On the nature of the bimodal kick velocity distribution: supernovae and deconfinement

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Abstract

We propose that the bimodal nature of the kick velocity distribution of radio pulsars is connected with dichotomy between neutron stars and quark stars. Bimodality can appear due to two different mechanisms of explosions or two different sets of parameters mastering a particular mechanism. The low velocity maximum (at ~ 100 km s^{-1}) is connected with neutron star formation. The second peak corresponds to quark stars. In the model of delayed collapse deconfinement leads to the second energy release, and so to the second (additional) kick. If the electromagnetic rocket mechanism of kick is working then the second peak can be connected with shorter initial spin periods of quark stars. We discuss *pro et contra* of these scenarios.

1 Introduction

An important property of neutron stars (NSs) is their spatial velocity distribution (here and below by NS sometimes we will mean both normal NSs and quark stars — QSs — if it does not mislead the reader). At present there are many measurements of radio pulsars (PSRs) proper motions (Brisken et al. 2003 and references there in). Together with distance measurements it leads to determination of transverse velocities, V_t. In the ATNF catalogue (for example Hobbs et al. 2003) there is data on transverse velocities for 137 PSRs (including millisecond etc.). Typical spatial velocities of PSRs are about 300-400 km s^{-1} (Lyne, Lorimer 1994, Lorimer et al. 1997). Maximal velocities are higher than 1000 km s^{-1}.

These high velocities are thought to be connected with supernova (SN) explosions which lead to huge energy release (see recent reviews in Lai 2002, Burrows et al. 2003). Understanding of the nature of velocity distribution can give an important information about physics of SN.

There were several attempts to reconstruct the initial velocity distribution basing on observed properties of radio pulsars and other NSs (for example NSs in SN remnants — SNR; NSs in close binaries etc.). The most widely accepted at the present time is the distribution obtained by Arzoumanian et al. (2002). It is a bimodal distribution with two maxwellian components. Velocity dispersion, σ, of the first peak is 90 km s^{-1} . The fraction of objects in the first peak is about 0.4 ± 0.2. The second peak corresponds to $\sigma = 500$ km s^{-1}. Recent results by Brisken et al. (2003) also support two-component velocity distribution (however, in their model fraction of the low-velocity component is only about 0.2).

In principle the initial velocity distribution can be multi-component as far as there are many potential sources for different velocity maxima (binaries of different types, different types of SNae etc.), but relative contribution of many of them should be small (for example, contribution of accretion induced collapse – AIC, or possible compact remnants of faint SNIa etc.). In addition compact objects which never appear as PSRs can have different velocity distribution from PSRs. But here we will concentrate on the following problem: even for observed radio pulsars there is a bimodality with comparable contribution of both peaks.

There were many papers in which authors tried to explain this bimodality. For example Colpi and Wasserman (2002) suggested a modification of Imshennik (1992) SN mechanism to explain high-velocity part of the distribution. This mechanism (as noted by the authors) is not valid for low-velocity NSs as Crab and Vela, for which spin is nearly aligned with spatial velocity, which is impossible in the mechanism suggested by Colpi and Wasserman. Podsiadlowski et al. (2003) discussed a possibility of a low kick velocities for a particular type of HMXBs as a result of mass exchange influence on the stellar evolution.

We propose a different scenario connected with deconfinement.

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2 The Model

In the following we assume as a fundamental fact: the initial velocity distribution of radio pulsar is at least bimodal, and fractions of stars in low and high velocity parts of the distribution are more or less equal. It means, that among normal radio pulsars there should be at least two different types of objects.

The fact, that we are speaking about radio pusalrs tells us, that to produce different kicks we cannot use ideas which involve parameters for which radio pulsars do not exist (for example, too low magnetic field or too long initial periods). Binaries also cannot explain this bimodality: they do not produce enough high-velocity NSs. So, one have to think about some significant dichotomy among normal single (isolated) radio pulsars. Actually, the strongest known dichotomy among compact objects is the dichotomy between NSs and QSs. It is a surprising fact that nobody (for our knowledge) discussed in detail a possibility of different kick velocities for these two types of compact objects as an explanation of the bimodality. Only Zhang et al. (2000) briefly noticed in connection with large displacement of SGRs from centers of their SNRs that quark stars can have high kick velocities due to two-step kicks.

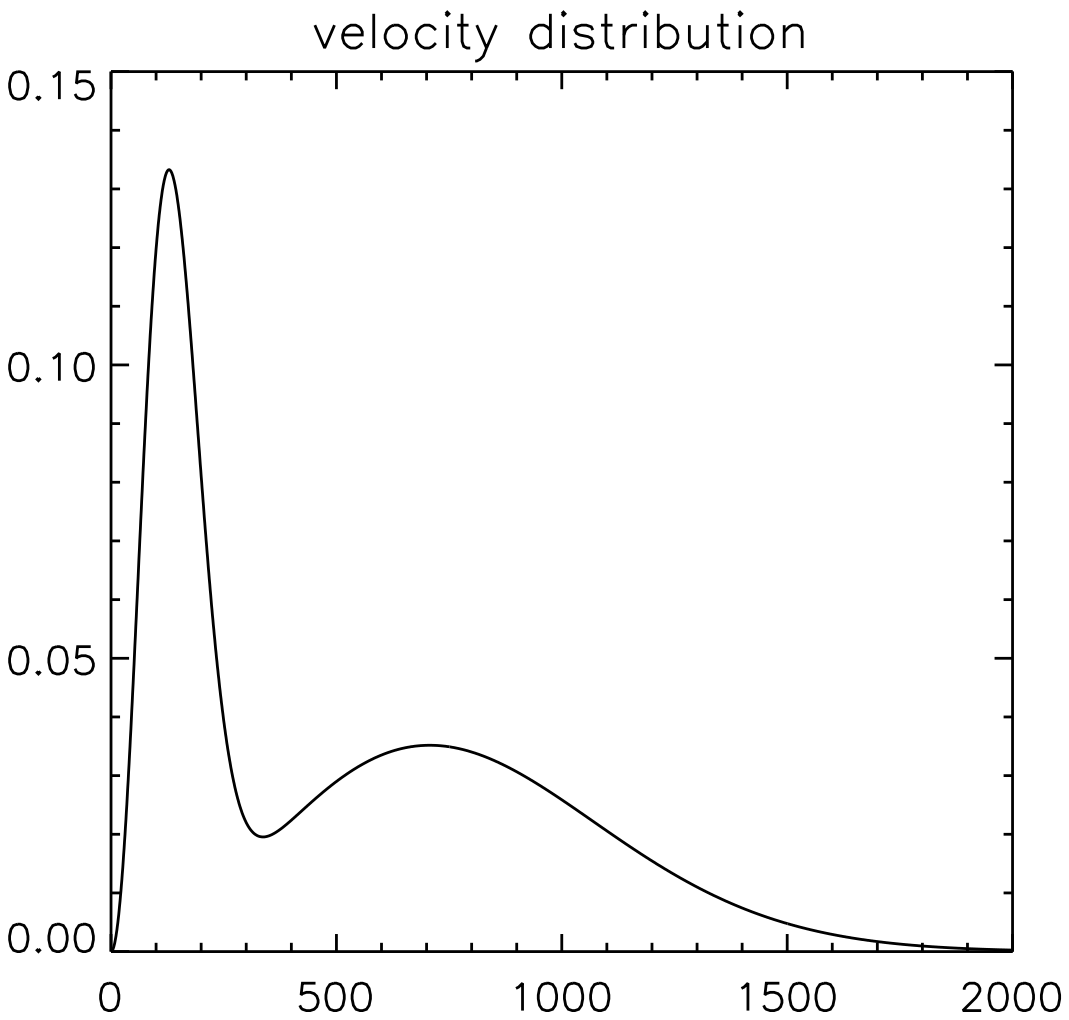

Figure 1: Modelled initial velocity distribution with two maxwellians (Arzoumanian et al. 2002). Low velocity part includes 40% of all objects. Maximum corresponds to $\sim$130 km s^{-1}. High velocity part has maximum at $\sim$710 km s^{-1}.

Since early 70-s theoreticians discuss a possibility of existence of quark (strange) stars (the first paper on QSs was published in 1965 by Ivanenko and Kurdgelaidze, see a review in Xu 2002 and recent results and a discussion from more observational point of view in Thoma et al. 2003).

If both normal NSs and QSs exist in nature in comparable amount, then we can expect dichotomy of many

Table 1: Kick mechanisms

Mechanism	Time scale	V_{max}, km s^{-1}	Alignment (spin and V)	Main recent refs.
Hydrodynamical	0.1 s	$\sim (100-200)$	random	Lai et al. (2001)
ν-driven	$\sim$ few s	$\sim 50\,B_{15}$	parallel	Lai et al. (2001)
Electromagnetic rocket	long	$\sim$1400 P_{ms}^{-2}	parallel	Lai et al. (2001), Huang et al. (2003)
Binary disruption (without add. kick)	$<< P_{orb}$	~ 1000	perpend.	Iben, Tutukov (1996)
NS instability	few ms	~ 1000	perpend.	Colpi, Wasserman (2002)

properties of observed compact objects. In fact, even if QSs are so-called hybrid stars and in many senses are very similar to normal NSs, their initial properties can be different as far as the process of their birth can have pecularities. A dichotomy between NSs and QSs can be connected with initial mass distribution of compact objects (see Timmes et al. 1996). A quark (or a hybrid) star can form in a delayed collapse (see Berezhiani et al. 2003) or in a direct collapse with additional energy release (see for example Hong et al. 2001).

At first let us discuss the delayed collapse. Delayed collapse from a metastable hadron phase can happen due to fall-back (i.e. after a short time since SN explosion; what the fall-back does is just decrease of the waiting time before transition) or due to accretion in a binary. (As far 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 as far as the outcome of NSs from binary systems is rather small to constitute $\sim 1/2$ of the total PSR population.) Anyway an additional energy input can form a bimodal distribution of many parameters of objects which we usually call just NSs.

We suggest that the process of delayed deconfinement can lead to the second kick of a compact object. So, the low velocity part of distribution is mainly formed by normal NSs which passed through one explosion. The high velocity part is mostly composed of QSs which received the second kick due to deconfinement.

Of course, as far as both explosions produce *distributions* of velocities, it is possible to find low velocity QSs which passed through two kicks, and high velocity NSs which recieved kicks just once. Also among mid- and high-velocity objects there can be a contribution of NSs from massive binaries (Iben, Tutukov 1996).

The second possibility for a QS to obtain a larger kick is the following. Higher velocities obtained due to deconfinement could be a result of shorter initial periods if electromagnetic rocket mechanism is operating (Harrison, Tademaru 1975). In this scenario the maximum velocity can be calculated as follows (Lai et al. 2001):

$$V_{max} \sim 1400 R_{10}^2 P_{ms}^{-2}\,\mathrm{kms}^{-1}. \quad (1)$$

Radii of QSs are typially 1.5-2 times lower than radii of NSs. If P of QSs are 4-5 times shorter then we can expect velocities 5-6 times larger. That is what is necessary to explain the difference between two peaks in the initial velocity distribution.

In the model of delayed collapse it is difficult to increase spin frequency by a factor of 4 in the process of a NS contraction into a QS (unless there is some additional spin-up due to kick). However, if a QS is formed on early stage (ie. without delay), then the difference in initial periods between QSs and NSs can be significant, as far as NSs are believed to suffer different instabilities which lead to spin-down, while QSs, for example, are not subject to the r-mode instability (Madsen 1998). Typical initial periods of NSs are about 20 ms and longer. With such periods electromagnetic rocket mechanism is not effective. If QSs has typical radii about 7 km and are born with typical periods about 1 ms then they can form a peak around 700 km s^{-1}. Woosley et al. (2002) note, that compact objects are expected to be born with periods ~ 1 ms, and only due to r-mode instability or similar processes NSs are expected to slow down to > 20 ms.

In principle, if the exact shape of the second velocity peak is known then for electromagnetic rocket mechanism it is possible to reconstruct the form of QSs spin period distribution (see for example a paper by Huang and Wu 2003). But at the moment there is no data on the exact shape. Maxwellian distribution is just a reasonable hypothesis used by Arzoumanian et al. (2002). Reconstruction of the initial velocity distribution (especially on the high end) basing on the radio pulsar proper motion data cannot distinguish between maxwellian and similar shapes.

3 Discussion

3.1 Problems of the scenarios

One problem for a delayed collapse is connected with the surviving of close binaries where compact objects accreted significant amount of mass which could lead to deconfinement. Otherwise it is necessary to claim, that all observed accreting NSs in LMXB are normal NSs yet, not QSs which suffered deconfinement in their interiors (or that in the case of binaries deconfinement does not lead to large recoil). However, even with a strong kick there is non negligible probabilty of binary survival. Cir X-1 which has high spatial velocity (see discussion in Lai et al. 2001) can be an example. (Compact objects in HMXBs with moderate kicks discussed by Podsiadlowski et al. (2003) also should be normal NSs accroding to our scenario.)

We note, that in the electromagnetic rocket model binaries can survive, as far as the time of acceleration is long unless the NS is a magnetar (Lai et al. 2001, Huang et al. 2003). In that case runaway binaries can form.

Another problem comes from millisecond PSR (mPSR) velocity distribution. These objects are assumed to originate in LMXBs, where they accreted a significant amount of matter, so in the scenario of Berezhiani et al. (2003) one can expect, that most of mPSRs are QSs. As it was shown by Lyne et al. (1998) average velocity of mPSR is rather low: ~ 130 km s^{-1}. And it is consistent with investigations of binary evolution. After the first SN explosion most of survived binaries correspond to the low velocity part of kick velocity distribution. I.e. in our scenario it means that nearly all NSs in LMXBs have to be NSs, not QSs as far as mPSR population does not show any signs of enhanced velocities (there is a higher probability, that a QS can stay bound in a HMXB system).

If the idea of the second kick due to deconfinement is proved to be in contradiction with observations of mPSRs and LMXBs, then it is a serious problem for the whole scenario of delayed deconfinement due to accretion in binaries as far as it is diffucult to understand symmetry of an energy release of $\sim 10^{53}$ erg s^{-1} from a compact object which is not a black hole. However, conditions for the second collapse can be different in a binary and in a fall-back. In the first case pre-collapsed object is a millisecond NS with low magnetic field ($\sim 10^9$ G). In the second case there is a protoNS with longer spin period and higher magnetic field. This can lead to different asymmetries of explosions.

The rocket scenario also has some problems. The main is that we need to assume significant displacement of the dipole relative to the spin axis. Otherwise the coefficient in eq.(1) is much smaller and it is necessary to assume very short periods together with relatively large radii to explan PSRs with $V > 1000$ km s^{-1}.

3.2 Glitches and internal structure

Starting from the most early discussions on the astrophysical manifestations of QSs (see for example Alcock et al. 1986) it was noted, that glitches could be a problem for the QS hypothesis. At present 76 glitches from 25 PSRs were reported (Krawczyk et al. 2003). For 6 of these objects in the ATNF catalogue (Hobbs et al. 2003) transverse velocities are available. (See the table. Data from Krawczyk et al. 2003, Lyne et al. 2000, and ATNF catalogue; also we add several estimates from Kaspi (1998) marking them with [k]; in bold we show more probable ones, according to Kaspi with Kaspi's coefficient equal to 3 or smaller and bolded in here table.) We note, that data for PSRs B1930+22 and B1727-33 is very uncertain.

For two-component distribution of Arzoumanian et al. (2002) contribution of the low velocity component dominate up to ~ 300 km s^{-1}, which corresponds to the transverse velocity ~ 250 km s^{-1}. As we see all but one velocity measurments are below this limit. The best known glitchers — Crab and Vela — definitely represent the low-velocity component. The only high-velocity PSR in the list (table 2) — 2224+65 — was reported to have a glitch just once (Shemar, Lyne 1996).

Another proposal, connected with internal structure of NSs, was made by Larson and Link (1999). They suggested, that in the case of two NSs (namely PSR B1929+10 and 0950+08), for which high temperatures have been estimated, it is necessary to include internal source of heating — superfluid friction. However, later at least temperature estimate for 0959+08 was doubt. But in any case, if the proposal by Larson and Link is valid, it is interesting to note, that both NSs are low velocity objects ($V_t \sim 162.9$ and 36.4 km s^{-1} according to ATNF catalogue). So, they should be normal NSs, and for them this source of energy is available.

Glitches were also detected for AXP 1RXS J170849.0–400910 (Dall'Osso et al. 2003, Kaspi, Gavriil 2003). Note the comment of Zhang et al. (2000) about lower velocities of AXPs in comparison with SGRs, so that AXPs can be normal NSs and SGRs can be QSs.

Table 2: PSRs with glitches

Name	P (s)	$\dot{P}$	Dist (kpc)	Age (Yr)	B (G)	V_t (km/s)	Ref.
B0154+61	2.351	1.889254E-13	1.61	1.97e+05	2.13e+13	*	[1]
B0355+54	0.156	4.396862E-15	2.07	5.64e+05	8.39e+11	137.39	[2,3]
B0525+21	3.745	4.003633E-14	2.28	1.48e+06	1.24e+13	227.00	[2,3]
B0531+21	0.033	4.22765E-13	2.0	1.24e+03	3.78e+12	142.23	[3]
B0833-45	0.089	1.25008E-13	0.29	1.13e+04	3.38e+12	79.55	[3]
B1325-43	0.532	3.014E-15	2.29	2.80e+06	1.28e+12	*	[3]
B1338-62	0.193	2.53107E-13	8.55	1.21e+04	7.08e+12	*	[2,3]
B1535-56	0.243	4.8493E-15	4.01	7.95e+05	1.10e+12	*	[2,3]
B1641-45	0.455	2.00902E-14	5.3	3.59e+05	3.06e+12	*	[3,3]
B1706-44	0.102	9.298454E-14	1.82	1.75e+04	3.12e+12	$<$**50** [k]	[2,3]
B1727-33	0.139	8.482941E-14	4.25	2.60e+04	3.48e+12	460 [k]	[2,3]
B1736-29	0.322	7.87979E-15	3.19	6.49e+05	1.61e+12	*	[2,3]
B1737-30	0.606	4.6587E-13	3.28	2.06e+04	1.70e+13	*	[1,3]
B1758-03	0.921	3.3101E-15	7.13	4.41e+06	1.77e+12	**200** [k]	[1]
B1758-23	0.415	1.12882E-13	13.49	5.84e+04	6.93e+12	*	[1,2,3]
B1800-21	0.133	1.341047E-13	3.94	1.58e+04	4.28e+12	$\sim$ **0** [k]	[1,2,3]
J1806-2125	0.482	1.214E-13	10.02	6.5e+4	7.74e+12	*	[4]
B1823-13	0.101	7.506081E-14	4.12	2.14e+04	2.79e+12	$\sim$ **0** [k]	[2,3]
B1830-08	0.085	9.170719E-15	5.67	1.47e+05	8.95e+11	200 [k]	[2,3]
B1859+07	0.643	2.2872E-15	5.49	4.46e+06	1.23e+12	*	[2,3]
B1907-03	0.504	2.18734E-15	10.25	3.66e+06	1.06e+12	*	[1]
B1917+00	1.272	7.66978E-15	3.32	2.63e+06	3.16e+12	31.48	[1]
B1930+22	0.144	5.75718E-14	9.8	3.98e+04	2.92e+12	750 [k]	[1]
B2224+65	0.682	9.65918E-15	2.00	1.12e+06	2.60e+12	1725.71	[2,3]
B2255+58	0.368	5.75295E-15	6.40	1.01e+06	1.47e+12	*	[1]

All data from ATNF catalogue (Hobbs et al. 2003).
References corresponds to papers, where recently glitches from these PSRs were discussed
[1] Krawczyk et al. (2003); [2] Shemar, Lyne (1996); [3] Lyne et al. (2000); [4] Hobbs et al. (2002)

Table 3: Other NSs with know velocities

Name	Type	P	V_t	Ref. for V_t	Comments
B0656+14	Cooler	0.385	~ 155	ATNF	
B1929+10	Cooler	0.227	~ 163	ATNF	marked by Larson, Link (1999) as a candidate for additional heating
B0950+08	Cooler ?	0.253	~ 36	ATNF	marked by Larson, Link (1999) as a candidate for additional heating
Geminga	γ-PSR	0.237	~ 128	ATNF	
J1856.5-3754	Magnificent seven	—	~ 185	Walter, Lattimer (2002)	
J0720.4-3125	Magnificent seven	8.4	$\sim 92 d_{200}$	Motch et al. (2003)	distance is uncertain, 200 pc was assumed
J0437-4715	cooler?	0.006	~ 94	ATNF	marked by Kargaltsev et al. (2003) as a candidate for additional heating

Table 4: NSs with know initial periods (from Migliazzo et al. 2002)

Name	P, ms	V_t	Ref. for V_t
J0537-6910	< 14	~ 600	Kaspi, Helfand (2002)
B0531+21	19	~ 142	ATNF
B1951+32	27 ± 6	~ 296	ATNF
B0540-69	30 ± 8	—	—
J0205+6449	60	—	—
J1811-1925	62	< 110	Kaspi, Helfand (2002)
J1124-5916	90	—	—

Table 5: SN frequencies (from Cappellaro and Turatto 2000)

Type of SN	SOa-Sb	Sbc-Sd
Ia	$0.32 \pm .12$	$0.37 \pm .14$
Ib/c	$0.2 \pm .11$	$0.25 \pm .12$
II	$0.75 \pm .34$	$1.53 \pm .62$

3.3 Supernovae

At the moment nearly 3000 SNae were observed. Potentially different types of SN can give different velocity distributions of resulting compact objects (if they are formed). So, as it was mentioned above, the initial velocity distribution should have many components. Different components can be associated with different SNae. It is very difficult to check obsevationaly which SNae produce different compact objects. Most of the know SNae are extragalactic and recent — for them there is good data about types (and even data on SN progenitors! See Van Dyk et al. 2002), but no information about compact objects. For historical SNae (Green, Stephenson 2003) we often know a compact object, but it is very difficult to reconstruct the SN type. Then there are SNRs associated with compact objects (see Kaspi 1998, Kaspi, Helfand 2002), but it is also difficult to know for sure the type of SN which produced a given SNR.

Among core-collapse SN fractions are the following: SN IIP (0.3), SN IIL (0.3), SN IIn (0.02), SN 1987A-like (0.15), SN Ib/c (0.23) (Chevalier 2003). SN IIP probably originate from the most low massive stars which can still produce a SNII. SN Ib/c probably are product of binary evolution (or originate from very massive single stars). Obviously, compact objects which originate from single (isolated) stars and compact objects which appeare after disruption of close binaries, should have different velocities simply due to additional orbital velocity. Detailed analysis of this situation was given for example by Iben and Tutukov (1996). They assumed, that no natal kick is added. As it is clear from their fig.10 massive binaries can give velocities up to 1000 km s^{-1}, but the fraction of these high-velocity objects in the total number of NSs is small. Oppositely accretion induced collapse (AIC) can produce low velocity NSs, but the contribution is also rather low: $3 \cdot 10^{-3}$ yr^{-1} (Podsiadlowski et al. 2003).

The Crab pulsar is probably associated with SN IIP. In some sense it goes in a line with our scenario, as far as compact objects, formed from low massive stars (i.e. $\sim 10 - 15\, M_\odot$) should be low velocity (i.e. $V_t < 250$ km s^{-1}) normal NSs and their fraction is $\sim 0.3 - 0.5$.

3.4 Predictions and speculations

There are many predictions connected with the proposed scenario, and much more speculations can be done.

As far as fractions of compact objects in the first and in the second components of the *initial* velocity distribution are more or less equal, then the number of *formed* NSs and QSs are also nearly equal. On the other hand, high velocity objects quickly leave our Galaxy. So, among observable sources the number of QSs should be not that high. QSs can fill the galactic halo. In the galacit disc there should be not many old isolated QSs, so for example, old accreting isolated compact objects are expected to be normal NSs. If QSs are fast objects, then their fraction in globular clusters should be low as far as escape velocity is usually $<$100 km s^{-1}.

Due to different cooling history of NSs and QSs we can expect correlation temperature-velocity for young compact objects. However, cooling history is mass-dependent both for normal NSs and QSs, so this kind of correlation should not be a clear one.

In SNRs closer to the centers we expect to see normal NSs, and QSs with higher average velocities should be more displaced (for the same age). (See also Zhang et al. 2000, where the authors briefly discuss this topic in connection with AXPs and SGRs.) Also it is important to note, that the characteristic age $\tau = P/2\dot{P}$ in the case of delayed deconfinement should not be a good estimate of a real age of a compact object.

It is unclear if kick is correlated with initial spin period. Postnov and Prokhorov (1998) argued, that kick can be a reason of fast initial rotation. Contrary, Spruit and Phinney (1998) gave arguments for longer periods due to kick. If this point is clarified one can speculate about different initial periods of QSs in comparison with normal NSs.

Different rotation rates for nuclei of stars of different masses (see Woosley et al. 2002) can be important, as far as in our scenario formation of an isolated QS can be connected with a fall-back. And fall-back can be different for stars with different masses due to their different structures and histories. Fall-back process can bring additional correlations between different parameters of compact objects (as it was suggested by Popov et al. 2002), especially as far as this process can play a key role in shortening time of the delay.

An outcome of a SN explosion depends on metallicity (Woosley et al. 2002). Masses of iron core and shells, amount of fall-back, rotation rates etc. are different for stars with different fraction of heavy elements. Metallicty is changing during the lifetime of the Galaxy. Because of that one can expect different fraction of newborn QSs among compact objects at different galactic ages.

As far as formation of a QS from a NS is accompanied with shrinking of the compact object, it can lead (in principle) to increase of the magnetic field and decrease of a spin period. However, details of the process are uncertain. For example, Frail et al. (1994) note, that in their set of PSRs high-velocity ones have higher magnetic fields. But results of that paper (mainly the reality of associasions of PSRs and SNRs) were later doubted. Results mentioned in Kaspi, Helfand (2002) are against any correlation between initial spin and velocity (see the table of initial spin periods for 7 PSRs in Migliazzo et al. 2002). We note, that we do not expect clear general correlations between velocity and magnetic field or even spin period and velocity, but average parameters of low-velocity and high-velocity PSRs can be different.

If there is a delayed deconfinement of a single object, then we can expect (even if the scenario of explanation of bimodality is wrong) young PSRs without pronounced SNR.

If velocities of QSs are produced in two steps and two kicks are uncorrelated then among low velocity compact objects there should be some fraction of QSs.

There are reasons to suspect, that magnetic field distribution of compact objects is also bimodal because of a significant number of magnetars. However, high-field population is at most 10%, not comparable with high-velocity fraction of PSRs.

Now it is more or less clear that not all NSs pass the stage of active PSR (or at least this stage is very short for them). In that sense it is interesting to understand if they can be QSs. In connection with the proposed scenario it is important to note that two of the Magnificent seven (seven ROSAT radioquiet NSs) for which velocities are known, definitely are low-velocity objects: $V_t < 200$ km s^{-1}.

4 Conclusion

Bimodal initial velocity distribution of PSRs can be due to two different explosion mechanisms or due to different initial parameters of compact objects. Normal SN are responsible for low velocity part of the distribution, and the high velocity part is connected with phase transition of NS interiors to deconfined state, i.e. with QSs.

This scenario leads to some astrophysical predictions, which were discussed above.

References

[1] Alcock, C., Farhi, E., Olinto, A. 1986, "Strange stars", ApJ 310, 261

[2] Arzoumanian, Z., Chernoff, D.F., Cordes, J.M. 2002, "The velocity distribution of isolated radio pulsars", ApJ 568, 289

[3] Z. Berezhiani, I. Bombaci, A. Drago, F. Frontera, A. Lavagno 2003, "Gamma-ray bursts from delayed collapse of neutron stars to quark matter stars", astro-ph/0209257

[4] Bombaci, I., Datta, B. 2001, "Conversion of neutron stars to strange stars as the central engine of gamma-ray bursts", astro-ph/0001478

[5] Brisken, W.F., Fruchter, A.S., Goss, W.M., Herrnstein, R.S., Thorsett, S.E. 2003, "Proper-motion measurements with the VLA. II. Observations of twenty-eight pulsars", astro-ph/0309215

[6] Burrows, A., Ott, C.D., Meakin, C. 2003, "Topics in core-collapse supernova theory", astro-ph/0309684

[7] Cappellaro, E., Turatto, M. 2000, "Supernova types and rates", astro-ph/0012455

[8] Cheng, K.S., Dai, Z.G. 1996, "Conversion of neutron stars to strange stars as a possible origin of gamma-ray bursts", Phys. Rev. Lett. 77, pp.1210-1213

[9] Chevalier, R.A. 2003, "Pulsar wind nebulae and their supernovae", astro-ph/0310730

[10] Colpi, M., Wasserman, I. 2002, "Formation of an evanescent proto-neutron star binary and the origin of pulsar kicks", ApJ 581, 1271 (astro-ph/0207327)

[11] Dall'Osso, S., Israel, G.L., Stella, L., Possenti, A., Perozzi, E. 2003, "The glitches of the Anomalous X-ray Pulsar 1RXS J170849.0–400910", astro-ph/0307235

[12] Frail, D.A., Goss, W.M., Whiteoak, J.B.Z. 1994, "The radio lifetime of supernova remnants and the distribution of pulsar velocities at birth", ApJ 437, 781

[13] Green D.A., Stephenson F.R. 2003, "The historical supernovae", astro-ph/0301603

[14] Harrison, E.R., Tademaru, E. 1975, "Acceleration of pulsars by asymmteric radiation", ApJ 201, 447

[15] Hobbs, G., Lyne, A. G., Joshi, B. C., Kramer, M., Stairs, I. H., Camilo, F., Manchester, R. N., D'Amico, N., Possenti, A., and Kaspi, V. M. 2002, "A very large glitch in PSR J1806-2125", MNRAS 333, L7

[16] Hobbs, G. et al. 2003, "The ATNF Pulsar Catalogue", astro-ph/0309219

[17] Hong, D.K. Hsu, S.D.H. Sannino, F. 2001, "Supernovae, hypernovae and color superconductivity", Phys.Lett. B516, 362-366 (hep-ph/0107017)

[18] Huang, Y.F., Dai, Z.G., Lu, T., Cheng, K.S. Wu, X.F. 2003, "Gamma-ray burst from neutron star kicks", ApJ 594, 919

[19] Huang, Z-K., Wu, X-J. 2003, "An estimation of the initial period of pulsars", Chin. J. Astron. Astroph. 3, 166

[20] Iben, I, Tutukov, A.V. 1996, "On the origin of the high space velocities of radio pulsars", ApJ 456, 738

[21] Imshennik, V.S. 1992, " The probable scenario of a supernova explosion as a result of massive stellar core gravitational collapse", PAZh 18, 489

[22] Ivanenko, D.D., Kurdgelaidze, D.F. 1965, 'Hypothesis of quark stars", Astrofizika 1, 479

[23] O. Kargaltsev, G. G. Pavlov, and R. W. Romani 2003, "Ultraviolet emission from the millisecond pulsar J0437-4715", astro-ph/0310854

[24] Kaspi, V. 1998, "Neutron star/supernova remnant associations", astro-ph/9803026

[25] Kaspi, V.M., Helfand, D.J. 2002, "Constraining the birth events of neutron stars", astro-ph/0201183

[26] Kaspi, V.M., Gavriil, F.P. 2003, "A second glitch from the "Anomalous" X-ray Pulsar 1RXS J170849.0-4000910", astro-ph/0307225

[27] Krawczyk, A., Lyne, A.G., Gil, J.A., Joshi, B.C. 2003, "Observations of fourteen pulsar glitches", astro-ph/0302585

[28] Lai, D. 2002, "Core-collapse supernovae and neutron star kicks", astro-ph/0212140

[29] Lai D., Chernoff D.F., Cordes J.M. 2001, "Pulsar jets: implications for neutron star kicks and initial spins", ApJ 549, 1111

[30] Larson, M.B., Link, B. 1999, "Superfluid friction and late-time thermal evolution of neutron stars", ApJ 521, 271

[31] Lorimer, D.R., Bailes, M. Harrison, P.A. 1997, "Pulsar statistics - IV. Pulsar velocities", MNRAS 289, 592

[32] Lyne, A.G., Lorimer, D.R. 1994, "High birth velocities of radio pulsars", Nature 369, 127

[33] Lyne, A.G. et al. 1998, "The Parkes southern pulsar survey - II. Final results and population analysis", MNRAS 295, 743

[34] Lyne, A.G., Shemar, S.L., Graham Smith, F. 2000, "Statistical studies of pulsar glitches", MNRAS 315, 534

[35] Madsen, J. 1998, "How to identify a strange star", Phys. Rev. Lett. 81, 3311

[36] Migliazzo, J.M., Gaensler, B.M. et al. 2002, "Proper-motion measurements of pulsar B1951+32 in the supernova remnant CTB 80", ApJ 567, L141

[37] Motch, C., Zavlin, V.E., Haberl, F. 2003, "The proper motion and energy distribution of the isolated neutron star RX J0720.4-3125", astro-ph/0305016

[38] Ouyed, R., Sannino, F. 2001, "Quark stars as inner engines for Gamma-ray bursts?", astro-ph/0103022

[39] Ouyed, R. 2002, "Quark stars and color superconductivity: A GRB connection?", astro-ph/0201408

[40] Podsiadlowski, Ph., Langer, N., Poelarends, A.J.T., Rappaport, S., Heger, A., Pfahl, E. 2003, "The effects of binary evolution on the dynamics of core collapse and neutron-star kicks", astro-ph/0309588

[41] Popov, S.B., et al. 2002, "Young compact objects in the solar vicinity", astro-ph/0210688

[42] Postnov, K.A., Prokhorov, M.E. 1998, "Possible spinup of young neutron stars during asymmetric supernova explosions", Astronomy Letters 24, 568

[43] Shemar, S.L., Lyne, A.G. 1996, "Observations of pulsar glitches", MNRAS 282, 677

[44] Spruit, H. Phinney, E.S. 1998, "Birth kicks as the origin of pulsar rotation", Nature 393, 139

[45] Thoma, M.H., Trümper, J, Burwitz, V. 2003, "Strange quark matter in neutron stars? — New results from Chandra and XMM", astro-ph/0305249

[46] Timmes, F.X., Woosley, S.E., Weaver, T.A. 1996, "The neutron star and black hole initial mass function", ApJ 457, 834

[47] Van Dyk S.D., Li W., Filippenko, A.V. 2002, "A search for core-collapse supernova progenitors in HUBBLE SPACE TELESOPE images", astro-ph/0210347

[48] Walter, F.M., Lattimer, J. 2002, "A revised parallax and its implications for RX J185635-3754", ApJ 576, L145

[49] Woosley S.E., Heger, A., Weaver T.A. 2002, "The evolution and explosion of massive stars", Reviews of modern physics 74, 1015

[50] Xu, R. 2002, "Strange quark stars — A review", astro-ph/0211348

[51] Zhang, B., Xu, R.X., Qiao, G.J. 2000, "Nature and nurture: a model for soft gamma-ray repeaters", ApJ 545, L127