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# Evolution of close binaries after the burst of starformation for different IMFs

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## Abstract

We use "Scenario Machine" – the population synthesis simulator – to calculate the evolution of populations of selected types of X-ray sources after a starformation burst with the total mass in binaries (1–1.5) $\cdot 10^6 M_\odot$ during the first 20 Myr after a burst. We present here the results of two sets of runs of the program.

In the first set we examined the following types of close binaries: transient sources– neutron stars with Be- stars; "X-ray pulsars"– neutron stars in pairs with supergiants; Cyg X-1-like sources– black holes with supergiants; "SS443-like sources"– superaccreting black holes. We used two values of the exponent $\alpha$ in the initial mass function: 2.35 (Salpeter's function) and 1 ("flat spectrum"). The calculations were made for the folowing values of the upper limit of the mass function: 120 and 30 $M_\odot$. For the "flat spectrum", suggested in (Contini et al, 1995), the number of sources of all types significantly increased. With the "flat spectrum" and with the upper mass limit 120 $M_\odot$ we obtained hundreds of sources of *all* calculated types. Decreasing of the upper mass limit below the critical mass of a black hole formation increase the number of transient sources with neutron stars up to $\approx 300$.

In the second set we examined the evolution of of 12 other types of X-ray sources for $\alpha = 1$, $\alpha = 1.35$ and $\alpha = 2.35$ and for three upper mass limits: 120 $M_\odot$, 60 $M_\odot$, 40 $M_\odot$ (see Perez-Olia & Colina 1995 for the reasons for such upper limits) on the same time scale 20 Myr after a star formation burst.

## 1 Introduction. Why do we do it?

Theory of stellar evolution and one of the strongest tools of that theory – population synthesis – are now quickly developing branches of astrophysics. Very often only the evolution of single stars is modelled. But it is well known that about 50% of all stars are members of binary systems, and a lot of different astrophysical objects are products of the evolution of binary stars. We argue, that often it is necessary to take into account the evolution of close binaries while using the population synthesis in order to avoid serious errors.

Partly this work was stimulated by the article by Contini et al. (1995), where the authors suggested a very unusial form of the initial mass function (IMF) for the explanation of the observed properties of the galaxy Mrk 712 . They suggested the "flat" IMF with the exponent $\alpha = 1$ instead of the Salpeter's value $\alpha = 2.35$. Contini et al. (1995) didn't take into account binary systems, so no words about the influence of such IMF on the populations of close binary stars could be said. Later Shaerer (1996) showed that the observations could be explained without the IMF with $\alpha = 1$. Here we try to determine the influence of the variations of the IMF on the evolution of compact binaries.

Previously (Lipunov et al, 1996a) we used the "Scenario Machine" for calculations of populations of X– ray sources at the Galactic center. Here we model a general situation — we made calculations for a typical starformation burst. We present two sets of calculations. In the first one only four types of binary sources were calculated for two values of the upper mass limit for two values of $\alpha$. In the second one we show results on twelve types of binary sources with significant X-ray luminosity for three values of the upper mass limit for three values of $\alpha$.

## 2 Model. How do we do it?

Monte-Carlo method for statistical simulation of binary evolution was originally proposed by Kornilov & Lipunov (1983a,b) for massive binaries and developed later by Lipunov & Postnov (1987) for low-massive binaries. Dewey & Cordes (1987) applied an analogous method for analysis of radio pulsar statistics, and de Kool (1992) investigated by the Monte-Carlo method the formation of the galactic cataclysmic variables.

Monte-Carlo simulations of binary star evolution allows one to investigate the evolution of a large ensemble of binaries and to estimate the number of binaries at different evolutionary stages. Inevitable simplifications in the analytical description of the binary evolution that we allow in our extensive numerical calculations, make those numbers approximate to a factor of 2-3. However, the inaccuracy of direct calculations giving the numbers of different binary types in the Galaxy (see e.g. Iben & Tutukov 1984, van den Heuvel 1994) seems to be comparable to what follows from the simplifications in the binary evolution treatment.

In our analysis of binary evolution, we use the "Scenario Machine", a computer code that incorporates all current scenarios of binary evolution and takes into account the influence of magnetic field of compact objects on their observational appearance. A detailed description of the computational techniques and input assumptions is summarized elsewhere (Lipunov et al. 1996b), and here we briefly list only principal parameters and initial distributions.

We trace the evolution of binary systems during the first 20 Myr after their formation in a starformation burst. Obviously, only massive enough stars (with masses $\geq 8-10$ M$_\odot$) can evolve off the main sequence during the time as short as this to yield compact remnants (NSs and BHs). Therefore we consider only massive binaries, i.e. those having the mass of the primary (more massive) component in the range of $10-120$ M$_\odot$.

The distribution in orbital separations is taken as deduced from observations:

$$f(\log a) = \mathrm{const}\,, \qquad \max\ \{10\ \mathrm{R}_\odot,\ \mathrm{Roche\ Lobe}\ M(M_1)\} < \log a < 10^4\ \mathrm{R}_\odot. \tag{1}$$

We assume that a NS with a mass of 1.4 M$_\odot$ is formed as result of the collapse of a star, whose core mass prior to collapse was $M_* \sim (2.5-35)$ M$_\odot$. This corresponds to an initial mass range $\sim (10-60)$ M$_\odot$, taking into account that a massive star can lose more than $\sim (10-20)\%$ of its initial mass during the evolution with a strong stellar wind.

The most massive stars are assumed to collapse into a BH once their mass before the collapse is $M > M_{cr} = 35$ M$_\odot$ (which would correspond to an initial mass of the ZAMS star as high as $\sim 60$ M$_\odot$ since a substantial mass loss due to a strong stellar wind occurs for the most massive stars). The BH mass is calculated as $M_{bh} = k_{bh} M_{cr}$, where the parameter $k_{bh}$ is taken to be 0.7.

The mass limit for NS (the Oppenheimer-Volkoff limit) is taken to be $M_{OV} = 2.5$ M$_\odot$, which corresponds to a hard equation of state of the NS matter.

We made calculations for several values of the coefficient $\alpha$:

$$\frac{dN}{dM} \propto M^{-\alpha} \tag{2}$$

We calculated $10^7$ systems in every run of the program. For the normalization we used the lower mass limit $0.1 M_\odot$. Then the results were normalized to the total mass of binary stars in the starformation burst. We also used different values of the upper mass limit.

We also take into account that the collapse of a massive star into a NS can be asymmetrical, so that an additional kick velocity, $v_{kick}$, presumably randomly oriented in space, should be imparted to the newborn NS. We used the velocity distribution in the form obtained by Lyne & Lorimer (1994) with the characteristic value 200 km/s (twice less than in Lyne & Lorimer (1994)).

## 3 Results. What have we done?

On the figures we show the results of our calculations for both sets. On all graphs on the X- axis we show the time after the starformation burst in Myrs, on the Y- axis — number of the sources of the selected type that exist at the particular moment (not the birth rate of the sources!).

On figure 1 we present the results of our calculations of the evolution of populations of X- ray sources of the four types (the first set) for the upper mass limit 120 $M_{\odot}$ (upper graph) and 30 $M_{\odot}$ (lower graph).

- Transient sources- a neutron star with a Be- star (graphs (1a) and (2a)).
- "X-ray pulsars"– a neutron star in pair with a supergiant (of course not all X- ray pulsars belong to this type of sources, but all systems of that type should appear as X- ray pulsars) (graphs (2b)and (1b)).
- Black holes with supergiants. Cyg X-1 is a prototype of the sources of that kind (graph (2d)).
- And at last superaccreting black holes (graphs (2c) and (1c)). We call this type – "SS 433"-like sources, as the well known object SS 433 can belong to that class of astrophysical sources.

Solid line — Salpeter's mass- function, dot-dashed line — "flat" IMF. The calculated numbers were normalized for $1.5 \cdot 10^6\, M_{\odot}$ in binary stars.

On figures 2-4 we show our calculations for X- ray sources of 12 differnt types (the second set, see a brief description of that types below).

- Figure 2 — $\alpha = 1$,
- Figure 3 — $\alpha = 1.35$,
- Figure 4 — $\alpha = 2.35$.

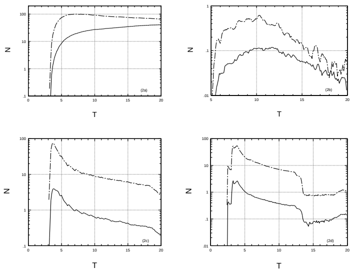
For upper mass limits:

- $120 M_{\odot}$ – solid lines,
- $60 M_{\odot}$ – dashed lines,
- $40 M_{\odot}$ – dotted lines.

The calculated numbers were normalized for $1 \cdot 10^6\, M_{\odot}$ in binary stars. We show on the figures 2-4 only systems with X-ray luminosity greater than $10^{33}\, erg/s$.

Curves were not smoothed. We calculated $10^7$ binary systems in every run, and then the results were normalized.

We used the "flat" mass ratio function, i.e. binary systems with any mass ratio appear with the same probability. The results can be renormalized to any other form of the mass ratio function.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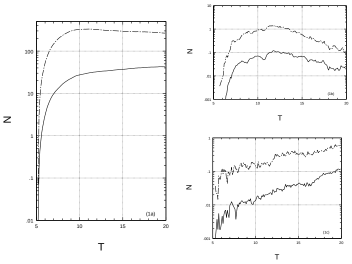
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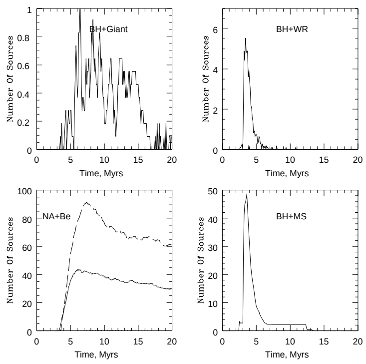


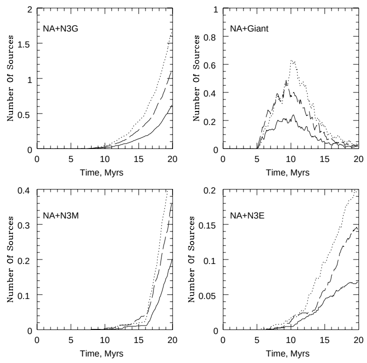


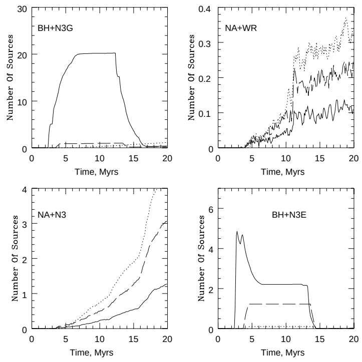


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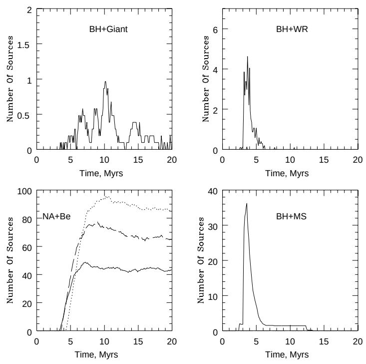


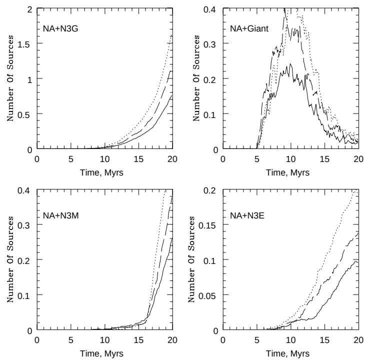


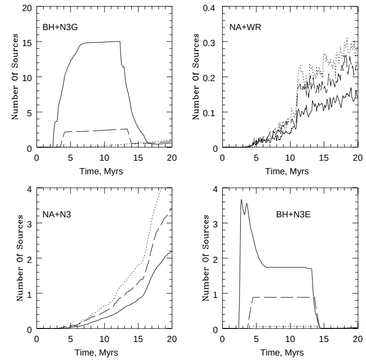


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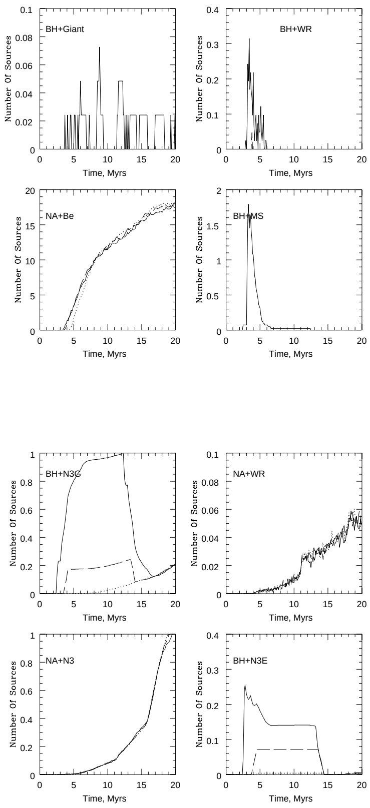


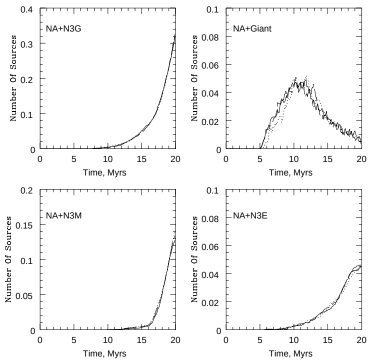


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## TWELVE TYPES OF X-RAY SOURCES

**BH+N2** — A BH with a He-core Star

**NA+N1** — An Accreting NS with a Main Sequence Star

**BH+WR** — A BH with a Wolf–Rayet Star

**BH+N1** — A BH with a Main Sequence Star

**BH+N3G** — A BH with a Roche-lobe filling star, when the binary loses angular momentum by gravitational radiation

**NA+N3** — An Accreting NSt with a Roche-lobe filling star (fast mass transfer from the more massive star)

**NA+WR** — An Accreting NS with a Wolf–Rayet Star

**BH+N3E** — A BH with a Roche-lobe filling star (nuclear evolution time scale)

**NA+N3G** — An Accreting NS with a Roche-lobe filling star, when the binary loses angular momentum due to gravitational radiation

**NA+N3M** — An Accreting NS with a Roche-lobe filling star, when the binary loses angular momentum due to magnetic wind

**NA+N2** — An Accreting NS with a He-core Star

**NA+N3E** — An Accreting NS with a Roche-lobe filling star (nuclear evolution time scale)

## 4 Approximations. How to use it?

For the first set of our calculations we give analytical approximations of our results.

In the case of the Salpeter's mass- function ($\alpha = 2.35$) and upper mass limit $M_{up} = 120 M_\odot$ (see fig.1) we have the following equations for X–ray transients in the interval from 5 to 20 Myr after the burst (t– time in Myrs):

$$N(t) = -0.14 \cdot t^2 + 5.47 \cdot t - 14.64. \tag{3}$$

For superaccreting BH in the interval from 4 to 20 Myr:

$$N(t) = \frac{2.2}{t - 3.05}. \tag{4}$$

For Cyg X-1– like sources in the interval from 4 to 20 Myr:

$$N(t) = \frac{4.63}{t - 2.9}. \tag{5}$$

For binary systems with accreting NS and supergiants in the interval from 5 to 20 Myr we have:

$$N(t) = 2.12 \cdot 10^{-4} \cdot t^3 - 9.6 \cdot 10^{-3} \cdot t^2 + 0.13 \cdot t - 0.47. \tag{6}$$

For "flat" mass- function ($\alpha = 1$) and upper mass limit $M_{up} = 120 M_\odot$ (see fig.1) for X–ray transients in the interval from 3 to 7 Myr we have:

$$N(t) = -8.9 \cdot t^2 + 1.2 \cdot 10^2 \cdot t - 3 \cdot 10^2, \tag{7}$$

and in the interval from 7 to 20 Myr:

$$N(t) = -2.8 \cdot t + 1.2 \cdot 10^2. \tag{8}$$

For superaccreting BH in the interval from 4 to 20 Myr we have:

$$N(t) = \frac{39.97}{t - 3.17}. \tag{9}$$

For Cyg X-1 – like sources in the interval from 4 to 20 Myr we have:

$$N(t) = \frac{58.44}{t - 3.08}. \tag{10}$$

For binary systems with accreting NS and supergiants in the interval from 5 to 20 Myr we have:

$$N(t) = 1.45 \cdot 10^{-3} \cdot t^3 - 5.96 \cdot 10^{-2} \cdot t^2 + 0.74 \cdot t - 2.41. \tag{11}$$

## 5 Discussion and conclusions. So what?

Different types of close binaries show different sensitivity to variations of the IMF. When we replace $\alpha = 2.35$ by $\alpha = 1$ the numbers of all sources increase approximately by an order of magnitude. Systems with BHs are more sensitive to such variations.

When one try to vary the upper mass limit, another situation appear. In some cases (especially for $\alpha = 2.35$) systems with NSs show little differences for different values of the upper mass limit, while systems with BHs become significantly less (or more) abundant for different upper masses. Luckily, X-ray transients, which are the most numerous systems in our calculations, show remarkable sensitivity to variations of the upper mass limit. But of course due to their transient nature it is difficult to use them to detect small variations in the IMF.

If it is possible to distinguish systems with BH, it is much better to use them to test the IMF.

The results of our calculations can be easily used to estimate the number of X- ray sources for different parameters of the IMF if the total mass of stars is known.

In this poster we tried to show, that, as expected, populations of close binaries are very sensitive to the variations of the IMF. One must be careful, when trying to fit the observed data for single stars with variations of the IMF.

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