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Effect of Photon Rocket in X-ray Binaries

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Abstract.
It is shown that X-ray binaries can be accelerated by their own radiation. It is possible if the magnetic field of a neutron star in a binary differs from the dipolar field. Asymmetric X-ray emission generated due to accretion of matter onto a neutron star surface creates an accelerating force. Its magnitude can be comparable or even larger than gravitational attraction of the binary to the Galaxy.

Consider a neutron star in an X-ray binary under condition that the neutron-star magnetic field differs from the dipolar one. Then X-ray radiation which accompanies accretion onto the neutron star will be asymmetrical. This will create a radiative reaction force that acts onto the binary. After averaging over neutron star rotation the force component survives directed along the spin axis. The strength of the radiative force F_X depends on X-ray luminosity of the star, L_X, and on the X-ray asymmetry parameter ξ: $F_X = \xi L_X/c = \xi \dot{M} c r_g/(2a)$, where c is the light speed, a is the neutron-star radius, r_g is its gravitational radius; $r_g/a \sim 0.4$ for $M_1 = 1.4\,M_\odot$ and $a = 10$ km. The asymmetry parameter is the mean value of cosine of an angle between the spin axis and direction of X-ray emission: $\xi = \int \psi(\vartheta, \varphi) \cos\vartheta\, d\Omega$, where $\psi(\vartheta, \varphi)$ is the beaming pattern of X-ray emission from the neutron star in spherical coordinates with the z axis along the spin axis. For an accretion rate $\dot{M} = 2 \times 10^{17}$ g s^{-1} and asymmetry parameter $\xi = 0.2$ the radiation force is $F_X = 2.4 \times 10^{26}$ dyne and for low-mass X-ray binaries (LMXBs) exceeds the force of gravitational attraction to the Galactic center (by a factor of 2.4 for total mass of the binary system $2.5 M_\odot$ and distance from the Galactic center equal 8.5 kpc). On the other hand, F_X is smaller (by nine orders of magnitude) than the attractive force between the neutron star and its optical companion. For the disk accretion onto the neutron star, its rotational axis aligns quickly (in about 10^5 yr for the magnetic field $\sim 10^{12}$ G, as compared to mass exchange time, $\tau \sim 10^7$ yr) perpendicular to the accretion disk (and the orbital plane). The radiation reaction force will accelerate the neutron star perpendicular to the binary orbital plane. The neutron star will start to spiral up dragging the optical companion. Notice that this mechanism does not introduce additional eccentricity of the binary orbits. Generally, F_X may create some force momentum $\sim aF_X$ with respect to the neutron star center. However this momentum is three orders of magnitude smaller than the momentum of forces $H_A^2 r_A^3$ which act at the Alfven surface (H_A is the magnetic field at the Alfven radius r_A). Let us present a simple estimate for a velocity gain Δv of the system at $\tau/T \ll 1$, where T is Keplerian period of the system in the Galaxy ($T = 2.2 \times 10^8$ yr for

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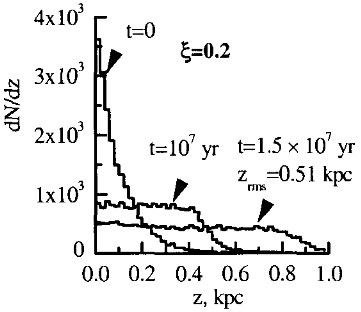

Fig. 1

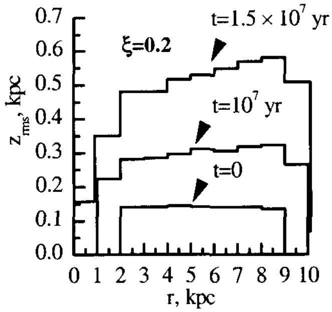

Fig. 2

$r = 8.5$ kpc): $\Delta v = (M_1 + M_2)^{-1} \int F_X \, dt = (\xi r_g c/2a)(M_1 + M_2)^{-1} \int \dot{M} \, dt$, i.e., Δv is determined by the mass transfer $\Delta M = \int \dot{M} \, dt$ onto the neutron star. For $\Delta M = 0.1 \, M_\odot$ and $(M_1 + M_2) = 2.5 \, M_\odot$, the velocity increase is $\Delta v = 2.4 \times 10^3 \, \xi$ km s^{-1}. This mechanism has been proposed and considered by the authors (Pal'shin & Tsygan 1998). In this note, we study the other manifestation of the photon rocket phenomenon, the broadening of their distribution above the galactic plane.

In order to obtain the spacial distribution function of the objects we have solved the equations of their motion in the Galactic potential suggested by Carlberg & Innanen (1987). The initial distribution function, in cylindrical coordinates, has been taken in the form $\rho(r, z) = \rho_0 \exp(-r/r_0) \exp(-z/z_0)$ in the range of $r = 2 \div 9$ kpc, with $r_0 = 4.5$ kpc (see Paradijs & White 1995) and $z_0 = 100$ pc. The radiative force has been assumed to be oriented freely. The z-component of initial velocity of the system has been neglected since it is small as compared with the velocity gain Δv. Time dependence of the accretion rate has been written as $\dot{M} = \dot{M}_0 \, [\tau/(t + \tau)]^\beta$ ($t > 0$, $\beta = 1.5$, $\dot{M}_0 = 2 \times 10^{17}$ g s^{-1}, $\tau = 10^7$ yr). Figure 1 shows distributions over height above the Galactic plane for the value of the asymmetry parameter $\xi = 0.2$ (we have made Monte Carlo simulations for 2×10^4 systems). It is seen that for $\xi = 0.2$ and $t \simeq 1.5 \times 10^7$ yr LMXBs gain typical heights above the Galactic plane $z_{rms} = 0.5$ kpc which agree with observations. Figure 2 shows z_{rms} of the LMXBs as a function of the distance from the Galactic center for $\xi = 0.2$. It is seen that for times greater than 10^7 yr, z_{rms} grows with increasing of the distance from the Galactic center.

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