SCATTERING OF THE LOW FREQUENCY PULSAR RADIATION

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Abstract. We report the results of the measurements and analysis of the pulse broadening due to interstellar scattering on 43 pulsars at 102 MHz. This is the largest uniform sample of direct measurements of pulsar scattering τ_{sc}, which make it feasible to analyze the dependence of this value on other pulsar parameters. The measured dependence of τ_{sc} on dispersion measure $\tau_{sc}(DM) = 40(DM/100)^{2.1}$ is close to theoretically expected relation $\tau_{sc}(DM) \propto DM^2$. A frequency dependence of the scattering pulse broadening is weaker than commonly accepted $\tau_{sc} \propto \nu^{-4.4}$.

1. Introduction

Pulsars are a very good tool for probing the interstellar medium. The fact that pulsars are effectively point sources and their signals are of pulsed nature makes them ideal for studying interstellar scattering.

Multipath propagation caused by interstellar scattering leads to time-frequency scintillations, characterized by decorrelation bandwidth $\Delta\nu_{sc}$, angular broadening of a source, characterized by scattering angle θ_{sc} and temporal pulse broadening, characterized by τ_{sc}-time constant for exponential broadening of a pulse by interstellar scattering. The subject of our study is the measurement of τ_{sc} and analysis of its dependence on dispersion measure and frequency.

From the basic theory,

$$\tau_{sc} \propto DM^2\nu^{-4}, \tag{1}$$

where DM is dispersion measure and ν is frequency. Existing experimental data yield very controversial evaluation of $\tau_{sc}(DM)$ and $\tau_{sc}(\nu)$ dependencies.

2. $\tau_{sc}(DM)$ Dependence

The most extensive data on τ_{sc} for 143 pulsars are presented in the catalog of 706 pulsars (Taylor *et al.*, 1995). For these data $\tau_{sc}^{ctlg}(DM) \propto DM^{3.9}$ which is very different from the theoretical dependence.

However most of the catalog data are based not on direct measurements of τ_{sc}, but on the measurements of $\Delta\nu_{sc}$ and conversion of this value to τ_{sc} assuming that

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TABLE I

Scattering broadening of pulsar profiles at 102 MHz (in millisecond)

PSR	τ_{sc}	PSR	τ_{sc}	PSR	τ_{sc}
B0011+47	4	J1012+5307	0.5	B1915+13	40
B0045+33	7	J1022+10	0.7	B1920+21	200
B0114+58	13	J1025–0709	0.3	B1953+50	0.9
B0136+59	20	B1257+12	0.5	J2019+2425	0.6
B0138+59	1.4	B1541+09	15	B2111+46	150
B0144+59	4.7	B1639+36A	3	B2113+14	25
B0331+45	3.5	B1642–03	1.5	B2145+40	60
B0355+54	5	B1706–16	1.8	B2217+47	3
B0402+22	50	J1713+0747	0.7	B2224+65	6
B0531+21	30	B0818–04	100	B2310+42	2.3
B0611+22	30	B1821+05	6	J2322+2057	0.5
B0626+24	10	B1831–04	50	B2334+61	5
B0818–13	8.5	B1839+56	1.3	B2351+61	25
B0823+26	0.4	B1907+03	95		
B0919+06	2.5	BJ1911–04	35		

$2\pi\,\tau_{sc}\Delta\nu_{sc} = 1.53$. Besides this in order to reduce these data to the same frequency one assumes the frequency dependence $\tau_{sc} \propto \nu^{-4.4}$. Therefore, the catalog data are not uniform and are based on assumptions which need to be experimentally tested.

Direct measurements of τ_{sc} have been made for only a small number of pulsars. The largest samples are 17 pulsars at a frequency of 410 MHz and 15 pulsars at 160 MHz by Alurkar *et al.* (1986), 17 pulsars at 102 MHz by Kuzmin *et al.* (1988) and 25 pulsars at 640 MHz by Johnston (1990). The small number of pulsars and the different measurement frequencies complicate the analysis of τ_{sc} and its dependence on dispersion measure and other parameters. We provided direct measurements of the scattering pulse broadening τ_{sc} for the largest number of pulsars (43) at one frequency, 102 MHz.

The scatter broadening τ_{sc} was derived from our observations of pulsar profiles (Kuzmin and Losovsky, 1999). We utilize the Alurkar *et al.* (1986) procedure of generating a model scattering profile by the scatter of a Gaussian template pulse and a least-squares fit to the observed profile. The values of τ_{sc}, the width and position of a Gaussian template pulse were obtained as adjustable parameters by the fitting procedure. Results are listed in the Table I and are shown in Figure 1 as a dispersion measure $\tau_{sc}(DM)$ dependence.

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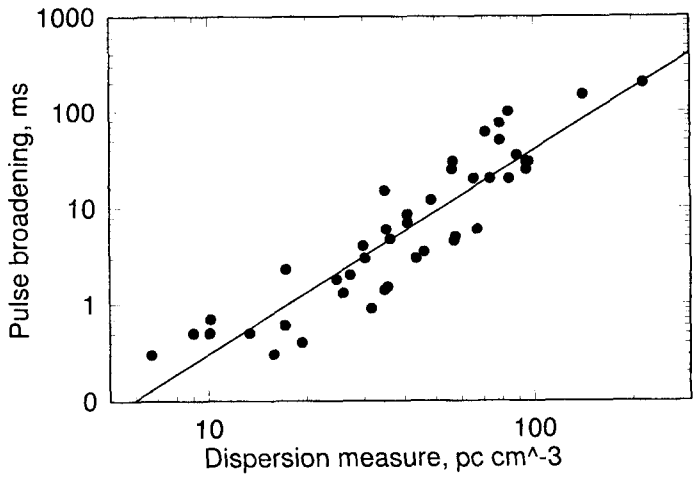

Figure 1. Dependence of the pulse broadening on dispersion measure. This solid line is the regression $\tau_{sc}(DM) = 40DM^{2.1\pm0.2}$.

The dispersion measure dependence, $\tau_{sc}(DM) \cong 40_{milisecond} DM^{2.1\pm0.2}$, confirms the basic theory that $\tau_{sc}(DM) \propto DM^2$, but substantially differs from this dependence for the catalog data, $\tau_{sc}^{ctlg} \propto DM^{3.9}$. This suggests that the conversion of the scatter broadening from the decorrelation bandwidth $\Delta\nu_{sc}$ as $2\pi\tau_{sc}\Delta\nu_{sc} = 1.53$ and its frequency dependence $\tau_{sc}(\nu) \propto \nu^{-4.4}$ need to be reconsidered.

3. $\tau_{sc}(\nu)$ Dependence

The frequency dependence $\tau_{sc}(\nu) \propto \nu^{\beta}$ is even more uncertain. The main difficulty is that there are very few measurements of $\tau_{sc}(\nu)$ of the same pulsar at different frequencies.

Direct measurements of τ_{sc} over a wide frequency range were performed for only one pulsar, PSR 0833-45 (Ables *et al.*, 1970). They derived $\beta = -4$. However this sole measurement was not confirmed for other pulsars. An analysis of τ_{sc} measured at 102 and 160 MHz (Kuzmin *et al.*, 1988) indicates much weaker frequency dependence. A mean value of β for 7 the pulsars under analysis is –3.0.

Using Gould and Lyne (1998) pulsar profiles we performed measurements of the τ_{sc} for 6 pulsars over the wider frequency range 0.1–1.6 GHz and obtained a weak frequency dependence also. The mean value of $\beta = -2.7$ is much less than the theoretical $\beta = -4$ or the commonly adopted $\beta = -4.4$. However, this analysis of the frequency dependence of $\tau_{sc}(\nu)$ was made with a small number of pulsars and needs further study.

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4. Summary

Direct measurements of the temporal scatter broadening of pulsar profiles, τ_{sc}, for the largest uniform sample of 43 pulsars including 8 millisecond ones have been performed. The dispersion measure dependence $\tau_{sc}(DM) \cong 40 \times DM^{2.1\pm0.2}$ has confirmed the basic theory that $\tau_{sc}(DM) \propto DM^2$. The frequency dependence of the scatter pulse broadening is weaker than the commonly accepted $\tau_{sc}(\nu) \propto \nu^{-4.4}$.

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References

Ables, J.G., Komesaroff, M.M. and Hamilton, P.A.: 1970, Pulse broadening of PSR 0833-45 by interstellar scattering, *Astrophys. Lett.* **6**, 147–150.

Alurkar, S.K., Slee, O.B. and Borba, A.D.: 1986, Scattering of pulsar radiation and electron density turbulence in the interstellar medium, *Aust. J. Phys.* **39**, 433–448.

Gould, D.M. and Lyne, A.G.: 1998, Multifrequency polarimetry of 300 radio pulsars, *Mon. Not. R. Astron. Soc.* **301**, 235–260.

Johnston, S.: 1990, PhD thesis, Univ. of Manchester.

Kuzmin, A.D., Izvekova, V.A., Malofeev, V.M. and Shitov, Yu.P.: 1988, The scattering of pulsar radio emission at 102 MHz. A difference from the dependence $\tau_{sc}(\nu) \propto \nu^{-4}$, *Soviet Astron. Lett.* **14**, 140–144.

Kuzmin, A.D. and Losovsky, B.Ya.: 1999, Observations of the Mean profiles of Radio Pulsars and the Structure of their Emission Region at 102 MHz, *Astron. Rep.* **43**, 288–304.

Taylor, J.H., Manchester, R.N., Lyne, A.G. and Camilo, F.: 1995, Catalog of 706 pulsars, Unpublished work.