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An estimate of the central black hole mass in NGC 6814

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ABSTRACT
Ginga observations have added to our knowledge of the dramatic X-ray variability of the Seyfert galaxy NGC 6814. The X-ray continuum flux was observed to decrease by a factor of two in 50 s. The intensity of the iron Kα line at ~ 6.5 keV and the X-ray continuum was determined to vary virtually simultaneously, with an upper limit to the delay of less then 250 s. Based on an idealised model consisting of a relativistic accretion disk illuminated by an extended central source of hard radiation, we calculate the stationary characteristics of the line profile as well as the line intensity variations in response to variability at the central source. A comparison with the observed properties of the iron Kα line allows to constrain the disk geometry and the mass of the central object. Iron Kα lines likely originates from highly ionised iron ions; in this interpretation we estimate an inner radius of the line emitting region between $6-30$ gravitational radii (GM/c^2), a disk inclination $i \lesssim 40^\circ$ and a central black hole mass $8 \times 10^4\, L_{43} \lesssim M \lesssim 3.9 \times 10^6\, M_\odot$, where L_{43} is the accretion luminosity in units of 10^{43} erg s^{-1}. Alternative accretion disk scenarios are also discussed. The energy conversion efficiency implied by the fastest X-ray continuum variations, $\eta \sim 0.1$, is suggestive of a storage mechanism of gravitationally released energy or the presence of a rotating black hole.

Key words: galaxies: individual (NGC 6814) – galaxies: Seyfert – galaxies: nuclei – X-rays: galaxies

1 INTRODUCTION

Very fast X-ray variations in Active Galactic Nuclei (AGNs), displaying no evidence for relativistic jets (such as Seyfert I galaxies), most likely involve phenomena occurring in the innermost regions of accretion flows toward the central black hole. The presence of a UV bump in the spectrum of several of these AGNs is commonly interpreted in terms of optically thick emission from the surface of an accretion disk around the central object (Sun & Malkan 1989, Laor 1990). The origin of the X-ray continuum and its variations is still largely unknown. The iron Kα emission lines revealed in a number of AGNs likely originate from the reprocessing of the X-ray continuum flux by matter in the accretion disk in the vicinity of the central engine (Kallman & White 1989, Fabian et al. 1989). The profile of these lines is expected to be strongly affected (in particular, broadened and shifted) by the Doppler, gravitational and transverse shifts of the matter orbiting in the innermost disk regions.

The Seyfert I galaxy NGC 6814 is the fastest X-ray variable AGN known to date. Tennant et al. (1981) observed it with the A-2 experiment on board HEAO-1 and measured a X-ray variability timescale of ~ 100 s. Recently, observations with the Large Area Counters on board *Ginga* were used to determine a timescale of ~ 50 s for the 2–20 keV source flux to decrease by a factor of two (Kunieda et al. 1990). The average X-ray luminosity of NGC 6814 during these observations was estimated to be $L_{2-20\ keV} \sim 10^{43}$ erg s^{-1}. The bolometric luminosity is probably uncertain by a factor of 2–3: Bassani et al. (1983) estimate $L_{bol} = 3.5 \times 10^{43}$ erg/s for the nuclear region; Padovani & Rafanelli (1988) give $L_{bol} = 7.2 \times 10^{43}$ erg/s for whole galaxy. These values are derived under the assumption that hard X-rays ($\gtrsim 30$ keV) do not contribute significantly. In the following we assume an accretion-powered luminosity of $L_{acc} = L_{43} = 10^{43}$ erg s^{-1}.

The X-ray spectrum of NGC 6814 shows an intense emission line from iron Kα transitions; by fitting the spectra above 4 keV with a power-law plus an emission line, a centroid energy of 6.37 ± 0.09 keV, an average equivalent width (EW) of ~ 300 eV and an upper limit line width of $\sigma \lesssim 1$ keV were derived (Kunieda et al. 1990). The iron line intensity variations were strongly correlated with the variations of the X-ray continuum. The corresponding cross-correlation function consists of a broad symmetric peak centered around zero lag, which allows to set an upper limit of ~ 250 s to any delay of the iron line intensity variations.

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Kunieda et al. (1990) applied the accretion disk scenario for the iron line production to the case of NGC 6814. By using an approximated treatment for the expected line centroid and width, they derived constraints on the line emitting region of a relativistic disk and the mass of the central object ($r \sim 25\, r_g$ and $M \sim 10^6\ M_\odot$).

A more detailed analysis of the same data, was carried out by Turner et al. (1992). These authors fitted the spectra with a power law plus either a narrow or a broad Gaussian profile, the latter providing a marginally better fit with $E_c = 6.28 \pm 0.13$ keV, $EW = 381 \pm 125$ eV and $\sigma \lesssim 0.7$ keV. A cross-correlation analysis of the light curves from the X-ray continuum indicates that variations in the 7–20 keV band lag those in the 3–5 keV band by 50–200 s, suggesting the occurrence of reprocessing. These authors consider a hot accretion disk model in which the iron line is produced by H-like ($E_0 \simeq 6.9$ keV) or He-like ($E_0 \simeq 6.7$ keV) ions.

Ginga observed NGC 6814 twice more in 1990 (Kunieda et al. 1991). All available data were analysed by Yamauchi et al. (1992). Owing to the improved statistics, these authors found evidence for an absorption edge around $7.4 - 8.3$ keV. The $3 - 30$ keV spectrum was fitted with a power-law model, low energy absorption from neutral matter and an iron emission line. The best fit was obtained for a line centroid energy of $E_c = 6.5 \pm 0.1$ keV. A composite spectrum consisting of a primary power law spectrum and a component arising from the reprocessing by optically thick cold or warm matter (Lightman & White 1988) does not provide a satisfactory fit, as it cannot reproduce the excess below ~ 3 keV and predicts an iron K-edge and a Compton reflected component above ~ 10 keV much more pronounced than observed. A model involving partial coverage by warm matter was preferred. Larger line EWs are expected in this case, due to the increased fluorescence yield of the higher ionisation stages of iron; this fit provides also an upper limit for the line width $\lesssim 0.6$ keV. In a different model (Hayakawa 1991), the X-ray continuum and iron line are both produced by a toroidal region around the central object by optically thin clumps. Also in this picture, the ~ 6.5 keV line arises from recombination onto H-like and He-like iron ions.

Common to all models involving transitions from the highest ionisation stages of iron is the fact that the rest line energy ($\sim 6.7 - 6.9$ keV) must be redshifted to the observed value by gravitational and transverse redshifts. Any projected velocity along the line of sight must be small in order to avoid the blueshift resulting from Doppler boosting. This excludes geometries in which velocities are distributed almost isotropically. In the case of an accretion disk geometry, low inclinations are required.

The purpose of this paper is to show how, despite the different interpretations, the available observations can be used to derive constraints on an accretion disk scenario for the iron line formation and, in turn, on the mass of the accreting black hole (Section 2). Alternative accretion disk models and scenarios in which the rapid X-ray variations are generated by a local storage and sudden release of accretion energy are considered in Section 3. Our results are summarised and discussed in Section 4.

2 THIN ACCRETION DISK SCENARIO

The observation of a flattening above ~ 10 keV in the spectra of several AGNs, likely arising from reflection of primary X-rays by cold matter, and the detection of fast variability in the UV continuum of NGC 5548 and NGC 4151, probably induced by the reprocessing of higher energy radiation, are strongly suggestive of a geometry in which a considerable fraction of the luminosity from the central regions is intercepted further out by relatively cold accreting matter (for NGC 4151 Perola et al. 1986, Ulrich et al. 1991; for NGC 5548 Clavel et al. 1991, Krolik et al. 1991). The size of the irradiated regions can be constrained by the variability timescale of the reflected and reprocessed spectral components.

If the accretion flow is mediated by a disk, then the illuminated regions must subtend a significant solid angle with respect to the central source of radiation. Scenarios of self-irradiating disks require an extended central source of high energy radiation in order to account for the observed spectral and variability properties (Molendi et al. 1992). Renewed attention has been recently given to modifications of the standard thin accretion disk picture which include a central, geometrically thick region.

Along these lines, we consider for the production of the iron Kα line in NGC 6814 a simple model consisting of a flat Keplerian disk illuminated by a spherical central source of hard radiation. In order to maximize the fraction of radiation intercepted by the disk, and therefore the EW of the iron line which is produced in response, we assume that the radius of the central source r_c coincides with the disk inner radius r_i. The disk line emissivity for this geometry is derived by adopting the prescription of Chen & Halpern (1989) for the case of an optically thin central source. Under stationary conditions, the profile observed at infinity can be calculated by using the fully relativistic treatment of Fabian et al. (1989) for a disk around a Schwarzschild black hole, the only free parameters being the inner disk radius r_i and the disk inclination i.

If the measured centroid energy and width of the line are representative of the average values of these quantities for a disk illuminated by a strongly variable central source (as in the case of NGC 6814), then constraints on the disk geometry can be derived. To this aim, we adopt the centroid energy reported by Yamauchi et al. (1992) ($E_c = 6.5 \pm 0.1$ keV), which is obtained by fitting all *Ginga* spectra, and the upper limit to the line width derived by Turner et al. (1992) ($\sigma \lesssim 0.7$ keV), in the absence of a limit from all *Ginga* data.

Fig. 1a shows the stationary centroid energy of the line profiles obtained as a function of inclination and for a range of different inner radii. The centroid energy is calculated from the ratio of the 1st and 0th moments of the energy distribution in the line and is normalised to the line rest energy. An observed energy of 6.5 ± 0.1 keV can result from a substantially redshifted line from recombination into the highest ionisation stages of iron. The horizontal lines of Fig. 1 mark the regions for which the observed line energy is produced by redshifted photons from He-like iron ions (dashed delimited region and stars), or hydrogenic iron ions (dot-dashed delimited region and circles). Small radii, so that gravitational and transverse redshifts are pronounced, and low inclinations, reducing projected velocities and Doppler boosting,

Figure 1 to go here

Figure 1. (a) Normalised line centroid energy versus inclination for the accretion disk geometry discussed in the text. Different curves correspond to different inner radii (r_i = 6, 8, 10, 12.5, 15, 17.5, 20, 25 ,30, 40, 50, 100r_g, where $r_g = GM/c^2$). Here and in the other figure, the points consistent with the interpretation in which the 6.5 $\pm$ 0.1 keV line centroid energy results from He-like iron ($E_0 = 6.70$ keV) and H-like iron ($E_0 = 6.93$ keV) are indicated by stars and circles respectively. The horizontal lines mark the regions of applicability of the He-like (dotted line) and H-like iron (dot-dashed line) interpretation. Squares and the region marked by dot-dashed lines are consistent with a line from weakly ionised iron ($E_0 \simeq 6.4$ keV).
(b) Normalised r.m.s. width, σ, versus inclination for different inner radii. Marked values are consistent with a σ limit of ~ 0.7 keV.
(c) Delay in the response of the line intensity versus inclination in units of $r_g/c = GM/c^3 = 4.9 \times 10^{-6}\, M/M_\odot$ s.

are required in order to produce a substantial redshift. The range of allowed parameters is $i \lesssim 30°$, $6\,r_g \lesssim r_i \lesssim 10\,r_g$ for H-like iron ions and $i \lesssim 45°$, $6\,r_g \lesssim r_i \lesssim 30\,r_g$ for He-like ions. The observed line can also result from fluorescence by neutral or weakly ionised iron ($E_0 \simeq 6.4$ keV) with only a little blueshift. Squares in Fig. 1a are consistent with this interpretation. In this case, inclinations $\gtrsim 50°$ are required, whereas a wide range of inner radii is acceptable.

Fig. 1b shows the stationary r.m.s. line width of the line profile, calculated from the ratio of the square root of the 2nd moment and 0th moment of the energy distribution. A normalisation factor of $1/E_0$ is used. Circles and stars are consistent with the observed $\sigma \lesssim 0.7$ keV for recombination lines from H-like and He-like iron. Fig. 1b also shows the stationary width for a fluorescence line (squares). Only relatively high inclinations for small inner radii are not allowed.

A variable central source will induce changes in the line emissivity. For an observer at infinity any variation of the flux from the central source will be echoed by different locations in the disk at different times. In general this will introduce an additional angular and time dependence of the disk line emissivity (Blandford & McKee 1982, Stella 1990).

The response of the line profile and its moments for such a system is usually described in terms of transfer functions, characterising the response to a δ-function flux variation at the central source (Blandford & McKee 1982). In the case of an extended central source this approach must be generalised in order to describe the fastest possible variation that can be attained. To this aim, we suppose that the emission at each point in the volume of the central source varies simultaneously with that at any other point and calculate the line response accordingly (for more details see Campana & Stella 1993). For simplicity we approximate with straight lines the photon geodesics from the central source to the disk. Fig. 1c shows the delay in the line intensity variation as evaluated from the maximum of the line intensity response from the disk. Delays are expressed in units of the gravitational radius light crossing time $G\,M/c^3 = 4.9 \times 10^{-6}\, M/M_\odot$ s. The finite size of the central source tends to smear out the fast response from the parts of the disk which are closest to the line of sight. The line intensity response was determined to peak for delays of $\sim 2-4\ r_i/c$, with only a relatively weak dependence on inclination.

Symbols in Fig. 1c mark the points consistent with the constraints from the E_c and σ of the line. For iron lines emitted by hydrogenic ions only a small region in the r_i and i parameter space is acceptable (circles in Fig. 1c). This is due to the substantial redshift necessary to produce an observed line energy centroid of ~ 6.5 keV. For He-like iron transitions a larger region, corresponding to $6\,r_g \lesssim r_i \lesssim 30\,r_g$ and $i \lesssim 40°$, is allowed (stars in Fig. 1c). The range of parameters permitted in the case of a low ionisation fluorescence line is $r \gtrsim 10\,r_g$ and $i \gtrsim 50°$ (squares in Fig. 1c).

The delays in Fig. 1c are to be compared with those inferred from the observations. The peak of the cross-correlation function between the continuum variations from the central source and the induced line intensity variations is often used as a fiducial delay. In the case of NGC 6814 the delay of the iron Kα line from the 2–20 keV intensity continuum variations is constrained to be $\Theta \lesssim 250$ s. Concerning the delays the following considerations apply:

(i) The assumed flat geometry and Keplerian velocity distribution of the disk require that the luminosity is in the sub-Eddington regime; this constrains the mass of the central object to $M \gtrsim 8 \times 10^4\, L_{43}\ M_\odot$, and therefore the time delay axis in Fig. 1c must convert to 0.4 s, at least.

(ii) By imposing that the shortest delay in Fig. 1c, τ_{min}, compatible with the constraints on E_c and σ is $\Theta =$ 250 s (Kunieda et al. 1990), the mass is restricted to $M \lesssim 5 \times 10^7 (\Theta_{250}/\tau_{min})\ M_\odot$. Here Θ_{250} is the measured delay in units of 250 s and τ_{min} is in units of r_g/c.

(iii) A somewhat stronger constraint on the mass is obtained by requiring that the minimum variability timescale of the central source is shorter than $\delta t =$ 50 s (Kunieda et al. 1990). This implies $M \lesssim 10^7 (r_g/r_i)\, \delta t_{50}\ M_\odot$, where we have used $r_i = r_c$.

Within the assumptions of the model, therefore, all profiles with $r_i \gtrsim 125\,r_g$ are ruled out, as they would require a mass inconsistent with the sub-Eddington regime.

For a hydrogenic iron line, the following constraint on the mass of the central black hole can be derived:

from point *ii)* to $M \lesssim 3.9 \times 10^6\, \Theta_{250}\ M_\odot$ and

from point *iii)* to $M \lesssim 1.7 \times 10^6\, \delta t_{50}\ M_\odot$;

for helium like line:

from point *ii)* to $M \lesssim 3.6 \times 10^6\, \Theta_{250}\ M_\odot$ and

from point *iii)* to $M \lesssim 1.7 \times 10^6\, \delta t_{50}\ M_\odot$;

and for low ionisation fluorescence lines:

from point *ii)* to $M \lesssim 1.9 \times 10^6\, \Theta_{250}\ M_\odot$ and

from point *iii)* to $M \lesssim 10^6\, \delta t_{50}\ M_\odot$.

It should be noted, however, that the constraint provided by *ii)* and *iii)* depend on the assumption that the central source extends to the inner radius of the line emitting portion of the disk. By allowing $r_c < r_i$, the minimum variability timescale of the central source $\sim r_c/c$ can be made faster at the expenses of the line EW that, due to the smaller angle subtended by the line emitting disk, decreases approximately as r_c/r_i (Chen & Halpern 1989). Over a wide range of parameters, instead, the delay of the line intensity response remains virtually unaffected. In particular, for the low disk inclinations allowed by H-like and He-like lines, the mass limit provided by *ii)* remains valid. Correspondingly, for values of $r_c \lesssim 2r_i$, condition *iii)* provides a less tight mass constraint, while the predicted line EW reduces drastically (by a factor $\gtrsim 2$).

For the high inclinations and relatively large inner radii, allowed by low ionisation iron Kα lines, the response of the line intensity from the disk can be made substantially faster by lowering r_c/r_i (Stella & Campana 1991, Campana & Stella 1993). This is a consequence of the fact that the decreasing variability timescale at the central source reduces the smearing of the response from the disk regions closest to the line of sight. For the highest inclinations we consider here ($i = 85°$), condition *iii)* dominates and the central source radius can be decreased down to the smallest value compatible with the observed EW. In the limit in which $r_c = 2\,r_g$ we have $M \lesssim 5 \times 10^6\, \delta t_{50}\ M_\odot$ (e.g. Tennant et al. 1981).

While a detailed physical model of the line production mechanism which would allow detailed predictions for the line EW is beyond the scope of this paper, we can conservatively adopt as upper limits to the mass the value provided by *ii*) for H-like and He-like iron lines and the value provided by *iii*) with $r_c = 2\,r_g$ for fluorescence lines.

3 ALTERNATIVE MODELS

Fabian & George (1991) sketched several scenarios in which the continuum and line variations can be produced either by *global* changes in the regions where most of the energy is released (similar to the ones of the model in Section 2), or by more *local* phenomena involving only a small region in the accretion flow.

A number of authors have developed two-phase accretion disk models, typically consisting of an optically thick cold disk surrounded by a tenuous hot corona (Galeev et al. 1979, Haardt & Maraschi 1991), which can subtend relatively large solid angles at the central object. If a central source provides a burst of (unseen) very hard radiation, this radiation can be intercepted by the hot corona, where can cause substantial Compton heating and photoionisation. If most of the observed X-ray continuum is produced by the response of the corona, then the iron line can originate from recombination into H-like and He-like ions in the corona (Kallman & White 1989, Hayakawa 1991) or from fluorescence from the surface of the underlying cold disk, where part of the continuum X-ray radiation impinges.

In this scenario the constraints provided by the line E_c and σ are approximately the same as in Section 2, as long as the radial dependence of the line emissivity is not drastically altered by the geometry of the corona. The strongest constraint on the mass is derived from the condition that the minimum variability timescale of the X-ray continuum, generated by the response of the corona, has to be $\lesssim 50$ s. This timescale was calculated by considering the intensity response of a disk to a rectangular impulse of duration $2\,r_g/c$ at the central source of (unseen) radiation. In particular the minimum timescale for the source flux to decrease by a factor of two is evaluated based on the time during which the intensity response function halves from its maximum.

The results are shown in Fig 2. For highly ionised iron ions, the mass of the central object is limited by $M \lesssim 1.7 \times 10^6\, \delta t_{50}\ M_\odot$. In the case of cold matter, high inclinations are allowed and a faster response of the line intensity can be achieved, providing a less tight constraint on mass, $M \lesssim 5.7 \times 10^6\, \delta t_{50}\ M_\odot$. Note that in this model the upper limit of 250 s to the delay of the line variations does not provide any additional constraint.

In another scenario involving *global* variations, the central regions of a disk may be blown up into a geometrically thick configuration. If the accretion rate $\dot{M}$ is close to or higher than the critical value corresponding to the Eddington limit, radiation pressure can support an innermost thick region which is characterised by non-Keplerian velocities. This scenario would require $M \lesssim 8 \times 10^4 L_{43}\ M_\odot$.

A different class of models attributes the variations in the X-ray continuum to a localised storage and sudden release of energy. The iron line emission can take place within the same region or be induced by the illumination of a nearby region (Begelman & de Kool 1990). Contrary to the case of global variations in the accretion flow, the size of the region of localised emission does not necessarily hold information about the size, and therefore the mass, of the central object. Constraints can be derived from the iron line E_c and σ only once a dynamical model for the emitting region is specified.

The shortest X-ray variability timescale measured in NGC 6814 can be used to derive a lower limit to the efficiency η of the mass-radiation energy conversion (Cavallo & Rees 1978, Fabian & Rees 1979); we obtain $\eta \sim 0.1\,\Delta L_{43}/\Delta t_{50}$. This value is somewhat higher then the energy conversion efficiency, $\eta_{Sch} = 0.057$, for disk accretion into a Schwarzschild black hole. In the absence of relativistic beaming effects, higher values of η are expected for rotating black holes or for models involving the temporary storage of gravitationally released energy in the form of *e.g.* shock waves or magnetic fields. In the latter case a localised production model for the X-ray variability would be favored†.

4 DISCUSSION AND CONCLUSIONS

Different methods to derive or constrain the mass of the central object in AGNs have been discussed by a number of authors. Wandel & Mushotzky (1986) estimate the nuclear mass of many Seyfert galaxies and quasars, assuming that the motion of matter in the inner part of the Narrow Line Region (NLR) is dominated by gravity ($M = \beta\, r\, v^2/G$, with $1 < \beta < 3$). By using the width and intensity of the $[OIII]$ line and assuming typical values for the observable covering factor, for the density and the column density of the emitting gas, they found for NGC 6814 a mass of $\sim 2 \times 10^6\ M_\odot$. In a similar way Padovani & Rafanelli (1988) estimated a central mass $\sim 7 \times 10^6\ M_\odot$, by using lines from the Broad Line Region (BLR). These estimates provide only a rough value of the mass of the central object, depending on parameters known with uncertainties of order of magnitude.

By using the iron Kα line properties, Yamauchi et al. (1992), restrict the black hole mass to $7 \times 10^4 < M < (1.8 \div 4) \times 10^6\ g\ M_\odot$ (with g a geometrical factor of about 1), this limit is obtained for He-like iron; these authors argue against the possibility of hydrogenic lines, due to the small range of allowed inner radii.

We have developed a method that, using an idealised disk model for the production of the iron line, allows to derive constraints on the geometry of the accretion disk and mass of the central object, based on the observed values E_c, σ and on the timescale of variability at the central source or the delay between continuum and line intensity variations.

† We note that the results of Section 2 are applicable also to the case of an extreme Kerr geometry, since the effects of black hole rotation are only minor for $r_i \gtrsim 6\,r_g$ (Koijama 1991, Laor 1991). It appears from Fig. 1 that for the smaller inner disk radii allowed for by the Kerr geometry, an additional small region of the parameter space, characterised by $r_i \lesssim 6\,r_g$ and $i \simeq 30°$, might be consistent with the observed line centroid and width. To further investigate this point detailed calculations are required which are beyond the scope of the present paper.

Figure 2 to go here

Figure 2. Minimum timescale for the line intensity response function to decrease by a factor of two from its maximum, in units of r_g/c. Constraints from the line centroid energy and line width (Fig. 1a, 1b) are superposed, indicating regions consistent with different iron ionisation stages (circles refer to H-like, stars to He-like and squares to low ionisation iron Kα lines).

A range of masses of $8\times10^4\,L_{43} \lesssim M \lesssim 5\times10^6\,\delta t_{50}\,M_\odot$ is obtained, if the observed line originates from fluorescence of neutral or weakly ionised iron ions. Turner et al. (1992) and Yamauchi et al. (1992) argue that in this interpretation it is very difficult to achieve EWs as high as observed. Moreover, the relatively high disk inclinations required by the model would decrease further the EW (see George & Fabian 1991, Matt et al. 1992 for detailed calculations in a slightly different geometry). Turner et al. (1990) estimate a ionisation parameter of $\xi = L_x/n\,R^2 \sim 10^3$ erg cm s^{-1}, by using the standard Shakura & Sunyaev (1973) disk model to derive the number density $n \sim 10^{14}$ cm^{-3}. For such a high value of ξ iron is almost fully stripped. Furthermore, if the iron line came from cold matter in a disk-like geometry, a conspicuous reflection bump is expected above ~ 10 keV, which is not detected in the data.

Therefore, it seems likely that iron Kα lines arise from highly ionised iron ions. These ions provide also a larger fluorescence yield, which helps attaining high EWs. In the interpretation in which the lines are produced by hydrogenic or He-like iron ions we can infer that:

(a) the inner radius of the line emitting region is between $6-30\,r_g$;
(b) the inclination is limited to $\lesssim 40°$;
(c) the allowed range of masses is $8\times10^4\,L_{43} \lesssim M \lesssim 1.7\times10^6\,\delta t_{50}\,M_\odot$.

Our mass constraint is in the same range but somewhat stronger and shifted towards lower values than the one obtained by Yamauchi et al. (1992). This is mostly due to the adopted geometry (with the disk extending up to the central source) which constrains the minimum timescale for the variability of the central source (see Section 2 *iii*). If the radius of the central source is smaller than the disk inner radius, we derive $8\times10^4\,L_{43} \lesssim M \lesssim 3.9\times10^6\,\Theta_{250}\,M_\odot$, based on point *ii*). However much lower EWs would be expected in this case.

Recently, Matt et al. (1993) have calculated self-consistently the ionisation structure and iron Kα line properties from an accretion disk illuminated by an external hard X-ray source. They find that, for accretion rates $\dot M \gtrsim 0.3\,\dot M_{Edd}$, a K$\alpha$ line from highly ionised iron can be produced with an equivalent width as high as 200–400 eV. These calculations further support the view that the intense iron line of NGC 6814 is emitted from the inner regions of a low inclination accretion disk. Note that their constraint on the mass accretion rate would provide $M \lesssim 2.6\times10^5\,L_{43}\,M_\odot$.

Abramowicz et al. (1993) interpreted the reported periodicity of $\sim 12,000$ s in the X-ray luminosity of NGC 6814 and the shape of its modulation in terms of the orbital motion of a few bright spots in the innermost region of an accretion disk. From this model, they derive a disk inclination $i \sim 85°$ and a black hole mass $M \sim 9\times10^6\,M_\odot$. We note that these values are inconsistent with the limits obtained in this work for an accretion disk scenario.

If the energy release is local in form, no limit on the mass and other parameters can be set. An estimate of the energy conversion efficiency, $\eta \sim 0.1\,\Delta L_{43}/\Delta t_{50}$, can in any case be given. This value is somewhat higher than the value for accretion into a non-rotating black hole, therefore suggesting the presence of a Kerr black hole, or the storage of gravitationally released energy or beamed emission.

Should the accretion disk scenario for the production of the iron line in NGC 6814 be confirmed, detailed observations of the changes of the line profile or its moments induced by variations at the central source, or a better estimate of the line width, can be used to estimate more accurately the the disk parameters and of mass of the central object (Stella 1990, Matt & Perola 1992, Campana & Stella 1993). These measurements should be within reach of large area experiments with solid state detectors planned for the next generation of X-ray astronomy satellites.

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