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Can quick nonperiodic variations in X-ray luminosity be produced in outer part of accretion flow

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Introduction

With the progress in computing machinery and numerical methods during last decades, the numerical models of accretion flows revealed a lot of detailes, which were not possible to be predicted analytically. The simplest standard model [1, 2] was replaced by two-dimensional [3-6] and during the last years by tree-dimensional numerical calculations [7-13].

It was shown that an accretion flow possesses a complicated structure and its parameters depend on radial distance from central object as well as on azimutal angle [3, 4, 13 - 15].

There are not yet fully studied all relationships between structure, respectively luminousity and external parameters (such as direction and accretion rate of inflow gas stream), internal mechanisms (such as type of viscousity and opacity) and their variations.

On the other hand, with the accumulation of more and more observational data about the X-ray sources, identified as binaries with accretion flows, it is seen that in many cases the luminosity and spectra are strongly variable. The variations are very different in amplitude as well as in timescale. The most of quasi- and nonperiodic behaviour can not be explained in terms of standard analytical or one-dimensional calculations.

Most of the scientists believe that quick variations are caused by the instabilities in the inner regions of the accretion flow.

This paper is one of a series where we try to investigate the stability of the accretion flow structure towards the exchanges of external parameters and resulting behaviour of X-ray luminosity produced at the inner boundary of the accretion flow.

Using a two-dimensional numerical model we investigate the influence of inflow direction and inflow stream debit changes on the structure of an accretion flow. It is shown that such changes may produce quick variations in the X-ray luminosity.

Numerical model

The numerical model is based on the largescale particle method [16]. The calculations are performed in cylindrical coordinates in the noninertial corotating frame, with origin in the center of the compact object.

In the computation equations are included the gravitational forces of the both stars and the centrifugal force. The presure is the sum of gas and radiative ones. The energy equation is written for the case of an opticaly tick flow. The basic equations and numerical method are fully described in Ref. 17.

The calculations have been performed for a close binary, containing a red giand with a mass $M_2 = 4M_0$ wich filled its Roche lobe. The compact object is a neutron star with the standard parameters as follous-the mass equal to 1,5 M_0 and the radius of 10^6 cm. The magnetic field was assumed to be small enough not to be important for the gas motion. The distance between the binary system components is 10^{11} cm. We considered a region up to 5.10^{10} cm from the center of neutron star which include the first Lagrangian point.

The gas stream through the inner Lagrangian point is with a constant accretion rate of 10^{-9} M_0 per year and tangential velocity equal to the Keplerian one. The changes in direction are modelled with variations in radial part of the inflow velocity.

Results and discussion

In this paper we try to investigate the influence of instabilities in an inflow gas stream, caused by instabilities in companion star atmosphere, on the accretion flow. These instabilities can be modell by change of the accretion rate and the direction of the gas in first Lagrangian point.

As a base of investigations it is used the stationary state that the accretion flow has reached in the case of radial inflow velocity equal to 0,5 of the azimutal one. The radial inflow velocity is changed to the value of two times azimutal for a time of about 0,1 s. This value corresponds to the computation time step. When the accretion flow reaches a new stationary state, the radial inflow velocity V_{rp} is changed back to the value of 0,5 azimutal inflow velocity V_{fp}.

In Fig. 1 and 2 are shown the surface density distribution in stationary states in the cases of V_{rp} equal respectively to 0,5 and 2 times V_{fp}. On the Fig. 3 is shown the surface density distribution in stationary state after the change of V_{rp} to the initial value of 0,5 V_{fp}.

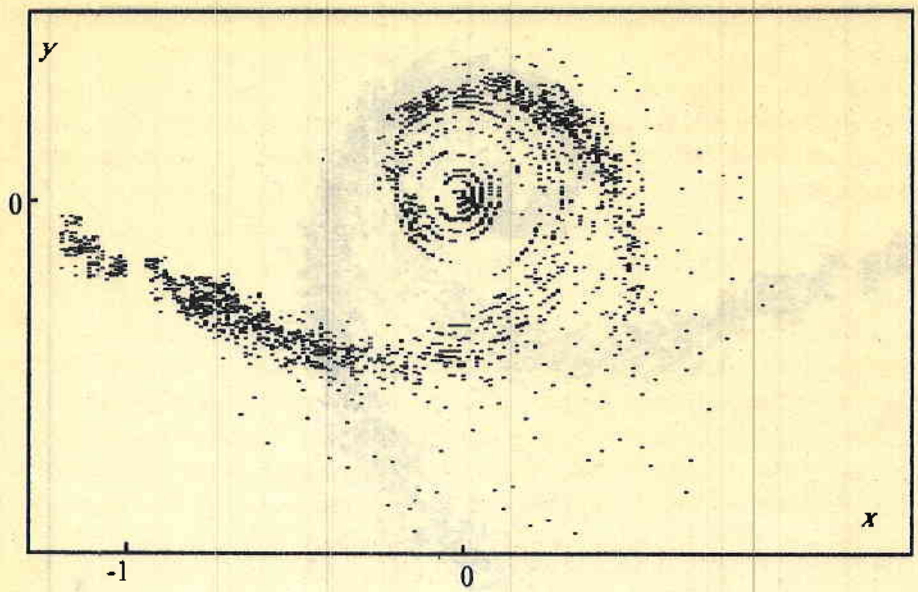

Fig. 1. The surface density distribution in stationary state in the case of $V_{rp} = 0{,}5\,V_{\varphi}$. The compact object is placed in the point (0;0). The first Lagrangian point have coordinates (-1;0)

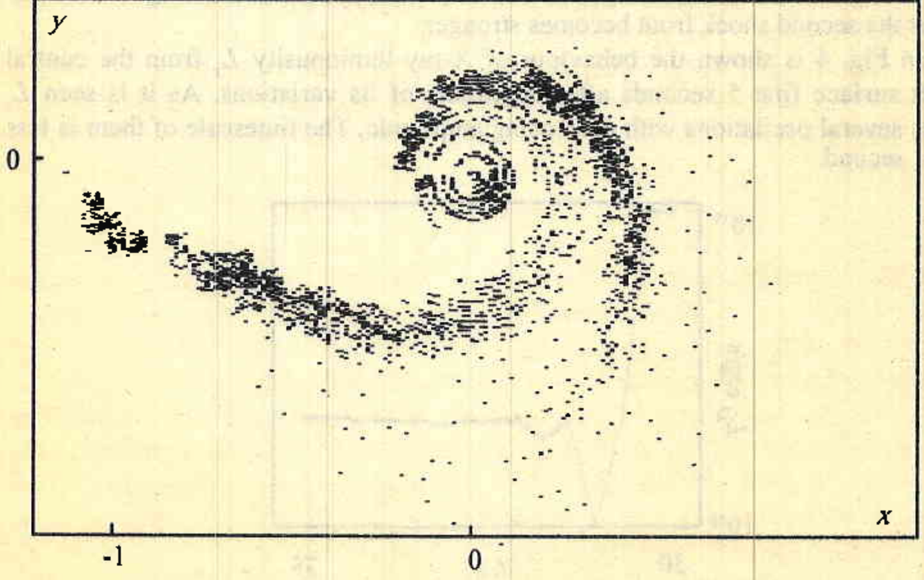

Fig. 2. The surface density distribution in stationary state in the case of $V_{rp} = 2\,V_{\varphi}$. The compact object is placed in the point (0;0). The first Lagrangian point have coordinates (-1;0)

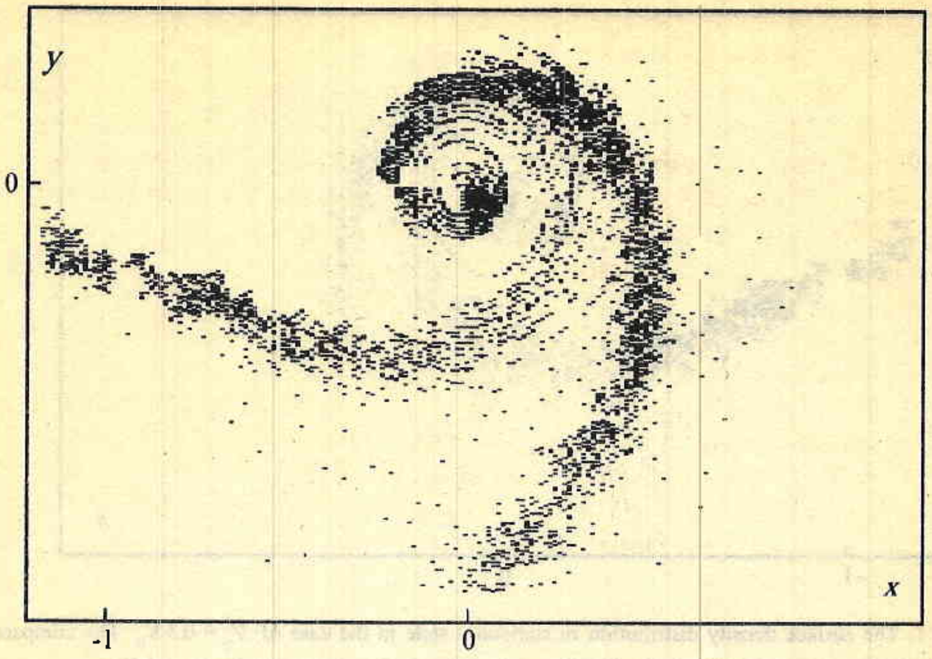

Fig. 3. The surface density distribution in stationary state after the change of V_{rp} from 0,5 to 2 times V_{tp}. The compact object is placed in the point (0;0). The first Lagrangian point have coordinates (-1;0)

As it is seen from these figures, the accretion flow does not change its character but the second shock front becomes stronger.

In Fig. 4 is shown the behaviour of X-ray luminousity L_x from the central object surface first 5 seconds after beginning of its variations. As it is seen L_x shows several oscilations with decreasing amplitude. The timescale of them is less than 1 second.

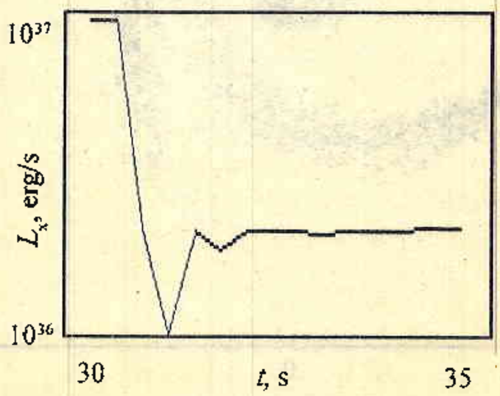

Fig. 4. The behaviour of X-ray luminousity from the compact object surface first 5 seconds after begining of its variability, defined from the increase of radial inflow velocity

The variability of L_x begins at distance more than 10^{10} cm after less than 30 seconds. It means that the signal has travelling with a speed of order of 10^9 cm/s while the maximal radial velosity in the flow is at least 10 times less than this value. All this gives the reason to say that the change of flow parameters at the outer part of the flow produces wave propagation throuth all the flow region.

Comparing this with the results of investigations of an accretion flow in binary system with elliptical orbit [15] we can say that the waves are propagating along the shock fronts.

In Fig. 5 is shown the behaviour of L_x after the first change of V_{rp} till the moment when it reaches new constant value and than after the back change of V_{rp} to the initial value. As it is seen from this figure and from the Fig. 1 and 3, after all above described processes the accretion flow reaches the new stationary state, with stronger second shock front and as a result of this, whith strongar outflow from the region around the outer part of the flow. This new state are less luminous. All the process after the change of V_{rp} takes less than one minute.

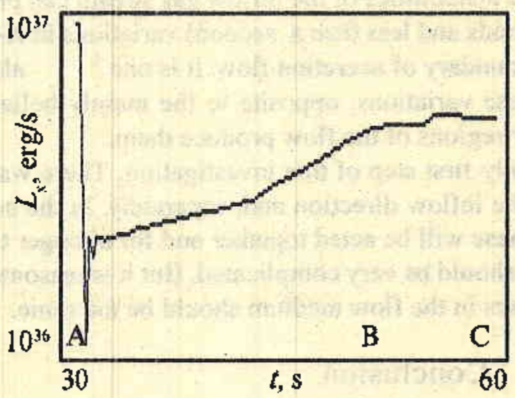

Fig. 5. The behaviour of X-ray luminosity from the compact object surface after the increase of radial inflow velocity till the moment of reaching a new constant value - segment AB and then after back change of V_{rp} to the initial value - segment BC

In Fig. 6 is shown the behaviour of L_x after increase of the accretion rate 10 times for a time of 0,5 s. As a basic state it is taken the same stationary state with $V_{rp} = 0{,}5\ V_{fp}$ as in previous calculations. As it is seen from this figure and Fig. 4, the increase of V_{rp} coused the similar behaviour like that which is coused by an increase in accretion rate of inflow stream.

Recently many authors have considered the shock fronts, formed in the accretion flow in close binary systems as the main place where the energy and angulare moment transfer occur [18-21].

Some authors have investigated the wave propagation in axisymmetric

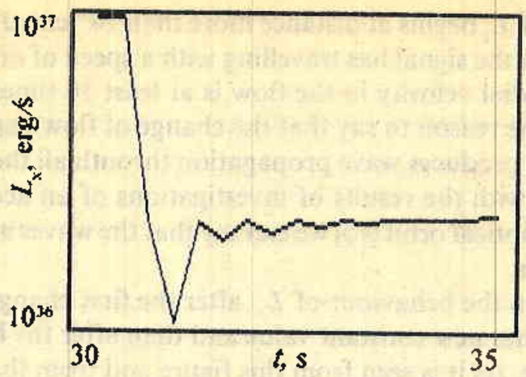

Fig. 6. The behaviour of X-ray luminosity from the compact object surface during the first 5 seconds after begining of its variability defied from the increasing of the inflow stream debit

acretion flow [22-24] as a possibility to defy quick variability in X-ray luminosity.

In this paper we show an evidence for wave propagation in two-dimensional flow. As a result, the instabilities of the inflow gas stream can produce quick (of the order of several seconds and less than a second) variations in X-ray luminosity produced at the inner boundary of accretion flow. It is one alternative possibility for the origin of these variations, opposite to the mainly believed now that some instabilities at inner regions of the flow produce them.

This work is only first step of this investigation. There was modelled only an isolated change in the inflow direction and, separately, in the accretion rate. In the realistic case both these will be acted together and for a longer time. The behaviour of X-ray luminosity should be very complicated. But it is reasonable to think that the nature of the processes in the flow medium should be the same.

Conclusion

We have presented two-dimensional largescale particle numerical investigation of the reaction of the accretion flow in close binary coused by quick changes of inflow stream direction.

The shock fronts formed in the accretion flow not destroied, moreover they become stronger as a result of such variation of inflow direction.

The numerical model does not show any computation instabilities in this case, so it seams to be usefull for modelling of the flows with variable inflow streams.

The X-ray luminosity produced at the inner boundary of the accretion flow shows strong variations very soon after changes in the parameters at outer boundary which is one evidence for wave propagation along the shock fronts. This gives one alternative possibility for explanation of the quick aperiodic variation in X-ray luminosity as a result of variation in inflow stream parameters.

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Могат ли бързите непериодични вариации в рентгеновата светимост да се пораждат във външната част на акреционния поток

Мария Димитрова

(Р е з ю м е)

С помощта на двумерен числен модел се изследва реакцията на акреционния поток в тясна двойна звездна система спрямо резки промени в направлението на втичащия се газов поток.

Изследвано е поведението на рентгеновата светимост, излъчена от вътрешната граница на течението след тези промени. Изследвана е стабилността на структурата на течението спрямо тези промени. В същото време това е тест за приложимостта на числения модел в случай на силно нестационарни режими.

Наблюдават се няколко осцилации в рентгеновата светимост няколко

секунди след промените на външната граница на течението. Това е едно доказателство за разпространението на вълни по дължината на ударните фронтове, формиращи се в резултат от приливното въздействие на втората компонента на двойната система. Осцилациите са с период от порядъка на една секунда. Това дава алтернативна възможност за обяснение на бързите непериодични промени в рентгеновата светимост като резултат от нестабилност във втичащия се газов поток.