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PHL 1092 as a transient extreme X-ray weak quasar

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ABSTRACT

We report a dramatic variability event in the X-ray history of the narrow-line quasar PHL 1092 ($z = 0.396$). Our latest 2008 *XMM-Newton* observation reveals a flux drop of ~200 with respect to the previous observation performed about 4.5 yr earlier, and a drop of ~135 with respect to its historical flux. Despite the huge X-ray variation, the UV flux remains constant producing a very significant steepening of the optical to X-ray slope $\alpha_{\rm ox}$ from -1.56 to -2.44, making PHL 1092 one of the most extreme X-ray weak quasars. The similarity in the soft X-ray spectral shape between the present and previous observations, together with the persistent UV flux and the lack of any dramatic change in the optical spectrum, suggests that an absorption event is not likely to be the origin of the observed variation. If absorption is ruled out, the sudden X-ray weakness of PHL 1092 must be produced by a transient significant weakening or disruption of the X-ray emitting corona.

Key words: galaxies: active – X-rays: galaxies.

1 INTRODUCTION

PHL 1092 ($z = 0.396$) is a radio-quiet quasar (QSO) characterized in the optical band by outstanding Fe II emission with a Fe IIλ4570/Hβ ratio of ~5.3 (Bergeron & Kunth 1980, 1984; Kwan et al. 1995). Its line widths of ~1800 km s^{-1} and [O III]λ5007/Hβ ratio of ~0.9 classify PHL 1092 as a high-luminosity representative of the narrow-line Seyfert 1 (NLS1) galaxy population (Osterbrock & Pogge 1985; Goodrich 1989). In fact, strong Fe II emission seems to be a further characteristic of the optical spectra of NLS1 galaxies (e.g. Véron-Cetty, Véron & Gonçalves 2001). NLS1 galaxies also exhibit remarkable properties in the X-ray regime. They are characterized by large-amplitude time-scale X-ray variability and their X-ray spectra are steeper than in broad-line sources (e.g. Boller, Brandt & Fink 1996; Brandt, Mathur & Elvis 1997; Leighly 1999a,b). This is more dramatic in the soft X-ray band, where a prominent soft excess of debated origin is very often observed. A number of NLS1 are X-ray weak if compared to optically-selected standard QSO and their X-ray variability is generally larger than in the optical/UV producing changes in the optical to X-ray spectral slope $\alpha_{\rm ox}$ up to $\Delta\alpha_{\rm ox} \sim$ 0.3–0.4 (e.g. NGC 4051, 1H 0707−495, see Gallo 2006).

PHL 1092 is one of the most X-ray variable NLS1 known, despite its QSO-like X-ray and optical luminosities (see also the remarkable case of IRAS 13224–3809, Boller et al. 1997). During the 1997 *ROSAT* monitoring of PHL 1092, a maximum variability amplitude of a factor of ~14 was reported (Brandt et al. 1999). The typical luminosity in the 0.2–2 keV band is ~1 × 10^{45} erg s^{-1}.

PHL 1092 was observed with *XMM-Newton* on three occasions. The first observation was performed on 2000 July 31 and lasted ~32 ks. The ODF files for the EPIC cameras could not be recovered, but X-ray and UV light curves from the RGS and optical monitor (OM) could be obtained (Gallo et al. 2004). The source was then re-observed 3 yr later on 2003 July 18 for ~29 ks, resulting in complete set of ODF files for all detectors. Finally, we obtained a further ~60 ks observation on 2008 January 20 which is the main subject of this Letter. Besides the simultaneous UV observations with the OM, we also obtained quasi-simultaneous optical spectra at the Hobby–Eberly Telescope (HET; 600 s on 2008 January 30) and at the William Herschel telescope (WHT, 900 s on 2008 February 14).

2 DRAMATIC LONG-TERM X-RAY VARIABILITY

The most striking result of our new 2008 *XMM-Newton* observation is that PHL 1092 is much fainter than during any previous X-ray observation. This is readily visible by examining X-ray images of the region. In Fig. 1, we show the EPIC pn images from the two available good quality *XMM-Newton* observations clearly showing that a dramatic variability event has taken place, so that PHL 1092 is not even the brightest X-ray source in the region in 2008. The 0.5–2 keV flux of PHL 1092 from all previous available X-ray observations is shown in Fig. 2. As will be discussed below, the flux drop between

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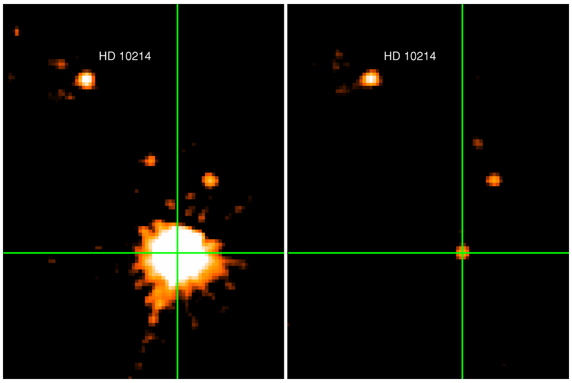

Figure 1. The 0.2–0.9 keV EPIC pn images of the PHL 1092 region from the 2003 (left) and 2008 (right) observations. Astrometry has been checked by cross-correlating the X-ray images with the USNO A 2.0 catalogue. One of the common sources (the G5 star HD 10214) is labelled. Cross-hairs are locked at the nominal coordinates of PHL 1092 and the images share the same scale (about 5 × 7 arcmin.) and colour-bar scheme. The raw images have been slightly smoothed for clarity.

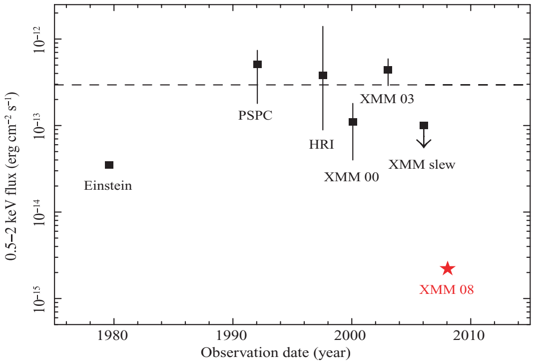

Figure 2. The historical 0.5–2 keV flux of PHL 1092. Count rates have been converted in fluxes using PIMMS. The vertical lines display the intra-observation flux variability range (when available). From earlier to latest, fluxes from *Einstein*/IPC (Wilkes et al. 1994), *ROSAT*/PSCP (Forster & Halpern 1996), *ROSAT*/HRI (Brandt et al. 1999), *XMM-Newton* (2000 and 2003, Gallo et al. 2004), a *XMM-Newton* slew passage, and our latest 2008 *XMM-Newton* observation are shown. A further *ASCA* observation, simultaneous with the *ROSAT* HRI monitoring (Leighly 1999a,b), is not reported here since flux and variability are encompassed by the HRI data point. The horizontal line shows the average flux excluding the *XMM-Newton* slew upper limit and the last observation ($\sim 3 \times 10^{-13}$ erg cm^{-2} s^{-1}).

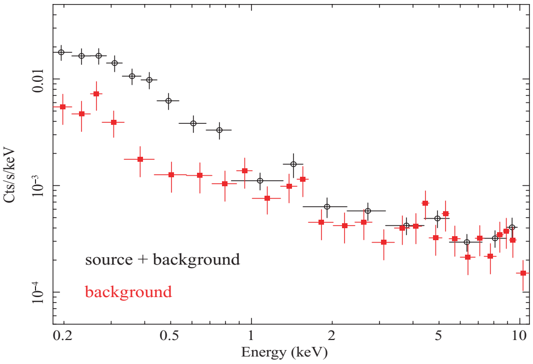

Figure 3. The source plus background spectrum of PHL 1092 from the 2008 *XMM-Newton* observation is compared with the background from a nearby region.

the latest *XMM-Newton* pointed observation in 2003 is about a factor of 200, while a drop of a factor of ∼135 is observed with respect to the average historical flux ($\sim 3 \times 10^{-13}$ erg cm^{-2} s^{-1}).

In Fig. 3, we compare the 2008 EPIC pn source plus background spectrum of PHL 1092 with the background itself. PHL 1092 is well detected above the background level up to ∼0.9 keV only. Hence, we here focus on the 0.2–0.9 keV range only, corresponding to the ∼0.28–1.26 keV band in the rest frame. Given that the main interest of our work is to assess the long-term X-ray variability of PHL 1092, we proceed by analysing the new 2008 data together with the earlier 2003 *XMM-Newton* observation, which represents a typical X-ray flux state of the source (see Fig. 2).

2.1 Comparison with the 2003 *XMM-Newton* observation

In Fig. 4, we show the EPIC pn spectrum from the 2008 observation together with the 2003 data (above ∼7 keV, the background dominates during the 2003 observation). In order to compare the source fluxes during the 2003 and 2008 *XMM-Newton* observations in more detail, we apply the same spectral model to the two data sets, and we first adopt a simple power-law model absorbed by a column of neutral gas which we allow to vary in the range of the measured Galactic value ($3.6 \pm 0.2 \times 10^{20}$ cm^{-2}; Murphy et al. 1996).

The 2008 data are well described [$\chi^2 = 12$ for 23 degrees of freedom (dof)] by a very steep but loosely constrained photon index $\Gamma = 4.5 \pm 0.7$. We measure a flux of $(7.0 \pm 3.5) \times 10^{-15}$ erg cm^{-2} s^{-1} in the 0.2–0.9 keV band, corresponding to a 0.2–0.9 keV unabsorbed luminosity of $\sim 3.1 \times 10^{43}$ erg s^{-1}. The 2003 data are only relatively well described ($\chi^2 = 162$ for 130 dof), but we can none the less obtain a good measure of the spectral shape with $\Gamma = 4.07 \pm 0.05$ with a 0.2–0.9 keV flux of $1.28 \pm 0.06 \times 10^{-12}$ erg cm^{-2} s^{-1}, corresponding to an unabsorbed luminosity of $\sim 4.1 \times 10^{45}$ erg s^{-1} in the same energy range.

Given that the 0.2–0.9 keV spectral shape is consistent with being the same in the 2003 and 2008 observations, we then consider a joint fit to the two data sets (in the 0.2–4 keV range for the 2003 observation to avoid the high-energy complexities discussed by Gallo et al. 2004, and in the 0.2–0.9 keV range for the 2008 one). We use the simplest best-fitting model for the higher flux 2003 spectrum, comprising a phenomenological disc blackbody (BB) model plus a power law, modified by neutral absorption fixing all parameters to be the same except for an overall normalization. We obtain an acceptable joint fit ($\chi^2_\nu = 1.2$ for 202 dof) with $kT \sim 100$ eV, $\Gamma \sim 2.6$ and $N_{\rm H} = 2.6 \pm 0.3 \times 10^{20}$ cm^{-2} (less than the Galactic value). If the column density is allowed to vary between the two observations, no significant improvement is obtained and the 2008 data are inconsistent with $N_{\rm H} \geq 6 \times 10^{20}$ cm^{-2}. The BB temperatures are also consistent with each other. By using the common spectral model, we infer that the flux drop during the 2008 pointing with respect to the previous one is of a factor of 200 ± 40. If the low flux state is compared with the historical one shown in Fig. 2, the drop is of a factor of ∼135. Incidentally, if the two flux states are indeed associated with the same spectral component in the soft band, our result implies that interpreting the soft X-ray excess in NLS1 galaxies as BB emission is implausible as the luminosity drop occurs here at fixed temperature without following the standard BB-defining $L_{\rm BB} \propto T^4$ relationship. As shown in Fig. 3, the hard X-rays during the 2008 observation are background dominated. A simple power-law fit to the 2–10 keV data is however useful to set a 2–10 flux upper limit of $\leq 9.9 \times 10^{-15}$ erg s^{-1} cm^{-2} for future reference.

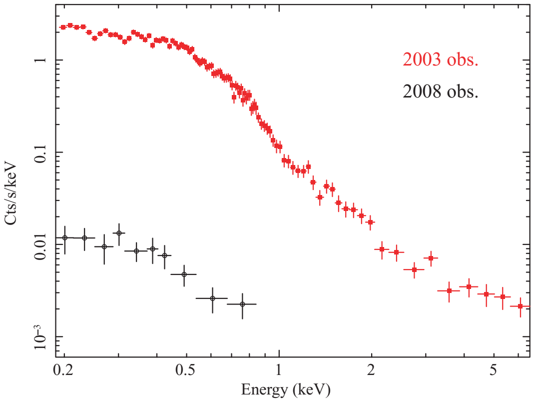

Figure 4. A comparison between the 2003 and 2008 *XMM-Newton* EPIC pn spectra of PHL 1092. The huge flux drop is clearly visible in the soft band, where data are available for both pointings.

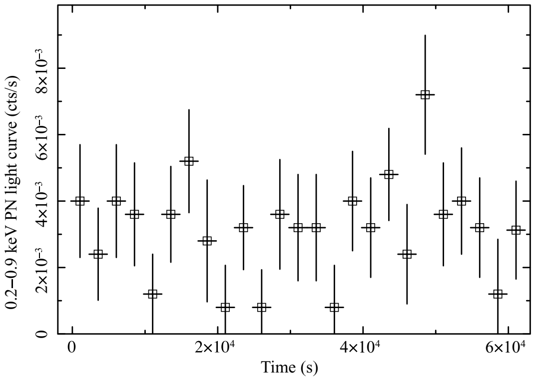

Figure 5. The 0.2–0.9 keV pn light curve from the 2008 *XMM-Newton* observation of PHL 1092 with time bins of 2.5 ks.

2.2 X-ray variability

In Fig. 5, we show the EPIC pn light curve of PHL 1092 in the 0.2–0.9 keV band. No short-time-scale variability is significantly detected in the whole ~60 ks light curve, while variability of 50 per cent or more is normally observed on similar time-scales (see e.g. Brandt et al. 1999; Gallo et al. 2004).

The lack of X-ray variability could in principle indicate that a different spectral component is responsible for the 2008 spectrum. It is, for instance, possible that soft X-rays are associated with a large-scale scattered/reprocessed component, overwhelmed by the nuclear continuum emission in normal flux states. A rich spectrum of soft X-ray emission lines is indeed observed in obscured Seyfert 2 (see e.g. Guainazzi & Bianchi 2007) and in unobscured Seyfert 1 galaxies when observed at very low X-ray flux levels (e.g. NGC 4051; Pounds et al. 2004; Ponti et al. 2006; Mrk 335, Grupe et al. 2008a; Longinotti et al. 2008). This gas is likely associated with the narrow-line region (Bianchi, Guainazzi & Chiaberge 2006), thus responding to continuum variation on very long time-scales, and it typically represents a few per cent of the soft 0.5–2 keV nuclear flux (Bianchi & Guainazzi 2007). In PHL 1092, the soft X-ray flux (or luminosity) observed in 2008 is about 0.7 per cent of the historical, which means that a scattering/reprocessing interpretation is viable provided that the average flux of PHL 1092 in the past few hundreds years (assuming a size of few hundreds parsecs for the reprocessing medium) was a factor of a few smaller than that we observed over the past 30 yr.

It should however be stressed that in all cases for which sufficiently high-quality data can be collected, accreting black holes satisfy the so-called linear rms–flux relationship on all time-scales (Uttley & McHardy 2001). This means that sources in low flux states are much less likely to exhibit large amplitude variability than at higher flux levels. Thus, the apparent lack of X-ray variability is not necessarily related to some physical difference in the X-ray emission, but could simply be an extension to low flux levels of the variability properties of the source.

2.3 Simultaneous UV and quasi-simultaneous optical data

All three *XMM-Newton* observations provide data from the OM. In particular, exposures are available in the UVW2 filter (effective wavelength of ~1480 Å in the rest frame). The OM data for the 2000 and 2003 observations were analysed by Gallo et al. (2004) who report an average UVW2 flux of 4.43 ± 0.05 × 10^{-15} erg $\mathrm{s^{-1}}$ $\mathrm{cm^{-2}}$ $\mathrm{Å^{-1}}$ in 2000 and of ~3.79 ± 0.05 × 10^{-15} erg $\mathrm{s^{-1}}$ $\mathrm{cm^{-2}}$ $\mathrm{Å^{-1}}$ in 2003. Moreover, Gallo et al. (2004) also claim tentative evidence for UV short-time-scale variability of the order of few per cent, especially during the 2003 observation. During our deep minimum 2008 observation, the UV flux is (3.79 ± 0.05) × 10^{-15} erg $\mathrm{s^{-1}}$ $\mathrm{cm^{-2}}$ $\mathrm{Å^{-1}}$, i.e. consistent with the 2003 flux. The UV light curve (not shown here, 20 exposures of ~2700 s each in UVW2) is consistent with a constant ($\chi^2_\nu = 0.8$) as is the X-ray light curve (see Fig. 5).

Our UV flux measurement implies that the PHL 1092 spectral energy distribution (SED) is now characterized by a much steeper optical to X-ray spectral slope $\alpha_{\rm ox}$, defined as the hypothetical power-law slope between the 2500 Å and 2 keV rest-frame flux densities, than in 2003. A $\alpha_{\rm ox}^{(03)} \simeq -1.56$ slope from the simultaneous 2003 UV and X-ray data was computed by Gallo (2006). By applying the well-known relationship between $\alpha_{\rm ox}$ and the 2500 Å luminosity l_{2500} (e.g. Steffen et al. 2006; see also Vignali, Brandt & Schneider 2003; Strateva et al. 2005; Gibson, Brandt & Schneider 2008), we infer that PHL 1092 should have $\alpha_{\rm ox} \simeq -1.48$. The 2003 value (−1.56) is consistent with the spread in the relationship for objects with $\log l_{2500} \simeq 30$–31 (Steffen et al. 2006), while in 2008 we measure $\alpha_{\rm ox}^{(08)} \simeq -2.44$, well outside the $\alpha_{\rm ox}$–l_{2500} spread.

Following Gibson et al. (2008), we define $\Delta\alpha_{\rm ox}$ as the difference between the observed $\alpha_{\rm ox}$ and the one that can be predicted from the optical luminosity. While $\Delta^{03}\alpha_{\rm ox} = -0.08$ is quite typical for optically-selected QSO, the 2008 value is $\Delta^{08}\alpha_{\rm ox} = -0.96$, so extreme that much less than 1 per cent of optically-selected QSO with no broad absorption line (BAL) systems are expected to share with PHL 1092 such X-ray weakness (Gibson et al. 2008).

Quasi-simultaneous optical spectra were also obtained at the HET [Low-Resolution Spectrograph (LRS)] and WHT [Intermediate Dispersion Spectrograph and Imaging System (ISIS)], 10 and 25 d, respectively, after the *XMM-Newton* observation. It is not the purpose of this Letter to present detailed optical spectroscopy, but only to check whether, given the huge X-ray flux variation, a corresponding dramatic change in the optical properties of the source has occurred. The HET spectrum (~3100–5250 Å in the rest frame) is shown in Fig 6 (top panel). It is dominated by optical and UV Fe II lines with relatively weak Hβ and [O III], and does not show any striking deviation from the one presented by Bergeron & Kunth (1980). The same is true for the WHT spectrum which extends down to Mg II and up to ~6500 Å (rest frame), the observed wavelength range. We do not have coverage of the C IV region which would be interesting to search for the appearance of a BAL signature in

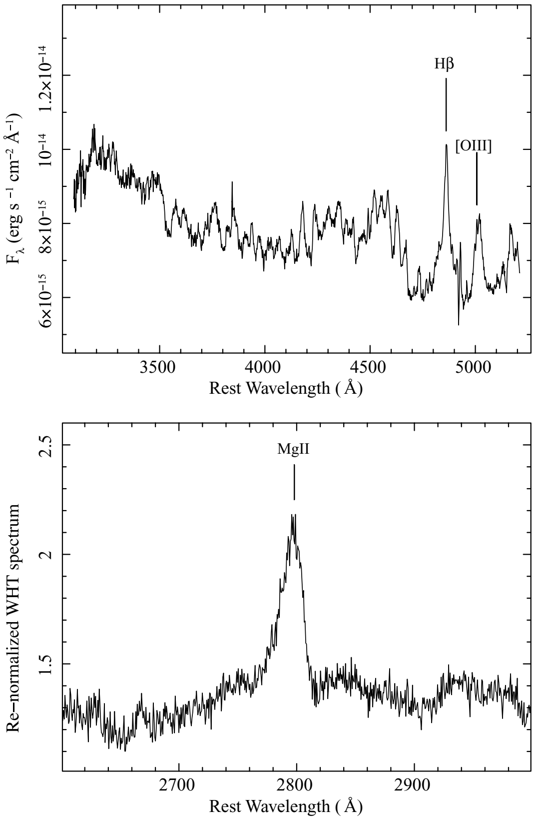

Figure 6. The quasi-simultaneous 2008 HET–LRS spectrum (top, no absolute flux calibration). We only identify the H $\beta\lambda$4861 Å and [O III]λ5007 Å lines as a reference (both affected by blended Fe II lines). Shorter wavelength lines mostly belong to Fe I and Fe II optical/UV multiplets (see e.g. Bergeron & Kunth 1980). In the bottom panel, the Mg IIλ2798 Å portion of the arbitrarily renormalized WHT–ISIS spectrum is shown.

PHL 1092 (Brandt, Laor & Wills 2000). We show however the Mg IIλ2798 Å region, which does not show the developing of any low-ionization BAL (Fig. 6, bottom panel). We conclude that no dramatic change in the optical properties of the source has shown up on time-scales of tens of days after the observed extreme X-ray flux drop of PHL 1092.

3 DISCUSSION

The major result of our *XMM-Newton* observation of PHL 1092 is the discovery of a dramatic X-ray flux drop with respect to any previous observation, together with a persistent constant UV flux. This produces a very significant steepening of $\alpha_{\rm ox}$ from −1.56 to −2.44 in just ∼4.5 yr. The X-ray weakness during 2008 is such that the $\alpha_{\rm ox}$ deviation from a normal optically-selected QSO with the same 2500 Å luminosity is one of the largest observed so far for non-BAL QSO ($\Delta\alpha_{\rm ox} = -0.96$).

A similar case in terms of extreme X-ray weakness is that of PHL 1811 ($\Delta\alpha_{\rm ox} = -0.70$; Leighly et al. 2007a,b; see also LBQS 0102-2713 for which Boller et al. 2009 report $\Delta\alpha_{\rm ox} \simeq -0.50$). Both PHL 1092 and PHL 1811 represent the high-luminosity end of the NLS1 population (with PHL 1811 being about five times more optically luminous than PHL 1092). Moreover, they both have strong Fe II emission, relatively weak [O III] and unusually blue far-UV spectra, while lacking strong Lyα and C IV lines (Leighly et al. 2007a,b). However, PHL 1811 has always been observed to be X-ray weak over the past ∼20 yr (in seven different observations) while, for a comparable number of X-ray observations and monitoring period, PHL 1092 has been observed to be extremely X-ray weak only once. Our 2008 observation of PHL 1092 implies that transitions from relatively standard QSO states (in terms of $\alpha_{\rm ox}$) to extreme X-ray weak ones are possible on relatively short time-scales (few years). This in turn means that outliers in the $\alpha_{\rm ox}$–l_{2500} relation may be due to transient extreme X-ray variability phenomena and that they may change their status if sufficiently long monitoring is performed.

Despite the factor of ∼200 X-ray flux drop of PHL 1092, the persistent soft spectral shape, combined with the non-detection of (simple) intrinsic X-ray absorption, may suggest that an absorption event is unlikely. However, as discussed in Section 3.2, the nature of the soft X-ray emission in the 2008 observation of PHL 1092 is uncertain (either direct nuclear emission or large-scale scattered/reprocessed emission). If X-rays are scattered, the nuclear emission could be absorbed by, for example, Compton-thick matter. If so, the persistent UV flux in PHL 1092 means that the absorber would have to completely stop X-rays (e.g. being Compton-thick) while being transparent in the UV regime, which seems highly unlikely given that the UV and X-ray emission regions (accretion disc and X-ray corona, respectively, in the standard view) most likely share similar locations. Even by considering unusual absorber size and covering factor or non-standard physical properties (ionization state, grain size distribution), it seems difficult that the UV and optical would be unaffected. One possibility would be that the UV are also scattered so that they are spatially separated from the X-ray emitting region. However, tentative evidence for short time-scale UV variability during the 2003 (Gallo et al. 2004) argues against such a hypothesis.

A partial covering scenario has been invoked to account for the X-ray weakness of some other NLS1 galaxies (e.g. Mrk 335, Grupe et al. 2008a; WPVS 007, Grupe, Leighly & Komossa 2008b). However, UV variability was always observed, as opposed to the present case. Another possible scenario is one in which the direct nuclear emission is suppressed by light-bending effects near the black hole (Fabian et al. 2004; Miniutti & Fabian 2004). Light bending can be responsible for a maximum X-ray variability of a factor of ∼20, and the remaining factor ∼10 should have to be accounted for by intrinsic variability. This is more acceptable especially for NLS1 sources, but we consider somewhat unlikely that both effects conspire to act simultaneously and in the same direction.

Generally speaking, the UV to X-ray SED of active galactic nucleus (AGN) is interpreted in terms of accretion disc emission (peaking in the UV) and inverse Compton by one or more population of hot electrons (the so-called X-ray corona) upscattering the soft UV seed photons up to X-ray energies. Since the UV flux remains constant between the 2003 and 2008 observations, if we exclude an absorption origin for the sudden X-ray weakness of PHL 1092, we must conclude that the ability of the X-ray corona to upscatter the optical/UV seed photons through inverse Compton was very significantly reduced during the 2008 observation (see Grupe et al. 2000 for a similar explanation in the case of the radio-loud NLS1 galaxy RX J0134.2−4258). In order to get insights on the plausibility of genuine X-ray coronal variability in PHL 1092, it may be useful to compare the behaviour of PHL 1092 with that of Galactic black hole binaries. The much smaller size of these systems allows one to probe time-scales that are not accessible for AGN, thus providing potential clues to AGN studies. By making use of the analogy between the AGN and Galactic black hole SED, the question here would be to consider whether Galactic sources can exhibit large amplitude variability events in the X-ray corona component (power law) while the soft X-ray disc component is stable.

In a recent work, Sobolewska, Gierlinski & Siemiginowska (2009) introduced a $\alpha'_{\rm GBH}$ parameter defined as the equivalent of $\alpha_{\rm ox}$ for Galactic black hole binaries, i.e. the quantity measuring the spectral slope between the disc- and corona-dominated components. They show that $\Delta\alpha'_{\rm GBH}$ of the order of unity can be reached by a single source at a given disc luminosity during a given outburst. The observed time-scale for such variations is of the order of days. However, to the best of our knowledge, no firm constraints can be placed on the shortest possible time-scales, making it possible (though most probably very rare) that variability of this amplitude could be seen in AGN on time-scales of years. A small mass for the black hole in PHL 1092 would help to reduce its variability time-scale. In fact, while its optical luminosity would suggest a black hole mass of the order of 1–2 × $10^8\,{\rm M}_\odot$ (Dasgupta, Rao & Dewangan 2004), X-ray variability suggests instead a much smaller mass of $\sim 10^6\,{\rm M}_\odot$ (Bian & Zhao 2003; Nikolajuk, Czerny & Gurynowicz 2009). Although extrinsic explanations such as absorption or light bending cannot be firmly ruled out, we conclude that we have likely observed a rare and extreme variability event associated with a transient dramatic weakening or disruption of the X-ray corona in PHL 1092. Future X-ray and optical/UV monitoring of the source is mandatory to reveal the nature of the extreme event we have reported here.

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