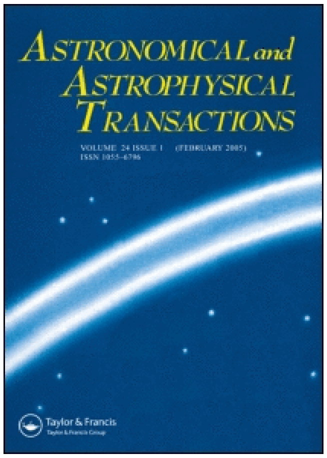

Astronomical & Astrophysical Transactions
The Journal of the Eurasian Astronomical Society
Publication details, including instructions for authors and subscription information:
http://www.informaworld.com/smpp/title~content=t713453505

Integrated profile of the Crab pulsar at low frequencies compensated for interstellar scattering

A. D. Kuzmin [a]; B. Ya. Losovsky [a]
[a] Pushchino Radioastronomical Observatory of the Lebedev Physical Institute, Russian Academy of Sciences, Pushchino, Moscow Region, Russia

Online Publication Date: 01 August 1999
To cite this Article: Kuzmin, A. D. and Losovsky, B. Ya. (1999) 'Integrated profile of the Crab pulsar at low frequencies compensated for interstellar scattering', Astronomical & Astrophysical Transactions, 18:1, 179 - 186
To link to this article: DOI: 10.1080/10556799908203054
URL: http://dx.doi.org/10.1080/10556799908203054

Astronomical and Astrophysical Transactions, 1999, Vol. 18, pp. 179–186
Reprints available directly from the publisher
Photocopying permitted by license only

INTEGRATED PROFILE OF THE CRAB PULSAR AT LOW FREQUENCIES COMPENSATED FOR INTERSTELLAR SCATTERING

A. D. KUZMIN and B. Ya. LOSOVSKY

Pushchino Radioastronomical Observatory of the Lebedev Physical Institute, Russian Academy of Sciences, 142292, Pushchino, Moscow Region, Russia

(Received December 17, 1996)

Integrated profiles of the Crab pulsar at frequencies 102, 111, 114, 127, 147, 158 and 196 MHz, compensated for interstellar scattering, are obtained. The component structure was analysed as a superposition of the Gaussian components. A previously unseen component preceding the interpulse has been detected. It is suggested that this so-called precursor is not a separate formation but the first component of the two-component main pulse. The widths of this two-component main pulse and the spacing between the components decrease with frequency but the space between the interpulse and the main pulse is nearly independent of frequency. The measured scattering broadening in the 100–196 MHz frequency range is $\tau_{sc}(f) = 25$ milliseconds $\times$ $(f_{\mathrm{MHz}}/100)^{-4}$.

KEY WORDS Integrated profile, PSR 0531+21, pulsars

1 INTRODUCTION

The Crab pulsar PSR 0531+21 is one of the few remarkable pulsars, which emit pulses in a very wide frequency range including radio wavelengths, optical X and γ-rays. At radio frequencies an integrated profile of the Crab pulsar has been observed by several authors (Rankin *et al.*, 1970; Manchester, 1971; Manchester *et al.*, 1972; Rankin and Counselman, 1973; Boriakoff and Payne, 1973; Vandenberg *et al.*, 1973; Lyne and Smith, 1993; Kuzmin *et al.*, 1996; Moffet and Hankins, 1996) at frequencies between 74 and 8400 MHz. At 400 MHz the integrated profile consists of three clearly visible components, referred to as the precursor, the main pulse and the interpulse. But low radio frequency observations of this pulsar, which are of specific interest for the study of the upper pulsar magnetosphere, are hampered by interstellar scattering. In Figure 1 we show the integrated profiles observed at 102 MHz (Kuzmin *et al.*, 1996), 111 MHz (Rankin *et al.*, 1970), 114, 127, 147 and 158 MHz (Manchester *et al.*, 1972), 196 MHz (Rankin *et al.*, 1970) and 410 MHz

(Manchester, 1971). At low frequencies the profiles are highly smoothed by scattering so the interpulse and the main pulse overlap to yield a broad single pulse which occupies the greater part of the pulsar period and no features corresponding to those at higher frequencies can be identified. The shape of the intrinsic pulsar profile at low frequencies was only a guess: it was taken as similar to that observed at high frequencies.

The method of compensation of the pulsar profiles for interstellar scattering, proposed by Kuzmin and Izvekova (1993), allows one to obtain the intrinsic pulse profile as derived from the observed profile. In the present work we apply this method for low frequency observations of the Crab pulsar in the 102–196 MHz frequency range and derive the intrinsic low frequency integral profiles.

2 OBSERVATIONS

Our observations at 102 MHz were performed in 1992–1994 with the Large Phased Array BSA radio telescope of Pushchino. Linear polarization was received. Dispersion was reduced by a 32×5 kHz filter bank. The sampling interval was 0.55 ms. The duration of the observing run of about 4 minutes was limited by the transit time of the pulsar through the beam of the radio telescope. Online synchronous integration of 6975 individual pulses in each of 39 observations was performed. An example of one observation integrated profile is shown in Figure 1. To increase the signal-to-noise ratio we averaged 15 observation sessions (104 625 individual pulses). This averaging also minimized the polarization distortion of the profile. At 111, 114, 127, 147, 158 and 196 MHz we used the Rankin *et al.* (1970), and Manchester *et al.* (1972) observing data, showed in Figure 1.

3 COMPENSATION FOR SCATTERING

To compensate the observed profile for interstellar scattering and restore the original profile we used a descattering method (Kuzmin and Izvekova, 1993). The descattered profile $x(t)$ was derived as

$$\begin{aligned} x(t) &= \frac{1}{2\pi} \int X(f) \exp(j2\pi f t)\, df \\ X(f) &= Y(f)/G(f). \end{aligned}$$

Here $X(f)$, $Y(f)$ are frequency spectra of the original, $x(t)$, and observed, $y(t)$, pulses and $G(f)$ is the frequency response of the scattering interstellar medium

$$G(f) = \frac{1}{2\pi} \int g(t) \exp(-j2\pi f t)\, dt.$$

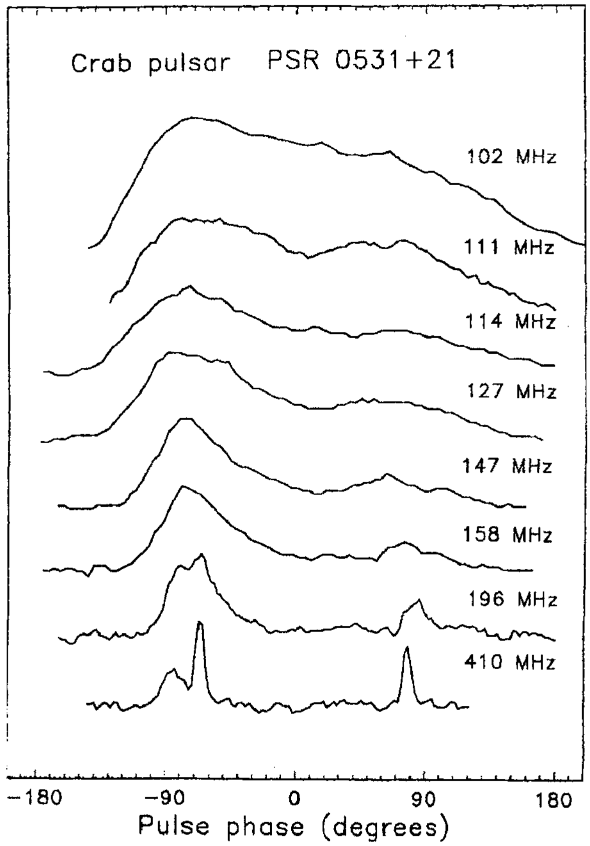

Figure 1 Observed integrated profile of Crab pulsar at 102 MHz (Kuzmin *et al.*, 1996); 111 MHz (Rankin *et al.*, 1970); 114, 127, 147 and 158 MHz (Manchester *et al.*, 1972); 196 MHz (Rankin *et al.*, 1970) and 410 MHz (Manchester, 1971).

We adopted a simple thin-screen scattering model with transfer function

$$g(t) = \begin{cases} \exp(-t/\tau_{sc}) & t \geq 0 \\ 0 & t \leq 0. \end{cases}$$

For more details of the descattering compensation procedure, including an account of the constant component of the observed pulsar radio emission, see Kuzmin *et al.* (1996).

The scattering pulse broadening τ_{sc} was measured from the observed profiles. At 102 MHz the mean value of all 39 observations is $\tau_{sc} \cong 30$ ms. For all 102–196 MHz profiles the measured value of the scattering broadening is approximated as $\tau_{sc}(f) = 25 \text{ ms} \times (f_{\text{MHz}}/100)^{-4}$. The product $\tau_{sc} \times f^4 = 25 \times 10^5 \text{ sec} \times \text{MHz}^4$ is close to the Rankin and Counselman (1973) estimation of this value at 111 and 196 MHz.

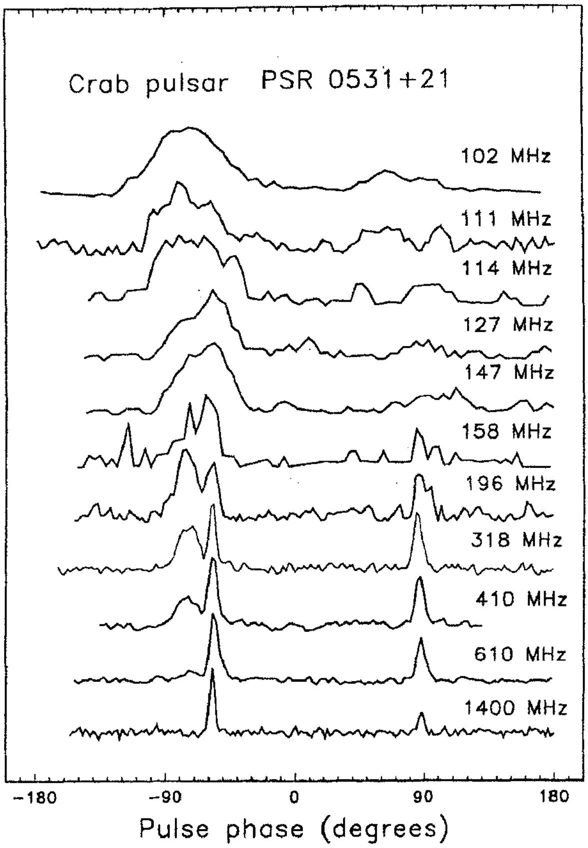

Figure 2 Descattered integrated profile at 102, 111, 114, 127, 147, 158, 196 MHz and observed integrated profiles at 318 MHz (Rankin *et al.*, 1970), 410 MHz (Manchester, 1971), 610 and 1400 MHz (courtesy of A. G. Lyne and F. G. Smith, 1993).

4 RESULTS

The resulting descattered profiles are shown in Figure 2. For frequency dependence analysis we also plot in this figure the integrated profiles at higher frequencies 318 (Rankin *et al.*, 1970), 410 (Manchester, 1971), 610 and 1400 MHz (Lyne and Smith, 1993).

In addition to the three known components, usually referred to as the precursor, the main pulse and the interpulse (Rankin *et al.*, 1970) in the 102, 111, 114, 127, 147 and 158 MHz integrated profiles we detected a previously unseen fourth component, which preceded the interpulse by approximately 30°.

To analyse the structure of the integrated profile in an objective and quantitative way we used the presentation of the pulsar profile as a superposition of Gaussian components as proposed by Wu *et al.* (1992) and Foster *et al.* (1991).

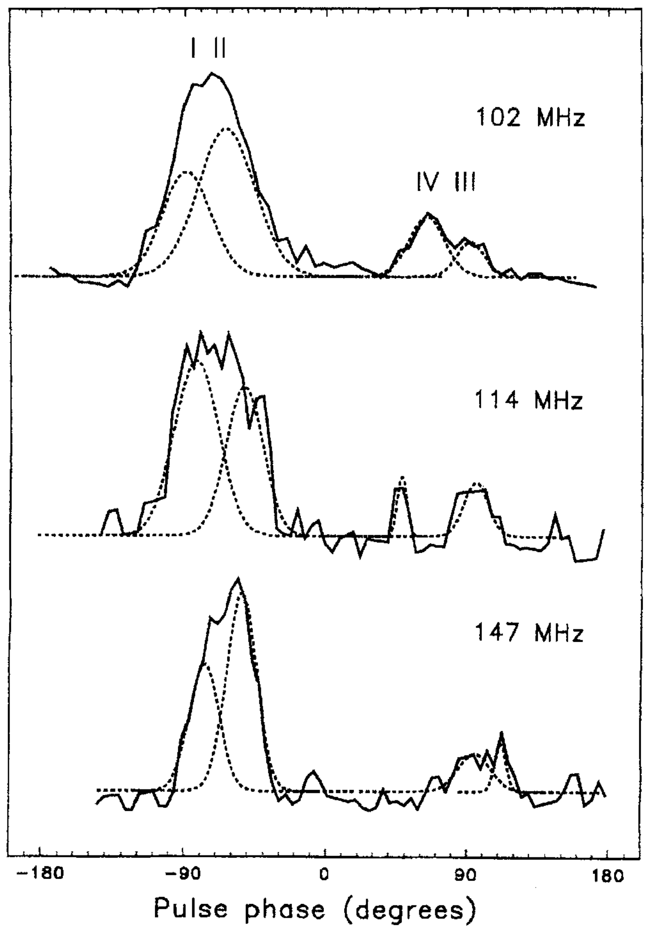

Figure 3 Descattered integrated profiles of Crab pulsar at 102, 114 and 147 MHz and its component structure.

The integrated profile $I(t)$ is represented as

$$I(\phi) = \sum a_k \exp(-2\ln((\phi - \phi_k)/w_k)^2)$$

where a_k, ϕ_k and w_k are the intensity, phase position and half-power width of the components. The component analysis of the 102, 114 and 147 MHz profiles is shown in Figure 3.

All the data of the component analysis are listed in Table 1. The phase of the component 2 was adopted as $\phi_2 = 0$.

The width of the components and the spacing between the first and second components decrease with frequency, but the space between the interpulse and the main pulse is nearly independent of frequency (Figure 4).

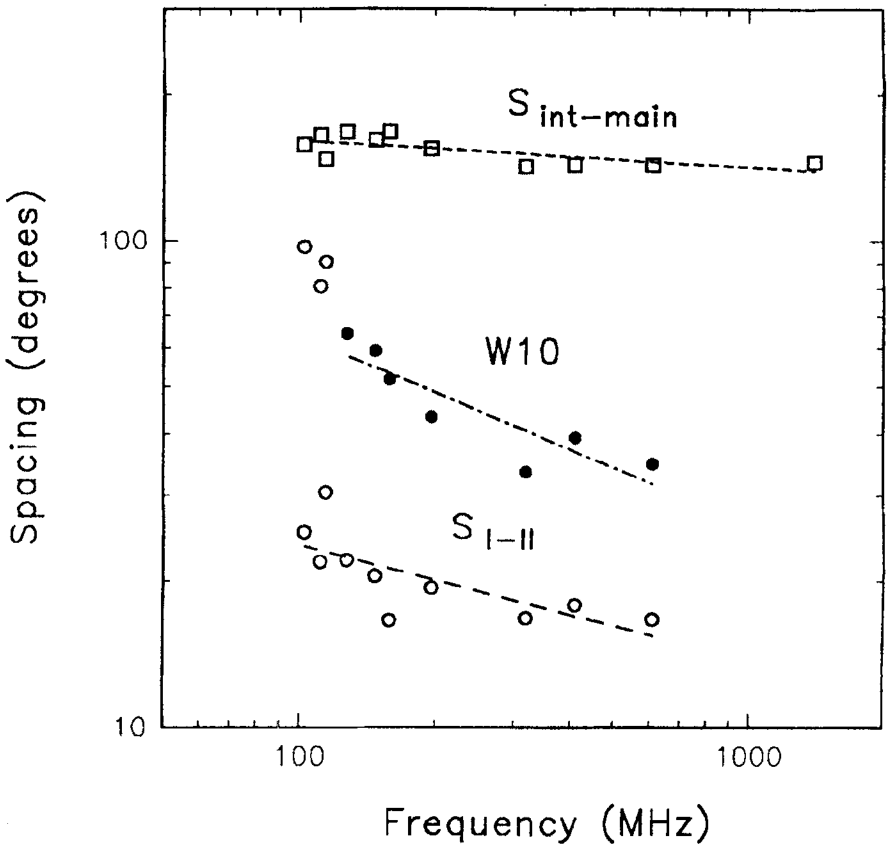

Figure 4 Frequency dependence of the spacing between the first and second components, the interpulse and the main pulse and the width of the two-component main pulse (at the 0.1 level).

The ratio of the amplitudes of the components depends on the frequency. The interpulse is a maximum near 300–400 MHz and decreases both to higher and to lower frequencies. The first component (precursor) is near equal to the main pulse below about 200 MHz and decreases at higher frequencies.

5 DISCUSSION

At 300–400 MHz the integrated profile consists of three components. The main pulse is usually referred to simply as the second component. The first, wider, highly polarized and steeper spectrum component, which precedes the main pulse, is referred to as the precursor (Rankin *et al.*, 1970). The third component, situated 13.37 ms after the main pulse is identified as the interpulse. However this identification is not indisputable. Differences in the spectra and polarization of the components of

Table 1. Gaussian fit parameters of the integrated profiles of the Crab pulsar (pulse widths w and phases ϕ are in degrees)

f (MHz)	102	111	114	127	147	158	196	318	410	608	1400
a_1	0.54	0.58	0.88	0.51	0.61	0.55	0.98	0.66	0.42	0.15	
w_1	36	37	33	24	20	26	18	16	16	12	
ϕ_1	−25	−22	−30	−22	−21	−17	−19	−17	−18	−17	
a_2	0.77	0.56	0.74	0.86	0.96	0.81	0.79	1.03	1.04	1.02	1.02
w_2	42	37	33	22	22	12	9	5	7	7	4
ϕ_2	0	0	0	0	0	0	0	0	0	0	0
a_3	0.18	0.32	0.27	0.1	0.23	0.29	0.60	0.88	0.73	0.61	0.30
w_3	21	10	22	10	10	17	12	7	7	7	4
ϕ_3	158	165	148	168	162	168	155	143	144	144	145
a_4	0.31	0.29	0.30	0.21	0.18	0.17					
w_4	27	26	10	24	24	7					
ϕ_4	128	126	100	134	142	112					
W_{10}	95	81	90	64	59	52	43	34	40	34	

the integrated profile are observed in a number of pulsars. For PSR 1952+29 and 2224+64 the spectrum of the first component is also steeper (Izvekova *et al.*, 1989); for PSR 1641–68, 1718–32 and 2020+28 the fist component exhibits a considerably greater polarization (Cordes *et al.*, 1978; Suleimanova, 1989; Wu *et al.*, 1993).

The frequency behaviour of the first and second components of the Crab pulsar integrated profile is similar to the frequency behaviour of the common pulsar profile. The spacing between the components and the width of this group decrease with frequency nearly as $f^{-1/3}$ (Figure 4) as is observed in many pulsar and is expected in a hollow-cone model. The width of this group fits the $W(P) = \theta \times P^{-1/2}$ dependence (Kuzmin and Dagkesamanskaja, 1983; Lyne and Manchester, 1988; Kuzmin *et al.*, 1996). We suggest that the so-called precursor is not a separate formation, but the first component of a two-component main pulse.

Acknowledgements

The authors are grateful to A. G. Lyne and F. G. Smith for provision of the 610 and 1400 MHz Crab pulsar data. This work was supported in part by INTAS (Grant 94–3097).

References

Boriakoff, V. and Payne, R. R. (1973) *Astrophys. J. Lett.* **15**, 175.
Cordes, J. M., Rankin, J. M., and Backer, D. C. (1978) *Astrophys. J.* **223**, 961.
Counselman, C. C. and Rankin, J. M. (1971) *Astrophys. J.* **166**, 513.
Foster, R. S., Fairhead, L., and Backer, D. C. (1991) *Astrophys. J.* **387**, 687.
Izvekova, V. A., Kuzmin, A. D., Malofeev, V. M., and Shitov, Yu. P. (1989) *Proc. Lebedev Phys. Inst.* **199**, 13.
Kuzmin, A. D. and Dagkesamanskaja, I. M. (1983) *Sov. Astron. Lett.* **9**, 80.
Kuzmin, A. D. and Izvekova, V. A. (1993) *Mon. Not. R. Astron. Soc.* **260**, 724.

Kuzmin, A. D., Losovsky, B. Ja., and Sitnikov, D. Yu. (1996) *Sov. Astron. Lett.* **22**, 359.
Lyne, A. G. and Manchester, R. N. (1988) *Mon. Not. R. Astron. Soc.* **234**, 477.
Lyne, A. G. and Smith, F. G. (1993) private communication.
Manchester, R. N. (1971) *Astrophys. J.* **163**, L61.
Manchester, R. N., Huguenin, G. R., and Taylor, J. H. (1972) *Astrophys. J.* **174**, L19.
Moffet, D. A. and Hankins, T. H. (1996) *Astrophys. J.* **468**, 779.
Rankin, J. M., Comella, J. M., Craft, H. D., Richards, D. W., Campbell, D. B., and Counselman, C. C. (1970) *Astrophys. J.* **162**, 707.
Rankin, J. M. and Counselman, C. C. (1973) *Astrophys. J.* **181**, 875.
Suleymanova, S. A. (1989) *Proc. Lebedev Phys. Inst.* **199**, 42.
Vandenberg, N. R., Clark, T. A., Ericson, W. C., Resch, G. M., Broderick, J. J., Payne, R. R., Knowless, S. H., and Youmans, A. B. (1973) *Astrophys. J.* **180**, L27.
Wu Xinji, Xu Wen, and Rankin, J. M. (1992) In: Hankin *et al.* (ed.), *Proceedings of IAU Symposium No. 128*, Pedagogical University Press, p. 172.