Session 3: Diagnostics of High Gravity Objects with X- and Gamma Rays

3-2. Black Hole Binaries

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A MODEL FOR A THIN MAGNETISED DISC IN LMC X-3

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1. Introduction and summary

A model for the stationary radial distribution of the magnetic energy-stress tensor $<\boldsymbol{BB}>$ in a standard thin disc is presented, with allowance for magnetic torques and dissipation, see Fig. 1. The model is an extension of earlier work by Schramkowski et al. (1996). For LMC X-3, $<B^2>^{1/2}$ reaches $\sim 4 \times 10^5$ G near the inner edge of the disc, and the magnetic pressure is much smaller than the sum of gas and radiation pressure.

2. Equations for a magnetised thin disc

A description of $\boldsymbol{B}$ in terms of $<\boldsymbol{BB}>$ permits to allow for: (1) small-scale fields, (2) the influence of magnetic stresses on accretion, and (3) magnetic heating of a disc corona. The relevant equations are (Hoyng 1998):

$$(\partial_t - \beta\nabla^2)\,\varepsilon \;=\; (\,2\gamma \;-\; \zeta\Omega)\,\varepsilon \;-\; 3\Omega\, m \tag{1}$$

$$(\partial_t - \beta\nabla^2)\,m \;=\; (-\tfrac{2}{5}\gamma - \zeta\Omega)\,m - \tfrac{1}{2}\Omega\,\varepsilon\;, \tag{2}$$

where

$$\varepsilon \equiv\; <B^2>/8\pi\;\;;\qquad m \equiv\; <B_r B_\theta>/8\pi\;, \tag{3}$$

with $\beta = \frac{1}{3}<v^2>\tau_c$ and $\gamma = \frac{1}{3}<|\nabla\times\boldsymbol{v}|^2>\tau_c$ ($\boldsymbol{v}$ is the turbulent flow); $\zeta = \nu/\beta$ is the turbulent Prandtl number and ν is the kinematic viscosity. The terms in (1) and (2) describe turbulent transport (β), amplification due to random field line stretching (γ), resistive dissipation ($\zeta\Omega$), and amplification by the keplerian shear flow $\boldsymbol{\Omega}$. No α-effect has been included.

The disc is modelled with the usual thin disc equations; those for energy and angular momentum have extra terms accounting for heating due to resistive dissipation and for magnetic stresses ($f = 1 - (r_0/r)^{1/2}$):

K. Koyama et al. (eds.), The Hot Universe, 379-380.

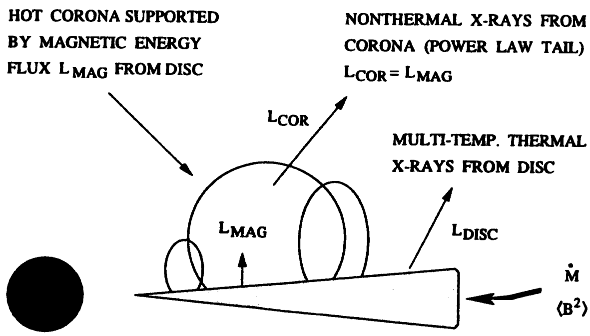

Figure 1. An optically thick magnetised disc in LMC X-3 radiates a multi-temperature blackbody X-ray spectrum. Like in the case of the solar corona, a magnetic flux density $-\beta\partial\varepsilon/\partial z$ supports a hot, optically thin corona emitting nonthermal Bremsstrahlung (the hard component of the X-ray spectrum).

$$\frac{4\sigma T^4}{3\tau} = \tfrac{1}{2}\nu\Sigma\left(r\frac{\partial\Omega}{\partial r}\right)^2 + \tfrac{1}{2}\zeta\Omega\int_{-H}^{H}\varepsilon\,\mathrm{d}z \tag{4}$$

$$\frac{\dot{M}\Omega f}{2\pi} = -\nu\Sigma\, r\frac{\partial\Omega}{\partial r} - 2\int_{-H}^{H} m\,\mathrm{d}z \tag{5}$$

By separating the vertical co-ordinate z in (1) and (2), two PDE's for ϵ and m in the central plane $z = 0$ are obtained, which are coupled to the algebraic thin disc equations that also refer to $z = 0$. Nonlinear effects are accounted for indirectly, by tuning (1) β so that the growth rate of the fundamental mode is zero, and (2) the constant determining the magnitude of $\varepsilon(r)$ so that the sum of the disc luminosity $L_{\rm disc}$ and magnetic luminosity $L_{\rm mag}$ equals the gravitational energy liberated during accretion.

3. Application to LMC X-3

The stationary solution applicable to LMC X-3 features: (1) a maximum r.m.s. field strength $<B^2>^{1/2}$ of 4×10^5 G at $r = 2r_0 = 6r_{\rm s}$; (2) a $<B_{\rm r}B_\theta>$ that is always negative, while $\varepsilon/\rho c_{\rm s}^2 \lesssim 0.09$; (3) $L_{\rm mag}/L_{\rm disc} \simeq 0.02$, implying that the nonthermal X-ray flux should also be about 0.02 of the thermal X-ray flux, as is observed (Treves et al. 1990; Ebisawa et al. 1993).

References

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