Космічна наука і технологія. ДОДАТОК. 2001. Т 7. № 2. С. 47—51.

RADIATION FROM COLLAPSING STARS

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The non-thermal emission in the magnetospheres of collapsing stars with the initial dipole magnetic fields and a certain initial energy distribution of charged particles in the magnetospheres (power-series, relativistic Maxwell, and Boltzmann distributions) are considered. When the star magnetosphere compresses under the collapse, its magnetic field increases considerably. The three factors (particle pressure, collisions between them and stellar rotation) can influence the field structure and the particles dynamics in the magnetosphere. The analysis shows, that these factors may be neglected for the magnetosphere of collapsing star. As it follows from this result, the plasma in magnetosphere is frozen in magnetic field and is collision-free. Therefore, the method of adiabatic invariant may be used to investigate the particle dynamics in magnetosphere. The vortex electric field in magnetosphere accelerates the charged particles, which generate the radiation moving in the magnetic field. The collapsing stars can be powerful sources of a non-thermal radiation produced by the interaction of charged particles with the magnetic field, as it follows from the analysis of particles dynamics and its emission in the stellar magnetosphere under collapse. The radiation flux grows with decreasing of stellar radius and frequency and it can be observed in the form of radiation burst with duration, equal to the stellar collapse time. A value of the radiation flux depends on the distance to the star, its magnetic field, and the particle spectrum in the magnetosphere. In this paper the radiation fluxes are calculated for various collapsing stars. The conclusion is made, that these fluxes can be observed by means of modern astronomical instruments.

INTRODUCTION

Collapse begins when the mass of stellar core exceeds the Chandrasekhar bound, and the star becomes dynamically unstable. The star compresses and its radius decreases. After that, the stars can evolve by several ways. The first possibility is that the stars explodes and lose their masses. The massive stars ($M \le (3...6)M_\odot$) will collapse to neutron stars or black holes. The stars can los their mass and we will observe this phenomenon as supernovae. The stars with the smaller mass will collapse to white dwarfs [16, 17]. The second possibility will realise when stars collapse without the loss of mass. In this case it is very difficult to observe the collapse, and hitherto we not have precise astronomical data conforming the evidences of this stage.

The star emits electromagnetic radiation under the collapse. In this paper the non-thermal radiation from the collapsing stars with the initial dipole magnetic field on the non-relativistic stage is investigated, and the method for the search of collapsing stars is proposed.

PARTICLE DYNAMICS IN MAGNETOSPHERES OF COLLAPSING STARS

The external electromagnetic field of a collapsing star is given [2, 6—12]

$$B_r = 2r^{-3}\mu(t)\cos\theta, \tag{1}$$

Here $F_0 = B_0R_0^2$ is the initial magnetic flux of star with the radius R having the initial radius R_0 and the initial magnetic field B_0.

Equation (1) has obtained by solving of Maxwell equations in Newton approximation which is valid during the collapse except the region near the gravitational radius. The formulae (1) apply if there are negligible external sources of electromagnetic fields. When the star magnetosphere compresses under the collapse, its magnetic field increases considerably. Thus the cyclic electric field will be generated which accelerates the charged particles to relativistic energy. These particles moving in the magnetic field generate a radiation. The field structure and particles dynamics in the magnetosphere can be changed due to influence of such factors as the particles pressure, collisions, and star rotation. These factors can be neglected during the collapse as it follows from the analysis [10, 11].

The initial concentrations of charged particles in the magnetosphere have been chosen as the power-series, relativistic Maxwell, and Boltzmann distributions, which can be described as [15]

$$N_P(E) = K_p E^{-\gamma}; \tag{2}$$

$$N_M(E) = K_M E^2 \exp(-E/kT); \tag{3}$$

$$N_B(E) = K_B \exp(-E/kT); \tag{4}$$

Here K_P, K_M, K_B are the spectral coefficients; k is the Boltzmann constant; is the particles energy and T is the temperature in the magnetosphere; y is the power spectrum.

The power-series distribution is typical for the high-energy particles in cosmic plasmas (in the magnetospheres of neutron stars, the shells of supernova stars and the high-energy cosmic rays). The relativistic Maxwell distribution is typical for some sources of non-thermal radio emission [15].

To investigate particle dynamics in the magnetosphere of collapsing star, the method of adiabatic invariants may be used, so that magnetosphere plasmas is frozen in magnetic field and is collision-free. We considered two mechanisms of the particles interaction with the magnetic field, namely: 1) a betatron acceleration and 2) bremsstrahlung energy losses in magnetic field. The particles energy will change as result of these mechanisms with the rate [10, 11]

$$\frac{dE}{dR} = \left(\frac{dE}{dR}\right)_a + \left(\frac{dE}{dR}\right)_s = a_1 \left(\frac{2GM}{R_*}\right)^{1/2} \left(\frac{R_* - 1}{R^3}\right)^{1/2} E - a_2 F_0^2 R^2 E^2 r^{-6}. \tag{5}$$

$$a_1 = (5k_1/3)(3\cos^4\theta + 1.2\cos^2\theta - 1)(1 + 3\cos^2\theta)^{-2},$$

$$a_2 = \frac{e^4}{6m^4c^7}(1 + 3\cos^2\theta)\sin^2\theta,$$

$k_1 = 2$ and $k_1 = 1$ for relativistic and non-relativistic particles respectively; $R_* = R_0/R$; G is gravitational constant, M is the mass of collapsing star.

The particle dynamics in the magnetosphere can be considered by means of the equation for particle transition in the regular magnetic field, which can be written as [10, 11]

$$\frac{\partial N}{\partial R} = f_1(E, R)\frac{\partial N}{\partial E} + f_2(E, R)N = 0, \tag{6}$$

Here

$$f_1(E, R) = ER^{-1}\left\{a_1 - a_2 F_0^2 [R^7 R_*/2GM(R_* - 1)]^{1/2} E r^{-6}\right\},$$

$$f_2(E, R) = R^{-1}\left\{a_1 - 2R^3[R/(R_0 - R)]^{1/2} E\right\},$$

Equation (6) has been solved for two special cases. In the first case it is assumed that the energy losses do not influence the particles spectrum in the magnetosphere. Then we can neglected the second term in the right hand part of Equation (5), and thus the solution of Equation (6) for the initials distribution (2)—(4) are as follows

$$N'_P(E, R) = K_p E^{-\gamma} R_*^{-\beta_P}, \tag{7}$$

$$N'_M(E, R) = K_M E^2 R_*^{-\beta_M} \exp(-E/kT), \tag{8}$$

$$N'_B(E, R) = K_B R_*^{-\beta_B} \exp(-E/kT). \tag{9}$$

Here $\beta_P = a_1(\gamma - 1)$, $\beta_M = a_1(E/kT\ln E - 3)$, $\beta_B = a_1(E/kT\ln E - 1)$;

Equations (7)—(9) determine the particle spectrum in the magnetosphere and itsevolution during collapse for the first case when the energy losses can be neglected. This case is typical for the initial stage of the collapse and we consider it in this paper. The second case will be realise in the final stage of the collapse, when the magnetic field increases to the extreme value and the energy losses will influence the particle spectrum considerably. We will consider this case later, on not in this paper.

ELECTROMAGNETIC RADIATION FROM COLLAPSING STARS

The ratio between the radiation flux from collapsing stars and their initial radiation flux for the power-series, relativistic Maxwell, and Boltzmann distributions (7)—(9) respectively are

$$I_{\nu P}/I_{\nu P0} = (\nu/\nu_0)^{(1-\gamma)/2} R_*^{\gamma-2} \int R_*^{\{} - a_1(\gamma-2)\sin\theta d\theta, \quad (10)$$

$$I_{\nu M}/I_{\nu M0} = (\nu/\nu_0) R_*^{-3}(1/kT) \int R_*^{-\beta_M} \exp(-E/kT)\sin\theta d\theta dE, \quad (11)$$

$$I_{\nu B}/I_{\nu B0} = (\nu/\nu_0) R_*^{-3}(kT) \int_0^{\pi/2} R_*^{-\beta_B} E^{-2} \exp(-E/kT)\sin\theta d\theta dE. \quad (12)$$

Using Equations (10)—(12), the ratio between the radiation flux from collapsing stars and their initial flux can be calculated. This ratio for the different radius R, the temperature 1 eV $\leq kT \leq$ 10 eV by $\nu/\nu_0 = 1$ is given in Tables 1—2. The value obtained by the numerical integration of the Equations (10)—(12) within the range 2 eV $\leq kT \leq 10^9$ eV, $0 \leq \theta \leq \pi/2$.

CONCLUSIONS

The general conclusions from the obtained results are the following. The magnetic field will increase during the collapse. The charged particles will accelerate to relativistic energy in the magnetospheres of collapsing stars. These particles will emit the electromagnetic waves in the wide frequency range, from radio waves to gamma rays. We can see from these results, that the radiation flux increases during the collapse very rapidly (by millions and more comparing with the initial flux). The radiation flux increases most rapidly for the collapsing stars with the cool magnetospheres. For these stars the flux increases by millions yet at the initial stage of collapse, when the stellar radius decreases ten times (Table 2). For the magnetospheres with middle the flux increases at more late stage of collapse, when the stellar radius decreases by tens times. By collapse of the stars with the high-temperature magnetospheres the radiation flux grows at a late stage collapse, when the stellar radius decreases by hundreds times. The radiation flux from stars with Boltzmann distribution increases more rapidly than for stars with the relativistic Maxwell distribution. This radiation can be observed as the impulses in the whole frequency range, from radio impulses to gamma ray bursts. The impulse duration is equal to the duration of stellar collapses defining the mass and radius of stars. The intensity of this impulse is very strong. The radiation flux from collapsing stars exceeds the initial flux by millions at the final stage of collapse. We can see from Tables 1, 2 that the radiation fluxes for stars with the initial fluxes in range 10^{-22} erg/cm^{2}s $\leq I\nu_0 \leq$ $\leq 10^{-30}$ erg/cm^{2}s [2, 6—12] can increase to the value 10^{-16} erg/cm^{2}s $\leq I\nu_0 \leq 10^{-24}$ erg/cm^{2}s and more.

Thus, the collapsing stars can be the powerful sources of the non-thermal radiation impulses. Where can these impulses be observed? First of all, in the middle of powerful gamma bursts and X bursts which are not periodical and can be connected with the precollapse stars. These impulses can be observed also from the presupernovae. The star goes to this stage when the pressure in the stellar core falls and the star becames dynamically unstable on account of the depletion of nucleas Si, the photodissociation of nucleas Fe and the neutronisation of stellar core. After that, the star begins to compress under the

Table 1. The value $I_{\nu P}/I_{\nu P0}$ for various R_*, γ and $\nu/\nu_0 = 1$

R_*	γ								
	2.4	2.6	2.8	3.0	3.2	3.4	3.6	3.8	4.0
10	4.75	12	32.6	93.7	281	864	2.71 E3*)	8.60 E3	2.76 E4
20	8.2	29.5	117	494	2.17 E3	9.74 E3	4.44 E4	2.05 E5	9.56 E5
40	14.6	76.1	443	2.74 E3	1.75 E4	1.15 E5	7.60 E5	5.09 E6	3.43 E7
60	20.7	135	981	7.57 E3	6.03 E4	4.91 E5	4.04 E6	3.36 E7	2.82 E8
80	26.7	203	1.74 E3	1.57 E4	1.46 E5	1.38 E5	1.33 E7	1.29 E8	1.26 E9
100	32.6	281	2.71 E3	2.76 E4	2.89 E5	3.09 E6	3.35 E7	3.67 E8	4.04 E9
200	61.2	774	1.09 E4	1.61 E5	2.46 E6	3.81 E7	5.98 E8	9.47 E9	1.51 E11
400	117	2.17 E3	4.44 E4	9.56 E5	2.11 E7	4.74 E8	1.08 E10	2.47 E11	5.71 E12
600	172	3.98 E3	1.02 E5	2.72 E6	7.45 E7	2.08 E8	5.87 E10	1.67 E12	4.80 E13
800	226	6.14 E3	1.83 E5	5.71 E6	1.83 E8	5.94 E8	1.96 E11	6.50 E12	2.17 E14
1000	281	8.60 E3	2.89 E5	1.02 E7	3.67 E8	1.34 E10	4.98 E11	1.86 E13	7.03 E14

*) 2.71 E3 ≡ $2.71 \cdot 10^3$

Table 2. The value $I_{\nu M}/I_{\nu M0}$ and $I_{\nu B}/I_{\nu B0}$ for 1 eV ≤ kT ≤ 10 eV and various R_*

R_*	$I_{\nu B}/I_{\nu B0}$	$I_{\nu M}/I_{\nu M0}$	R_*	$I_{\nu B}/I_{\nu B0}$	$I_{\nu M}/I_{\nu M0}$	R_*	$I_{\nu B}/I_{\nu B0}$	$I_{\nu M}/I_{\nu M0}$
	$kT = 1$ eB			$kT = 5$ eB			$kT = 8$ eB	
34	16.4	1.11	135	58.4	1	180	1.99	1
36	86.2	6.04	140	310	1.12	190	21.7	1
38	491	35.2	145	1.72 E3	6.28	200	260	1
40	3.01 E3	221	150	9.93 E3	36.6	210	3.42 E3	5.06
42	1.98 E4	1.48 E3	155	5.99 E4	222	220	4.91 E4	73.3
44	1.40 E5	1.06 E4	160	3.77 E5	1.40 E3	230	7.68 E5	1.15 E3
46	1.05 E6	8.09 E4	165	2.46 E6	9.23 E3	240	1.30 E7	1.97 E4
48	8.35 E6	6.54 E5	170	1.67 E7	6.30 E4	250	2.40 E8	3.65 E5
50	7.06 E7	5.61 E6	175	1.18 E8	4.47 E5	260	4.77 E9	7.30 E6
52	6.32 E8	5.08 E7	180	8.65 E8	3.29 E6	270	1.02 E11	1.57 E8
	$kT = 2$ eB			$kT = 6$ eB			$kT = 9$ eB	
60	4.44	1	150	11.6	1	200	3.7	1
65	70.8	1.43	160	220	12.3	210	34.9	1
70	1.34 E3	27.7	170	4.77 E3	309	220	357	1
75	2.97 E4	626	180	1.18 E5	8.73 E3	230	3.95 E3	4.66
80	7.64 E5	1.64 E4	190	3.31 E6	2.78 E5	240	4.70 E4	55.9
85	2.26 E7	4.92 E5	200	1.05 E8	9.95 E6	250	6.03 E5	721
90	7.67 E8	1.69 E7	210	3.72 E9	3.98 E8	260	8.30 E6	9.98 E3
95	2.96 E10	6.58 E8	220	1.48 E11	1.77 E10	270	1.22 E8	1.48 E5
100	1.29 E12	2.89 E10	230	6.52 E12	8.72 E11	280	1.92 E9	2.34 E6
105	6.31 E13	1.43 E12	240	3.20 E14	4.76 E13	290	3.23 E10	3.95 E7
	$kT = 4$ eB			$kT = 7$ eB			$kT = 10$ eB	
105	2.8	1	160	1.14	1	220	7.12	1
110	17.1	1	170	14.8	1	230	59.7	1
115	111	1	180	216	1	240	536	1
120	770	4.3	190	3.53 E3	6.78	250	5.15 E3	4.96
125	5.66 E3	31.9	200	6.42 E4	124	260	5.27 E4	51.1
130	4.41 E4	250	210	1.29 E6	2.52 E3	270	5.76 E5	561
135	3.63 E5	2.07 E3	220	2.87 E7	5.63 E4	280	6.67 E6	6.54 E3
140	3.15 E6	1.81 E4	230	7.00 E8	1.38 E6	290	8.22 E7	8.09 E4
145	2.88 E7	1.67 E5	240	1.87 E10	3.73 E7	300	1.07 E9	1.06 E6
150	2.78 E8	1.62 E6	250	5.48 E11	1.10 E9	310	1.48 E10	1.47 E7

influence of the gravitational field. The star can throw out the part of mass and we will observed this phenomenon as supernovae. The stage of collapse during which the stars can be the powerful source of the non-thermal radiation must preceded this stage. The impulse of non-thermal radiation can also be observed before the explosion of novae. The powerful sources of the non-thermal radiation can also be the white dwarfs in double systems at the stage of the accretion-induced collapse. The periodical impulse of non-thermal radiation can be generated also by the pulsation of the stars with magnetic field, since in this case the charged particles will accelerate and the non-thermal emission will be generated. We draw the conclusion that the collapsing stars can be observed by means of the impulse of non-thermal radiation. What problems can arise by a realisation of the observational astrophysics program for search of collapsing stars? The first problem is that we can not point at the location of precollapses stars accurately enough, since the theory of stellar evolution does not make it possible to do that. We indicated only the types of stars that can collapse. But the theory does not enable as to make the detailed chronology of collapse, therefore we can not indicate where and when exactly the collapsing star can arise. This fact is a principal problem for the observational astrophysics program for the search of collapsing stars. The second problem is that the stellar collapse passes very rapidly and this stage is very short. This problem can be solved by means of the modern instruments, for example, gamma- and X-telescopes. But new problems arise, how the impulse from collapsing stars can be chooses between the great numbers of bursts of the unknown origin.

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