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Magnetic fields in active galactic nuclei and microquasars

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ABSTRACT

Observations of active galactic nuclei and microquasars by *ASCA*, *RXTE*, *Chandra* and *XMM–Newton* indicate the existence of wide X-ray emission lines of heavy ionized elements in their spectra. The emission can arise in the inner parts of accretion discs where the effects of general relativity must be counted; moreover, such effects can dominate. We describe a procedure to estimate an upper limit of the magnetic fields in the regions where X-ray photons are emitted. We simulate typical profiles of the iron K_α line in the presence of a magnetic field and compare them with observational data. As an illustration, we find $H < 10^{10}$–10^{11} Gs for Seyfert galaxy MCG–6-30-15. Using the perspective facilities of measurement devices (e.g. Constellation-X mission) a better resolution of the blue peak structure of the iron K_α line will allow us to find the value of the magnetic fields if the latter are high enough.

Key words: black hole physics – galaxies: individual: MCG – 6-30-15 – galaxies: Seyfert.

1 INTRODUCTION

Recent *ASCA*, *RXTE*, *Chandra* and *XMM–Newton* observations of Seyfert galaxies have demonstrated the existence of a wide iron K_α line (6.4 keV) in their spectra along with a number of other weaker lines (Ne X, Si XIII, XIV, S XIV–XVI, Ar XVII, XVIII, Ca XIX, etc.); see, for example, Fabian et al. (1995), Tanaka et al. (1995), Nandra et al. (1997a,b), Malizia et al. (1997), Sambruna et al. (1998), Yaqoob et al. (2001b) and Ogle et al. (2000).

Magnetic fields play a key role in the dynamics of accretion discs and jet formation. Bisnovatyi-Kogan & Ruzmaikin (1974, 1976) considered a scenario to generate superstrong magnetic fields near black holes. According to their results, magnetic fields near the marginally stable orbit could be about $H \sim 10^{10}$–10^{11} Gs. Kardashev (1995, 2001a,b,c) has shown that the strength of the magnetic fields near supermassive black holes can reach the values $H_{\max} \approx 2.3 \times 10^{10} M^{-1}{}_9$ Gs due to the virial theorem.[1] Also, Kardashev considered a generation of synchrotron radiation, acceleration of $e^{+/-}$ pairs and cosmic rays in magnetospheres of supermassive black holes at such high fields. It is the magnetic field that plays a key role in these models. Below, based on the analysis of the iron K_α line profile in the presence of a strong magnetic field, we describe how to detect the field itself or at least obtain an upper limit of the magnetic field.

For cases when the spectral resolution is good enough, the emission spectral line demonstrates typical two-peak profile with the high ‘blue’ peak, the low ‘red’ peak and the long ‘red’ wing which drops gradually to the background level (Tanaka et al. 1995; Yaqoob et al. 1997). The Doppler linewidth corresponds to the velocity of the matter motion of tens of thousands kilometres per second,[2] e.g. the maximum value is about $v \approx 80\ 000$–$100\ 000$ km s^{-1} for the galaxy MCG–6-30-15 (Tanaka et al. 1995; Fabian et al. 2002) and $v \approx 48\ 000$ km s^{-1} for MCG–5-23-16 (Weaver, Krolik & Pier 1998). For both galaxies the line profiles are known rather well. Fabian et al. (2002) analysed the results of long-time observations of the MCG–6-30-15 galaxy using *XMM–Newton* and *BeppoSAX*. The long monitoring confirmed the qualitative conclusions about the features of the Fe K_α line, which were discovered by the *ASCA* satellite. Yaqoob et al. (2002a) discussed the essential importance of *ASCA* calibrating and the reliability of obtained results. Lee et al. (2002) compared *ASCA* results with *RXTE* and *Chandra* observations for MCG–6-30-15. Iwasawa et al. (1999), Lee et al. (2000) and Shih, Iwasawa & Fabian (2002) analysed in detail the variability in continuum and in Fe K_α line for the MCG–6-30-15 galaxy.

The phenomena of the broad emission lines are supposed to be related with accreting matter around black holes. Matt et al. (1992a,b), Wilms, Reynolds & Begelman (2001), Ballantyne & Fabian (2001) and Martocchia et al. (2002b) proposed physical models of accretion discs for the MCG–6-30-15 galaxy and their influence on the Fe K_α line shape. Boller et al. (2002) found the features of the spectral line near 7 keV in Seyfert galaxies using data from the *XMM–Newton* satellite. Yaqoob et al. (2002b) presented results of *Chandra* HETG observations of Seyfert I galaxies. Yu & Lu (2001) discussed possible identification of binary massive black holes analysing the Fe K_α shape. Ballantyne,

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[1] Recall that equipartition value of magnetic field is $\sim 10^4$ Gs only.

[2] Note that the measured line shape differs essentially from the Doppler one.

Fabian & Ross (2002) estimated the abundance of iron using the data of X-ray observations. Popovíc, Mediavilla & Munoz (2001); Popóvic et al. (2003) discussed the influence of microlensing on the distortion of spectral lines including the Fe K_α line, which can be significant in some cases. Matt (2002) analysed the influence of the Compton effect on the Fe K_α shape for emitted and reflected spectra. Morales & Fabian (2002) proposed a procedure to estimate the masses of supermassive black holes. Fabian (1999) presented a possible scenario for evolution of such supermassive black holes.

The general status of black holes is described in a number of papers; see, for example, Liang (1998) and references therein, Zakharov (2000) and Novikov & Frolov (2001). Because the matter motions indicate very high rotational velocities, we can assume the K_α line emission arises in the inner regions of accretion discs at distances ~1–3 r_g from the black holes. Let us recall that the innermost stable circular for a non-rotational black hole (which has the Schwarzschild metric) is located at the distance 3 r_g from the black hole singularity. Therefore, the rotation of the black hole could be the most essential factor. A possibility to observe the matter motion in such strong gravitational fields could make it possible not only to check general relativity predictions and simulate physical conditions in accretion discs, but also to investigate observational manifestations of astrophysical phenomena such as jets (Romanova et al. 1998; Lovelace et al. 1997), some instabilities such as Rossby waves (Lovelace et al. 1999) and gravitational radiation.

Wide spectral lines are considered to be formed by radiation emitted in the vicinity of black holes. If there are strong magnetic fields near black holes these lines are split by the field into several components. This phenomenon is discussed below. Such lines have been found in microquasars, gamma-ray bursters (GRBs) and other similar objects (Balucinska-Church & Church 2000; Greiner 2000; Mirabel 2001, also private communication; Lazzati et al. 2001; Martocchia et al. 2002a; Mirabel & Rodriguez 2002; Miller et al. 2002; Zamanov & Marziani 2002).

Observations and theoretical interpretations of wide X-ray lines (particularly the iron K_α line) in AGNs are actively discussed in a number of papers (Yaqoob et al. 1996; Wanders et al. 1997; Sulentic et al. 1998a,b; Paul et al. 1998; Bianchi & Matt 2002; Turner et al. 2002; Levenson et al. 2002). The results of numerical simulations in the framework of different physical assumptions on the origin of the wide emissive iron K_α line in the nuclei of Seyfert galaxies are presented in the following papers: Paul et al. (1998); Bromley, Chen & Miller (1997); Pariev & Bromley (1998a); Pariev & Bromley (1998b); Cui, Zhang & Chen (1998); Bromley, Miller & Pariev (1998); Pariev et al. (2001); Ma (2000); Ma (2002); Karas, Martocchia & Subr (2001). The results of Fe K_α line observations and their possible interpretation are summarized by Fabian (2001).

To obtain an estimation of the magnetic field we simulate the formation of the line profile for different values of magnetic field. As a result we find the minimal B value at which the distortion of the line profile becomes significant. Here we use an approach, which is based on numerical simulations of trajectories of the photons emitted by a hot ring moving along a circular geodesics near the black hole, described earlier by Zakharov (1993, 1994, 1995) and Zakharov & Repin (1999).

2 MAGNETIC FIELDS IN ACCRETION DISCS

One of the basic problems in understanding the physics of quasars and microquasars is the 'central engine' in these systems, in particular, a physical mechanism to accelerate charged particles and generate high energetic electromagnetic radiation near black holes. The construction of such a 'central engine' without magnetic fields could hardly ever be possible. On the other hand, magnetic fields make it possible to extract energy from rotational black holes via the Penrose process and the Blandford–Znajek mechanism, as shown in hydrodynamical simulations by Meier, Koide & Uchida (2001); Koide et al. (2002). The Blandford–Znajek process could provide huge energy release in AGNs (for example, for MCG–6-30-15) and microquasars when the magnetic field is strong enough (Wilms et al. 2001).

Physical aspects of generation and evolution of magnetic fields have been considered in a set of reviews (e.g. Asseo & Sol 1987; Giovannini 2001). A number of papers conclude that, in the vicinity of the marginally stable orbit, the magnetic fields could be high enough (Bisnovatyi-Kogan & Ruzmaikin 1974, 1976; Krolik 1999).

Agol & Krolik (2000) considered the influence of magnetic fields on the accretion rate near the marginally stable orbit and hence on the disc structure. They found the appropriate changes of the emitting spectrum and solitary spectral lines. Vietri & Stella (1998) investigated the instabilities of accretion discs when the magnetic fields play an important role.

3 PHOTON GEODESICS IN THE KERR METRIC

Many astrophysical processes, where large energy release is observed, are supposed to be related to black holes. Because a large fraction of astronomical objects, such as stars and galaxies, exhibits proper rotation, there are no doubts that the black holes formed in their nuclei, both stellar and supermassive, possess an intrinsic proper rotation. It is known that stationary black holes are described by the Kerr metric which has the following form in geometrical units ($G = c = 1$) and Boyer–Lindquist coordinates (t, r, θ, ϕ) (Misner, Thorne & Wheeler 1973; Landau & Lifshitz 1975)

$$\begin{aligned} \mathrm{d}s^2 = & -\left(1 - \frac{2Mr}{\rho^2}\right)\mathrm{d}t^2 + \frac{\rho^2}{\Delta}\,\mathrm{d}r^2 + \rho^2\,\mathrm{d}\theta^2 \\ & + \left(r^2 + a^2 + \frac{2Mra^2}{\rho^2}\sin^2\theta\right)\sin^2\theta\,\mathrm{d}\phi^2 \\ & - \frac{4Mra}{\rho^2}\sin^2\theta\,\mathrm{d}\phi\,\mathrm{d}t, \end{aligned} \tag{1}$$

where

$$\rho^2 = r^2 + a^2\cos^2\theta,$$

$$\Delta = r^2 - 2Mr + a^2.$$

Constants M and a determine the black hole parameters – M is its mass and $a \in (0, M)$ is its specific angular moment.

The particle trajectories can be described by the standard geodesic equations

$$\frac{\mathrm{d}^2x^i}{\mathrm{d}\lambda^2} + \Gamma^i_{kl}\frac{\mathrm{d}x^k}{\mathrm{d}\lambda}\frac{\mathrm{d}x^l}{\mathrm{d}\lambda} = 0, \tag{2}$$

where Γ^i_{kl} are the Christoffel symbols and λ is the affine parameter. These equations could be simplified if we use the complete set of the first integrals found by Carter (1968). $E = p_t$ is the particle energy at infinity, $L_z = p_\phi$ is the projection of its angular momentum on the rotation axis, $m = (p_ip^i)^{1/2}$ is the particle mass and Q is the Carter separation constant:

$$Q = p_\theta^2 + \cos^2\theta\left[a^2(m^2 - E^2) + L_z^2\big/\sin^2\theta\right]. \tag{3}$$

The equations of photon motion ($m = 0$) can be reduced to the following system of ordinary differential equations (Zakharov 1991, 1994):

$$\frac{dt}{d\sigma} = -a(a\sin^2\theta - \xi) + \frac{r^2+a^2}{\Delta}(r^2 + a^2 - \xi a), \tag{4}$$

$$\frac{dr}{d\sigma} = r_1, \tag{5}$$

$$\frac{dr_1}{d\sigma} = 2r^3 + (a^2 - \xi^2 - \eta)r + (a-\xi)^2 + \eta, \tag{6}$$

$$\frac{d\theta}{d\sigma} = \theta_1, \tag{7}$$

$$\frac{d\theta_1}{d\sigma} = \cos\theta\left(\frac{\xi^2}{\sin^3\theta} - a^2\sin\theta\right), \tag{8}$$

$$\frac{d\phi}{d\sigma} = -\left(a - \frac{\xi}{\sin^2\theta}\right) + \frac{a}{\Delta}(r^2 + a^2 - \xi a). \tag{9}$$

Here σ is an independent variable, $\eta = Q/M^2E^2$ and $\xi = L_z/ME$ are the Chandrasekhar constants (Chandrasekhar 1983) which should be derived from initial conditions in the disc plane; t and r are the appropriate dimensionless variables (in mass units), and a is the dimensionless rotation parameter of a black hole. The system (4)–(9) has two first integrals

$$\begin{aligned}\epsilon_1 \equiv {} & r_1^2 - r^4 - (a^2 - \xi^2 - \eta)r^2 - \\ & -2[(a-\xi)^2 + \eta]r + a^2\eta = 0,\end{aligned} \tag{10}$$

$$\epsilon_2 \equiv \theta_1^2 - \eta - \cos^2\theta\left(a^2 - \frac{\xi^2}{\sin^2\theta}\right) = 0, \tag{11}$$

which can be used for the accuracy control of computation.

The additional variables r_1 and θ_1 reduce equations (5)–(8) to a non-singular form. Such a representation allows us to avoid the integration difficulties which usually appear when the equations are written in standard form (Misner et al. 1973; Landau & Lifshitz 1975) for r and θ coordinates.

A qualitative analysis of the geodesic equations shows that types of photon motion can drastically change with small changes of chosen geodesic parameters (Zakharov 1986, 1989). Therefore, the standard way when there is one equation for each Boyer–Lindquist coordinate (reducing to calculation of the elliptical integrals) can lead to large numerical errors (Zakharov 1991). The integration of equations (4)–(9) allows us to avoid such problems and realizes this process without essential numerical errors.

Solving equations (4)–(9) for monochromatic quanta emitted by a hot ring rotating on circular geodesics at radius r in the equatorial plane, we can obtain the ring spectrum $I_\nu(r, \theta_\infty)$ which is registered by a distant observer in the position characterized by the angle $\theta_\infty = \theta|_{r=\infty}$. The numerical integration is performed using the Gear and Adams methods (Gear 1971) and the standard package realized by Hindmarsh (1983), Petzold (1983) and Hiebert & Shampine (1980). We obtain the entire disc spectrum by summation of sharp ring spectra.

4 DISC RADIATION MODEL

To simulate a radiated spectrum, first it is necessary to adopt some emission model. We assume that the source of the emitting quanta is a narrow and thin disc (ring) rotating in the equatorial plane of a Kerr black hole. For $a = 0.01$ the marginally stable orbit lies at $r_{\rm ms} = 2.9836\, r_{\rm g}$, the difference from $3\, r_{\rm g}$ ($r_{\rm g} = 2M$) is not important for our analysis. We also assume that the disc is opaque to radiation, so that a distant observer situated on one disc side cannot register the quanta emitted from its other side.

For the sake of computational simplicity, we suggest that the spectral line is monochromatic in its comoving frame. To approve this assumption, we can argue that even at $T = 10^8$ K the thermal width of the line

$$\frac{\delta f}{f} \sim \frac{1}{c}\sqrt{\frac{kT}{m_{\rm Fe}}} \approx 10^{-3}$$

appears to be much less than the Doppler linewidth associated with the disc rotation.

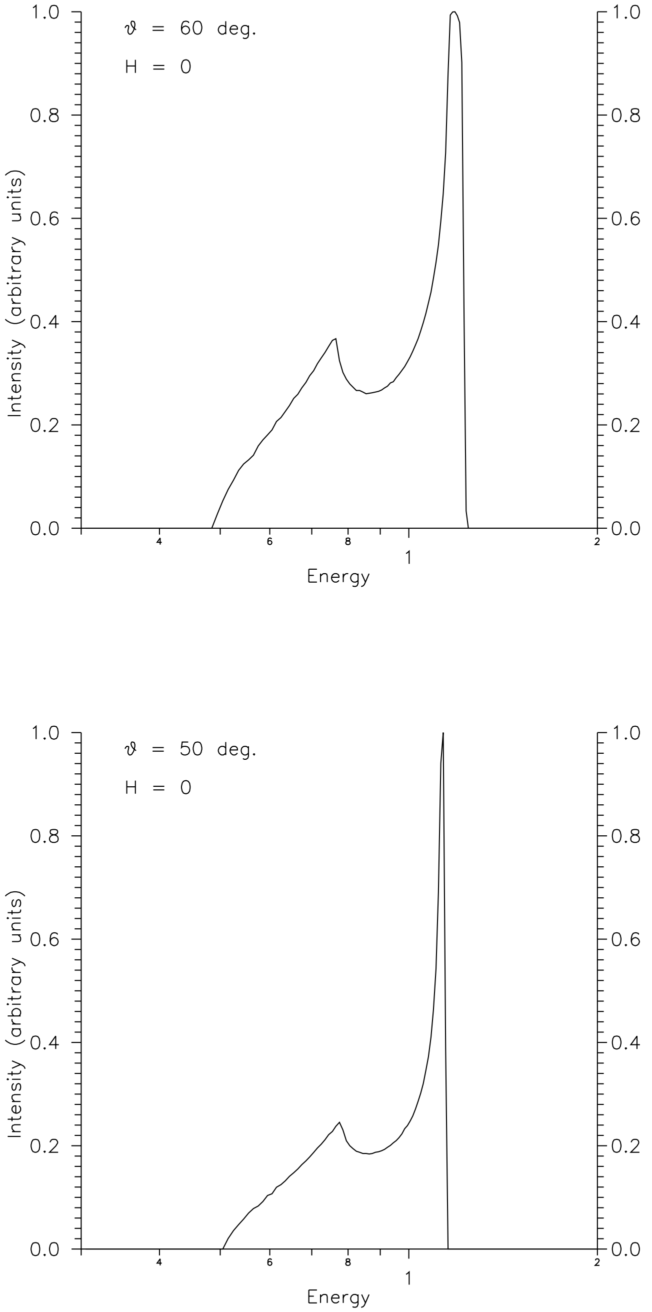

Figure 1. Profile of monochromatic spectral line, emitted by the α-disc in the Schwarzschild metric for $r_{\rm out} = 10\, r_{\rm g}$, $r_{\rm in} = 3\, r_{\rm g}$ and inclination angles $\theta = 60°$ (top panel) and $\theta = 50°$ (bottom panel) with zero value of magnetic field. The line profile is represented as it is registered by a distant observer.

Note that we do **not** assume any particular model of the accreting disc. **As an illustration** we determine the dependence of disc temperature on radial coordinate according to the standard α-disc model (Shakura & Sunyaev 1973; Shakura 1972; Lipunova & Shakura 2002). The radiation intensity is, as usual, proportional to T^4.

The emission intensity of the ring at a given radius r is proportional to the area of the ring. The area of the emitting ring of the width dr differs in the Schwarzschild metric from its classical expression $\mathrm{d}S = 2\pi r\, \mathrm{d}r$ and should be replaced with

$$\mathrm{d}S = \frac{2\pi r\, \mathrm{d}r}{\sqrt{1 - (r_\mathrm{g}/r)}}. \tag{12}$$

Thus, the total flux density emitted by the disc and registered by distant observer is proportional to the integral

$$J_\nu(\theta_\infty) = \int_{r_\mathrm{in}}^{r_\mathrm{out}} I_\nu(r, \theta_\infty) T^4(r)\, \mathrm{d}S, \tag{13}$$

where $I_\nu(r, \theta_\infty)$ is obtained from the solution of equations (4)–(9), $T(r)$ from the appropriate dependence for the α-disc, and d S from equation (12).

The radiation pressure predominates in the innermost part of the disc (*a*), while the gas pressure predominates in the middle (*b*). The boundary r_ab between these two regions can be found for the α-disc from the following equation (Shakura & Sunyaev 1973)

$$\frac{r_\mathrm{ab}/(3r_\mathrm{g})}{(1 - \sqrt{3r_\mathrm{g}/r_\mathrm{ab}})^{16/21}} = 150(\alpha M/\mathrm{M}_\odot)^{2/21} \dot{m}^{16/21}, \tag{14}$$

which we solve by an iteration procedure. In equation (14) we have $\dot{m} = \dot{M}/\dot{M}_\mathrm{cr}$, where $\dot{M}_\mathrm{cr} = 3 \times 10^{-8}$ Myr^{-1}. Thus, for $\alpha = 0.2$,

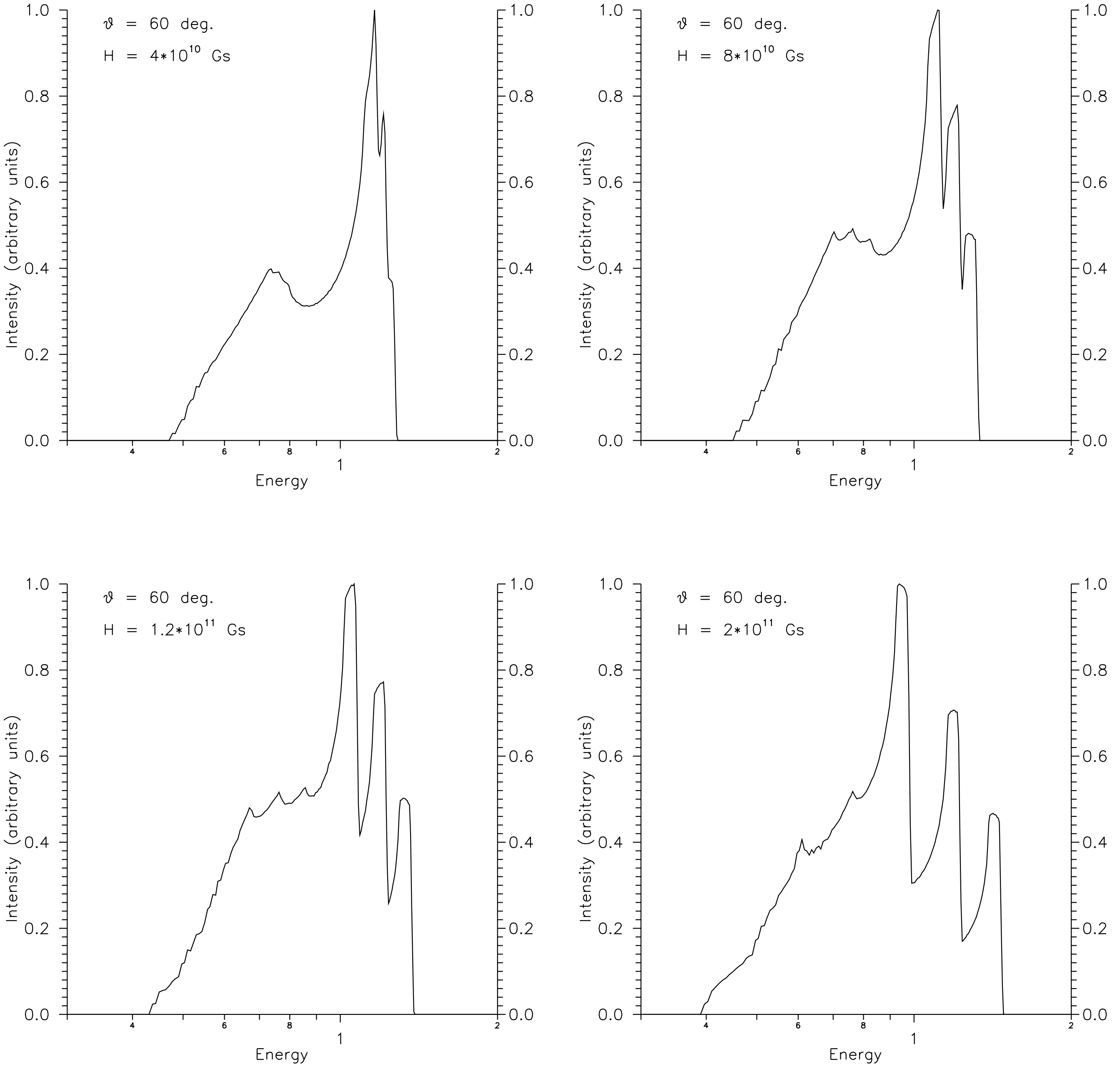

Figure 2. Distortions of the line profile from the top panel in Fig. 1, arising due to a quasi-static magnetic field existing in the disc. The Zeeman effect leads to the appearance of two extra components with energies higher and lower than the basic energy. The values of the magnetic field are shown in each panel.

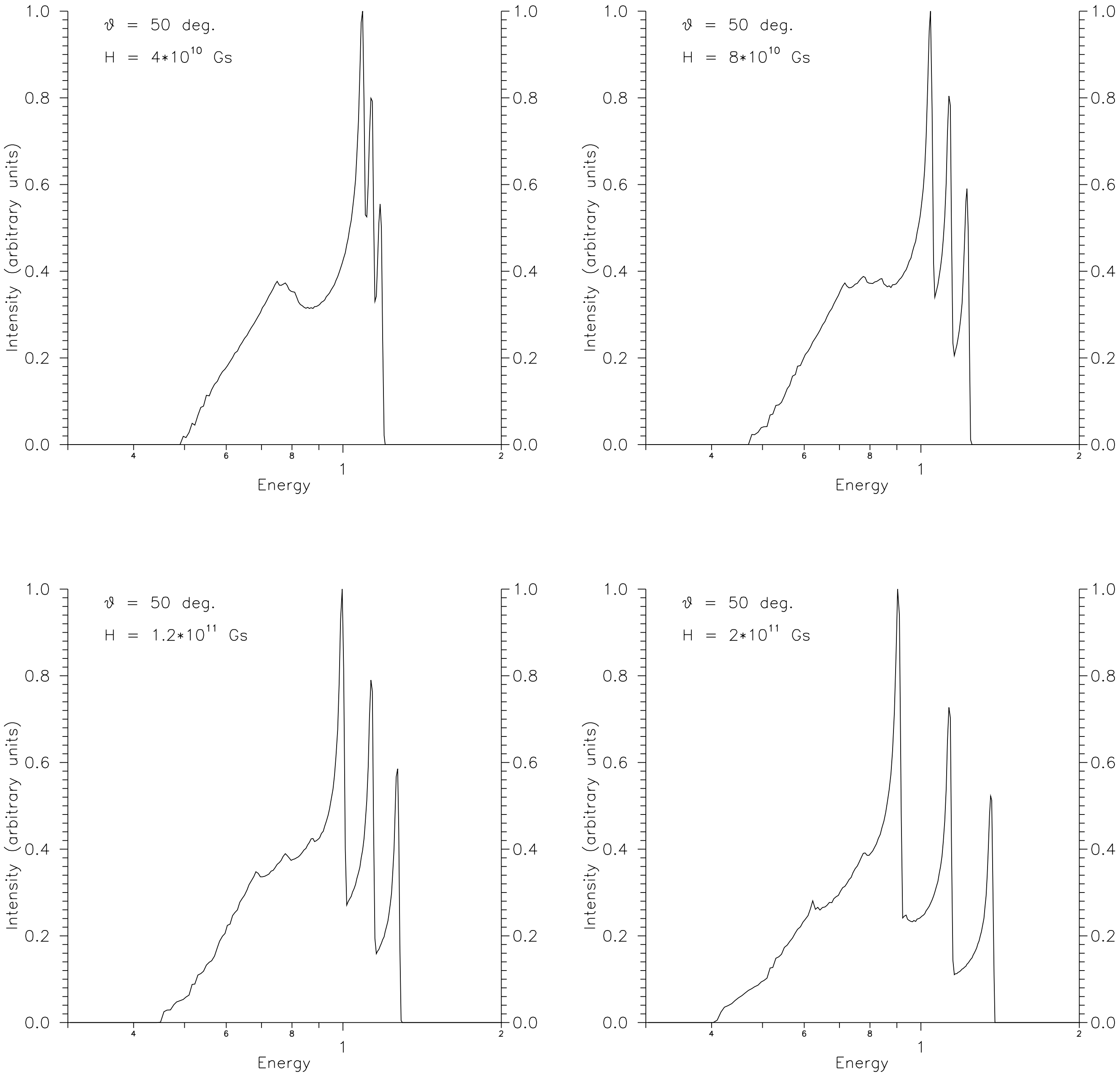

Figure 3. The same as in Fig. 2, but for $\theta = 50^\circ$. The bottom panel of Fig. 1 demonstrates the same spectrum without magnetic field.

$M = 10^8\ \mathrm{M}_\odot$ and $\dot{m} = 0.1$ we have $r_{\mathrm{ab}} \approx 360\ r_{\mathrm{g}}$ from equation (14).

For simulations we assume that the emitting region lies as a whole in the innermost region of the disc (zone *a*). If this is not the case, the profile of a spectral line becomes extremely complicated, so that it appears to be difficult to avoid the interpretation uncertainty. Thus, we assume that the emission arises in the region from $r_{\mathrm{out}} = 10\ r_{\mathrm{g}}$ to $r_{\mathrm{in}} = 3\ r_{\mathrm{g}}$ and the emission is monochromatic in the comoving frame. We set the frequency of this emission as unity by convention.

5 INFLUENCE OF A MAGNETIC FIELD ON THE DISTORTION OF THE IRON K_α LINE PROFILE

The magnetic pressure at the inner edges of the accretion discs and its correspondence with parameter *a* in the framework of disc accretion models has been discussed by Krolik (2001). However, the numerical value of the magnetic field is determined there from a model-dependent procedure, a number of parameters of which cannot be found explicitly from observations.

Here we consider the influence of a magnetic field on the iron K_α line profile[3] and show how we can determine the value of the magnetic field strength or, at least, an upper limit.

The profile of a monochromatic line (Zakharov & Repin 1999, 2002a,b) depends on the angular momentum of a black hole, the position angle between the black hole axis and the distant observer position, and the value of the radial coordinate if the emitting region

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[3] We can also consider X-ray lines of other elements emitted by the area of accretion disc close to the marginally stable orbit; furthermore, we talk only about the iron K_α line for brevity.

represents an infinitesimal ring (or two radial coordinates for outer and inner bounds of a wide disc). The influence of the accretion disc model on the profile of spectral line has been discussed by Zakharov & Repin (2003).

We assume that the emitting region is located in the area of a strong quasi-static magnetic field. This field causes line splitting due to the standard Zeeman effect. There are three characteristic frequencies of the split line that arise in the emission (Blokhintsev 1964; Dirac 1958). The energy of central component E_0 remains unchanged, whereas two extra components are shifted by $\pm\mu_{\rm B}H$, where

$$\mu_{\rm B} = \frac{e\hbar}{2m_{\rm e}c} = 9.273 \times 10^{-21} \text{erg Gs}^{-1}$$

is the Bohr magneton. Therefore, in the presence of a magnetic field we have three energy levels: $E_0 - \mu_{\rm B}H$, E_0 and $E_0 + \mu_{\rm B}H$. For the iron K_α line, these are as follows:

$$E_0 = 6.4 - 0.58\frac{H}{10^{11}\,\text{Gs}}\ \text{keV},$$

$$E_0 = 6.4$$

$$E_0 = 6.4 + 0.58\frac{H}{10^{11}\,\text{Gs}}\text{keV}.$$

Let us discuss how the line profile changes when photons are emitted in the comoving frame with energy $E_0(1 + \epsilon)$, but not with E_0. In that case, the line profile can be obtained from the original one by $1 + \epsilon$ times stretching along the x-axis which counts the energy. The component with $E_0(1 - \epsilon)$ energy should be $(1 - \epsilon)$ times stretched. The intensities of different Zeeman components are approximately equal (Fock 1978). A composite line profile can be found by summation of the initial line with energy E_0 and two other profiles, obtained by stretching this line along the x-axis in $(1 + \epsilon)$ and $(1 - \epsilon)$ times, respectively. The line intensity depends on the direction of the quantum escape with respect to the direction of the magnetic field (Berestetskii, Lifshitz & Pitaevskii 1982). However, we neglect this weak dependence (undoubtedly, the dependence can be counted and, as a result, some details in the spectrum profile can be slightly changed, but the qualitative picture, which we discuss, remains unchanged).

Another indicator of the Zeeman effect is a significant induction of the polarization of X-ray emission: the extra lines possess a circular polarization (right and left, respectively, when they are observed along the field direction) whereas a linear polarization arises if the magnetic field is perpendicular to the line of sight.[4] Despite the fact that the measurements of polarization of X-ray emission have not been carried out yet, such experiments could be realized in the near future (Costa et al. 2001).

The line profile without any magnetic field is presented in Fig. 1 for different values of disc inclination angles: $\theta = 60°$ and $\theta = 50°$. Note that, at $\theta = 50°$, the blue peak appears to be taller and more narrow. Figs 2 and 3 present the line profiles for the same inclination angles and different values of magnetic field: $H = 4 \times 10^{10}$, 8×10^{10}, 1.2×10^{11}, 2×10^{11} Gs. At $H = 4 \times 10^{10}$ Gs the shape of the spectral line does not practically differ from that with zero magnetic field. Three components of the blue peak are so thin and narrow that they can scarcely be distinguished experimentally today. For $H < 4 \times 10^{10}$ Gs and $\theta = 60°$, the splitting of the line does not arise at all. At $\theta = 50°$, the splitting can still be revealed for $H = 3 \times 10^{10}$ Gs (see Fig. 4), but below this value ($H < 3 \times 10^{10}$ Gs) it also disappears. With increasing the field the splitting becomes more explicit, and at $H = 8 \times 10^{10}$ Gs a faint hope appears to register experimentally the complex internal structure of the blue maximum.

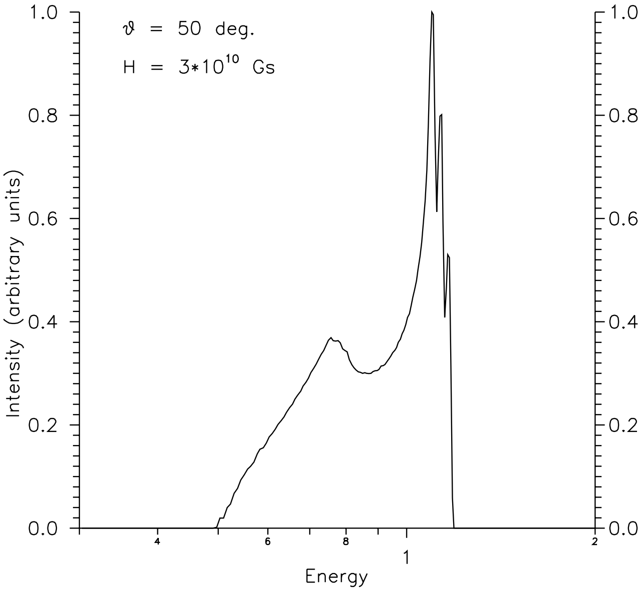

Figure 4. The same as in Fig. 3, but for the minimum value of magnetic field at which it is possible to observe the splitting of the line.

With a further increase of the magnetic field, the peak profile structure becomes apparent and can be distinctly revealed. However, the field $H = 2 \times 10^{11}$ Gs is rather strong, so that the classical linear expression for the Zeeman splitting

$$\Delta E = \pm\mu_{\rm B}H \tag{15}$$

should be modified. Nevertheless, we use equation (15) for any value of the magnetic field, assuming that the qualitative picture of peak splitting remains correct, whereas for $H = 2 \times 10^{11}$ Gs the exact maximum positions may appear slightly different. If the Zeeman energy splitting ΔE is of the order of E, the line splitting due to magnetic fields is described in a more complicated way. The discussion of this phenomenon is not an objective of this paper; our aim is to pay attention to the qualitative features of this effect.

Let us discuss the possible influence of high magnetic fields on real observational data. We try to estimate magnetic fields when we can find the typical features of line splitting from the analysis of the spectral line shape. Furthermore, we choose some values of magnetic field and simulate the spectral line shapes from observational data for these values, assuming that these observational data correspond to an object with no significant magnetic fields. We try to find signatures of the triple blue peak analysing the simulated data when magnetic fields are rather high. Assuming that there are no essential magnetic fields (compared to 10^{10} Gs) for some chosen object (for example, for MCG 6-30-15) we could simulate the spectral line shapes for the same objects but with essential magnetic fields. Fig. 5 demonstrates a possible influence of the Zeeman effect on observational data. As an illustration we consider the observations of the iron K_α line which have been carried out by *ASCA* for the galaxy MCG–6-30-15. These are presented in Fig. 5 by dashed curves. Let

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[4] Note that other possible polarization mechanisms in the α-disc have been discussed by Sazonov, Churazov & Sunyaev (2002).

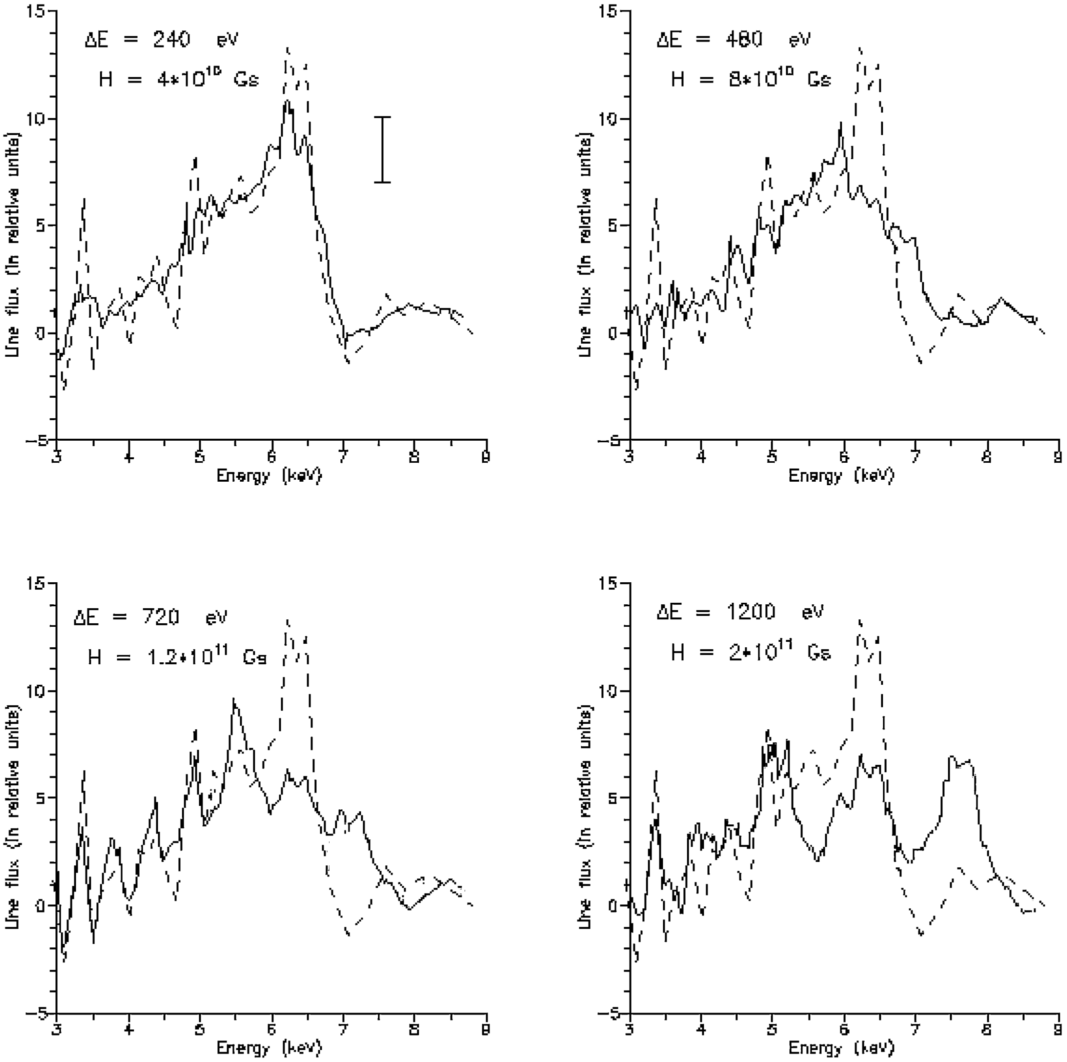

Figure 5. Influence of a magnetic field on the observational data. The dashed line represents the *ASCA* observations of MCG–6-30-15 (Tanaka et al. 1995). The vertical bar in the top-left panel corresponds to a typical error in observation data. Solid lines show possible profiles of the K_α line in the presence of a magnetic field. The field value and the appropriate Zeeman splitting are indicated in each panel.

us assume that the actual magnetic field in these data is negligible. Then we can simulate the influence of the Zeeman effect on the structure of observations and see if the simulated data (with a magnetic field) can be distinguishable within the current accuracy of the observations. The results of the simulated observation for the different values of magnetic field are shown in Fig. 5 by solid lines. From these figures we can see that the classical Zeeman splitting in three components, which can be revealed experimentally today, changes qualitatively the line profiles only for rather high magnetic field. Something like this structure can be detected, e.g. for $H = 1.2 \times 10^{11}$ Gs, but the reliable recognition of three peaks here is hardly possible.

Apparently, it would be more correct to solve the inverse problem: to try to determine the magnetic field in the disc, assuming that the blue maximum is already split due to the Zeeman effect. However, this problem includes too many additional factors, which can affect the interpretation. Thus, besides the magnetic field, the linewidth depends on the accretion disc model as well as on the structure of emitting regions. Such problems may become actual with much better accuracy of observational data in comparison with their current state.

6 DISCUSSION

It is evident that duplication (triplication) of a blue peak could be caused not only by the influence of a magnetic field (the Zeeman effect), but by a number of other factors. For example, the line profile can have two peaks when the emitting region represents two narrow rings with different radial coordinates (it is easy to conclude that two emitting rings with finite widths separated by a gap would yield a similar effect). Despite the fact that a multiple blue peak can be generated by many causes (including the Zeeman effect as one possible explanation), the absence of the multiple peak can lead to a conclusion about the upper limit of the magnetic field.

It is known that neutron stars (pulsars) could have huge magnetic fields. So, this means that the effect discussed above could appear in binary neutron star systems. The quantitative description of such systems, however, needs more detailed computations.

With a further increase of observational facilities, it may become possible to improve the above estimation. Thus, the Constellation-X launch suggested in the coming decade seems to increase the precision of X-ray spectroscopy by as many as approximately 100 times with respect to the present-day measurements (Weaver 2001).

Therefore, there is a possibility, in principle, that the upper limit of the magnetic field can also be 100 times improved in the case when the emission of the X-ray line arises in a sufficiently narrow region.

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