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The Origin of Millisecond Pulsar Velocities

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Summary

We have developed a computer code (Tauris & Bailes 1996) to follow the evolution of a binary system from the zero-age main sequence to its "final" state as a binary millisecond pulsar (BMSP), at all stages keeping careful track of the mass and orbital separation of the two stars.

To help determine the origin of millisecond pulsars, we compute the space velocities predicted by various models of their formation. It is difficult to produce a millisecond pulsar velocity greater than 270 km s^{-1} with any model, unless the formation of the neutron star is accompanied by some form of asymmetric kick. We obtain average 3-D system velocities of $\langle v_{\rm recoil}\rangle = 99.6$, 137.6 and 160.7 km s^{-1} using Gaussian kicks of $\langle v_{\rm kick}\rangle$=0, 200 and 450 km s^{-1} (σ=0, 100 and 200 km s^{-1}, respectively). Our computations show that, in general, we expect those systems with shorter orbital periods to have larger velocities than those with longer periods, but any relation between the final orbital period and space velocity is fairly weak, especially if asymmetries are involved.

Only a very few proper motions of binary pulsars have been measured. These are presented in Table 1. The magnitude of the transverse velocities observed are consistent with those 3-D velocities ($\bar{v}_{\rm recoil} = 4/\pi \times \bar{v}_{\perp}$) predicted in the simulations – cf. Fig. 1. PSRs B1257+12 has a high recoil velocity of >280 km s^{-1}. We have shown that such a high velocity can only be obtained when the supernova explosion is asymmetric. The expected recoil velocities of the rest (7 out of 9) of these binary millisecond pulsars seem to be $\lesssim$ 100 km s^{-1}, depending on the unknown line-of-sight velocity.
More millisecond pulsar proper motions and distances will help to constrain the various formation models, but early indications are that low-velocity millisecond pulsars are over-represented in the sample, especially if the most recent estimates of kick velocities are used. However, quantifying the magnitude of the selection effects is very important.

References

Tauris T. M., Bailes M. 1996, A&A submitted

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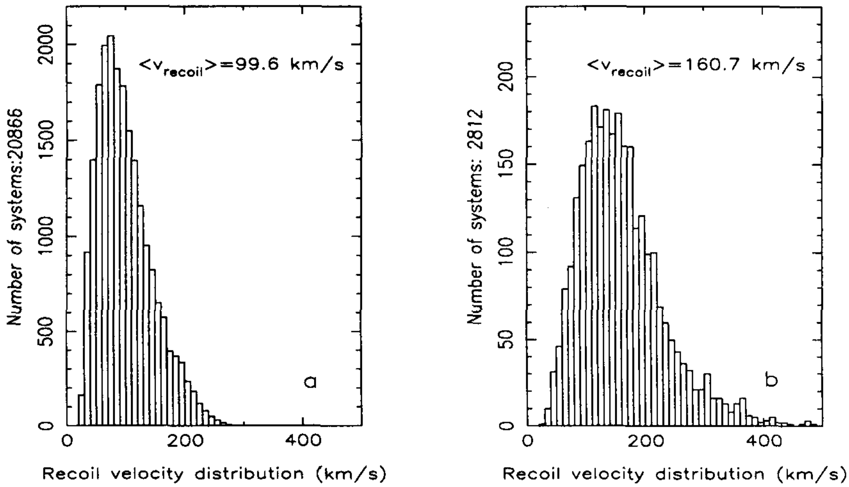

Figure 1. Velocity distribution of Binary Millisecond pulsars. To produce this figure we evolved 100 000 binaries with initial parameters as indicated in Tauris & Bailes (1996). Of these binaries $\sim 1/5$ evolve into BMSPs (or at least binaries containing a neutron star and a white dwarf) in the case of a symmetric SN and $\eta_{ce} = 2.0$ (the efficiency parameter of the common envelope phase), cf. Fig. 1a. The remaining binaries either coalesced, became disrupted in the SN, evolved into bound or unbound double neutron star systems or produced the neutron star after the white dwarf. If a random orientated Gaussian kick of $\langle v_{\rm kick} \rangle = 450$ km s^{-1} ($\sigma = 200$ km s^{-1}) is added to the newborn neutron star in the SN due to asymmetry, then the number of surviving BMSPs is further reduced by a factor of $\sim$7, cf. Fig. 1b.

Table 1. Transverse velocities of BMSPs

PSR–name	μ mas. yr^{-1}	dist. kpc	$v_\perp$ km s^{-1}	$P_{\rm orb}$ days
J0437–4715	135	0.14	91	5.7
J1012+5307	<33	0.52	<75	0.60
B1257+12	95.0	0.62	280	planets
J1455–3330	-	0.73	60	76.2
J1713+0747	6.3	0.89	27	67.8
B1855+09	6.2	0.70	21	12.2
B1957+20	30.4	1.53	220	0.38
J2019+2425	23.5	0.91	101	76.5
J2145–0750	-	0.50	31	6.8

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