POPULATION SYNTHESIS OF HIGH ENERGY TRANSIENTS

RELATIVISTIC BINARY MERGING RATES

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1. Introduction

Binary relativistic stars merging — the most powerful high energy transient in the Universe: $L_{merging} \sim Mc^2/R_g/c = c^5/G \sim 10^{58}$ erg/s. That is equal to Planckian luminosity (Lipunov 1992) $L_{Planck} = E_{Planck}/t_{Planck} = c^5/G$.

There are 3 types of merging reactions ("M–reaction") of relativistic stars:

$$NS + NS \rightarrow GWB + \nu B + GRB(?) + NS/BH$$
$$NS + BH \rightarrow GWB + BH + \nu B + GRB(?)$$
$$BH + BH \rightarrow GWB + BH$$

After the outstanding experiment BeppoSAX (Costa *et al.,* 1997, IAUC 6572) and discovery of optical afterglow phenomenon in GRB 970228 (Groot *et al.,* 1997, IAUC 6584; Sahu *et al.,* 1997, IAUC 6606) and discovery of spectral lines in GRB 970508 ($z = 0.835$) (Metzger *et al.,* 1997, IAUC 6655) we know that in the Universe there are real sources with luminosities more than 10^{50} erg/s.

The merging relativistic binaries may underlie the origin of cosmic gamma–ray bursts (GRB) (Blinnikov *et al.,* 1984; Pazcyński, 1986; Meszaros and Rees, 1992).

In a few years several initial ground–based laser interferometers aimed at searching for gravitational waves (GW) will start to work (LIGO (Abramovici *et al.*, 1992), VIRGO (Ciufolini *et al.*, 1992), GEO–600 (Schutz, 1996), TAMA-300, so at present time the question: what kind of events and how frequently will the interferometer register? — is very important. Undoubtedly, the most reliable GW sources are the merging compact binary stars — double neutron stars (NS) and black holes (BH) of different stellar masses.

There are two branch of theoretical research:

- physical investigation of M–reactions (Mergingology: fairball formation, numerical relativity, hydrodynamics. The pulsar mechanism also can act (Lipunov & Panchenko, 1996b), (Lipunova, 1997).
- astrophysical calculation of "crossection" or "probability" of the M–reaction in our Universe (Population synthesis).

2. Observations

1. A few binary radiopulsars are known to have the secondary NS component.
2. Three of these binary pulsars must coalesce due to the orbital angular momentum removal by GW in a time scale shorter than the age of the Universe (the Hubble time $t_H \simeq 15 \cdot 10^9$ yrs).
3. No binary pulsars with BH is known yet (although from evolutionary considerations one may expect one such object to be formed in the Galaxy per about 1000 single pulsars, (Lipunov *et al.*, 1994))
4. No binary BH has been found so far.
5. In contrast, 10 BH candidates are already known in X-ray binary systems with normal companions (Cherepashchuk, 1996). Note that the mean BH mass in these systems is $< M_{BH} > \simeq$

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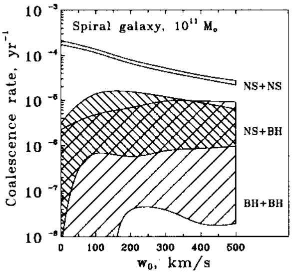


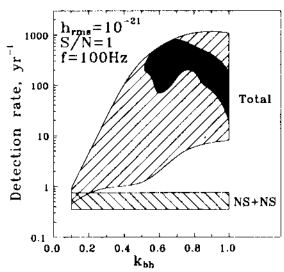


Figure 1. (left)**Lipunov, Postnov & Prokhorov, 1997a** The dependence of different compact binary systems coalescence rates on the characteristic kick velocity w_0 in a spiral galaxy with $10^{11}M_\odot$.

Figure 2. (right)**Lipunov, Postnov & Prokhorov, 1997b** The total merging rate of NS+NS, NS+BH, and BH+BH binaries which would be detected by a laser interferometer with $h_{rms} = 10^{-21}$ as a function of k_{bh} for Lyne–Lorimer kick velocity distribution with w_0 = 200–400 km/s and BH progenitor's masses $M_* = 15$–$50M_\odot$, for different scenarios of binary star evolution. NS+NS mergings are shown separately. In all cases BH+BH mergings contribute more than 80% to the total rate. The filled "Loch–Ness–monster–head"-like region corresponds to BH formation parameters $M_* > 18M_\odot$ and $k_{bh} > 0.5$.

8.5 $M_\odot$, i.e. BH formed in stellar evolution are notably more massive than NS (with the typical mass $1.4M_\odot$).

3. Population synthesis: key parameters

At present time, it is possible to estimate binary NS merging rate in two ways: using the binary radiopulsar statistics observed and making various computations of binary stellar evolution (Population Synthesis).

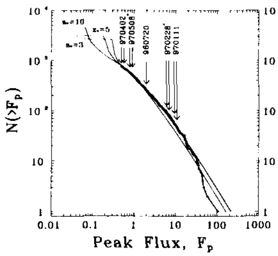
"Observational" estimates		"Theoretical" estimates	
(Phinney, 1991)	$1/10^6$ yr	(Clark *et al.*, 1979)	$1/10^4$–$1/10^6$ yr
(Narayan *et al.*, 1991)	$1/10^6$ yr	(Lipunov *et al.*, 1987)	$1/10^4$ yr
(Curran & Lorimer, 1995)	$3/10^6$ yr	(Hils *et al.*, 1991)	$1/10^4$ yr
(van den Heuvel & Lorimer, 1996)	$8/10^6$ yr	(Tutukov & Yungelson, 1993)	$3/10^4$–$1/10^4$ yr
"Bailes limit"(Bailes, 1996)	$< 1/10^5$ yr	(Lipunov *et al.*, 1995a)	$< 3/10^4$ yr
		(Portegies Zwart & Spreeuw, 1996)	$3/10^5$ yr
		(Lipunov *et al.*, 1997a)	$3/10^4$–$3/10^5$ yr

We emphasize that although theoretical merging rates are systematically higher than observational ones, both estimates do not contradict each other. The main argument is that the first (observational) estimates of binary NS merging rate are based on the statistics of binary systems, in which only one of the components shines as radiopulsar, which is not at all the *necessary* conditions for merging to occure (Lipunov et al.1997a).

To calculate binary evolution, one have used the population synthesis method (the Scenario Machine code), which is in fact a version of Monte–Carlo calculations. The most important (and practically unique) parameter changing the galactic binary NS merging rate is the distribution of an additional (kick) velocity imparted to NS at birth (Kornilov and Lipunov (1984), Lyne & Lorimer (1994), Lipunov, Postnov & Prokhorov (1996a, 1997a),Hansen & Phinney(1997)).

In contrast, for BH, two additional parameters appear. First of them is a threshold main sequence stellar mass M_{cr} for the star to collapse into a BH after its nuclear evolution has ended. This parameter is still poorly determined and varies in a wide range: e.g., according to (van den Heuvel & Habets, 1984), M_{cr} = 40–80$M_\odot$; (Tsujimot *et al.*, 1997) give 40–60$M_\odot$; (Portegies Zwart & Spreeuw, 1996) derive >20$M_\odot$.

The second parameter is the fraction of the presupernova mass, k_{bh}, collapsing into BH. This parameter is fully unknown, so we varied it from 0.1 to 1 in our calculations.



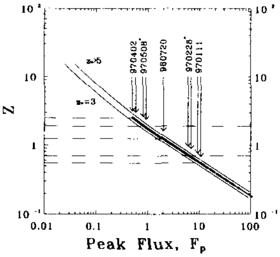


Figure 3. (left)**Lipunov, Postnov & Prokhorov, 1997c** The log N–log F_{peak} distribution of 3B BATSE GRBs from 256-ms 1-3 (50-300 keV) channels fitted with the cosmological model distributions in a flat, $\Omega = 1$, Universe with a cosmological term $\Omega_\Lambda = 0.7$ assuming gamma-ray photon power law $s = -1.1$. The locations of Beppo–SAX GRBs are shown. GRB970228 and GRB970508 are marked with asterisks.

Figure 4. (right)**Lipunov, Postnov & Prokhorov, 1997, Astro-ph/9703181** The redshift - peak flux dependence in the cosmologocal models assumed for different z_* and $s = -1.1$. 3B BATSE catalog data are also plotted.

4. Detection rate of binary compact star merging

Under the assumptions made above, we can calculate the binary merging rate R in the Galaxy. The results are presented in Fig. 1. After having found the merging rate R in a typical galaxy, we need to go over the event rate D at the detector. Applying the optimal filtering technique (Thorne, 1987), the signal-to-noise ratio S/N at the spiral-in stage is $S/N \propto M_h^{5/6}/d$. Here $M_{ch} = (M_1M_2)^{3/5}(M_1 + M_2)^{2/5}$ is "chirp"–mass of the binary system. This means that for a given S/N our detector can register more massive BH from larger distances than NS. The volume within which BH or NS is to be detected should be proportional to $M_{ch}^{15/6}$. Then the ratio of detection rates of BH and NS can be written as (Fig.2): $D_{BH}/D_{NS} = (R_{BH}/R_{NS})(M_{BH}/M_{NS})^{15/6}$.

5. Gamma–Ray Bursts

Using the dependence on time of compact binary merging rate for "elliptical" galaxy (Lipunov *et al.*, 1995b) and assuming the cosmological origin of GRBs as products of binary NS/NS coalescences, we can compute the theoretical log N–log S curve.

Recently, Lipunov, Postnov and Prokhorov (1997c) estimated the redshift of GRB 970228 and GRB 970508 using the mean statistical properties of observed GRBs. They assume the cosmological origin of GRBs as standard–candle binary neutron star mergers.

Same result was obtained independently by Totany (1997). Recent progress of observations of high redshift galaxies, however, gives more detailed information on the cosmic star formation history (Lilly *et al.*, 1996; Madau *et al.*, 1996). The Canada–France Redshift Survey (CFRS) revealed a remarkable evolution of 2800 Å luminosity density, that is considered to be a star formation indicator, as $\mathcal{L}_{2800} \propto (1+z)^{3.9\pm0.75}$ to $z \sim 1$ (for $\Omega_0 = 1$, Lilly *et al.*, 1996). The constant SFR approximation in spiral galaxies is therefore no longer justified even at $z < 1$.

The redshift of GRB 970508 is apparentely about 2, just below the upper limit that is recently determined, and the absorption system at $z = 0.835$ seems not to be the site of the GRB.

6. Conclusion

1) NS+NS merging rate: $\sim 1/10^4$ yr per Galaxy; $\sim$1/yr for GEO-600, VIRGO, TAMA-300, LIGO-type detector ($h > 10^{-21}$); $\sim$1/minute per Universe.

2) BH+BH merging rate: First LIGO–type interferometer events give us simultaneous discovery of GRAVITATIONAL WAVES and BLACK HOLES (Lipunov *et al.*, 1997d).

Expected detection rate for BH+BH merging: $\sim$10–100/yr for LIGO-type detector ($h > 10^{-21}$).

3) GRB mystery:

i) log N–log S is fine; ii) Reasonable estimates of redshifts for February and May Beppo–Sax GRBs;

iii) NS+ NS — needs collimation (several degree); iv) NS+ BH — no anisotropy.

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