On the bimodality of the kick velocity distribution of radio pulsars

S.B. Popov

Universitá di Padova, via Marzolo 8, 35131, Padova, Italy;

Sternberg Astronomical Institute, Universitetski pr. 13, 119992 Moscow, Russia

I. Bombaci

Universitá di Pisa, via F. Buonarroti 2, 56127 Pisa, Italy

Abstract. We propose that the bimodal nature of the kick velocity distribution of radio pulsars is connected to the dichotomy between hadronic stars (*i.e.* neutron stars with no quark matter content) and quark stars. Bimodality can appear due to different mechanisms of explosion which lead to the formation of two types of compact stars or due to two different sets of parameters driving a particular kick mechanism. The low velocity maximum (at ~ 100 km s^{-1}) is associated with hadronic star formation, whereas the second peak corresponds to quark stars. In the model of delayed collapse of hadronic stars to quark stars (Berezhiani et al. 2003) quark deconfinement leads to a second energy release, and to a second kick, in addition to the kick imparted to the newly formed hadronic star during the supernova explosion. If the electromagnetic rocket mechanism can give a significant contribution to pulsar kicks, then the high velocity peak can be associated with the shorter initial spin periods of quark stars with respect to hadronic stars.

An important property of the compact stars usually called *neutron stars* (NSs) is their spatial velocity distribution. At the present time the most widely accepted velocity distribution is the one obtained by Arzoumanian, Chernoff & Cordes (2002) . It is a bimodal distribution with two Maxwellian components. Here we propose a scenario in which the low-velocity part of the distribution is connected with normal (hadronic) compact stars, and high-velocity part is formed by objects with some amount of quark matter inside (hybrid or strange stars).

The fact that we are dealing with radio pulsars tells us that to produce different kicks we cannot use ideas which involve physical conditions in which radio pulsars do not exist (for example, too low magnetic fields, or too long initial rotational periods). Binaries also cannot explain this bimodality (they do not produce enough high-velocity NSs if isolated and binary progenitor stars produce PSRs with comparable probabilities). So we come to a conclusion that some significant dichotomy among normal single (isolated) radio pulsars is required. The strongest theoretically known dichotomy in compact stars is the dichotomy between pure *hadronic stars* (HSs) and *quark stars* (QSs). Among many differences between HSs and QSs, typical kick velocities for the members of these two families of compact stars can be different too.

A quark star can be formed in a delayed collapse (see Berezhiani et al. 2003) or in a direct collapse with additional energy release. In both cases additional energy release and, correspondently, additional kick can be expected. As we suggest that about one half of all PSRs are QSs, then *most* of QSs should be formed due to fall-back or directly in the SN explosion (so that the delay time is significantly shortened), since the outcome of NSs from binary systems is rather small to constitute $\sim$1/2 of the total PSR population. Anyway, an additional energy release can produce a bimodal distribution of many physical properties of the compact stars which we usually call just NSs.

We suggest that the delayed stellar conversion process of a pure HS to a QS, triggered by quark deconfinement, can give a second kick to the compact star. Thus, the low velocity component of the pulsar velocity distribution receives contributions mainly from "normal" NSs (hadronic stars) which have passed through a single explosion (the SN explosion). The high velocity part is mostly composed of QSs which have received a second kick due to the energy release associated with the stellar conversion process.

Of course, as far as both explosions produce *distributions* of velocities, it is possible to find low velocity QSs which experienced two kicks, and high velocity HSs which received just a single natal kick. Also, among mid- and high-velocity objects there can be a contribution of HSs from massive binaries.

More details can be found in a recent paper Bombaci & Popov (2004).

Compact object with different velocities can be very similar to each other if they belong to the same peak of the velocity distribution (i.e. there will be no correlations of different parameters vs. velocity if NSs belong to the same component of the distribution). However, if our hypothesis is correct low-velocity objects on average can be distinct from high-velocity ones. They can have different average values of some parameters, or demostrate differences in behaviour, especially if it is connected with their internal structure. An interesting problem is the possibility of glitches in QSs. As internal structure of QSs and HSs are different, it is reasonable to expect that glitches of the two types of compact objects are different too (see recent discussion in Horvath 2004). At present more than 100 glitches from about 35 PSRs have been reported (see Shemar & Lyne 1996, Krawczyk et al. 2003 and references therein). For 9 of these objects transverse velocities are available. For the two-component distribution of Arzoumanian et al. (2002), contribution of the low velocity component dominates up to ~ 300 km s^{-1}, which corresponds to the transverse velocity $V_{\rm t} \sim 250$ km s^{-1}. All but two velocity measurements of glitchers are below this limit. The best known glitchers – Crab and Vela – definitely represent the low-velocity component. High velocity glitchers can be products of disruption of close binaries.

Full text of the poster is available at **http://xray.sai.msu.ru/~ polar/**.

References

Arzoumanian, Z., Chernoff, D.F., & Cordes, J.M. 2002, ApJ 568, 289
Berezhiani, Z., Bombaci, I., Drago, A., Frontera, F., & Lavagno, A. 2003, ApJ 586, 1250
Bombaci, I., & Popov, S.B. 2004, A&A 424, 627
Horvath, J.E. 2004, astro-ph/0404324
Krawczyk, A., Lyne, A.G., Gil, J.A., & Joshi, B.C. 2003, MNRAS 340 1087
Shemar, S.L., & Lyne, A.G. 1996, MNRAS 282, 677