A Further Investigation on the Central Beam of PSR B1237+25

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Abstract By using Gaussian-components fitting, Qiao et al (2000) pointed out that the central or core emission beam may be hollow. In this paper, by developing a quantitative criterion for the fitting procedure, we prove that the mean profile of the pulsar PSR B1237+25 is composed of six Gaussian components, which confirms that the core beam is hollow. From the fitted results, further information of the radio emission region is obtained based on the Invert Compton Scattering model (ICS model). The Lorentz factor of secondary particles for this pulsar is estimated to be 1000 ~3000.

1 Introduction

Various kinds of pulse shapes have been observed, which results from a combination of certain configurations within the radio emission beam and the viewing geometry (how the line of sight sweeps across the emission beam). In the early days, the limited handful of profiles are mostly single or double-peak ones, leading to the hollow cone model (Radhakrishnan & Cooke 1969, Ruderman & Sutherland 1975). As more and more complex profiles were observed, Rankin (1983) firstly made an empirical classification for pulsar average profiles and distinguished two different kinds of emission components, the central 'core' and outer 'cone' components, which was confirmed by Lyne & Mancherster (1988, hereafter LM88). However, whether the mechanisms of the core and conal emission are the same (LM88) or not (Rankin 83) is still an open issue.

Since the 90s' last century, the method of Gaussian decomposition for the mean pulse profile has been developed (Wu et al 1992, Kramer et al. 1994, Kuz'min & Izvekova 1996, Wu et al 1998) to study the emission structure of the pulsar. Qiao et al.(2000) applied this method to PSR B1237+25, and found that six individual components could be separated at five observing frequencies. They suggested that the core beam may be hollow. This provides a severe challenge to the previous concept that the core beam is solid conceived by various models(e.g. Beskin et al 1988, Wang et al.1989, Rowe 1992, Weaherfall & Eilek 1997). The authors suggested that the Inverse Compton Scattering (ICS) model (Qiao 1988 a,b, Qiao 1992, Qiao & Lin 1998) could naturally explain the very complex emission beam composed of a hollow core and two outer cones.

Here we further investigate the profile decomposition of this pulsar by improving the criterion of goodness-of-fit for the fitting procedure. In section 2 the method of decomposition is described and the results are presented. In section 3 we derive the initial Lorentz factor of secondary particles and the impact angle based on the ICS model. Conclusions and discussions are made in section 4.

2 The Gaussian Decomposition of PSR B1237+25 with New Criteria

In this section we introduce our new criteria and show the numerical results of the decomposition of PSR B1237+25 at four frequencies (0.1, 0.925, 1.4 & 4.75 GHz). The mean profiles of high signal-to-noise ratio are chosen from the EPN database.

We follow the description of the decomposition approach given by Wu et al. (1998). Suppose that N Gaussian functions are selected to fit a mean profile, the reconstructed profile $f(x)$ is

$$f(x) = \sum_{i=1}^{N} \frac{h_i}{w_i\sqrt{\pi/2}} e^{\frac{(x-p_i)^2}{w_i^2}} , \tag{1}$$

The difference between $f(x)$ and the observational data $x_{\rm i}, y_{\rm i}$ is defined as

$$Q = \sum_{j=1}^{M} [f(x_{\rm i}) - y_{\rm i}]^2 , \tag{2}$$

where M is the number of the data. And the fitting residual is

$$Res = \sqrt{\frac{Q}{M}} = \sqrt{\frac{\sum_{j=1}^{M}[f(x_i) - y_i]^2}{M}} . \tag{3}$$

It is easily to see that when Q reaches its minimum so does the Res.

For a given number of Gaussian components, two conditions must be satisfied to obtain the best fitting. First, the residual should be minimized, and second, the residual should have similar amplitude to the off-pulse noise (Kuzmin et al 1996).

Obviously, the residual keeps decreasing when more and more Gaussians are involved. But the best fitting is not to let the residual as small as possible. Because the excessive ones are only used to fit the noise, and these redundant components do not reflect the reality. Here we present a new criterion to determine the best-fitting number.

When we use less Gaussians than the real number of components to fit the profile, each Gaussian fits a component. And the reduction will become slower than before when excessive Gaussians are involved, because the excessive Gaussians are just used to fit the noise and the noise is much weaker than the emission component. (That is why we chose the data with high signal to noise ratio.) Therefore, the breaking point of the residual-to-number curve is a good indicator of the real component number.

In this paper, we synthesize the above three points, viz., (a) the breaking point, (b) the residual should have similar amplitude as the off-pulse noise, and (c) the residual should be minimized, to decide the best-fitting number.

The mean profiles of PSR B1237+25 are fitted by 4, 5, 6 and 7 Gaussians at four frequencies; an additional 8-component fitting is made at 1.4 GHz. The residual-to-number curve is presented by Fig.1. We can see that when N=5 the residual is larger than the off-pulse noise at each frequency. So the N should be greater than 5. The residual of 6 Gaussians is similar to that of 7. But the braking point apparently indicates that the number should be less than 7. So 6 is the best fitting.

3 Discussion

The improved criterion make the result a further and solider support to the previous suggestion that the core beam is hollow (Qiao et al. 2000). In is section we reanalyze the physical implications of the new data in the frame of ICS model.

The main idea of this model is: the low frequency ($\nu_0 \sim 10^6$ Hz) photons produced by the inner gap sparking are inverse Compton scatted up to high frequency (observed radio bands) photons by the relativistic particles moving along the magnetic fields, when they are propagating through the magnetic field line, (Qiao 1988a,b, Qiao & Lin 1998). The

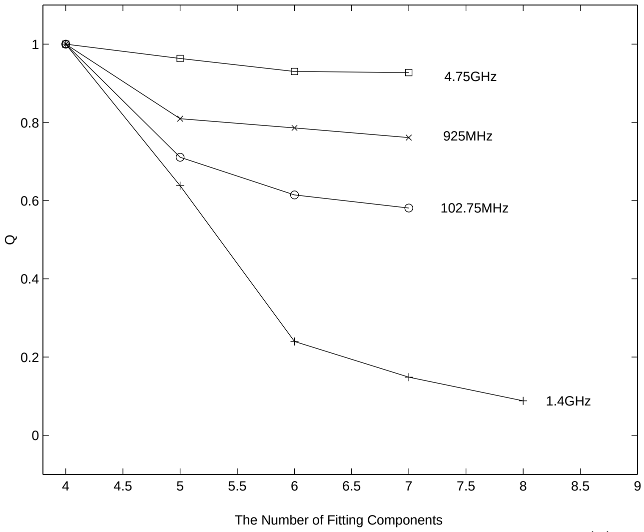

Fig. 1 This figure give the relation between the Q defined by (2) and the number of fitting components

frequency of the up-scattered radio photons is

$$\nu \simeq 2\gamma^2\nu_0\,(1-\beta\cos\theta_i)\ , \tag{4}$$

where γ is the Lorentz factor of the relativistic particles, $\beta=(1-1/\gamma^2)^{1/2}$, and θ_i is the incidence angle between a particle and a low frequency photon.

From emission geometry we have the relation between the θ_μ and θ_i, where θ_μ is the emission angle (cf. Qiao & Lin 1998). θ_μ is a function of the peak separation $\Delta\phi$ between the two counterparts of the same emission component (Gil 1984).

$$\sin^2(\theta_\mu/\,2)=\sin^2(\Delta\phi/4)\sin(\alpha)\sin(\alpha+\beta)+\sin^2(\beta/2)\ , \tag{5}$$

wherein α is the inclination angle between the rotation and magnetic axes, and β is the impact angle. we obtain $\nu(\Delta\phi)$, which is dependent on a series of parameters (ν_0, γ_0, P, R, α, β) (P is the pulsar rotation period.).

We are now concerning the core emission. For PSR B1237+25, $P=1.38$ s, ν_0 and R are assumed to be 10^6 Hz and 10 km, respectively, $\alpha=48.2^o$ given by LM88 is accepted. Then the free parameters reduce to two, γ_0 and β, which are expected to be constrained by fitting the peak separation of the core components. As demonstrated by Fig.2, β and γ_0 are confined from 0.9 to 1.1 degrees and from 1000 to 3000, respectively. Our result of β is coincident with that of LM88 (0.9^o)

4 Conclusions

Basing on the Gaussian decomposition method, we develop a new criterion for the decomposition procedure to determine the exact number of Gaussians. The mean pulse profiles of PSR B1237+25 are thus decomposed to six Gaussians at four frequencies, which are consistent with the results of Qiao et al.(2000) and provide a further and solider support to their viewpoint that the core beam is actually hollow.

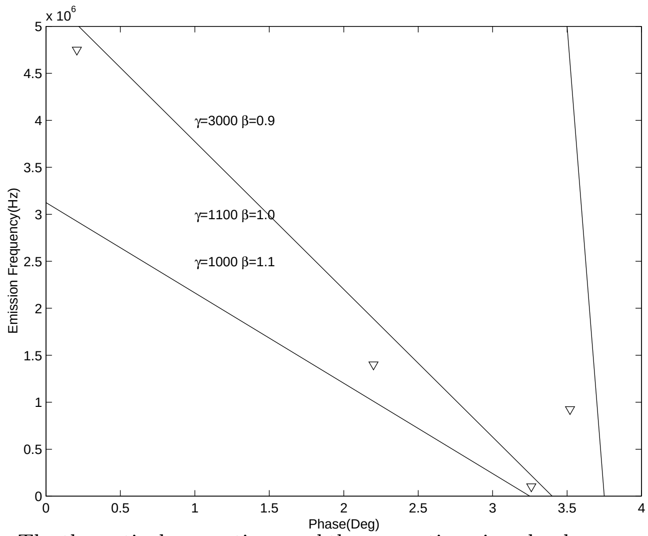

Fig. 2 The theoretical separations and the separation given by decomposition. By this fitting procedure we can constrain the β and the initial Lorentz factor from 0.9 to 1.1 and from 1000 to 3000. The delta symbol is the results by decomposition and the line is the theoretical results

The Inverse Compton Scattering model (ICS model) can naturally explain the hollow core. By comparing the model results and the phase separation between the two counterparts of the core, the initial Loretz factor of secondary particles and the impact angle are constrained to be from 1000 to 3000 and the impact angle from 0.9 to 1.1 degrees. The impact angle is consistent to LM88's results.

ACKNOWLEDGEMENTS We are grateful to Mr.Wang X.D for illuminative discussions. This work is partly supported by NSF of China, the Climbing Project-the National Key Project for Fundamental Research of China, and the Doctoral Programm Foundation of Institution of Higher Education in China.

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