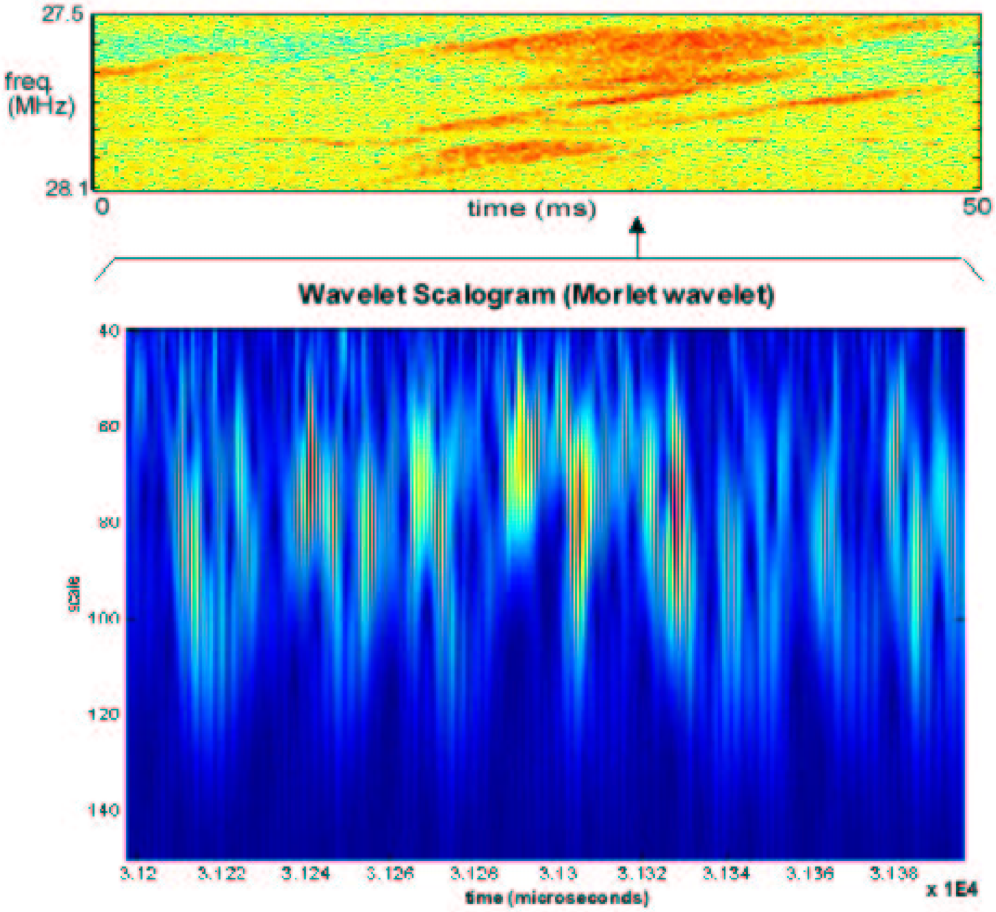


*Figure 9: A Jovian S–burst (millisecond burst) signal displayed in a dynamic spectrum (top) and part of it (see arrow) shown in a wavelet scalogram (bottom). Apparently the S–burst consists of short signal trains as short as 10 microseconds (the complete time axis comprises 200 microseconds), with phase discontinuities inbetween.*

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