On the Origin of Hyperfast Neutron Stars

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Abstract. We propose an explanation for the origin of hyperfast neutron stars (e.g. PSR B1508+55, PSR B2224+65, RX J0822–4300) based on the hypothesis that they could be the remnants of a symmetric supernova explosion of a high-velocity massive star (or its helium core) which attained its peculiar velocity (similar to that of the neutron star) in the course of a strong three- or four-body dynamical encounter in the core of a young massive star cluster. This hypothesis implies that the dense cores of star clusters (located either in the Galactic disk or near the Galactic centre) could also produce the so-called hypervelocity stars – ordinary stars moving with a speed of $\sim 1 000 \text{ km s}^{-1}$.

Keywords. Stars: neutron, pulsars: general, pulsars: individual (B1508+55), galaxies: star clusters, methods: n-body simulations

1. Introduction

Recent proper motion and parallax measurements for the pulsar PSR B1508+55 (Chatterjee \textit{et al.} 2005) gave the first example of a high velocity ($1 083_{-90}^{+103} \text{ km s}^{-1}$) directly measured for a neutron star (NS). A possible way to account for extremely high velocities of NSs\footnote{Other possible examples of hyperfast NSs are PSR B2224+65 (Chatterjee \& Cordes 2004) and RX J0822–4300 (Hui \& Becker 2006).} is to assume that they are due to a natal kick or a post-natal acceleration (Chatterjee \textit{et al.} 2005). In this paper, we propose an alternative explanation for the origin of hyperfast NSs (cf. Gvaramadze 2007) based on the hypothesis that they could be the remnants of symmetric supernova (SN) explosions of hypervelocity stars [HVSs; the ordinary stars moving with extremely high ($\sim 1 000 \text{ km s}^{-1}$) peculiar velocities; e.g. Brown \textit{et al.} 2005]. A strong argument in support of this hypothesis comes from the fact that the mass of one of the HVSs is $\geq 8 M_\odot$ (Edelmann \textit{et al.} 2005) so that this star ends its evolution in a type II SN leading to the production of a hyperfast NS.

2. Hypervelocity stars and young massive star clusters

It is believed that the origin of HVSs could be connected to scattering processes involving the supermassive black hole (BH) in the Galactic centre (Hills 1988; Yu \& Tremaine 2003; Gualandris \textit{et al.} 2005). It is therefore possible that the progenitors of some hyperfast NSs were also ejected from the Galactic centre. The proper motion and parallax

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measured for PSR B1508+55, however, indicate that this NS was born in the Galactic
disk (Chatterjee et al. 2005). The kinematic characteristics of some high-velocity early B
stars also suggest that these objects originated in the disk (e.g. Ramspeck et al. 2001).
We consider the possibility that the HVSs (including the progenitors of hyperfast NSs)
could be ejected not only from the Galactic centre but also from the cores of young (< 10^7
yr) massive (∼ 10^4 − 10^5 \(M_\odot\)) star clusters (YMSCs), located either in the Galactic disk
or near the Galactic centre (cf. Gualandris & Portegies Zwart 2007).

3. Origin of hyperfast neutron stars

To check the hypothesis that the hyperfast NSs could be the descendants of HVSs
which were ejected from the cores of YMSCs, we calculated (see Gvaramadze et al. 2007)
the maximum possible ejection speed produced by dynamical processes involving close
encounters between: i) two hard (Heggie 1975) massive binaries (e.g. Leonard 1991), ii) a
hard binary and an intermediate-mass (∼ 100 − 1000 \(M_\odot\)) BH (e.g. Portegies Zwart
& McMillan 2002), and iii) a single star and a hard binary intermediate-mass BH (e.g.
Gürkan et al. 2006). We find that main-sequence O-type stars cannot be ejected from
YMSCs with peculiar velocities high enough to explain the origin of hyperfast NSs, but
lower mass main-sequence stars or the stripped helium cores of massive stars could be
accelerated to hypervelocities. We find also that the dynamical processes in the cores
of YMSCs can produce stars moving with velocities of ∼ 200 − 400 km s\(^{-1}\) which there-
fore contribute to the origin of high-velocity NSs as well as to the origin of the bound
population of halo stars (Ramspeck et al. 2001; Brown et al. 2007).

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