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Decametric Emission by Pulsars*

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Abstract

A brief review of the main features of radio emission by pulsars in the decametre range is presented. Data on intensity, spectra, main pulse form, structure and properties of the interpulses are also presented.

1. Introduction

Pulsars are relatively weak emitting objects. Furthermore, at low frequencies their detection and detailed study is made difficult by high background temperatures, reduced emission bandwidths of the pulsars themselves, and scattering in the interstellar medium. Therefore, successful observations are possible only for a few pulsars, through the use of large radio telescopes. However, interest is considerable owing to the changes in pulsar radio emission at low frequencies and the possibility of detecting new phenomena.

Although only eight pulsars have been detected below 30 MHz, they have shown a number of common features: (i) a change in the sign of the spectral index of radiation in the main pulse (average spectrum) and an associated drop in intensity and (ii) the existence of an intense interpulse emission (IPE). The present paper briefly reviews the specific behaviour of pulsar radio emission at decametre wavelengths, using as examples the well-known strong pulsar PSR 1133+16 and the recently detected weak object PSR 1530+27.

2. Antennas, Equipment and Data Processing

Both the search for and measurement of pulsars has been performed with the N–S arm of the large UTR-2 radio telescope with effective area $A_e \approx 10^5$ m^2 (Megn *et al.* 1978). Each pulsar is tracked for one to four hours, with the signal integrated either in a mini-computer (Ustimenko 1982*a*, 1982*b*) or in a special hybrid storing device (Bruck and Ustimenko 1973*a*). Normally the integrated data are read out after 3 to 5 min and the integration continues without loss of the signal phase. The integration time is equal to one or several periods of the pulsar. In the latter case, the

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reliability of determining the noise level and identifying the interference and sporadic radio emission in the interpulse domain can be improved.

The signal is received with 30 standard P-250M receivers which can be tuned to any frequency in the range 1·5–25 MHz. Their passbands can be set in the range 1·5–14 kHz, depending on the time resolution chosen. Further processing of the signal involves, along with simple averaging, linear and threshold detection of drifting components, correlational classification procedures and cleaning of wide- and narrow-band interference (Bruck *et al.* 1985).

3. Detection

The first pulsar observed at the low frequency of 40 MHz was PSR 1133+16 (Arecibo Observatory 1968, unpublished). In 1969–70 PSR 0809+74 and PSR 1133+16 were detected at 25 MHz (Bruck 1970). Regular observations of pulsed radio emission at decametre wavelengths have been carried out since 1972. In 1973 the emission of three pulsars was detected (Bruck and Ustimenko 1973*b*). Until now radio emission from eight pulsars has been detected, and upper estimates of the flux density have been made for another 14 (Bruck and Ustimenko 1973*b*, 1976, 1983; Bruck *et al.* 1986). Between 25 and 40 MHz, large-scale observation programs (e.g. Izvekova *et al.* 1981) and occasional studies (Bash *et al.* 1970; Reyes *et al.* 1981) have been carried out.

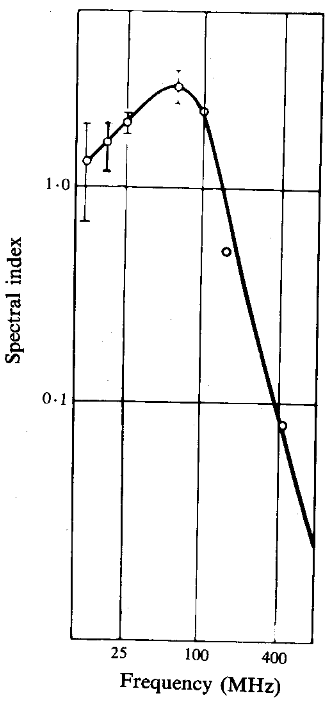

Fig. 1. Mean spectra of PSR 0809+74.

4. Fluxes and Spectra

The numerous measurements performed over a number of years have shown that the intensity of pulsar emission undergoes considerable fluctuation at decametre

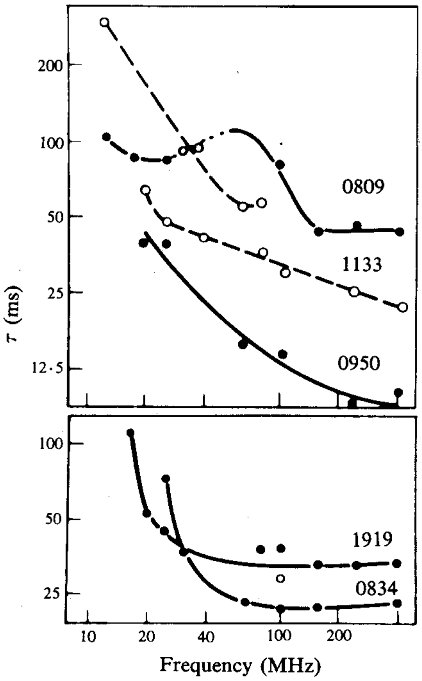

Fig. 2. Half-width of the main pulse (solid curves) and the spacing between the components (dashed curves).

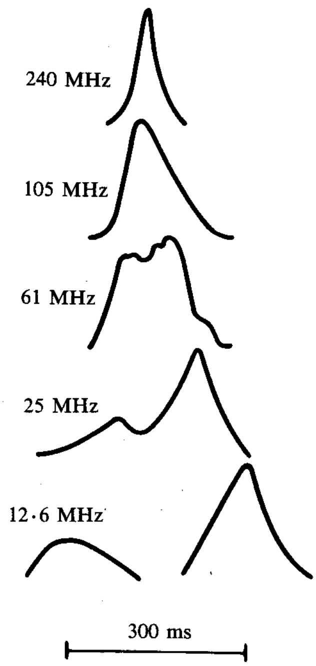

Fig. 3. Main pulse form of PSR 0809+74 at different frequencies.

wavelengths. The modulation index is weakly dependent on the degree of averaging and the time scale (Ustimenko 1982*a*, 1982*b*), as is observed at higher frequencies as well. Nevertheless, averaging over several years reduces the fluctuations and permits the determination of mean fluxes and spectra. The mean fluxes of strong pulsars are about 1 to 3 Jy, while those of weaker sources are about 10 times lower. The upper estimates for the 14 pulsars mentioned lie below 0·03 to 0·1 Jy (Bruck and Ustimenko 1983). Using the data at higher frequencies, as well as special simultaneous observations performed at essentially different frequencies in Pushchino (the Moscow region), Kharkov and Jodrell Bank, we have obtained spectra of the main pulse (Bruck *et al.* 1978). Both simultaneous and mean spectra display a feature common to all pulsars, namely a change in the sign of the spectral index at low frequencies (Kuzmin *et al.* 1978). A typical example is given in Fig. 1. A consideration of plausible radiation mechanisms of pulsars led to the suggestion that such a spectrum could result from the proper emission spectrum of relativistic electrons, taking into account the degree of their coherence and structure of the magnetic field (Kuzmin and Solovev 1986). This assumption seems all the more reasonable in view of the pronounced correlation between the decreased intensity of the main pulse and an increase in the sporadic radio emission off the main pulse.

5. Mean Profiles

The observations show that mean pulse shapes become stable if averaged for one to six hours. Therefore, integration of a great number of observations allows the determination of pulse widths quite accurately, even with a relatively low resolution of the equipment (Ustimenko 1982*b*). This was in fact corroborated by results of high resolution observations. Comparing the data measured in the decametre band with those of higher frequencies one can see the mean pulse width increase as frequency decreases through the range from 100 to 10 MHz, the dependence being stronger than between 400 and 100 MHz. The corresponding curves showing the pulse width and spacing between the components are given in Fig. 2. For PSR 0809+74 the pulse width shows a non-monotonic frequency dependence caused by splitting of the mean profile in the band 10 to 240 MHz. The splitting can be seen distinctly in Fig. 3 and is interpreted quite naturally in terms of the larger cone angle of open magnetic lines, while the difference of the component spectra can be explained in terms of twisting of the magnetic field lines (Shitov 1983; Shitov and Malofeev 1985). For the pulsar PSR 1133+16 the profile splitting, asymmetric amplitudes and subpulse widths all show agreement with the high frequency measurements.

A 'micropulse' decametric emission has been found so far only for PSR 0809+74 (Novikov *et al.* 1984). Parameters of the microstructure at 25 and 100 MHz are in agreement.

A characteristic feature of mean pulsar profiles in the decametre wave band is an extended component adjacent to the main pulse. In many cases it occupies almost the whole period, with its relative and absolute intensities growing at lower frequencies (Bruck and Ustimenko 1976, 1977; Ustimenko 1982*a*, 1982*b*). The energy in the extended component can greatly exceed that of the main pulse.

6. Interpulse Emission

As noted above, with a decrease in frequency the main pulse gradually vanishes, and the profile changes so that identification of the main pulse may sometimes be impossible. Closer examination shows that the emission retains its pulsed character;

however, the mean profile (representing the occurrence probability and intensities of the pulses) changes substantially. Since the emission is generated at all longitudes, the efficiency of long-term cyclic integration decreases. In this case the effective methods are as follows: (a) various threshold procedures; (b) classification of signals with subsequent summation over frequency and time of observation; and (c) comparison of numerous data obtained in a single or several observatories. We consider some examples.

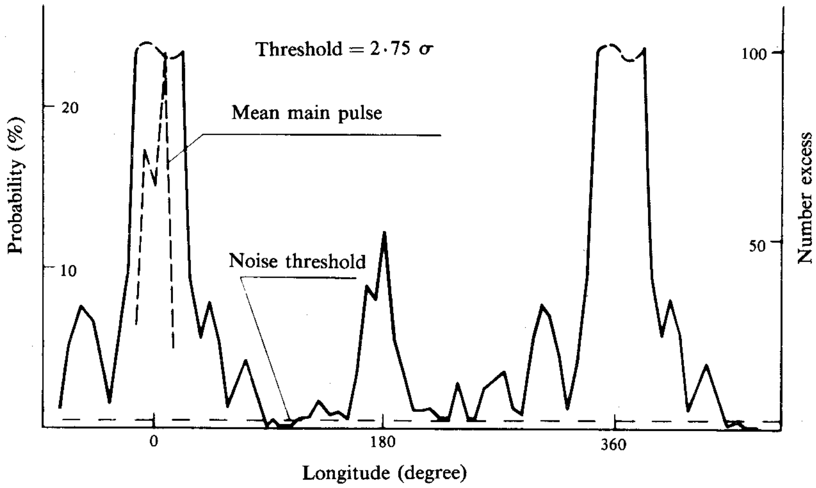

Fig. 4. IPE occurrence probability for the radio emission from PSR 1133+16 for a whole period.

Fig. 4 shows the dependence upon longitude of the number in excess of the threshold $2 \cdot 75\sigma$ for the pulsar PSR 1133+16 (frequency 25 MHz). The dashed horizontal line represents the probability of excess of the same threshold for normally distributed noise. The main pulse region, minima of the intensity and at least three more regions of intense interpulse emission (IPE) which have been detected by this method are typical for this pulsar. The two regions close to the main pulse (about $\pm 60°$ from its centre) are probably related to the same pole of the pulsar. The third one close to the centre can admittedly be related to the other pole. Both integral and differential distributions of the intensity fluctuations conform to the normal law near the minima (and hence this is noise), whereas in the IPE regions high fluctuation amplitudes are more probable. Similar data allow an estimation of the IPE occurrence probability for any phase of the period.

The IPE structure can be analysed using the self-consistent classification algorithm. Its efficiency is illustrated in Fig. 5 showing one of the two modes of PSR 1530+27, whose emission was detected and analysed at 25 MHz (Bruck *et al.* 1986). As follows from the dynamic spectrum presented, all the important maxima and minima are characterised by the same dispersion measure (DM), and hence all belong to the pulsar. The two modes have waveforms coinciding within the correlation factor of 0·92, although shifted in longitude by 145° (Fig. 6*a*). Their superposition results in a mean profile (Fig. 6*b*) which is typical for pulsars in the decametre band (Bruck and Ustimenko 1979). As has been shown (Bruck 1987), emission of a similar structure but of lower intensity is generated at other longitudes of the pulsar. Admittedly, the two modes of highest intensity correspond each to a magnetic pole of its own. Analysis of the probable radiation mechanisms seems to favour the antenna-type mechanism.

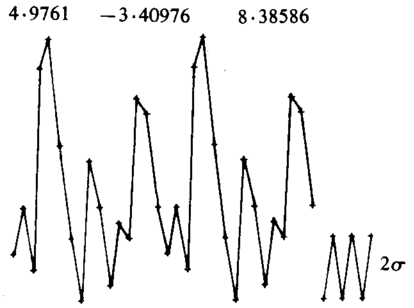

Fig. 5. Longitude–frequency structure for one of two models of radio emission from PSR 1530+27.

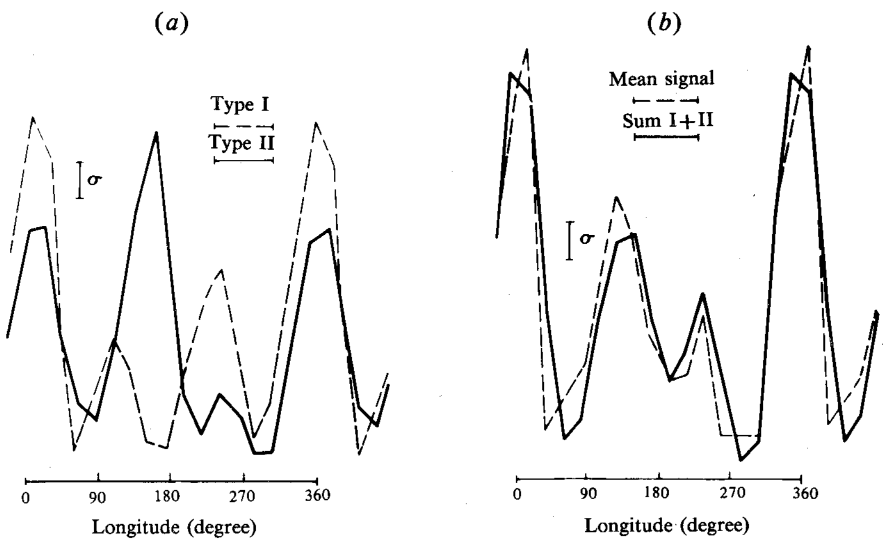

Fig. 6. Mean profiles of two modes (*a*) and the mean profile and sum of two modes (*b*) for PSR 1530+27.

Bursts of pulsar emission contain important information on the IPE structure. The features observed during such events are similar, even if the corresponding measurements are carried out at various frequencies or at different times. Fig. 7 shows the result of such a comparison for PSR 1133+16, observed in the USSR (Bruck and Ustimenko 1983) and in the USA (Reyes *et al.* 1981). The main pulse and the central IPE region are marked. The close resemblance of their shapes (even in details) is evident. It should be noted that similar results were also obtained for PSR 1919+21 and some other pulsars (Bruck and Ustimenko 1977; 1979).

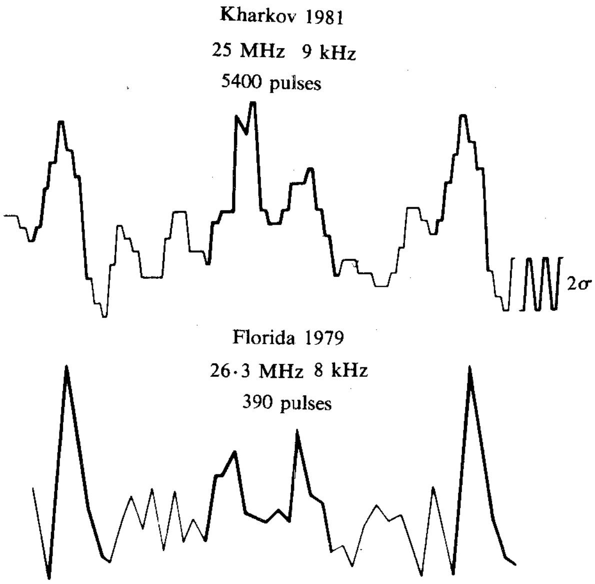

Fig. 7. Longitudinal structures of two bursts of radio emission from PSR 1133+16.

The mean longitudinal autocorrelation function (LACF) is an important statistical characteristic of the waveform. It is a cyclic correlation function whose form for PSR 1133+16 is presented in Fig. 8. It is characterised by the following features. The initial part of the LACF reflects the properties of the main pulse, while its central part is related to the interpulse. The width of this part depends on the duration of both pulses and their mutual spacing, and is affected by other emitting regions. It can be asserted in the case under consideration that the duration of the central interpulse is less than that of the main pulse. This is illustrated in Fig. 4. The regions from $\pm 40°$ to $\pm 60°$ describe the properties of the IPE near the main pulse, while the extended part of the LACF corresponds to the extended component of the profile. Thus, all the above conclusions on the IPE structure are corroborated by the analysis of the mean LACF.

Consider now the variations of the structure in longitude with frequency and time of observation. Fig. 9 shows examples of dynamic 'spectra' of PSR 1133+16 represented in terms of 'longitude–time–intensity' coordinates (in noise units), as well as mean longitudinal profiles for the whole 140 min observation interval. Both parts of Fig. 9 correspond to measurements within 30 kHz bands, with the frequency diversity between the bands equal to 60 kHz. They illustrate the strong variability of the signal with a small diversity, as well as the existence of long- and short-lived elements in the emission. The high symmetry of the IPE regions with respect to the main pulse should also be noted. As for the mean characteristics, neither the frequency (FACF) nor time autocorrelation (TACF) functions show any noticeable specific features for the main pulse. However, for the IPE the half-width of the FACF is 20–30 kHz and decreases only slowly, which is evidence for a wideband emission component. The TACF is a non-monotonic function with a half-width of the order of 10 min and with a characteristic repetition period of the emission structure of about 60 min. Obviously, integration of such signals over frequency or time should result in a loss

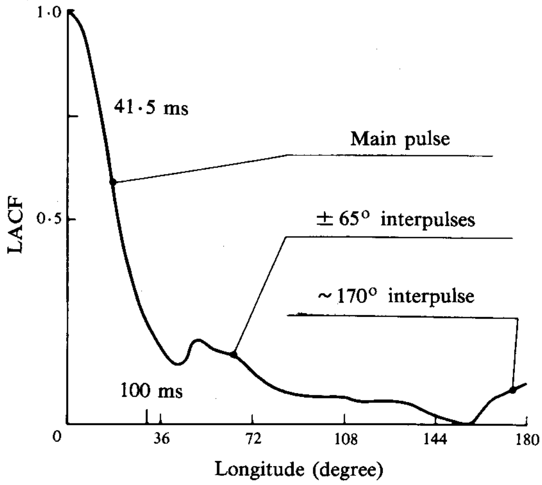

Fig. 8. Longitudinal autocorrelation function of PSR 1133+16.

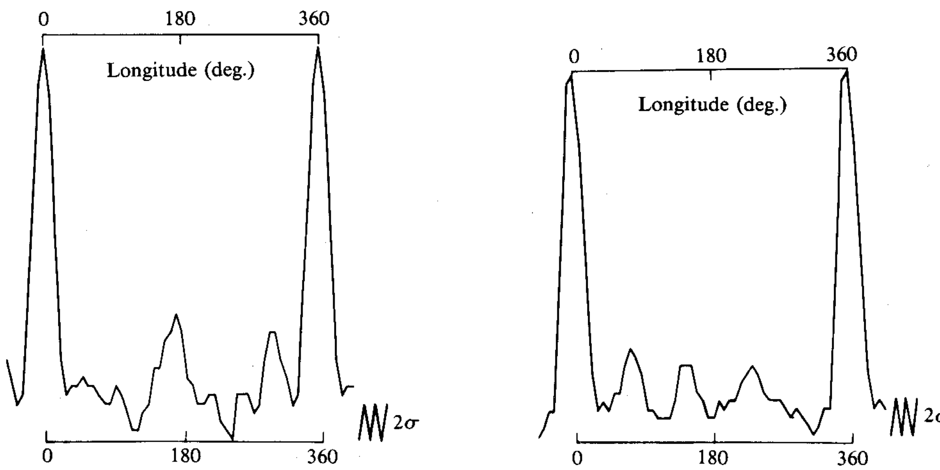

Fig. 9. Variations of the structure in longitude as functions of frequency and time for PSR 1133+16.

of information on the IPE, only the wideband and long-lived part remaining. All the rest disappears or, rather, is integrated in the same way as noise. The features described indicate the possibility of the long-term existence of an intense IPE in a narrow band. Such occasional events have actually been observed, e.g. considerable IPE was observed for 140 min about 180° from the main pulse centre (Fig. 4) through a band less than 8 kHz. Its intensity was 1·5 times higher than that of the main pulse, while the duration (less than 24 ms) was four times shorter. Apparently the angular density of emission, the 'quality factor' of the corresponding 'resonant' amplification or generation mechanism and its time stability, can be very high in the core.

All the data currently available on the IPE properties apparently speak in favour of some generation mechanism related to a turbulent plasma.

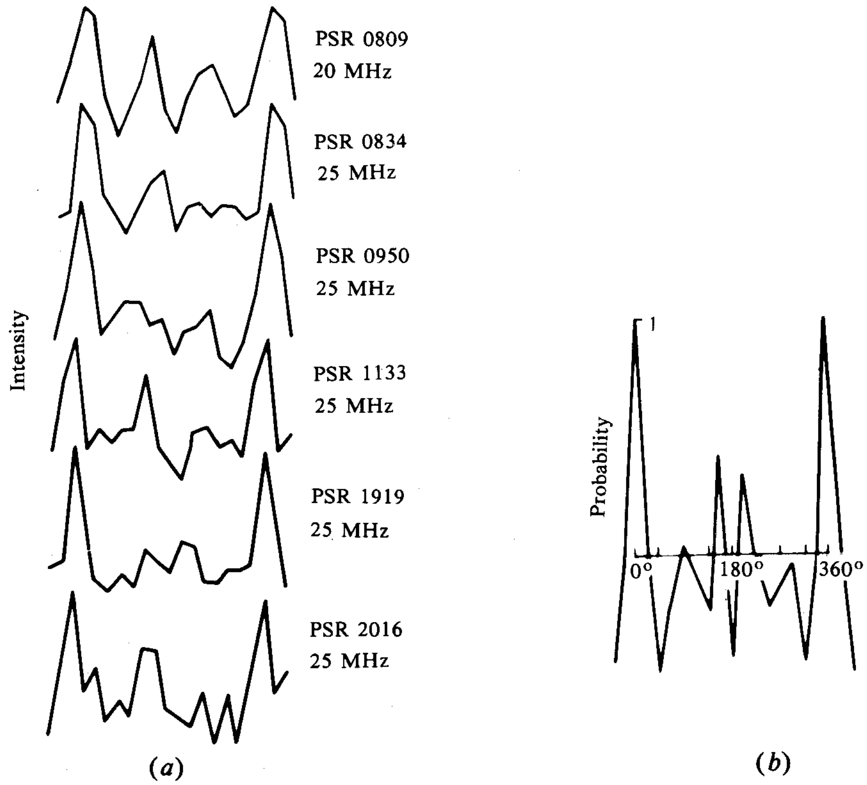

Fig. 10. (*a*) Typical decametric profiles of six pulsars. (*b*) The average profile obtained by special processing and characterising the IPE occurrence probability.

7. Longitudinal Structure of the IPE

The entire body of data accumulated on pulsed radiation, both mean profiles and the IPE bursts, shows the presence of similar features in the IPE structure of various pulsars (Bruck and Ustimenko 1979). This can be seen in Fig. 10 showing (*a*) typical decametre profiles of six pulsars and (*b*) the average profile obtained through special processing and characterising the IPE occurrence probability. Clearly shown are the symmetry of the longitudinal structure with respect to the main pulse, and the existence of at least five distinct structural regions, specifically of three minima (at 45°, 180° and 315°) with a reduced probability of the IPE and two maxima with the elevated probability. The regions characterised by an enhanced IPE probability are also typical for most pulsars showing interpulses at high frequencies. They seem to be related to the second pole (Bruck 1987).

8. Conclusions

The features of pulsar radio emission discussed above are typical for all pulsars which we observed in the decametre band. The features become particularly pronounced at lower frequencies. A factor of principal importance is the possible change in the generation mechanism. If this is also the reason for the drop in the emission spectrum, it would be reasonable to look for the IPE and investigate it near the break in the spectrum. Then, most of these pulsars would fall in the metre wave band. As for the decametre band, in view of the intrinsically poor signal-to-noise ratio, the measurements here should be confined to the range 20–30 MHz. Particularly promising could be an investigation of PSR 0809+74 whose pulsed emission is observable down to 10 MHz. It would be highly desirable to carry out a search for decametre radio emission from, as yet, unknown pulsars and also those in the Southern Hemisphere, possibly using a different technique.

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