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Pulsar Velocities

I Introduction

Observations of proper motions of single radio pulsars enable the determination of transverse velocities and hence provide a tool for measuring the amount of asymmetry (i.e., the magnitude of the kick velocity $\vec{w}$) in supernovae (SNe). However, single pulsars are thought to originate from both isolated early type stars which explode in a type II SN and from the collapse of He-stars in a SN of type Ib/c in massive binaries which are disrupted as a result of the explosion. Other, more exotic, formation mechanisms of isolated neutron stars (NS) include the possibility of accretion-induced collapse (AIC) of a white dwarf (WD) and a merging event of two white dwarfs in a very tight binary system (possibly resulting in a type Ia SN). It is therefore complicated to get a direct measure of the magnitude of kick velocities imparted to neutron stars at birth.

II Discussion

The possible evolutionary paths which lead to the formation of single pulsars are illustrated in the flow chart in Figure 1. The space velocity distribution (e.g., Lyne & Lorimer 1994) is not an actual measurement of the kick velocity distribution since it is "polluted" by escape velocities $\vec{v}_{esc}$ of disrupted binaries as well as systemic velocities $\vec{v}_{sys}$ imparted to binary systems as a result of the recoil effect due to a sudden mass loss. Furthermore, the magnitude of the kick velocity is possibly related to the type of SN (II, Ib/c or AIC) which creates a given NS.

In order to evaluate the expected velocity distribution of single pulsars which have their origin in a binary system, the aim is to use the evolutionary code of Tauris & Bailes (1996) to keep track of the binary parameters. This will enable us to use realistic input distributions of masses and separations prior to the SNe. The calculations of the runaway velocities of stellar components originating from disrupted binaries due to asymmetric SNe, can be performed using the analytic formulae of Tauris & Takens (1998).

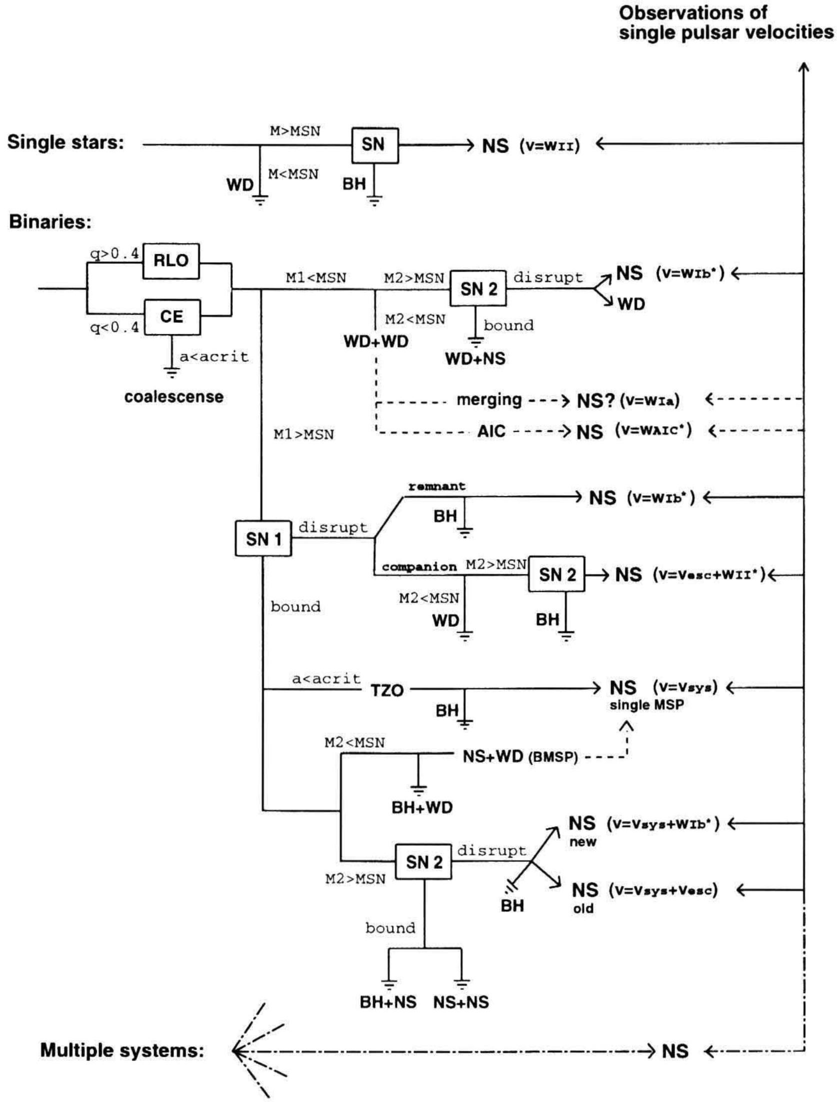

Figure 1. Possible formations of single pulsars. "NS"=neutron star; "WD"=white dwarf; "BH"=black hole; "SN"=supernova; "RLO"=Roche-lobe overflow; "CE"=common envelope; "TZO"=Thorne-Żytkow object; "M_1"=mass of primary star; "M_2"=mass of secondary star; "$M_{\rm SN}$"=threshold mass for SN; "q"=M_2/M_1; "a"=binary separation; "v"=velocity of single NS; "w"=kick velocity (index refer to type of SN, * indicates the effective velocity taken into account the energy loss due to escape); "$v_{\rm sys}$"=systemic velocity of binary due to a sudden mass loss; "$v_{\rm esc}$"=velocity of NS escaping a binary.

From the observed transverse velocity distribution of Lyne & Lorimer (1994) we have obtained a 3-D space velocity distribution assuming isotropy in velocity space:

$$P(v_{3d}) = \frac{(v_{3d}/200 \text{ km s}^{-1})^{1.3}}{1 + (v_{3d}/200 \text{ km s}^{-1})^{3.2}} \tag{1}$$

We have calculated the expected velocities of single (and binary) millisecond pulsars using this velocity distribution as the input kick distribution of type Ib/c SNe. The result of this analysis should match that of the observed velocities of millisecond pulsars *if* the Lyne-Lorimer distribution is a good representative of the kick velocities associated with type Ib/c SNe. Early indications are that Eq. (1) slightly overestimates the pulsar velocities. However, beware of selection effects at work here against observations of high velocity pulsars.

We plan to calculate velocity distributions for all the formations routes which lead to single NS.

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References

Lyne A.G. & Lorimer, D.R. 1994, Nature, 369, 127
Tauris T.M. & Bailes, M. 1996, A&A, 315, 453
Tauris T.M. & Takens, R. 1998, A&A, 330, 1047

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