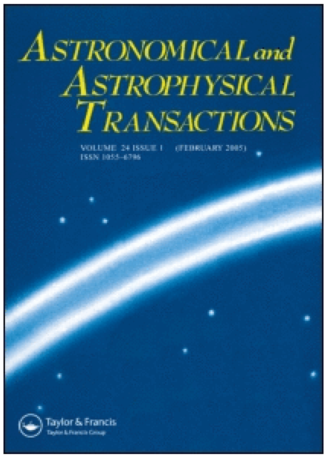

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Binary orbital orientation modelling

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BINARY ORBITAL ORIENTATION MODELLING

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The statistical dependence of the incline of the radiopulsar orbital plane to the Be-star equatorial plane on the characteristic kick velocity was calculated. These systems must have an orbital modulation effect of non-pulsatile Compton X-ray radiation if pulsar orbital and Be-star equatorial planes are not coplanar. The Be star is a rapidly rotating object and its temperature changes according to the von Zeipel theorem. That is why conditions for inverse Compton dispersion of optical photons emitted by the Be star on the relativistic particles in inclined systems change during the orbital period. This orbital modulation effect becomes about 10% or more if the angle between the pulsar orbital and Be-star equatorial planes is about 80° or higher. It is calculated that systems with this angle higher than 80° may exist owing to an additional kick during a supernova explosion and their number may reach 15% of visible binary 'radiopulsar–Be-star' systems.

Keywords: Pulsar; Radiopulsar; Kick; Be-star; Supernova Explosion

1 INTRODUCTION

Over 10 years have elapsed since the discovering of the first binary system consisting of a radiopulsar and a Be star: PSR B1259-63.

Pulsar PSR B1259-63 (spin period, 47.76 ms) was discovered using the 64 m Parks radiotelescope during a high-frequency watch of the southern Galactic plane (Johnston *et al.*, 1992a). The pulsar moves on a high elongated orbit ($e \geq 0.87$) around a massive optical companion identified as the tenth-magnitude Be star SS 2883 (Johnston *et al.*, 1992b).

This system has been observed more than once using X-rays. Non-pulsatile X-ray radiation of this system arises from the inverse Compton effect (Chernyakova and Illarionov, 1999).

In 1998 the possible evolutionary tracks for the systems psr B1259-63 and psr J0045-7319 were numerically calculated (Raguzova and Lipunov, 1998). Calculations were based on an evolutionary scenario that predicts the existence of systems including a radiopulsar and a massive optical star. The very high eccentricity was explained with the additional kick arising from anisotropic collapse during supernova explosion.

It was shown that the orbital modulation of the X-ray light curve of such systems must occur (Bogomazov and Lipunov, 2003). A pulsar is a source of relativistic particles that cause

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inverse Compton dispersion of soft optical photons from their companions. A Be star is a rapidly rotating object; so its temperature and brightness change for hot and bright at the pole to a ‘cool’ and ‘dark’ region on the equator according to the von Zeipel theorem. If the pulsar orbit lies in the Be-star equatorial plane, the conditions for the inverse Compton effect do not change but, in the case when the orbital plane is not coplanar with the Be-star equatorial plane, the optical light intensity (and Compton X-ray radiation too) must change between a maximum (the pulsar is over the pole of the optical star) and a minimum (the pulsar is over the equator). This effect modulates the orbit by about 10% or more if the angle between the pulsar orbital and Be-star equatorial planes is about 80° or higher.

Now one must ask the question: does such an inclined system exist? It is assumed that the additional kick velocity during supernova explosion is able to make the required modification of the orbital parameters.

2 NUMERICAL CALCULATIONS

A scenario machine was used for the numerical calculations. The statistical dependence of the pulsar orbital plane incline to the Be-star equatorial plane on the characteristic kick velocity was investigated.

A flat distribution of the kick direction was assumed; the kick quantity distribution is Maxwellian like:

$$f(v) \propto v^2 \exp\left(-\frac{v^2}{v_0^2}\right),$$

where $v_0 = 400\,\mathrm{km\,s^{-1}}$

Also circular star orbits lying in the equatorial plane of the companion just before supernova explosion were assumed.

In the case when the angle between the pulsar orbital and Be-star equatorial planes is lower than 10°, the system was regarded as ‘invisible’; the optical thickness for radio rays is too high in the Be-star disc plane.

3 RESULTS AND CONCLUSIONS

The results of the calculation are presented in Figure 1. If the order of magnitude of the characteristic kick velocity is $10\,\mathrm{km\,s^{-1}}$, there is an evident distribution peak near the smallest angles and no systems with large angles. Increasing the kick magnitude to $50\,\mathrm{km\,s^{-1}}$, a decrease in this peak is seen and some systems with large angles (over 80°) appear. Raguzova and Lipunov (1998) made their calculations for psr B1259-63 on the assumption of a kick velocity of $45\,\mathrm{km\,s^{-1}}$. In the case when the characteristic magnitude of the kick velocity is about $200\,\mathrm{km\,s^{-1}}$, the angular distribution is flat. Most systems with a kick velocity of $300\,\mathrm{km\,s^{-1}}$ or higher must decay; relic systems, which survived such a catalysm, do not form any distribution.

Thus we are able to assert that high-inclination systems must occur. If we assume a rational quantity for the characteristic kick velocity (between 50 and $300\,\mathrm{km\,s^{-1}}$), the number of systems with an inclination of about 80° or higher may reach 15% for kick velocities higher than $100\,\mathrm{km\,s^{-1}}$ and about 2–3% for kick velocities between 40 and $100\,\mathrm{km\,s^{-1}}$.

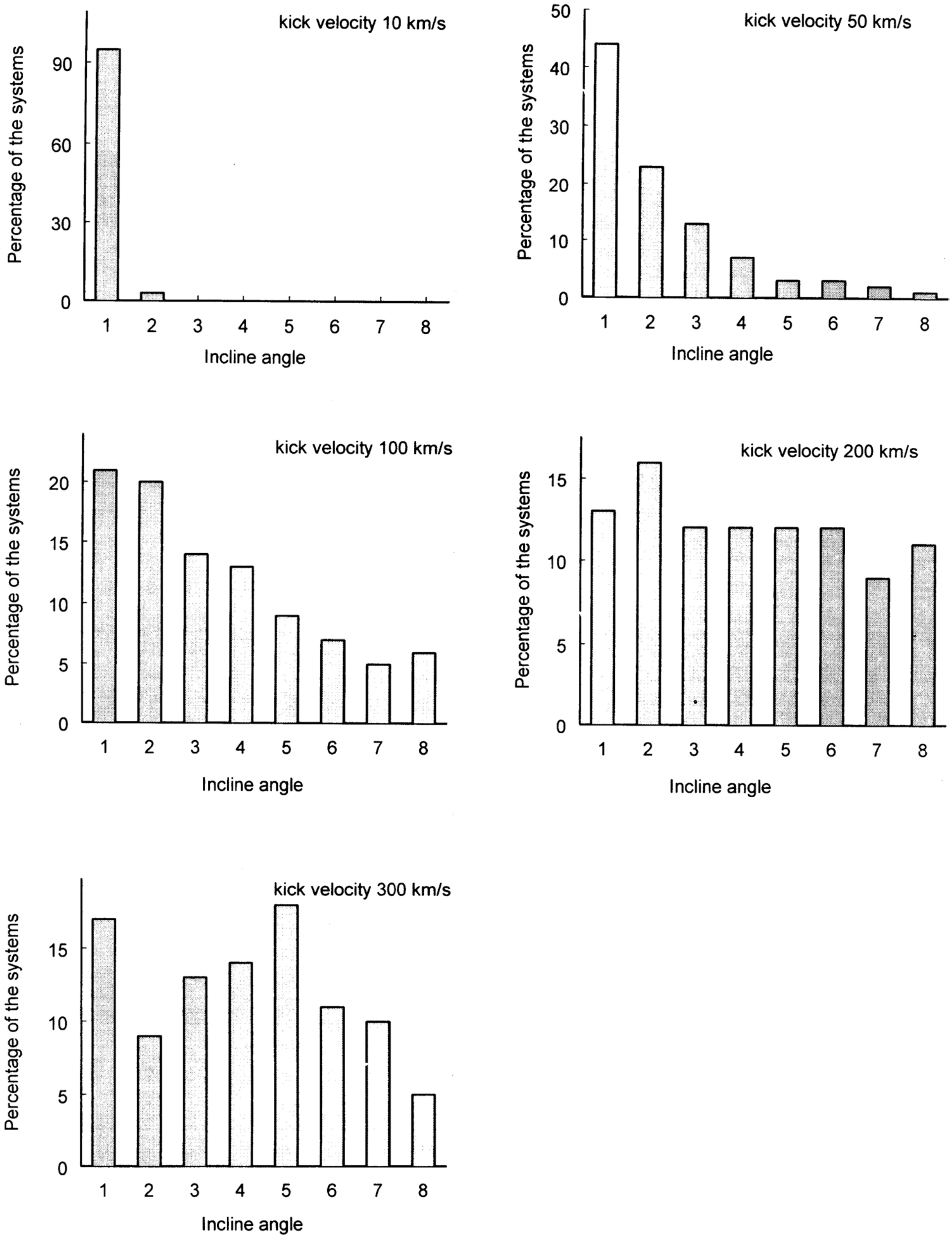

FIGURE 1 Bar graphs representing the percentage of systems according to their inclination α for various characteristickick velocities as indicated on the x axis with the following ranges: 1, $10^\circ < \alpha < 20^\circ$; 2, $20^\circ < \alpha < 30^\circ$; 3, $30^\circ < \alpha < 40^\circ$; 4, $40^\circ < \alpha < 50^\circ$; 5, $50^\circ < \alpha < 60^\circ$; 6, $60^\circ < \alpha < 70^\circ$; 7, $70^\circ < \alpha < 80^\circ$; 8, $80^\circ < \alpha < 90^\circ$.

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