THE NUMERICAL THREE-DIMENSIONAL HYDRODYNAMIC SIMULATION OF THE γ-RAY BURSTERS AND X-RAY BURSTERS

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ABSTRACT. An radiative wind accretion onto the compact object in a detached close binary system (CBS) where one of the components is a supergiant with radiation stellar wind that blows from its surface, and another component is a compact object (black hole or neutron star), is simulated applying methods of three-dimensional numerical hydrodynamics. The simulation of bursts similar to the gamma-ray bursters and X-ray bursters, i.e. isolated bursts with nearly zero in time ascending and descending branches with amplitudes from $6 - 7^m$ to $15 - 18^m$, commences in the vicinity of the compact object when the precession of the donor star starts. Due to the course numerical spatial grid of 0.01 units of the orbital separation, the duration of such isolated bursts is 10-40 minutes of the orbital time. The burst simulation is as follows: when the donor stars precession starts, small grid-cell-sized regions of higher density appear in the vicinity of the compact object due to the RayleighTaylor instability. The temperature in one of those regions increases abruptly when they interact with the stellar wind from the donor star. Prior to the temperature increase, the indicated regions were radiopaque. When the temperature reaches its peak, those regions become radiolucent, and all energy contained there is momentarily illuminated, giving off a burst that appears as an isolated sharp peak. That is how the bursts similar to the γ-ray bursts and X-ray bursts are simulated.

Key words: Stars: close binary system; X-ray bursters; gamma-ray bursters.

1. Introduction

In this study an attempt was made to simulate the X-ray bursters and γ-ray bursters, i.e. to model sharp peaks of emission with very large amplitudes (of more than 10^m), using the three-dimensional numerical hydrodynamic methods. As is known, the X-ray bursters and γ-ray bursters are unique objects with sharp bursts and total radiant energy output of approximately $10^{38} \div 10^{39}$ erg for the X-ray bursters and $10^{51} \div 10^{52}$ erg for the γ-ray bursters. It was found that some bursts exhibit optical emission along with the γ-ray bursts and X-ray bursts (McClintock et al., 1977; Grindlay et al., 1978). The presence of the optical echo allows of assuming that burster is a close binary system where the X-ray emission by one component is absorbed and re-emitted in the optical band by another component. The main objective of the presented numerical study was to simulate the radiation wind and precession of the CBS donor star.

2. Numerical simulation of a binary system, the wind from its donor star and accretion disc

We simulated the wind from the donor star based on the radiation wind model by Castor (1975), according to which the sonic point is reached close to the level of the layer near the donor stars photosphere, and 90is attained at the outer boundary of the atmosphere. In the present study the wind from the donor star was simulated implementing the algorithm reported by Nazarenko (2005, 2006, 2008). The CBS model in this study is as follows: the Roche model is applied to calculate the gravitational fields of the CBS components, the donor star rotation is deemed to be synchronised with its orbiting.

To simulate the driven precession, we assume that the donor star is embedded, and it is the compact object that moves in the numerical grid. In the present computations the built numerical grid is rectangular and uniform with the cell size of around 0.006085 in the orbital plane and approximately 0.02 along the z-axis. The computations were made in the Cartesian coordinate system, rigidly bound to the precessing donor star.

The numerical scheme of the astrophysical version of the large particle method by Belotserkovskiy and Davydov was applied in computations. To perform those, all space in the numerical domain was divided

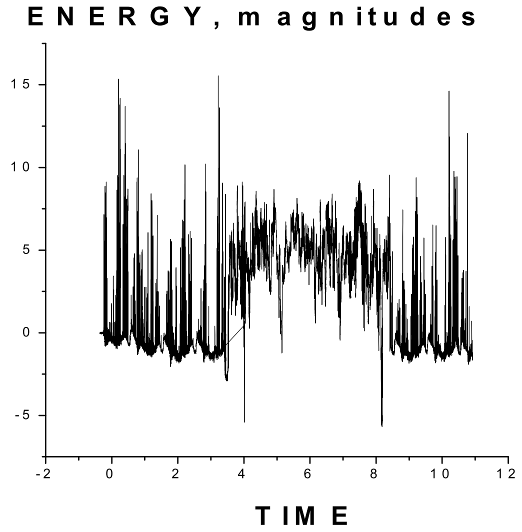

Figure 1: Radiation from the region where the burst occur for all the interval of calculation time.

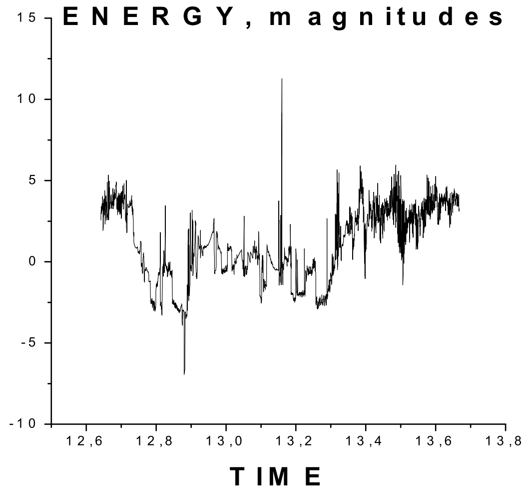

Figure 2: Radiation from the region where the burst occur for the time of 13.16.

into three-dimensional rectangular grid cells. All physical quantities are constant within the given cell.

The only effects that were taken into account at the first stage of computations with the given time-increment were the pressure and external fields effects; and the effect of the physical quantities transfer across the cell boundaries were the only accounted for at the second stage; that makes the numerical scheme of the large particle method absolutely stable, constant and strictly conservative on the whole.

One of the crucial aspects of this study is the radiative-cooling model. The magnitude of the radiative cooling is taken from Cox (1971) where it was computed applying the ionization-equilibrium optically-thin plasma model.

To estimate the phenomenon of the γ-ray bursters and X-ray bursters, we used several alternative sets of the CBS parameters, but in this paper we present the computations made with just one of them. The CBS parameters, used in computations, correspond to those of CYG -1: the orbital period is 5.86 days, the donor star mass is $40M_{\odot}$, and the accretor mass is $15M_{\odot}$.

3. Numerical results

The simulation of bursts proceeded during 18 precession periods, i.e. for a quite long to monitor how different physical factors affect modelling of bursts.

For the first four precession periods the simulation of bursts was performed with the precessing donor star and radiation wind that blew from its surface. For the selected CBS in that case the bursts (which are implied to be quite rare bursts with amplitudes of more than 10m) appeared as rather small series of 4-5 bursts in each with the time separation of 1.5-2 thousand of time-increments; thus, bursts become quite a rare case.

On the time interval between the fourth and eighth precession periods we deactivated formation of the wind from the donor star. As is seen in Figure 1, as soon as the supply of matter into the vicinity of the compact object ceased, the bursts discontinued. This points to the fact that as the actual radiation wind structure is intricate and ragged, i.e. discrete, and at that it can have a shape, which is far from any symmetry, then it can affect the generating of bursts in the vicinity of the compact object.

Starting from the eighth precession period the wind from the donor star was again factored in the computations, and bursts gradually resumed and continued almost in the same order as before the wind from the donor star had been deactivated. To show how the physical conditions in the near-accretor area, i.e. the area where bursts appear, affect the characteristics of the bursts and their number, the computation of the radiation force, which acts vertically upwards from the orbital plane in the near-accretor area, was factored in simulating of bursts from the 11th to 14th precession periods. As is seen in Figure 1, the bursts ceased almost immediately.

During three precession periods while the radiation force was factored in the computations, only one burst occurred; this is indicative of the fact that with such a change in the physical conditions in the near-accretor area bursts became a very rare case in our computations that corresponds to the observations. That isolated burst is shown on a short time interval in Figure

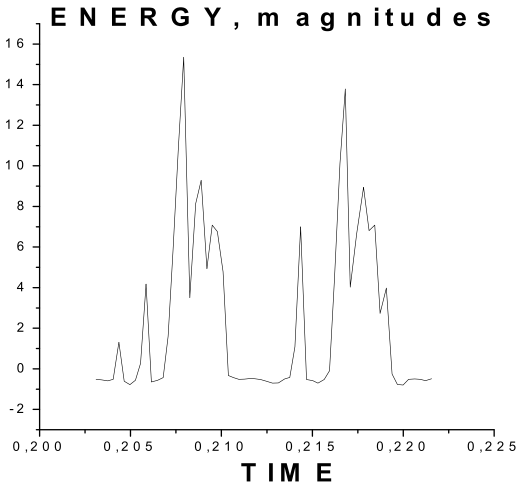

Figure 3: Radiation from the region where the burst occur.The partial bursts.

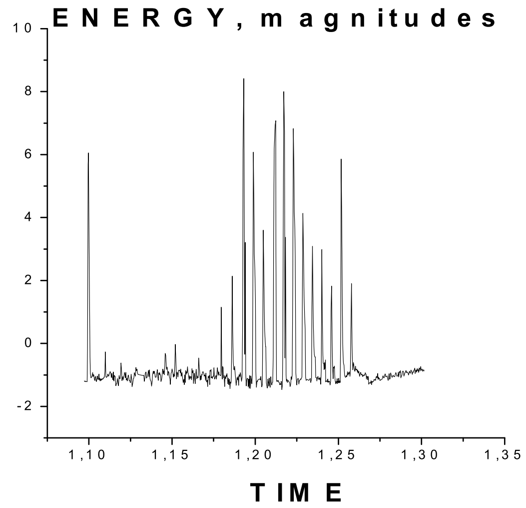

Figure 4: Radiation from the region where the burst occur for set of bursts.

2, and as is seen the indicated burst appears as a narrow sharp peak with amplitude higher than 10^m.

Isolated bursts are shown in Figures 3 and 4. As is seen in those figures, the bursts can have intricate structure, but all of them appear as isolated sharp peaks with amplitudes of up to $14 - 15^m$.

4. Conclusions

The wind accretion and driven precession of the donor star were simulated within the frame of the CBS model applying the three-dimensional numerical hydrodynamic methods. The computations showed that when the precession starts, isolated sharp peaks of emission with amplitudes from $3 - 4^m$ to 17^m are simulated in the nearest vicinity of the accretor. The durations of those bursts are short of about 5-7 or 50 time-increments (one time-increment equals to approximately 80 seconds of the orbital time). The bursts appear as rather small series of 4-5 bursts in each with the time separation of 1.5-2 thousand of time-increments. We interpreted those bursts as the γ-ray bursts and X-ray bursts due to their ascending and descending branches, which are nearly zero in time. In so doing, numerous bursts with smaller amplitude of around $4 - 7^m$ and lower temperature at the peak are reckoned in the X-ray bursters, and bursts with amplitude of more than $10 - 17^m$ and the peak temperature of about $3.5 \cdot 10^6$ were assigned to the γ-ray bursters.

Our model of the γ-ray bursters and X-ray bursters is very simple as such it is a massive detached close binary where the precessing donor star does not fill its Roche lobe and generates radiation stellar wind onto the surface of the compact object that can be either a neutron star or a black hole. At that, an radiative wind accretion onto the compact object is implemented. The size of the domain where the burst occurs is equal to its distance to the compact object. Given that, the smaller that domains size is, the shorter burst ensues, and the more energy is given off by that burst. With the smallest dimensions of the bursting domain, i.e. when the size of the bursting domain equals to that of the compact object, it will be the γ-ray burst occurred with duration of 10-4 seconds. The energy, given off by the burst, will reach up to 10^{62} erg/sec with the compact object mass of about $60 \div 80 M_\odot$. If the bursting domain size is about $10^{11} - 10^{12}$ cm, then, it will be the X-ray burst with duration of about several minutes.

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