Extreme X-ray variability in the luminous quasar PDS 456

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ABSTRACT

We present evidence from BeppoSAX and XMM-Newton of extreme X-ray variability in the high luminosity radio-quiet quasar PDS 456, the most luminous known AGN at z < 0.3. Repeated X-ray flaring is found in PDS 456, over the duration of the 340 ksec long BeppoSAX observation. The X-ray flux doubles in just 30 ksec, whilst the total energy output of the flaring events is as high as 10^{51} erg. Under the assumption of isotropic emission at the Eddington limit, this implies that the size of the X-ray emitting region in PDS 456 is less than 3 Schwarzschild radii, for a 10^9 M☉ black hole. From the rates of change of luminosity observed during the X-ray flares, we calculate lower limits for the radiative efficiency limit between 0.06 and 0.41, implying that accretion onto a Kerr black hole is likely in PDS 456. We suggest that the rapid variability is from X-ray flares produced through magnetic reconnection above the disc and calculate that the energetics and timescale of the flares are plausible if the quasar is accreting near to the maximum Eddington rate. A similar mechanism may account for the extreme rapid X-ray variability observed in many Narrow Line Seyfert 1s. In the case of PDS 456, we show that the X-ray flaring could be reproduced through a self-induced cascade of ~ 1000 individual flares over a timescale of the order 1 day.

Key words: galaxies: active – quasars: individual: PDS 456 – X-rays: quasars

1 INTRODUCTION

PDS 456 is a luminous, but low redshift (z = 0.184) radio-quiet quasar identified in 1997 (Torres et al. 1997). The optical and infra-red spectra (Simpson et al. 1999) show broad Balmer and Paschen lines (e.g. Hβ FWHM 3000 km s^{-1}), strong Fe II, a hard (de-reddened) optical continuum (f_ν ∝ ν^{−0.1±0.1}), and one of the strongest ‘big blue bumps’ of any AGN (Simpson et al. 1999, Reeves et al. 2000). It is also radio-quiet (F_{3 GHz} = 8 mJy; Reeves et al. 2000), and is presumably not jet dominated or strongly beamed. PDS 456 has a de-reddened, absolute blue magnitude of M_B ≈ −27 (Simpson et al. 1999), making it as luminous as the radio-loud quasar 3C 273 (z = 0.158, M_B ≈ −26). Indeed PDS 456 is the most luminous known AGN in the local Universe (z < 0.3), its luminosity being more typical of quasars at z=2-3, at the peak of the quasar luminosity function.

PDS 456 was first detected as the X-ray source RXS J172819.3-141600 in the ROSAT All Sky Survey (Voges et al. 1999). Subsequent ASCA and RXTE observations of PDS 456 showed that it was highly X-ray variable (see Reeves et al. 2000). In particular, during the RXTE observation, an X-ray flare occurred with a doubling time of just 15 ksec, implying that the X-ray emitting region was extremely compact, less than 2 Schwarzschild radii (or 2R_S) in size. Such rapid variability is very unusual for luminous quasars, as the variability timescale is thought to increase with luminosity, and black hole mass (e.g. Turner et al. 1999). One possibility is that the accretion rate is unusually high in PDS 456, perhaps close to Eddington. An analogy might then be drawn with the extreme events observed in several Narrow Line Seyfert 1 galaxies (e.g. Boller, Brandt & Fink 1996, Leighly et al. 1999), thought to have smaller black hole masses (10^6 M☉ - 10^7 M☉), accreting near to the Eddington rate. We report here on X-ray observations of PDS 456, conducted with BeppoSAX and XMM-Newton in February and March 2001. The prime motivation was to study the extraordinary variability of PDS 456 with an imaging X-ray telescope, thus negating the possibility of source contamination which may occur within the field of view of a non-imaging instrument.

2 THE X-RAY OBSERVATIONS

PDS 456 was observed by BeppoSAX between 26th February 2001 and 3rd March 2001, with a total duration of 345 ksec. Lightcurves were extracted from circular regions of 4' and 6' radius around PDS 456, for the MECS (Medium Energy Concentrator Spectrometer; Boella et al. 1997) and the LECS (Low Energy Concentrator Spectrometer; Parmar et al. 1997) detectors respectively. Background lightcurves were
taken from circular regions, offset from the source. The average net source count rates obtained were $(1.045 \pm 0.001) \times 10^{-1} \text{ct s}^{-1}$ and $(7.25 \pm 0.12) \times 10^{-2} \text{ct s}^{-1}$ for the MECS and LECS respectively, whilst the background rates were less than 10% of the source count rate. \textit{XMM-Newton} also observed PDS 456 on 26th February 2001, with a duration of 40 ksec. The start of the \textit{XMM-Newton} observation was coincident with the onset of the \textit{BeppoSAX} exposure. Here, we show only the timing data from the EPIC-pn detector (Struder et al. 2001). A full description of the \textit{XMM-Newton} data and spectroscopic observations will be presented in a subsequent paper (Reeves et al. 2002, in preparation). Values of $H_0 = 50 \text{ km s}^{-1} \text{Mpc}^{-1}$ and $q_0 = 0.5$ have been assumed throughout and errors are quoted at the 90% confidence level.

3 THE X-RAY VARIABILITY OF PDS 456

The background subtracted \textit{BeppoSAX} lightcurves are plotted in Figure 1, grouped into orbital length bins (96 minutes), and extracted over the energy bands 0.3-2 keV and 1-10 keV, for the LECS and MECS respectively. Large changes in flux are seen throughout the \textit{BeppoSAX} observation. The most extreme events are the flares seen toward the end of the observation at 230 ksec, where the MECS count rate increases by a factor of $\times 1.9$ over 35 ksec, whilst the LECS flux increases by $\times 4.1$ over 40 ksec.

The \textit{XMM-Newton} EPIC-pn lightcurve is plotted in Figure 2 (upper panel), extracted from 0.3-10 keV. The increase in flux corresponds to the initial rise of the \textit{BeppoSAX} lightcurves over its first 40 ksec of observation, where these two observations were concurrent. There is no variability over timescales as short as $\sim 1$ ksec, consistent with a large ($10^9 M_\odot$) black hole mass in this quasar. Using the \textit{XMM-Newton} data, we also searched for evidence of spectral variability in PDS 456. A ‘softness ratio’ was defined, taking the ratio of the pn count rate over the 0.3-1.0 keV and 2-10 keV bands; the time-averaged value was then renormalized to 1. A plot of softness ratio against time is shown in Figure 2 (lower panel). The spectrum becomes softer (by a factor $\sim 20\%$) when the count rate is higher during the course of the flare in the pn lightcurve. This is also illustrated in Figure 3, which plots the softness ratio as a function of total pn count rate, the correlation is significant at $> 99.99\%$ confidence using a Spearman-Rank test.

We also constructed cross correlation functions in order to search for any soft to hard time lags using both the \textit{BeppoSAX} and \textit{XMM-Newton} data. No delays were found, the upper-limit was $< 1$ ksec. It appears that both the soft (0.3-1.0) keV and hard (2-10 keV) bands vary coherently on timescales much shorter than that of the overall flare duration. For simple reprocessing models, where the thermal disc emission is Compton up-scattered to reproduce the hard X-ray power-law (e.g. Czerny & Elvis 1987), this implies that the size of the reprocessing region is $< 10^{13} \text{ cm}$ or $< 0.1 R_S$ (for a Thomson depth of $\tau \sim 1$). The spectral softening appears consistent with observations of some AGN, where the X-ray spectra are generally softer at higher fluxes (e.g. Vaughan & Edelson 2001).

4 THE SIZE AND EFFICIENCY OF THE X-RAY EMISSION IN PDS 456

Using light-crossing arguments, and assuming that relativistic beaming is unimportant, one can calculate the overall size of the X-ray emitting region in PDS 456 from the expression $l = ct/(1 + \tau)$, where $t$ is the rise-time of the flares and $\tau$ is the Thomson depth of the X-ray emitting region. Past multi-wavelength studies have shown that PDS 456 has a total bolometric luminosity of $10^{47} \text{ erg s}^{-1}$, peaking in the optical-UV band (Simpson et al. 1999, Reeves et al. 2000). With the assumption of isotropic emission (noting that PDS 456 is a radio-quiet, non-blazar AGN), this then requires a $10^9 M_\odot$ black hole accreting at the Eddington rate. As the X-ray flux from PDS 456 can double on timescales of $\sim 30$ ksec, then the X-ray emitting region has a maximum size of $l < 10^{15}$ cm, or $< 3 R_S$ for a $10^9 M_\odot$ black hole, consistent with the previous RXTE measurement in 1998 (Reeves et al. 2000). If one relaxes the assumption that PDS 456 is accreting at the Eddington rate, and thus the black hole mass is $> 10^9 M_\odot$, or if the Thomson depth of the region is large ($\tau > 1$), then the restriction on the radius of the emitting region is even more severe (i.e. $l < 3 R_S$). Thus the extreme variability suggests that the accretion rate in PDS 456 is indeed very high, with the X-ray emission originating from a very compact region (of $< 3 R_S$), presumably close to the event horizon of the putative $10^9 M_\odot$ black hole.

It is possible to calculate the efficiency of converting rest mass into energy from the flaring events. Firstly we estimate the total X-ray luminosity from the \textit{XMM-Newton} spectral fits to PDS 456. The \textit{XMM-Newton} EPIC MOS and pn spectrum of PDS 456 is shown in Figure 4; extrapolating a simple power-law fit to the 2-10 keV spectrum shows a clear excess of counts below 1 keV in both detectors. Fitting the continuum with a hard power-law ($\Gamma = 1.98 \pm 0.02$) and a
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Single temperature blackbody component to model the soft excess (with $kT = 101 \pm 5$ eV), then the time-averaged 0.3-10 keV luminosity obtained is $1.10 \times 10^{46}$ erg s$^{-1}$, compared to the bolometric output of $10^{47}$ erg s$^{-1}$ (Simpson et al. 1999, Reeves et al. 2000). Note that slightly higher values for the luminosity are obtained if one uses either a Comptonised blackbody or a disk blackbody spectrum.

The time-averaged count rate in the EPIC-pn detector is $3.33 \pm 0.01$ ct s$^{-1}$, hence one can calculate a constant factor for the conversion of count rate to luminosity of $f_{pn} = (3.30 \pm 0.01) \times 10^{45}$ erg ct$^{-1}$. From a linear fit to the increase in the XMM-Newton lightcurve after 20 ksec (Figure 2), we find a change in PN count rate of $1.64 \pm 0.13$ ct s$^{-1}$, over $18/(1+z)$ ksec (quasar rest frame), a factor of $1.62$ increase. Thus the corresponding rate of change in luminosity of PDS 456 is $\Delta L/\Delta t = (3.56 \pm 0.27) \times 10^{41}$ erg s$^{-2}$. Assuming photon diffusion through a spherical mass of accreting matter in which the opacity is dominated by Thomson scattering, the observed change in luminosity implies a minimum efficiency of $\eta > (\Delta L/\Delta t)/(2 \times 10^{52})$ (Fabian 1979, Guilbert, Fabian & Rees 1983). The derived efficiency, from this expression, of $\eta \approx 0.18 \pm 0.02$, exceeds the theoretical maximum for a Schwarzschild black hole, but is consistent with the limits for a Kerr metric (Thorne 1974).

Constraints can also be placed on $\eta$ from the BeppoSAX LECS lightcurve. A 0.3-2.0 keV luminosity of $9.65 \times 10^{45}$ erg s$^{-1}$ was derived from a power-law plus blackbody fit to the (high signal to noise) XMM-Newton spectrum. The mean LECS count rate, over the portion of the lightcurve simultaneous with XMM-Newton was $(6.5 \pm 0.2) \times 10^{-2}$ ct s$^{-1}$. Hence the constant factor for converting between luminosity and BeppoSAX LECS count rate is $f_{LECS} = (1.48 \pm 0.07) \times 10^{47}$ erg ct$^{-1}$. The two fastest events observed here correspond to an increase in count rate of $(5.42 \pm 1.53) \times 10^{-2}$ ct s$^{-1}$ in 11500/(1+z) sec after 230 ksec, and an increase of $(4.98 \pm 0.95) \times 10^{-2}$ ct s$^{-1}$ in 17280/(1+z) sec (after 253 ksec), corresponding to $\Delta L/\Delta t = (8.3 \pm 2.3) \times 10^{41}$ erg s$^{-2}$ and $\Delta L/\Delta t = (5.1 \pm 0.9) \times 10^{41}$ erg s$^{-2}$ respectively. The implied efficiency factors are then $\eta > 0.41 \pm 0.11$ and $\eta > 0.26 \pm 0.05$, near the maximum permitted value of $\eta \sim 0.3$ for extraction of energy around a Kerr black hole.

As discussed by Brandt et al. (1999), there are several caveats to note about the standard definition of the efficiency limit (Fabian et al. 1999, Reeves et al. 2000). The limit can be invalid if the X-ray emission is relativistically boosted, as can occur in a blazar like AGN, although we note here that PDS 456 is radio-quiet (the radio-loudness time-averaged 2-10 keV photon index, and the spectral steepening observed during a flare (Figures 2 and 3), makes this possibility unlikely.

The derived efficiency also assumes that the radiation is emitted at the centre of a spherical region; the limit can become invalid if the X-ray emission occurs in the outer layers of a sphere of high ($\tau > > 1$) optical depth, as the flare rise-time can then become unusually short (see the discussion in Brandt et al. 1999, Appendix A). Such a high value for $\tau$ seems unlikely in PDS 456, as from light-crossing arguments this would require a very compact region of $\ell << 3R_S$ for the X-ray emission. Nonetheless, in order to adopt a more conservative approach in estimating $\eta$, we calculated the total integrated increase in X-ray emission during the course of a flare, rather than using the rise-time of the event. The integrated energy emitted during the largest flare during the BeppoSAX observation (after 230 ksec) was $(9.1 \pm 0.6) \times 10^{45}$ erg, over a duration of 103.6/(1+z) ksec. Hence the rate of change of X-ray luminosity over the whole flare is $\Delta L/\Delta t = (1.19 \pm 0.08) \times 10^{43}$ erg s$^{-2}$ and the derived efficiency limit is then $\eta > 0.060 \pm 0.004$, close to the maximum possible value for accretion onto a Schwarzschild black hole.
The total X-ray luminosity measured from 0.3-10 keV is then $1.1 \times 10^{46}$ erg s$^{-1}$.

**Figure 4.** The XMM-Newton EPIC MOS (black) and pn (grey) spectrum of PDS 456. A power-law of photon index $\Gamma = 1.98 \pm 0.02$ has been fitted to the 2-10 keV spectrum. Extrapolation of this power-law model to lower energies (0.3 keV) results in a clear soft X-ray excess, which can be modelled by either blackbody or comptonised blackbody emission.

### 5 DISCUSSION

The tight limits placed on the timescale and size of the X-ray variations in PDS 456 allow us to place constraints on its physical origin. The rapid rise times and large amplitudes of the X-ray variations suggest that these are coherent events from the innermost regions ($R_\text{in} \sim 3R_S$) of the accretion disc. Moreover the high value of the radiative efficiency, measured between $\eta > 0.06$ (conservative) and $\eta > 0.41$ (optimal), is indicative of accretion onto a Kerr black hole. The timescale of the flares ($t_{\text{flare}} \sim 100$ ksec) is shorter than the dynamical time scale ($t_{\text{dynamical}}$) of the disc at $3R_S$ (here $t_{\text{dynamical}} \sim 350$ ksec at $3R_S$, for a pseudo-Newtonian potential, Abramowicz 1996). We suggest that X-ray flares produced via magnetic reconnection events in the corona of the inner disc are a plausible mechanism to explain the observed variations over such a short (sub-orbital) time scale.

Magnetic reconnection events are likely to arise as a direct result of buoyant magnetic flux tubes emerging randomly from the disc surface. Reconnection then takes place in regions of the corona in which oppositely directed magnetic field lines come in close contact. Di Matteo (1998) examined coronal heating and flare production via Petschek reconnection events in AGN. The discussion presented here is based on many of the results of that analysis. It is based on many of the results of that analysis. Flare events in many AGN can be accounted for by the onset of an ion-acoustic instability associated with slow MHD shocks and Petschek reconnection in the accretion disc corona. The fundamental energy source driving this process is the orbital energy of the inner disc, as shear stresses in the turbulent disc can rapidly amplify any seed fields. The resultant flux tubes are subject to a buoyancy (Parker) instability and emerge from the disc into the magnetically-structured corona. In this way a fraction of the accretion energy is converted into coronal magnetic energy. The emergence rate of magnetic energy into the disc corona should therefore be proportional to the the kinetic energy flux through the inner disc $E_{\text{disc}} = \partial_t (2\pi R \Sigma v^2_\phi) \sim M v^2_\phi \sim M c^2/\epsilon$ in steady state at $R = \epsilon R_S$, where $\Sigma$ is the disc surface density, $v_\phi$ is the azimuthal velocity and $M$ is the steady state accretion rate. Assuming a $10^9 M_\odot$ black hole accreting at the Eddington rate, we have $E_{\text{disc}}(3R_S) \sim 10^{37}$ erg s$^{-1}$ with $\epsilon = 3$ and from observation the total output of the flares is $E_{\text{flare}} \sim 10^{51}$ erg, over the lifetime (recurrence time) of the flares of $t_{\text{rec}} \sim 1$ day. A relatively high efficiency ($\gtrsim 0.1$) for the conversion of accretion energy to X-ray luminosity is required to power the flares in PDS 456, and is another indication that the massive black hole in this object is accreting at a rate close to the Eddington limit.

The buoyancy condition for magnetic flux tubes within the accretion disc is that the magnetic pressure should exceed the local gas pressure (e.g. Coroniti 1981), the critical condition being $B^2 \sim n_{\text{disc}} kT_{\text{disc}}$, where $B_s$ is the local magnetic field strength, $n_{\text{disc}}$ is the particle density within the disc and $T_{\text{disc}}$ is the disc temperature. The structure of the accretion flow close to the last stable orbit is unknown, however estimates can be made by assuming that accretion takes place via a thin disc. Using a steady-state Shakura-Sunyaev disc with a viscosity parameter $\alpha \sim 0.1$ yields the estimates $n_{\text{disc}} \sim 10^{17}$ cm$^{-3}$ and $T_{\text{disc}} \sim 10^5$ K at $r \sim 3R_S$. Applying these estimates to the magnetic pressure condition above, leads to a value for the field strength of a buoyant flux tube within the inner regions of the disc of $B_s \sim 5000$ G.

The observations provide two constraints on the density of the X-ray emitting region. These arise from the constraints on the fitted column density and the ionisation parameter of the highly ionised absorber in PDS 456. This is apparent in the hard X-ray spectrum of PDS 456 above 7 keV, in the form of deep K-shell edges of highly ionised iron (Fe xxv and Fe xxvi), present both in the current XMM-Newton EPIC spectrum (Reeves et al. 2002, in preparation) and in earlier ASCA and RXTE observations (Reeves et al. 2000). From the XMM-Newton observations, the X-ray spectrum of PDS 456 is well fit with a column density $n_{\text{H}} \sim n_{\text{in}}$, in the range $9 \times 10^{23} - 5 \times 10^{24}$ cm$^{-2}$ implying $9 \times 10^8$ cm$^{-3}$ < $n < 5 \times 10^9$ cm$^{-3}$. On the other hand, the ionisation parameter $U \approx L_x/nR_s^2$ lies in the range $3 \times 10^{-4} - 2.5 \times 10^3$, where $L_x \sim 10^{15}$ erg s$^{-1}$ is the hard X-ray ionising flux leading to the limits $4 \times 10^8 < n < 3 \times 10^{10}$ cm$^{-3}$. If we associate this density with the hot post shock gas we obtain the estimate $n_s \sim 5 \times 10^9$ cm$^{-3}$. The evolution of the buoyant flux tubes provides a natural explanation for this very low value of the density of the X-ray emitting region. As the flux tubes emerge from the disc and rise into the corona, gravitational downflow of plasma causes the density within the flux tube to decrease to the point at which reconnection can take place efficiently. The density estimate above implies that the buoyant flux tubes rise far into the corona before reconnection occurs. An estimate of the height at which reconnection occurs is in terms of the pressure scale height of the disc ($H$) can be obtained from (Di Matteo 1998)

$$H_{\text{flare}} \sim \left( \frac{n_{\text{disc}}}{n_s} \right)^{1/4} H \sim 50H.$$  

In the case of a Shakura-Sunyaev accretion disc $H/R \lesssim 0.1$ implying that $H_{\text{flare}} \gtrsim R_{\text{in}}$. Hence the total magnetic energy stored in the corona of the inner disc should be of the order $B_s^2 R_{\text{in}}^2/8\pi \sim 10^{51}$ erg. This large reservoir of stored...
accretion energy is enough to explain the large amplitude X-ray variations seen in PDS 456, and highlights the efficiency with which accretion energy must be converted to magnetic energy to explain these flaring events.

We now consider the rise time of the events in the light curves ($t_{\text{rise}} \gtrsim 30$ ksec) in the light of the above model. An attractive feature of the Petschek model is the short time scale on which reconnection can take place. This can be of the order of a few Alfvén times $\tau_\Lambda \sim 4v_\Lambda^{-1} R_{\text{in}}^{-1}$, where $v_\Lambda$ is the characteristic length scale associated with changes of the magnetic field (here $l \sim R_{\text{in}}$), $v_\Lambda$ is the local Alfvén speed and $m_p$ is the proton mass. The estimates above yield $\tau_\Lambda \sim 50$ ksec, encouragingly close to the observed rise time of the flares. The time scale $\tau_\Lambda$ provides a constraint on the density of the accretion disc and post shock gas. An accretion disc density significantly lower than $n_{\text{disc}} \sim 10^{17}$ cm$^{-3}$ or a shock density much higher than $n_s \sim 10^{19}$ cm$^{-3}$ would increase $\tau_\Lambda$ to a level inconsistent with the observations.

The energy production rate for an individual flare can be estimated from (Di Matteo 1998):

$$E_{\text{flare}} \sim \frac{n_s L (kT_{\text{flare}})^{3/2}}{n_s R_{\text{in}}^2 (kT_{\text{flare}})^{3/2}} \sim \frac{\dot{m} L}{\dot{m} c^2}$$

where $L$ is the length of the slow shock region, $T_{\text{flare}}$ is the X-ray temperature and $m_e$ is the electron mass. The dimension $L$ is the essentially the length of region of oppositely-directed magnetic field lines which we constrain to be of the order $L \sim R_{\text{in}}$. Adopting $T_{\text{flare}} \sim 10^8$ K we obtain $E_{\text{flare}} \sim 10^{43}$ erg s$^{-1}$. This suggests that the large scale X-ray variations in the light curve of PDS 456 involve $\gtrsim 1000$ so individual flares. These flares could not produce the large amplitude variations observed in PDS 456 if they were incoherent.

However it is possible that the magnetic structure within the disc corona could reach a self-organized, critical state in which the reconnection and flaring of one flux tube could prompt similar flares in its neighbors, allowing a coherent cascade of flares to develop (Leighly & O’Brien 1997). The timescale on which the global cascade could take place can be constrained from the Alfvén time in the region involved, which is consistent with observed timescale of the flaring events in the light curve.

This leads to a suggestion of why it is that PDS 456 releases such a large fraction of its accretion energy in the form of large-amplitude, coherent X-ray variations. A flare cascade along the lines of that suggested above would require that magnetic energy was stored in the disc corona until some triggering criterion was reached, promoting the first flare event. The energy involved in such a cascade is likely to be governed by the time scale on which magnetic energy is pumped into the disc corona ($t_{\text{mag}}$) and the time scale on which the triggering criterion is satisfied ($t_{\text{trigger}}$). Two possible cases emerge: (a) $t_{\text{mag}} \gg t_{\text{trigger}}$ in which case the flares will be incoherent and the resultant X-ray variability small-amplitude and (b) $t_{\text{mag}} \lesssim t_{\text{trigger}}$ producing the possibility of large-amplitude coherent flare cascades.

Unfortunately little is known about $t_{\text{trigger}}$, however $t_{\text{mag}}$ must be related to $E_{\text{disc}}$ via $t_{\text{mag}} \sim E_c / E_{\text{disc}}$ where $E_c$ is a measure of the minimum magnetic energy required to be stored in the disc corona before it can reach a critical state allowing a flare cascade. Hence $t_{\text{mag}} \propto E_c / \dot{m} \propto E_c / \dot{m} M_{\text{BH}}$, where $\dot{m}$ is the accretion rate in Eddington units. Hence systems in which a high mass black hole accretes at the Eddington limit should be more able to release stored magnetic energy in the form of a coherent flare cascade, providing at least a tentative explanation of why the X-ray variability of PDS 456 is so extreme. The similarity of the X-ray behavior of PDS 456 and the Narrow Line Seyfert 1s (see Leighly et al. 1999) suggests that $\dot{m}$ is the critical factor in determining the scale of the X-ray variability in AGN. The energy of X-ray flares in some NLS1s can be as high as $\sim 10^{48}$ erg (e.g. IRAS 13324-3809, Boller et al. 1997), a factor of $\sim 10^3$ less than the flares observed in the light curve of PDS 456, in good agreement with the ratio of black hole masses in these systems. If we use these observations to make the connection $E_c \propto M_{\text{BH}}$, then $t_{\text{mag}} \sim 1 / \dot{m}$. Such a relation would suggest that any system accreting close to the Eddington rate would be likely to show strong X-ray variability.

6 CONCLUSIONS

Recent BeppoSAX and XMM-Newton observations have shown that the luminous quasar PDS 456 exhibits rapid X-ray variability on timescales of $\sim 30$ ksec, with a total energy output of $10^{51}$ erg s$^{-1}$ for the flaring events. This limits the size of the X-ray emitting region to $< 3$ Schwarzschild radii for a $10^9 M_\odot$ black hole. The energetics of the of the accretion disc in PDS 456 can power its extreme X-ray variability if the black hole is massive ($\gtrsim 10^9 M_\odot$) and is accreting close to the Eddington rate. Coronal magnetic flare events can explain the X-ray variability as long as the disc is able convert accretion energy into coronal magnetic energy efficiently, and that this energy can be released in the form of a self-induced cascade of $\gtrsim 1000$ individual flare events on a timescale of the order 1 day.

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