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Catalogue of time aligned profiles of 56 pulsars at frequencies between 102 and 10500 MHz

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Abstract. A catalogue of integrated pulse profiles of 56 pulsars with observations at 102, 230, 408, 610, 1400, 4700, and 10500 MHz is presented. The profiles are aligned in time (phase) so that direct comparisons of changes in the profile shape and component composition can be made. Smearing due to interstellar scattering at low frequencies for pulsars with large dispersion measures was removed by means of a special "descattering" method (Kuzmin & Izvekova 1993).

Most pulsars show good alignment over the whole frequency range 0.1 to 10.5 GHz, if the dispersion measure is corrected slightly in comparison to the published value. We confirm a non-dispersive time shift of the integrated profile for PSR 0809+74 as presented by Bartel et al. (1981), Davies et al. (1984), and Kuzmin et al. (1986).

This paper presents the data in form of a catalogue of time aligned profiles. A detailed analysis of the change of pulse structure with frequency by means of a decomposition of the average pulse shape into gaussian components will be presented in a forthcoming paper.

Key words: pulsars: general

1. Introduction

The shape of integrated profiles is certainly one of the most important characteristics of pulsars. Integrated profiles and their frequency dependence are indications for the spatial structure of the emission region and of the structure of the neutron star's magnetic field. At present there exists already a variety of papers presenting multi-frequency integrated pulse profiles of pulsars, e.g. Morris et al. (1981), Hankins & Rickett (1986), Kuzmin et al. (1986), Izvekova et al. (1989), Izvekova et al. (1994), and Seiradakis et al. (1995).

Our catalogue is specific in covering a wider frequency range, including low-frequency profiles and many frequencies, i.e. 102, 230, 408, 610, 1400, 4700, and 10500 MHz. Low-frequency profiles of pulsars with large dispersion measures were corrected for interstellar scattering (see Kuzmin & Izvekova 1993). An important additional feature of this catalogue is that the profiles are aligned in time. This allows one to obtain correct identifications of individual components and their frequency evolution, an important feature for the analysis of the spatial structure of the emitting region and the magnetic field.

2. Observations

The observations were performed between August and October 1984 and August and September 1991. We used at 102 MHz the Large Phased Array Radio Telescope of the Lebedev Physical Institute at Pushchino (Russia), at 230, 408, 610, and 1380 MHz the 76-m Lowell radio telescope of the Jodrell Bank Radio Observatory (UK) and at 1400, 4700 and 10 500 MHz the 100-m radio telescope of the Max-Planck-Institut für Radioastronomie at Effelsberg (Germany). Additional measurements with higher resolution were made in 1994/96 at the Large Phased Array (Kuzmin & Losovsky 1996).

Two circular polarizations were received at all frequencies, except at 102 MHz, where the telescope accepted linear polarization. The distorting effect of the polarization at 102 MHz on the pulse profile was smoothed out by interstellar Faraday rotation across the receiver band and by averaging several observing sessions. The resulting profiles are expected to represent nearly total intensity, depending on the number of days used for the mean profiles.

The sampling interval was selected individually for each pulsar depending on the pulse period and the

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dispersion smearing. At Effelsberg the sampling interval was normally choosen to be 1/1024-th of the observing period. The influence of dispersion was removed by use of filter banks. The main characteristics of the receivers and the dispersion smearing $\Delta t_{\rm DM}$ for DM = 1 pc cm^{-3} are listed in Table 1. The amount of smearing due to the sampling interval and due to dispersion is indicated for each pulsar in Fig. 2 by horizontal bars.

Between 62 and 7600 single pulses were added synchronously to obtain the integrated profiles. The master clocks of all observatories were synchronized to better than 0.1 ms against the respective national main time standards.

Table 1. Receiver characteristics

Frequency (GHz)	Bandwidth (kHz)	$\Delta t_{\rm DM}$ for DM = 1 pc cm^{-3} (ms)
0.102	20 × 32	0.154
	5 × 32	0.039
0.23	125 × 32	0.085
0.408	125 × 32	0.015
0.61	125 × 32	0.0045
1.38	1000	0.0032
1.4	60 × 667	0.002
4.7	60 × 667	5.3 10^{-5}
10.5	500 MHz	0.0036

3. Data reduction

3.1. Descattering

Pulsars with large dispersion measures exhibited interstellar scattering at 102 MHz (and some pulsars even at 230 MHz) distorting the profile shape and delaying the pulse arrival time, inspite of the use of a 5 × 32 or 20 × 32 kHz filter bank. This effect was compensated for by application of a scattering correction method proposed by Kuzmin & Izvekova (1993), which is based on the classical solution of the transfer equation of a signal through the interstellar medium:

The intrinsic pulsar profile $x(t)$ is obtained from the observed profile $y(t)$ by Fourier transformation:

$$x(t) = \int X(f)\exp(j2\pi ft){\rm d}f, \tag{1}$$

where

$$X(f) = Y(f)/G(f) \tag{2}$$

and

$$Y(f) = \int y(t)\exp(-j2\pi ft){\rm d}t \tag{3}$$

$$G(f) = \int g(t)\exp(-j2\pi ft){\rm d}t. \tag{4}$$

$X(f)$ denotes the Fourier transform of the intrinsic pulsar profile $x(t)$, $Y(f)$ the transform of the observed profile $y(t)$, and $G(f)$ the transform of the interstellar medium transfer function $g(t)$. $g(t)$ was assumed - according to the thin screen model - to be given by

$$g(t) = \exp(-t/\tau_{\rm sc}), \tag{5}$$

where the scattering time scale $\tau_{\rm sc}$, which characterizes the broadening of the profile, was obtained from our observations using procedures as described in Kuzmin & Izvekova (1993). (We may remark, that this procedure removes both, the scattering and the receiver time constant.)

An example of our descattering procedure for the pulsar PSR 0136+57 at 102 MHz is shown in Fig. 1. $\tau_{\rm sc}$ is given - together with all the parameters important for the measurement and reduction procedure - in Table 3.

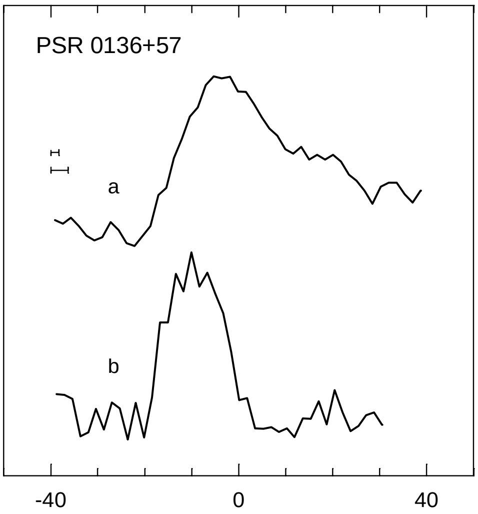


Fig. 1. Example of descattering for pulsar PSR 0136+57 at 102 MHz: **a)** observed profile, **b)** descattered profile with $\tau_{\rm sc}$ = 30 ms (abscissa in degrees of pulsar rotation period)

3.2. Reduction of the arrival times to a common frequency, epoch, and location

Our observations were performed at different frequencies, observatories and at nearby but different times. Alignment of the profiles in time requires the reference to a common frequency, location and epoch. This was achieved by referring all observations to the solar system barycenter (common location) by use of the JPL DE200 Earth ephemeris and by adding integral numbers of (barycentrical) periods to observations at different epochs (common epoch), as described in the next section. Applying the cold plasma dispersion relation allowed the reduction to a common frequency, as explained below.

Time alignment is difficult to achieve for observations stretched over long time intervals. We used therefore the fact that both our measurements, in 1984 and 1991, contained observations at nearly exactly 1400 MHz. Profiles measured at this frequency were aligned by overlaying the strongest components of the profiles observed at the two sessions.

3.2.1. Correction of the pulsar period

Referring observations at different times to a common epoch by adding an integral number of periods to the earlier time of arrival requires the knowledge of the exact value of the apparent period $P(t)$. Our first approach was to calculate the period from catalogued values of P and $\mathrm{d}P/\mathrm{d}t$ (at epoch t_0 and omitting the second period derivative, since it is generally not known for the pulsars in our sample)

$$P(t) = P(t_0) + (t - t_0) \cdot \mathrm{d}P/\mathrm{d}t \tag{6}$$

and applying a time dependent Doppler correction computed from the Earth ephemeris. The catalogued values of P and $\mathrm{d}P/\mathrm{d}t$ represent, however, in general fits to an extended and past time span giving sometimes appreciable residuals at the time of our observations. We decided therefore to correct the computed period values by an amount *CorP* derived from control measurements made at the same observatory and at the same frequency but at different dates. These control measurements showed often systematic shifts of the profile phase against observation date. The values of *CorP* are listed in Col. 6 of Table 3. In august-september 1992 special one-frequency measurements at 102 MHz were performed to confirm that pulsars, for which we applied the correction of the period, really need it.

Additional confirmation may be found by considering the changes of the listed values of $\mathrm{d}P/\mathrm{d}t$ in the 1995 catalogue of Taylor et al. (1995) with those of the 1993 catalogue (Taylor et al. 1993) (both are given in Table 3). The changes of the period ΔP computed from the 1993 and 1995 values of $\mathrm{d}P/\mathrm{d}t$

$$\Delta P = (\mathrm{JD} - \mathrm{JD}_0) \cdot (\mathrm{d}P/\mathrm{d}t_{95} - \mathrm{d}P/\mathrm{d}t_{93}) \tag{7}$$

are highly correlated with our corrections *CorP* of the period, as demonstrated clearly in Table 3.

3.2.2. Dispersion delay

Most critical for the alignment at low frequencies is the exact value of the dispersion measure DM, which determines the time delay Δt_{DM} between observations at different frequencies:

$$\Delta t_{\mathrm{DM}} = 10^7 \cdot (1/f_1^2 - 1/f_2^2) \cdot \mathrm{DM}/2.41 \tag{8}$$

(with Δt_{DM} in ms for f_ν in MHz and DM in cm^{-3} pc).

Table 2. Phase shift (in degrees) of high-frequency profiles relative to the corresponding 0.4 GHz profiles

	Frequency (GHz)		
PSR	1.4	4.7	10.5
0138+59	1		
0809+74	−4		
1822−09	0	0	−1.5
2154+40	−3		

As a first step we used the catalogued values of Taylor et al. (1993), shown in Col. 8 of Table 3. When deviations were still obvious, we tried, as the next step, to find more appropriate DM values which would align all profiles between 0.1 and 10 GHz as good as possible. These values of DM are shown in Col. 10 of Table 3 and in the figures. We list in addition, for comparison, the often slightly improved values of the catalogue of 1995 (Taylor et al. 1995).

The positions in time (phase) of the 102 MHz profiles depend heavily on these assumed dispersion measure values, since the corrections influence basically the low-frequency profiles. Independent, precise determinations of the dispersion measure would therefore be highly desirable. We will analyze this subject in a forthcoming paper.

4. Results

Multifrequency observations of integrated pulse profiles are shown in Fig. 2 for 56 pulsars. The profiles are descattered at low frequencies and aligned in pulse phase as outlined in Sect. 3. In very few cases, we added for comparison profiles, where no timing information was available; these profiles are marked with an asterix.

4.1. Alignment

It is obvious from Fig. 2 that most profiles are well aligned over the 0.1 to 10 GHz frequency range considered here. This fact is remarkable in itself, since it demonstrates that the cold plasma dispersion relation is applicable over the whole frequency range and that the different phase shifts over all the measurement frequencies can be described by just one free parameter, the dispersion measure DM. The alignment was achieved either by use of the catalogued value of DM or by applying small corrections as explained in Sect. 3. Changes in the dispersion measure value influence the phase of all profiles simultaneously; low-frequency profiles are shifted quite drastically but the high-frequency phase is left nearly unchanged. Misalignments at high frequencies can therefore hardly be removed by correction of the dispersion measure.

There exists, indeed, a group of pulsars where non-removable - “non-dispersive” - phase shifts appear

Table 3. Observational parameters

PSR	P	dP/dt		Epoch	*CorP*	ΔP	DM			τ_{sc}
		TML93	TMLC95				TML93	TMLC95	this work	
	(s)	(10^{-15} s/s)		(year)	(ns)	(ns)	(pc cm^{-3})			(ms)
1	2	3	4	5	6	7	8	9	10	11
0011+47	1.240	0.561	0.563	1991	0	0.4	30	31.1	31.1	
0136+57	0.272	10.6867	10.7003	1984	3.4	2.4	73.7	73.75	73.75	30
				1991	11.6	6.4				30
0138+59	1.222	0.3904	0.3904	1984	0	-	34.80	34.80	34.80	
0154+61	2.351	188.99	188.841	1991	−16.0	56.9	26	29.8	29.8	
0301+19	1.387	1.29613	1.2959	1984	0	0.1	15.69	15.69	15.665	
0329+54	0.714	2.04959	2.04959	1984	0	-	26.776	26.776	26.771	
				1991	0	-				
0355+54	0.156	4.3912	4.39747	1984	0	−0.4	57.03	57.14	57.14	5
				1991	1.4	1.0				5
0450−18	0.548	5.7564	5.7564	1984	1.7	-	39.93	39.93	39.93	
				1988	0	-				
0450+55	0.340	2.3581	2.3656	1984	0	−0.3	14.3	14.602	14.60	
				1991	0	1.4				
0525+21	3.745	40.045	40.0321	1984	0	3.0	50.877	50.877	50.877	
				1991	0	0.2				
0540+23	0.245	15.42869	15.42378	1991	−3	−2.6	77.58	77.698	77.58	
0628−28	1.244	7.107	7.107	1984	0	-	34.36	34.36	34.44	
0655+64	0.195	0.00069	0.00069	1984	0	-	8.774	8.774	8.774	
0656+14	0.384	55.032	55.0134	1991	0	−3.7	14	14.02	14.0	
0740−28	0.166	16.8219	16.81152	1984	0.8	0.8	73.77	73.77	73.77	
				1991	−1.4	−1.5				
0809+74	1.292	0.1676	0.1683	1984	0	0.3	5.751	5.7513	5.751	
				1988	0	0.4				
0818−13	1.238	2.1056	2.1056	1984	0	-	40.99	40.99	40.965	9
0820+02	0.864	0.1039	0.1039	1984	0	-	23.6	23.6	23.6	
0823+26	0.530	1.7236	1.7094	1984	0.3	−3.9	19.475	19.4751	19.475	
				1991	−0.2	−7.1				
0834+06	1.273	6.79918	6.7995	1984	0	0.1	12.857	12.8579	12.865	
				1991	0	0.2				
0919+06	0.430	13.7248	13.7202	1991	0	1.8	27.309	27.3091	27.31	2
0950+08	0.253	0.22915	0.22915	1984	0	-	2.970	2.9702	2.970	
1133+16	1.187	3.73273	3.73273	1984	0	-	4.847	4.8471	4.847	
				1991	0	-				
1237+25	1.382	0.95954	0.9605	1984	0	0.4	9.275	9.2755	9.29	
				1991	0	0.6				
1508+55	0.739	5.0327	5.0078	1984	−2	−11.4	19.599	19.599	19.62	
1530+27	1.124	0.803	0.803	1991	−3	-	14.61	14.61	14.61	
1541+09	0.748	0.4303	0.4327	1984	0	1.3	34.99	34.99	34.99	
1604−00	0.421	0.30607	0.30610	1984	0	0.0	10.684	10.6846	10.693	
1642−03	0.387	1.7810	1.7810	1984	−0.5	-	35.665	35.665	35.73	
				1991	−1	-				
1702−19	0.298	4.14	4.13828	1984	0	0.2	23.1	22.920	22.945	

Table 3. continued

PSR	P	dP/dt		Epoch	$CorP$	ΔP	DM			$\tau_{\rm sc}$
		TML93	TMLC95				TML93	TMLC95	this work	
	(s)	(10^{-15} s/s)		(year)	(ns)	(ns)	(pc cm^{-3})			(ms)
1	2	3	4	5	6	7	8	9	10	11
1706−16	0.653	6.3075	6.3088	1984	−8.5	−0.1	24.88	24.88	24.88	
				1991	25	0.2				
1737−30	0.606	465.67	465.3	1991	−1.8	5	153	153	152.1	
1742−30	0.367	10.6592	10.66487	1991	−13	−0.8	88.8	88.387	88.387	
1749−28	0.562	8.1394	8.1394	1991	−14	-	50.88	50.88	50.88	
1804−08	0.163	0.02868	0.02868	1991	−1.6	-	112.8	112.8	112.8	
1822−09	0.768	52.432	52.3636	1991	14	10.1	19.9	19.46	19.44	
1826−17	0.307	5.5619	5.5619	1991	−14	-	217.8	217.8	216	
1839+56	1.652	1.7	1.495	1984	40	28	26.2	26.54	26.72	
1845−01	0.659	5.2184	5.2184	1991	−40	-	159.1	159.1	159.1	
1929+10	0.226	1.15675	1.15661	1984	0.2	−0.1	3.176	3.176	3.18	
				1991	0.4	−0.1				
1933+16	0.358	6.00354	6.00354	1984	−0.3	-	158.53	158.53	158.47	
1952+29	0.426	0.00201	0.00104	1991	0	−0.2	7.91	7.91	7.91	
1953+50	0.518	1.366	1.366	1991	3	-	31.8	31.8	32.5	
2016+28	0.557	0.14936	0.14936	1984	−0.2	-	14.176	14.176	14.176	
				1991	−1.0	-				
2020+28	0.343	1.8935	1.8935	1984	0	-	24.62	24.62	24.62	
				1991	0.3	-				
2021+51	0.529	3.0518	3.06554	1984	3.0	6.3	22.580	22.580	22.55	
				1991	7.0	9.3				
2045−16	1.911	10.9610	10.9610	1991	0	-	11.51	11.51	11.48	
2110+27	1.202	2.6226	2.6226	1984	0	-	24.7	24.7	25.13	
2111+46	1.014	0.7195	0.7115	1984	−1.0	−3.4	141.50	141.50	141.36	200
2154+40	1.525	3.417	3.4257	1984	−0.3	3.3	71.0	70.61	71.1	30
2217+47	0.538	2.76421	2.76503	1984	0	0.4	43.54	43.54	43.53	
2224+65	0.682	9.671	9.6552	1984	1	−2.8	35.3	36.16	36.1	
2306+55	0.475	0.202	0.202	1991	−1	-	47.0	47.0	47.0	
2310+42	0.349	0.1155	0.1155	1984	−0.7	-	17.3	17.3	17.275	
				1991	−0.7	-				
2319+60	2.256	7.037	7.037	1984	0	0	93.8	94.78	94.32	
				1991	0	0				
2351+61	0.944	16.226	16.2641	1991	712*	15.1	95	94.34	94.34	

* A comparison between the tabulated period values in the catalogues of Taylor et al. (1993) and Taylor et al. (1995) shows indeed a major revision, which explains the need for such a high correction.

at high frequencies; these are the pulsars PSR 0138+59, 0355+54, 0450+55, 0540+23, 0809+74, 1541+09, 1822−09, 1839+56, 1929+10, 2021+51, and 2154+40. We will discuss the properties of these pulsars in detail below.

It should be mentioned here, that quantifying the phase shift between profiles at different frequencies is generally difficult. The reason is that a shift between unequally shaped curves has to be computed. There exist always - albeit sometimes very small - differences between the profiles at different frequencies. The apparent displacements of the measurements of some of the quoted pulsars - PSR 0355+54, 1541+09, 1839+56, and 1929+10 - can be explained by variations of the pulse shape in the sense, that some components weaken or increase drastically at higher frequencies. This interpretation becomes even more

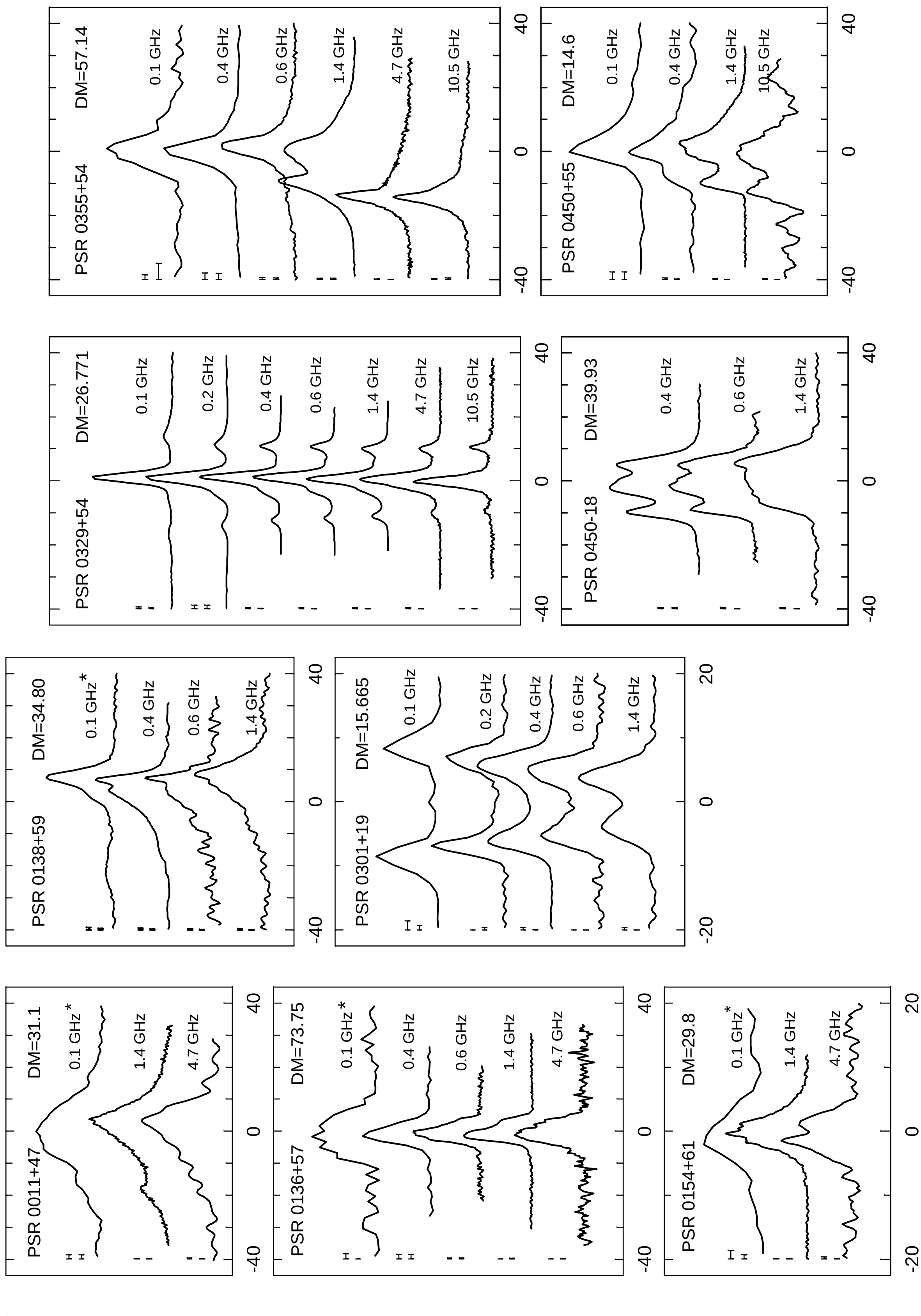
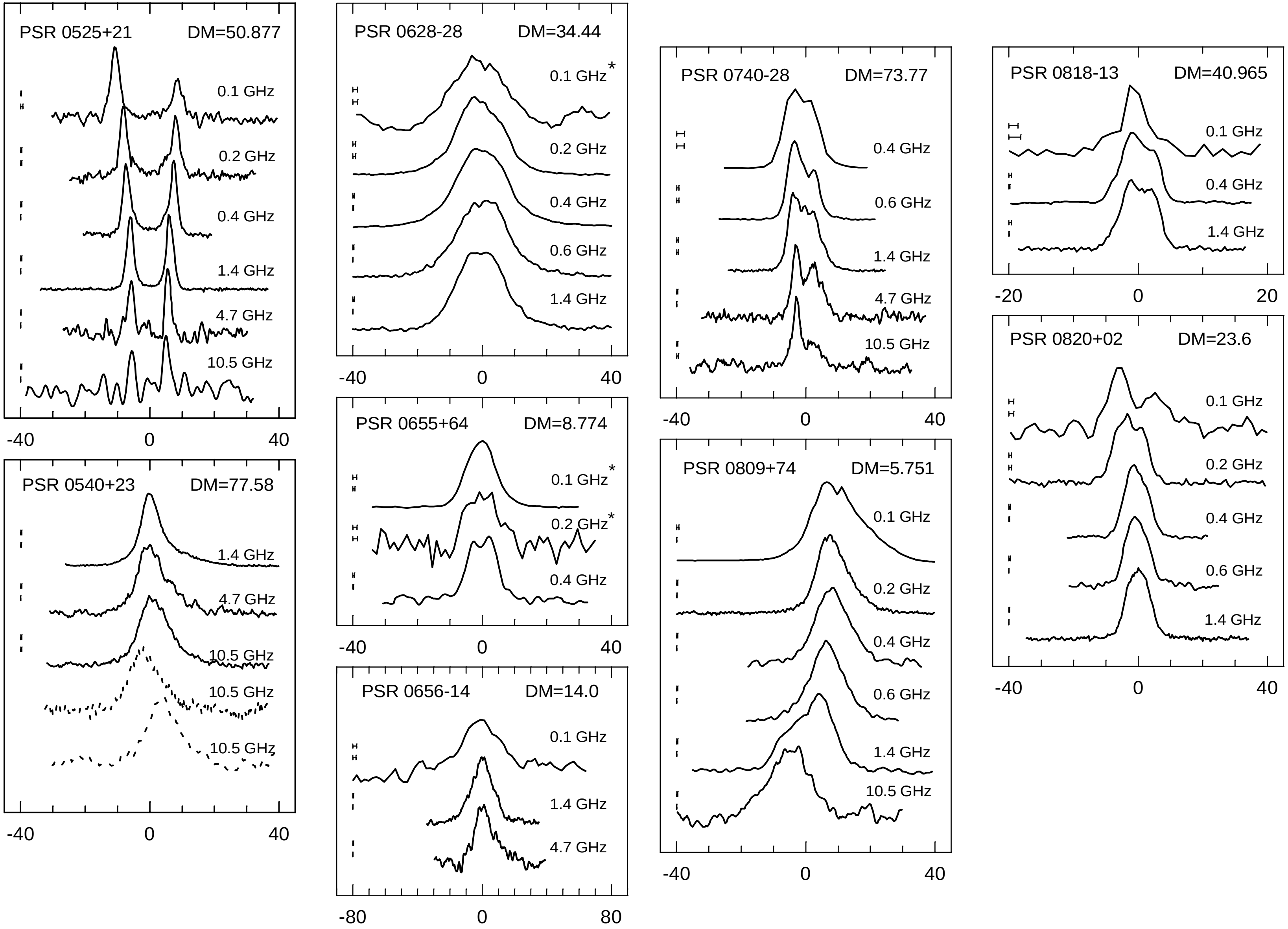


Fig. 2. Aligned profiles of 56 pulsars. The error bars in the upper left corner of each frame denote the smearing due to the sampling interval and due to the dispersion across the bandwidth. The dispersion measure used for the alignment is given in the upper right corner of each frame (abscissa in degrees of pulsar rotation period)



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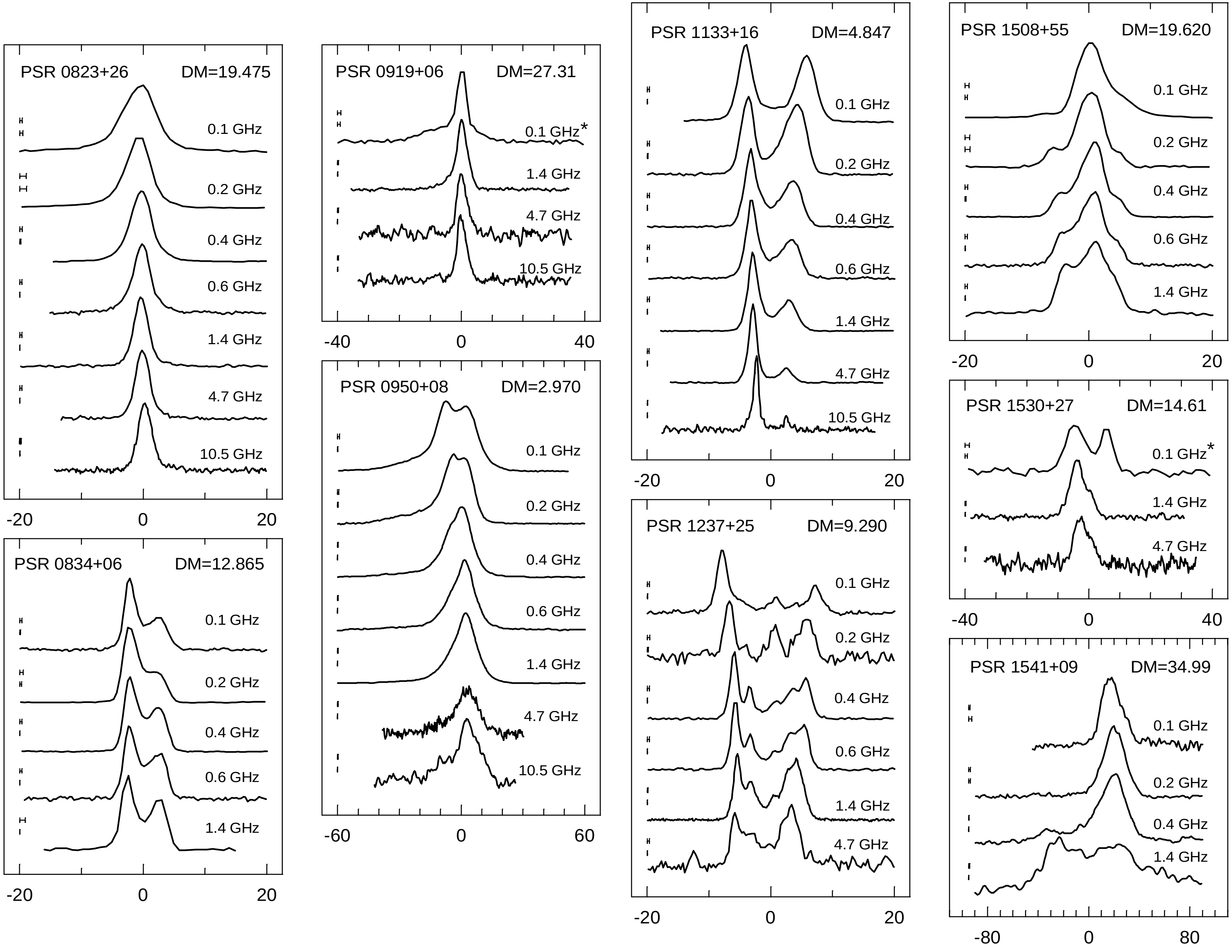

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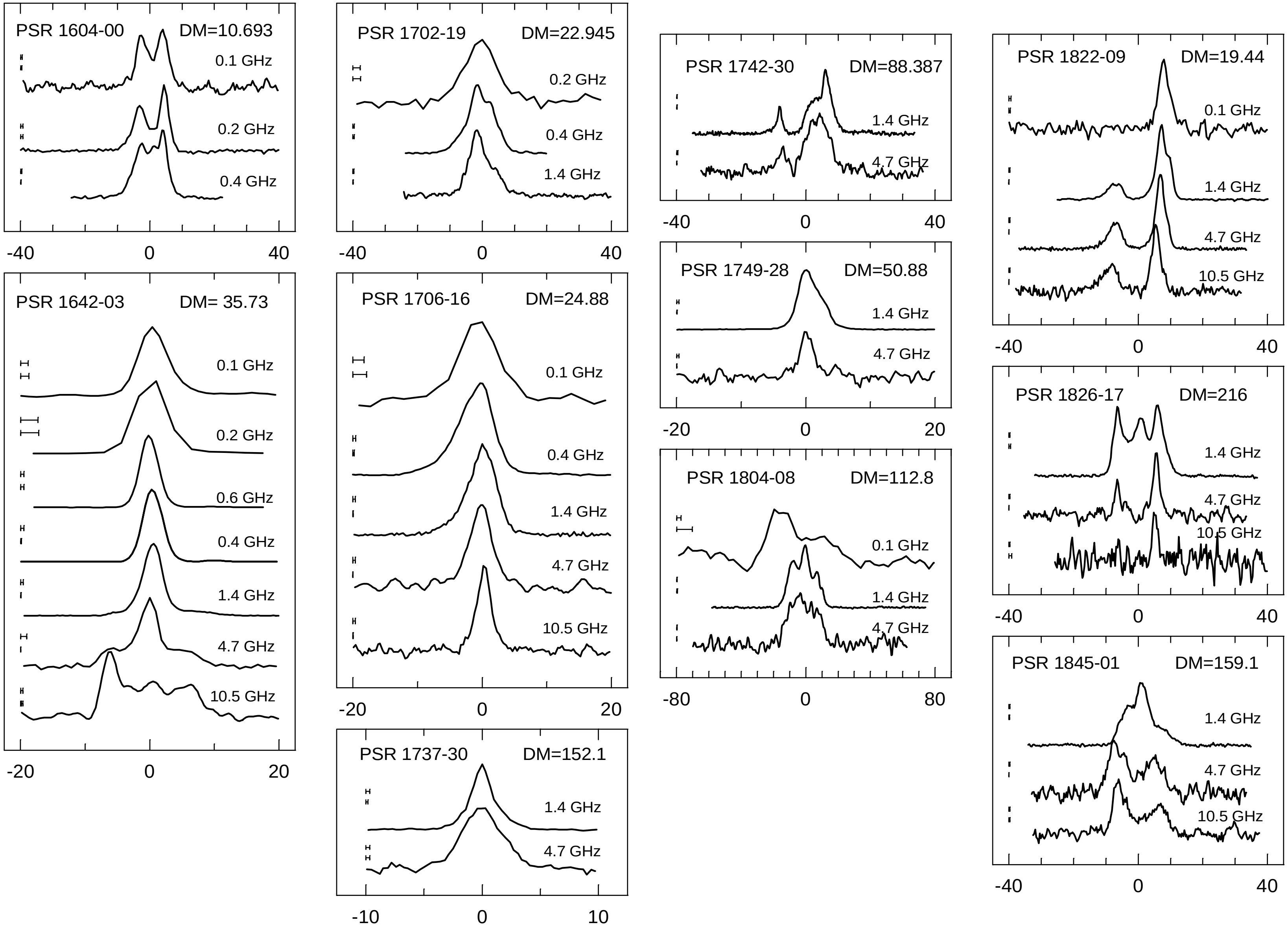

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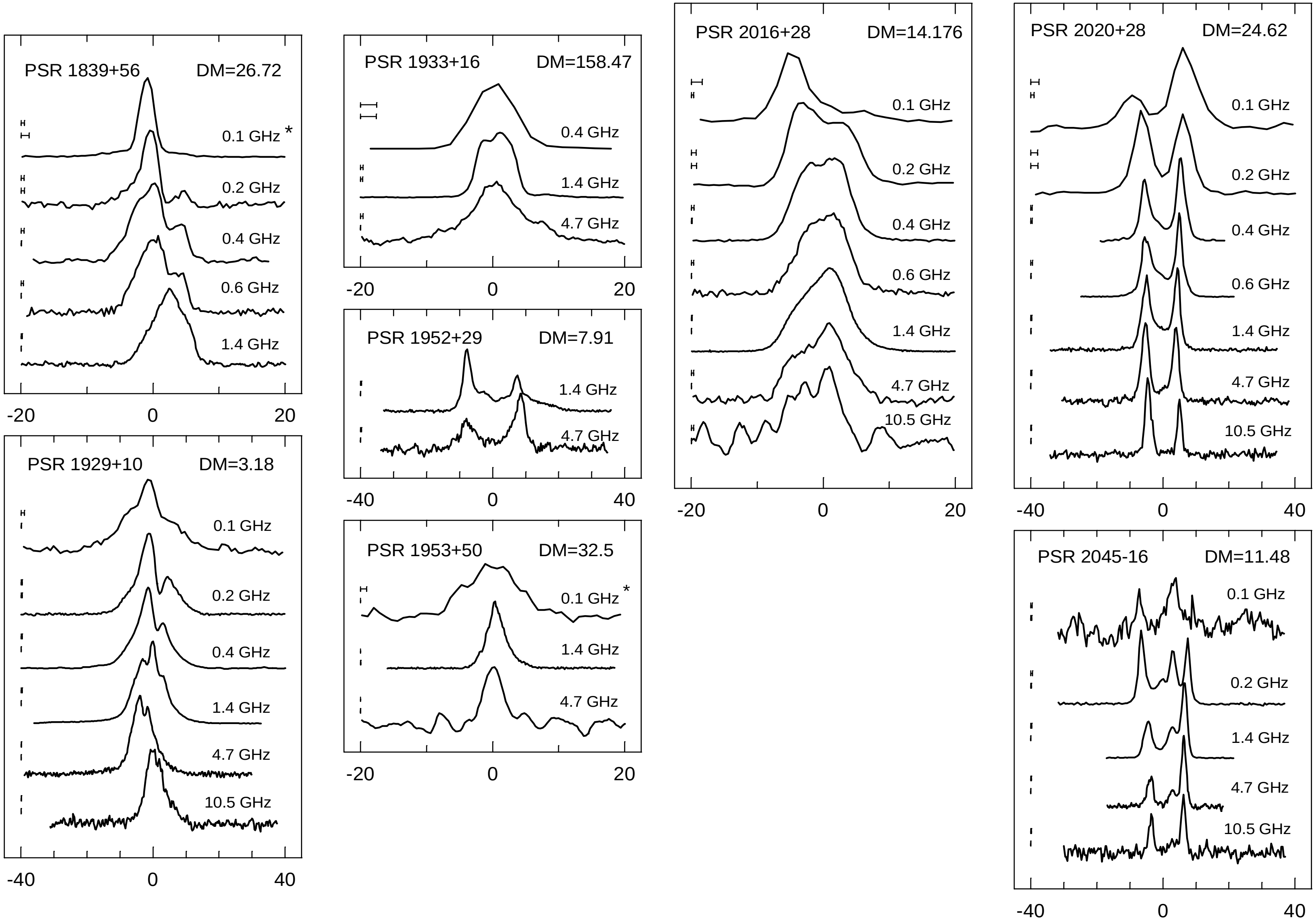

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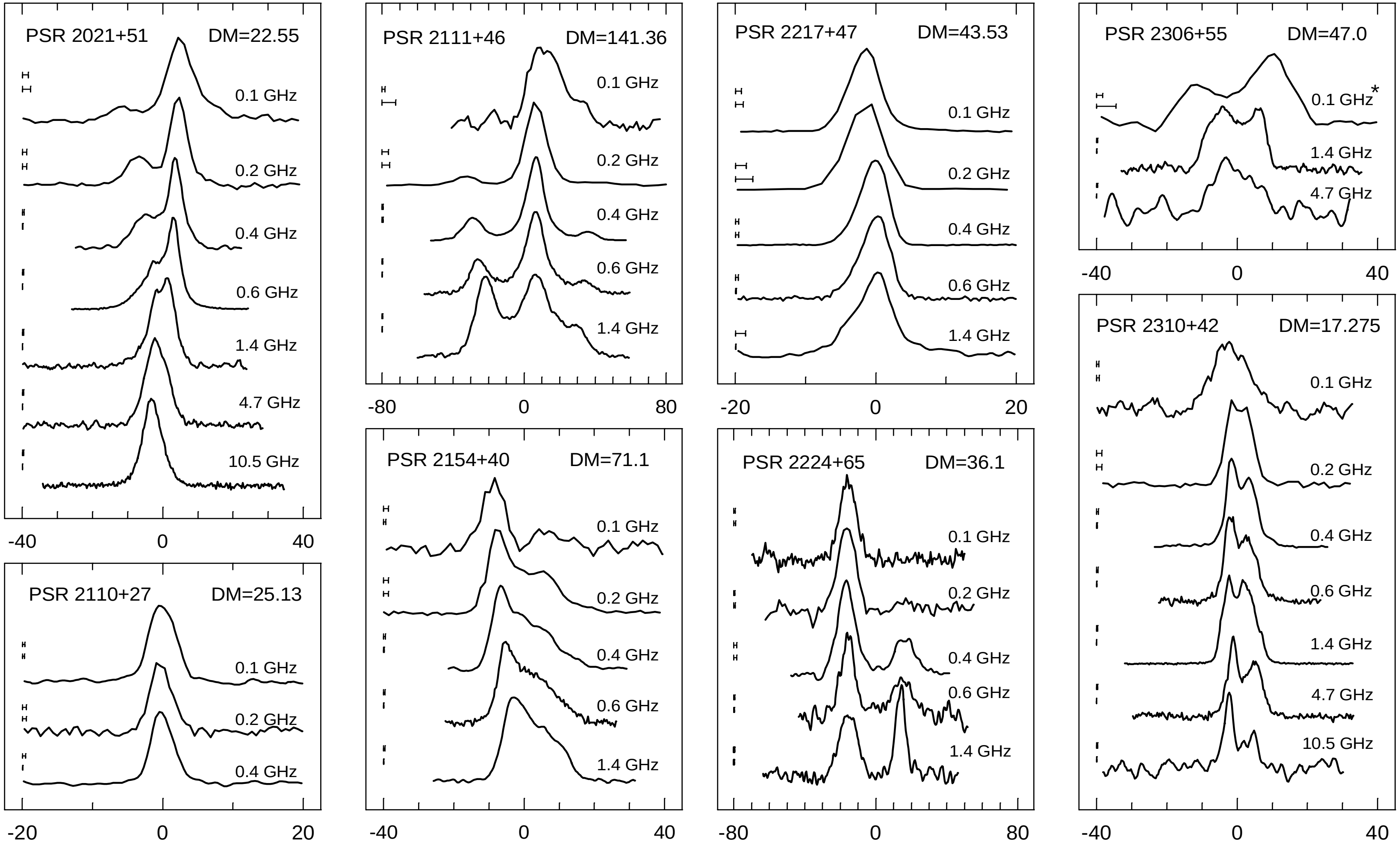

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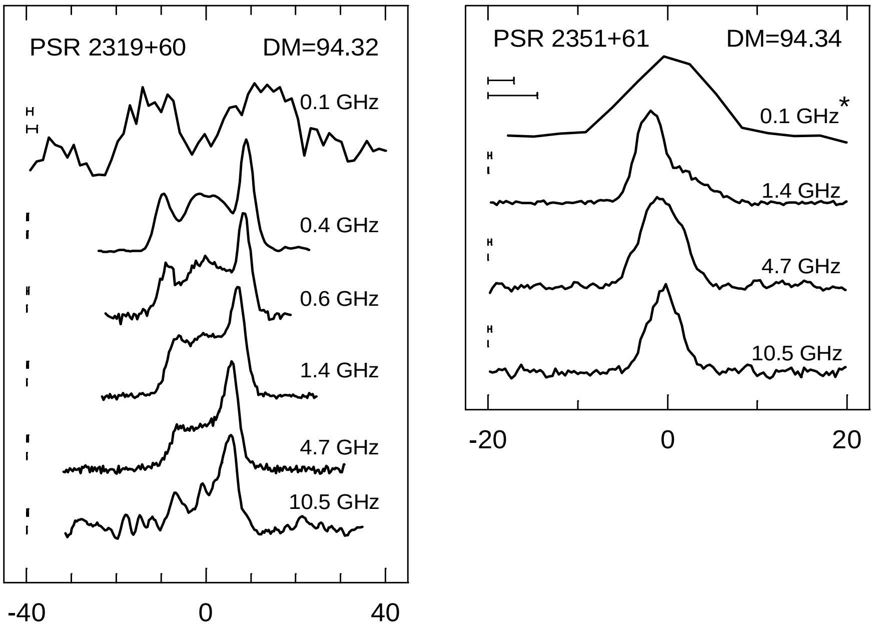

Fig. 2. continued

evident, when a decomposition of the average profile into gaussian components is undertaken, as will be shown in a forthcoming paper, which is devoted to the analysis of the catalogued aligned profiles.

However, not all non-dispersive phase shifts at high frequencies can be explained easily by intensity variations of the individual components. It is much harder to explain the non-dispersive phase shift at high frequencies of PSR 0809+74 as discussed already by Bartel et al. (1981), Davies et al. (1984), and Kuzmin et al. (1986). Non-dispersive time shifts at high frequencies are indicated also for the pulsars PSR 0138+59, 1822−09, 2021+51, and 2154+40. It must be said, however, that the data for PSR 0138+59, 1822−09, and 2154+40 are based on few measurements only and need further confirmation. We have listed these pulsars with their corresponding phase shifts in Table 2, a minus sign indicating that the profile is shifted to earlier phase. A detailed interpretation and model for this non-dispersive phase shift at high frequencies may be found in Davies et al. (1984) and Kuzmin et al. (1986).

The measurements of PSR 0450+55 at 10 GHz show only a weak signal-to-noise ratio so that exact conclusions on phase shift with respect to lower frequencies are hard to make. We should also remark that three differing profiles were observed for PSR 0540+23 at 10.5 GHz on the same day at different times. We show these profiles in Fig. 2 since there exists the possibility that all three are real, the difference being produced by mode changes. Future measurements must clarify this point.

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References

Bartel N., Kardashev N.S., Kuzmin A.D., Nicolaev N.Ya., Popov M.V., Sieber W., Smirnova T.V., Soglasnov V.A., Wielebinski R., 1981, A&A 93, 85

Davies J.G., Lyne A.G., Smith F.G., Izvekova V.A., Kuzmin A.D., Shitov Yu.P., 1984, MNRAS 211, 57

Hankins T.H., Rickett B.J., 1986, ApJ 311, 684

Izvekova V.A., Jessner A., Kuzmin A.D., Malofeev V.M., Sieber W., Wielebinski R., 1994, A&AS 105, 235

Izvekova V.A., Kuzmin A.D., Malofeev V.M., Shitov Yu.P., 1989, Change in the Shape and Temporal Position of Integrated Profiles of Pulsars with Frequency. In: Kuzmin A.D. (ed.), Pulsars, Proc. Lebedev Phys. Inst., Nayka Publ. Co. Moscow, Vol. 199, p. 13; translated into english by Nova Science Publ. Inc., New York, 1992, Vol. 196, p. 17

Kuzmin A.D., Malofeev V.M., Izvekova V.A., Sieber W., Wielebinski R., 1986, A&A 161, 183

Kuzmin A.D., Izvekova V.A., 1993, MNRAS 260, 724

Kuzmin A.D., Losovsky B.Ya., 1996 (in preparation)

Morris D., Graham D.A., Sieber W., Bartel N., Thomasson P., 1981, A&AS 46, 421

Seiradakis J.H., Gil J.A., Graham D.A., Jessner A., Kramer M., Malofeev V.M., Sieber W., Wielebinski R., 1995, A&AS 111, 205

Taylor J.H., Manchester R.N., Lyne A.G., 1993, ApJS 88, 529

Taylor J.H., Manchester R.N., Lyne A.G., Camilo F., 1995 (unpublished work)