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Magnetic flux inversion in a peculiar changing look AGN

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ABSTRACT

We argue that the changing-look event in the active galactic nucleus (AGN) 1ES 1927+654, followed by a dip of three orders of magnitude in the X-ray luminosity, is controlled by a change in the accretion rate and an inversion of magnetic flux in a magnetically arrested disc (MAD). Before the changing-look event, strong magnetic flux on the black hole powers X-ray emission via the Blandford–Znajek process, while the UV emission is produced by a radiatively inefficient magnetized disc. An advection event, bringing flux of the opposite polarity, propagates inward leading, first, to a rise in the UV/optical luminosity and, then, to a dip in the X-ray luminosity. We find that the observed time-scale between the beginning of the changing-look event and the minimum in the X-ray luminosity, ≈200 d, is in agreement with the time needed to cancel the magnetic flux in a MAD extending to ≈180 r_g. Although flux inversion events might be rare due to the large ratio of flux-to-mass that is needed, we argue that AGN showing an unusually high ratio of X-ray to UV luminosity are prime candidates for such events. We suggest that similar events may lead to jet interruptions in radio-loud objects.

Key words: accretion, accretion discs – magnetic fields – galaxies: active.

1 INTRODUCTION

Active galactic nuclei (AGN) are highly variable objects in the optical/UV, typically showing rms variability of 10–20 per cent and occasionally changes by a factor as large as 2 in their optical luminosity (Rumbaugh et al. 2018). The most extreme variability is found in 'changing-look' AGN, which are observed to transit from Type 1 to Type 2 or vice versa on a typical time-scale of a few months. Type 1 AGN exhibit both narrow and broad emission lines, while Type 2 AGN exhibit only narrow emission lines. The change from Type 2 to Type 1 is generally accompanied by a rise in the optical luminosity by a factor of ≃2–10 (or a corresponding decrease for Type 1 to Type 2). While the first changing-look AGN were detected in nearby Seyferts (Tohline & Osterbrock 1976, Cohen et al. 1986, Storchi-Bergmann et al. 1995), they are now also detected in luminous quasars at higher redshifts (LaMassa et al. 2015; MacLeod et al. 2016; Ruan et al. 2016; Runnoe et al. 2016; Wang; Xu & Wei 2018; Yang et al. 2018).

The difference between Type 1 and Type 2 AGN has long been attributed to obscuration along the line of sight to the central region by a dusty torus (Antonucci 1993). It seems unlikely that a dusty cloud appearing or disappearing from the line of sight could be the driver of changing-look events (Trakhtenbrot et al. 2019) since it would need to cover a large fraction of the broad line region (BLR) and move very fast to explain the time-scales observed. A change in the intrinsic accretion power of AGN seems a more plausible explanation for changing-look events. This idea is supported by a few changing-look AGN that transited to or from a so-called 'true' Type 2 AGN, i.e. a Type 2 AGN showing no sign of obscuration (LaMassa et al. 2015, Husemann et al. 2016, Trakhtenbrot et al. 2019).

One of these 'true' Type 2 AGN, 1ES 1927+654 (Gallo et al. 2013), recently underwent a peculiar changing-look event (Trakhtenbrot et al. 2019) that differentiates it from other changing-look AGN. Even before the changing-look event, 1ES 1927+654 had an X-ray luminosity in the 0.5–10 keV band approximately 1−2 orders of magnitude higher than the bolometric luminosity inferred from the optical or UV (Ricci et al. 2020), whereas AGN usually have an X-ray luminosity of the order of or lower than the UV luminosity (Svoboda, Guainazzi & Merloni 2017). The changing-look event, in which the optical luminosity rose by a factor of ≳10−100 and broad lines appeared, was then followed, near the peak of the UV luminosity, by a dramatic decrease of the X-ray luminosity by three orders of magnitude (Ricci et al. 2020). This dip in the X-ray luminosity lasted ≈100 d, after which the X-ray luminosity increased to a level 10 times higher than before the event. Moreover, the UV/optical luminosity steadily decreased during the dip in the X-rays, suggesting that the optical changing-look event and the X-ray luminosity dip are unrelated. Usually in changing-look AGN, the X-ray luminosity follows the trend of the optical luminosity (LaMassa et al. 2015; Husemann et al. 2016; Parker et al. 2018; Zetzl et al. 2018).

Ricci et al. (2020) suggested that the optical changing-look event and dip in the X-ray luminosity might be explained by the disruption of the inner accretion disc by a tidal disruption event (TDE). A TDE was suggested by a $t^{-5/3}$ fit to the rate of decrease of the UV luminosity. However, Trakhtenbrot et al. (2019) note that, due to uncertainty in the time of the UV luminosity peak, the slope is poorly constrained. Moreover, emission lines usually seen in TDEs are absent in this case (Trakhtenbrot et al. 2019). The smooth decrease of the UV luminosity during the X-ray luminosity dip also suggests

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that nothing as dramatic as the destruction of the inner disc happened after the optical changing-look event.

In this Letter, we propose an alternative scenario where the full series of events in 1ES 1927+654 is controlled by two main parameters: the rapid evolution of the magnetic flux close to the black hole (BH), and a change in accretion rate. While the time-scales are much shorter than expected for viscous inflow in a geometrically thin accretion disc, they would be comparable to what one could expect in strongly magnetized elevated discs (Dexter & Begelman 2019). In Section 2, we argue that the high ratio of X-ray to UV luminosity in 1ES 1927+654 before the event could be explained by a magnetically arrested disc (MAD). Then, in Section 3, we show that the advection of matter threaded by magnetic flux of opposite polarity can rapidly destroy the MAD, leading first to a rise in the optical/UV luminosity and then a dip in the X-ray luminosity. A similar mechanism has been suggested to explain state transitions in X-ray binaries (Igumenshchev 2009; Dexter et al. 2014). We estimate the amount of flux needed and the time-scale on which it can be advected across the optical/UV-emitting region of the accretion disc and on to the BH. The time-scale is consistent with the observed decrease of the X-ray luminosity. In Section 4, we discuss the source of opposite polarity magnetic flux. We conclude in Section 5 and discuss the prospects for observing similar phenomena in other sources.

2 ACCRETION STATE BEFORE AND AFTER THE CHANGING-LOOK EVENT

2.1 Compact X-ray corona

Timing and spectral properties of hard X-ray emitting BHs are well described by an extremely compact X-ray emitter located within a few inner gravitational radii (Reis & Miller 2013; Sanfrutos et al. 2013; Uttley et al. 2014), consistent with the compact X-ray sizes inferred from quasar microlensing (Morgan et al. 2008; Chartas et al. 2009; Dai et al. 2010). We assume that net magnetic flux deposited on the rotating BH extracts spin energy through the Blandford–Znajek (BZ) effect (Blandford & Znajek 1977), and that a fixed fraction of the BZ power is radiated in X-rays: $L_X = \epsilon_X P_{\rm BZ}$ where $\epsilon_X \equiv 0.1\epsilon_{X,-1}$. Synchrotron emission of energetic electrons in the corona is favoured over inverse Compton scattering for the origin of the X-rays due to the low UV luminosity before the event and the high magnetic energy density inferred from equation (2). We adopt a modest reference value of ϵ_X because of the other channels available to the BZ power, such as a magnetized wind, but note that the efficiency could be higher (Crinquand et al. 2020). The BZ power, in a split-monopole geometry, can be expressed as

$$P_{\rm BZ} \approx 6 \times 10^{43} F_a M_7^{-2} \Phi_{X,30}^2 \ {\rm erg\ s^{-1}} \quad (1)$$

(Blandford & Znajek 1977; Tchekhovskoy, Narayan & McKinney 2010; Sikora & Begelman 2013), where $F_a = x_a^2 f(x_a)$, $x_a = 0.5a(1+\sqrt{1-a^2})^{-1}$, $f(x_a) \approx 1 + 1.38x_a^2 - 9.2x_a^4$, a is the dimensionless spin of the BH, $\Phi_X \equiv 10^{30}\Phi_{X,30}$ G cm^2 is the amount of magnetic flux on the BH needed to power the X-rays, and $M_{\rm BH} \equiv 10^7 M_7 M_\odot$ is the BH mass. We can rewrite the magnetic flux on the BH as

$$\Phi_X \approx 4 \times 10^{30} \left(\frac{L_{X,43}}{\epsilon_{X,-1} F_{a,-1}}\right)^{1/2} M_7 \ {\rm G\ cm^2}, \quad (2)$$

where $L_X \equiv 10^{43} L_{X,43}$ erg s^{-1} is the X-ray luminosity and we have normalized F_a to 0.1, its value for a BH with $a \approx 0.9$ (the limiting value for $a = 1$ is 0.2). Following the dip, the X-ray luminosity recovers to a level roughly 10 times that before the event, suggesting that the magnitude of Φ_X has increased by a factor of $\approx$3.

2.2 Accretion rate, radiative efficiency, and magnetically arrested disc

MADs are the result of the accumulation, until saturation, of magnetic flux on a BH by the ram pressure of the accretion flow (Narayan, Igumenshchev & Abramowicz 2003). General relativistic magnetohydrodynamic (GRMHD) simulations show that once the saturation point is reached, MADs alternate between episodes of expulsion of highly magnetized, low-density fluid from the BH and advection of poloidal flux on to the BH (Igumenshchev 2008). The expulsions are due to non-axisymmetric instabilities such as the magnetic Rayleigh–Taylor instability.

Once the MAD state is reached, any incoming flux in the disc will either reconnect with the background field (if of opposite polarity) or accumulate in the disc instead of advecting on to the BH (if of the same polarity). In the case of accumulation, we expect a strongly magnetized disc threaded by net magnetic flux to form. MADs thus provide the optimal conditions for powering a compact X-ray corona or jet, for a given accretion rate.

To maintain the observed X-ray luminosity (in the absence of beaming effects), the accretion rate must satisfy

$$\dot{M} \gtrsim \dot{M}_{\rm MAD} \approx 2 \times 10^{-2} \left(\frac{L_{X,43}}{\epsilon_{X,-1} F_{a,-1}}\right) {\rm M_\odot\ yr^{-1}} \quad (3)$$

(McKinney, Tchekhovskoy & Blandford 2012). We can compare the MAD limit to the accretion rate needed to produce the bolometric disc luminosity $L_{\rm d}$, assuming a disc accretion efficiency of $\epsilon_{\rm d} \equiv 0.1\epsilon_{{\rm d},-1}$:

$$\frac{\dot{M}}{\dot{M}_{\rm MAD}} \approx \frac{\epsilon_X}{\epsilon_{\rm d}} \frac{L_{\rm d}}{L_X} F_{a,-1} \gtrsim 1. \quad (4)$$

Before the changing-look event, $L_{\rm d}/L_X \lesssim 0.1$ (Trakhtenbrot et al. 2019). This implies that the ratio of efficiencies must satisfy $\epsilon_X/\epsilon_{\rm d} \gtrsim 10$, suggesting that the UV/optical-emitting accretion disc is radiatively inefficient prior to the event.

We can check the plausibility of this deduction by comparing $\dot{M}$ to the Eddington mass accretion rate, $10L_{\rm Edd}/c^2$:

$$\frac{\dot{M}}{\dot{M}_{\rm Edd}} \approx 7 \times 10^{-3} \epsilon_{{\rm d},-1}^{-1} L_{{\rm d},43} M_7^{-1}. \quad (5)$$

For $\epsilon_{\rm d} \approx 10^{-2}$ and $L_{{\rm d},43} \approx 0.1$ prior to the event, we estimate an Eddington factor that is marginally within the range that permits inefficient cooling in the inner disc (Esin, McClintock & Narayan 1997) and that is consistent with the value of $\epsilon_{\rm d}$ we used according to Xie & Zdziarski (2019). If $L_{\rm d}$ were much lower than $0.1L_X$ before the changing-look event (which is possible because most of the pre-event optical data compiled by Trakhtenbrot et al. 2019 are upper limits), this would expand the parameter space open to radiatively inefficient accretion, but at the expense of driving ϵ_X to values close to or exceeding one.

We therefore suggest that condition (4) is close to being marginally satisfied, i.e. that the disc prior to the changing-look event could be in a MAD state, $\dot{M} \approx \dot{M}_{\rm MAD}$. A MAD, threaded by strong magnetic flux, could be radiatively inefficient regardless of the accretion rate. Strong, large-scale magnetic fields are very efficient at extracting angular momentum and energy in the form of magnetized outflows, while not depositing gravitational energy locally as would be the case with turbulent accretion (Ferreira & Pelletier 1995). Such fields are also able to support the disc vertically and decrease the density of the disc (Mishra et al. 2019). These two effects could lead to MAD discs producing little UV/optical emission compared to the X-ray emission coming from the compact corona. Indeed, radiative simulations by Morales Teixeira, Avara & McKinney (2018) indicate a MAD radiative efficiency about three times lower than that of a standard thin disc (Novikov & Thorne 1973).

If the MAD state is to cause a low UV/optical radiative efficiency, it has to extend at least to the radius where a thin disc would peak in the optical, $r_{\rm opt}$. Estimating $r_{\rm opt}$ using a local blackbody model, we find

$$r_{\rm opt} \approx 1.7 \times 10^2 \left(\frac{L_{X,43}}{\epsilon_{X,-1} F_{a,-1}} \right)^{1/3} M_7^{-2/3} r_g, \qquad (6)$$

where $r_g = GM_{\rm BH}/c^2$. The magnetic flux required to fill the MAD disc up to $r_{\rm opt}$, $\Phi_{\rm MAD}$, is then larger than Φ_X (equation 2) by a factor that scales $\propto (r_{\rm opt}/r_g)^{3/4}$, where we assumed that the poloidal magnetic field follows the self-similar scaling $r^{-5/4}$ (Blandford & Payne 1982; Sikora & Begelman 2013), but possibly with a small numerical coefficient due to the contribution of a large toroidal field in holding the poloidal flux on to the BH (Scepi, Begelman and Dexter, in preparation).

During the changing-look event, the disc bolometric luminosity increases by a factor of at least $\approx$100 at its peak. We suggest that the actual accretion rate increases by about a factor of 10, with the other factor of 10 accounted for by an increase of $\epsilon_{\rm d}$ from $\sim 10^{-2}$ to the standard thin disc value. Such an increase of radiative efficiency is consistent with an increase in the Eddington factor to $\sim$0.1, and also with a temporary increase in $\dot{M}/\dot{M}_{\rm MAD}$. Moreover, a factor $\sim$10 increase in $\dot{M}$ is also consistent with the long-term stable value of L_X following its recovery from the dip, if a new MAD state is established close to the BH.

In contrast, $L_{\rm d}$ gradually declines following its peak. We attribute this either to the reestablishment of MAD conditions and an associated decrease of radiative efficiency sufficiently far out in the disc, or to a decrease in the mass accretion rate in the disc that has not yet had time to reach the BH. In the latter case, L_X should eventually go down when the decrease in the accretion rate reaches the BH.

3 MASS ACCRETION RATE CHANGE AND MAGNETIC FLUX INVERSION AS A TRANSITION MECHANISM

3.1 Magnetic flux inversion

On its own, a sudden change in the mass accretion rate is not sufficient to explain the dramatic reduction in the X-ray luminosity by a factor of 1000, and its equally dramatic recovery. We suggest that this change is due to the annihilation and eventual replacement of the flux threading the BH by a sudden advection event bringing in magnetic field of opposite polarity. MADs are filled with a large poloidal magnetic field of one dominant polarity. By advecting enough magnetic flux of the opposite polarity, one can destroy and then reestablish a MAD state (McKinney et al. 2012; Dexter et al. 2014).

The advected magnetic field will first reconnect in the outer strongly magnetized regions of the disc, leaving a disc with a lower magnetization and potentially higher radiative efficiency behind, increasing the UV/optical luminosity first. As the accretion event propagates inwards, it will reach the BH and destroy the BZ corona. This leads to the dramatic decrease of L_X. The subsequent increase of L_X is due to the recreation of the corona by accumulation of the remaining net magnetic flux on the BH. Once the magnetic flux on the BH has reached saturation, the rest of the disc will continue

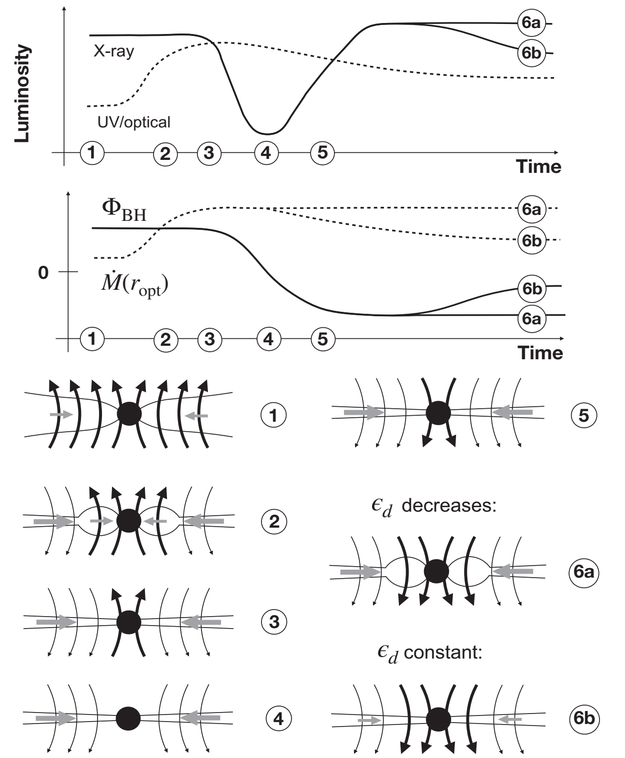

Figure 1. Sketch of the sequence of events during the cancellation and reestablishment of magnetic flux in a MAD disc as well as the expected observational behaviour. The direction and thickness of the black, vertical arrows represent the sign and strength of the magnetic field, respectively. The length and thickness of the grey horizontal arrows represent the amplitude of the mass accretion rate. Geometrically thick/thin discs represent radiatively inefficient/efficient accretion flows. In the upper panels, we also indicate inferred changes in the accretion rate during the changing-look transition of 1ES 1927+654. Curves 6a and 6b represent two possible scenarios for the future evolution of the disc.

accumulating net magnetic flux, reestablishing the MAD out to larger radii. Then, there are two options for explaining the decreasing UV luminosity. The onset of MAD may gradually reduce the disc radiative efficiency. Alternatively, the radiative efficiency might remain constant, indicating a decrease in the mass accretion rate. In the latter case, the X-ray luminosity will also decrease eventually. The sequence of events is sketched in Fig. 1 with a mock light curve as well as the physical states of the disc at different moments. This scenario is closely related to the magnetic flux paradigm of Sikora & Begelman (2013), invoked to explain the radio-loud/radio-quiet dichotomy in AGN.

In 1ES 1927+654, the recreation of the corona and the decrease in the UV luminosity are $\approx$4 times slower than the destruction of the corona and the rise of the UV luminosity. This is consistent with the disc after the event being less magnetized and geometrically thinner than the original disc, increasing the time-scale of advection of the flux as we will see in Section 3.2. If the decrease of the UV luminosity after the event is due to a decrease in the accretion rate that has not yet reached the BH, the X-ray luminosity decrease should occur on a time-scale of $\approx$2 yr, $\approx$4 times the lag time between the beginning of the optical event and the destruction of the corona.

3.2 Magnetic field advection time-scale

We use two models to estimate the time-scales for accretion and for advecting magnetic flux. First, we assume that in MADs, the accretion speed is dominated by the torque from a magnetized outflow (Ferreira & Pelletier 1995). If the magnetic flux is carried inwards at roughly the same speed as the accreted mass (Scepi et al. 2020), we obtain an advection speed for the magnetic flux of

$$v_\psi \sim \frac{4q}{\beta}\frac{H}{R}v_K, \tag{7}$$

where $q \equiv B_\phi/B_z = 0.36 \times \beta^{0.6}$ quantifies the strength of the magnetized outflow's torque (Scepi et al. 2020), β is the ratio of the thermal pressure to the magnetic pressure associated with the the B_z component of the field, H/R is the disc aspect ratio and $v_K \propto r^{-1/2}$ is the Keplerian velocity. The time it takes for an accretion event to go from $r_{\rm opt}$ to the event horizon of the BH, $t_{\rm acc} \equiv \int_{r_g}^{r_{\rm opt}} {\rm d}r/v_\psi$, is

$$\frac{t_{\rm acc}}{200\ {\rm d}} \approx 10^{-3}\frac{R}{H}\left(\frac{q}{\beta}\right)^{-1}\left(\frac{L_{X,43}}{\epsilon_{X,-1}F_{a,-1}}\right)^{1/2}. \tag{8}$$

For $\beta \approx 10^2$, $L_{X,43} = 10$, $\epsilon_{X,-1} = 1$ and $H/R \approx 0.3$, we have $t_{\rm acc}/200$ d $\approx 10^{-1}$.

If we assume instead that the accretion speed is given by a turbulent torque in a magnetically elevated disc (Dexter & Begelman 2019), we find

$$v_\psi \sim \alpha\left(\frac{H}{R}\right)^2 v_K. \tag{9}$$

This gives

$$\frac{t_{\rm acc}}{200\ {\rm d}} \approx 4\times 10^{-3}\alpha^{-1}\left(\frac{R}{H}\right)^2\left(\frac{L_{X,43}}{\epsilon_{X,-1}F_{a,-1}}\right)^{1/2}. \tag{10}$$

Since the disc is magnetically supported, we have $H/R \approx 0.3$. Assuming a reasonable $\beta \approx 10^2$, we have $\alpha \approx 1$ (Scepi et al. 2018). This also gives $t_{\rm acc}/200$ d $\approx 10^{-1}$. In both scenarios the accretion event, coming from $\approx 180\, r_g$, can explain the inversion event in the inferred time of 200 d for 1ES 1927+654.

4 SOURCE OF MAGNETIC FLUX

The scenario that we propose requires a very high ratio of magnetic flux to advected mass,

$$\frac{\Phi_{\rm MAD}}{M_{\rm adv}} \approx 3.7\times 10^2\left(\frac{1}{\epsilon F_a}\frac{L_X}{10^{43}}\right)^{-1/4} M_7^{1/2}{\rm G\,cm^2\,g^{-1}}. \tag{11}$$

A self-gravitating molecular cloud typically has a magnetic flux to mass ratio of 10^{-4}–10^{-3} G cm^2 g^{-1} (Mouschovias & Spitzer 1976), which is $\approx$6 orders of magnitude below what we need to power the event. A TDE of a solar mass star threaded by a strong dipolar magnetic field of 1 MG would only a provide a magnetic flux to mass ratio of $\approx 10^{-5} - 10^{-4}$ G cm^2 g^{-1} and so could not power the event either.

Other sources of flux might include a hot ambient medium or streams of cool gas that are confined by strong external thermal pressure rather than self-gravity. An internal disc dynamo might also provide the necessary inversion of the flux through the generation of loops of strong magnetic fields in the outer disc, which are then dragged inwards (Liska, Tchekhovskoy & Quataert 2020). In the 3D GRMHD simulation of Liska et al. (2020), the generation of strong poloidal field occurs on time-scales of the order of a month, when scaled to our assumed mass. However, their simulation is initialized with a strong toroidal field. Analytical estimates of this process with a weaker initial field suggest that a flux inversion might develop too slowly ($>10^4$ yr using the analysis of Begelman & Armitage 2014) to explain the X-ray behaviour of 1ES 1927+654.

While the above represent ab initio sources of frozen-in flux, an alternate resolution is that the flux has already been concentrated in the disc over a long period of time compared to the duration of the changing-look event. A natural way to accomplish this would be for MAD conditions to have existed out to radii $\gtrsim r_{\rm opt}$ (and possibly to much larger radii) long before the event. Under such conditions, a large amount of matter could have been accreted while leaving its magnetic flux behind over $\approx$400 yr, increasing the flux-to-mass ratio to the value required for the event.

The flux polarity reversal thus could have been 'baked' into the MAD long before the changing-look event. Such a reversal would presumably evolve as a result of reconnection, but if it developed a smooth enough gradient it might be sufficiently long-lived to provide suitable pre-conditions for the changing-look transient. We speculate that the sudden increase in $\dot{M}$ temporarily lifts the MAD condition since $\dot{M} \gg \dot{M}_{\rm MAD}$. This could quench the strong field diffusion that characterizes the MAD state and force a large amount of flux to be advected inward, driving a reconnection front towards the BH.

5 DISCUSSION AND CONCLUSIONS

We have argued that the sudden disappearance of the X-ray emitting corona in the changing-look AGN 1ES 1927+654 resulted from the sudden change of polarity of the magnetic flux advected on to the BH. If the corona is powered by the BZ effect, which is proportional to the square of the flux threading the BH, the decrease and reversal of this flux can lead to a dramatic decrease of the coronal power by orders of magnitude. The corona will be restored once the magnitude of the flux saturates again through continued advection.

We also argued that the accretion event associated with the magnetic flux inversion can trigger the increase of UV/optical flux (associated with the classical 'changing-look' event) that preceded the destruction of the corona. An increase of the mass accretion rate by a factor of 10, coupled with an increase of the accretion efficiency by a factor of 10, are consistent with the overall increase of both the X-ray luminosity (following recovery from the dip) and the optical/UV luminosity at its peak. We consider two scenarios, depending on the MAD radiative efficiency, to explain the smooth decrease of the UV luminosity after the event. If MADs are radiatively inefficient, the UV luminosity decrease could simply be due to the recreation of the MAD state and the X-ray luminosity would not be expected to change after the recreation of the corona, provided that $\dot{M}$ remains at its elevated value. If MADs are radiatively efficient discs, the decrease of the UV luminosity could be due to a decrease in the accretion rate that has not yet reached the BH; in this case we expect the X-ray luminosity to follow the trend of the UV luminosity with a delay of $\approx$2 yr. We estimate that plausible initial conditions can trigger the changing-look event and the destruction-recreation of the corona in $\approx$200 d (the time between the beginning of the changing-look event and the dip in L_X) for a BH mass of $2\times 10^7 {\rm M}_\odot$, as observed in 1ES 1927+654, provided that $\gtrsim$10 per cent of the power from the BZ effect goes into X-rays.

For this coronal efficiency, before the event the disc was accreting at $\approx 10^{-2}\dot{M}_{\rm Edd}$ with a radiative efficiency of $\approx$1 per cent. This low accretion rate is consistent with the absence of visible broad emission lines, according to the disc–wind scenario (Elitzur & Netzer 2016). After the event, the disc was accreting at $\approx 0.1\dot{M}_{\rm Edd}$ with a standard radiative efficiency of $\approx$10 per cent. The increase in the accretion rate and the radiative efficiency can account for the sudden illumination of an existing BLR, as suggested by the delay of $\approx$1–3 months between the increase in the UV/optical luminosity and the appearance of the broad emission lines (Trakhtenbrot et al. 2019). We note that a BLR at a few 10s of light-days ($10^4\, r_g$ for 1ES 1927+654; Trakhtenbrot et al. 2019) would be marginally consistent with an increase in the outflow mass loading rate up to $H/R = 0.3$ in the 100 d of the changing-look event, though it would require an outflow velocity close to the local rotation velocity of the disc. Hence, the case of 1ES 1927+654 cannot settle whether the BLR was already present or not when the change in the mass accretion rate and radiative efficiency illuminated it.

Simulations of MADs and the BZ effect often indicate the creation of collimated jets, extending to large distances. Given the X-ray luminosity of 1ES 1927+654, and using equation (10) of Sikora & Begelman (2013) to estimate the radio power of the jet, one would expect 1ES 1927+654 to be radio loud. However, the radio-quiet nature of 1ES 1927+654 (Boller et al. 2003) suggests that the jet is somehow quenched, perhaps by interaction with the external medium, or internal instabilities leading to a lack of collimation. This is consistent with the coronal efficiency being large as the portion of BZ energy that does not end up as jet kinetic energy at large distances is potentially available for powering the X-rays. If a jet is, however, present and the disc is relatively face-on, the X-ray efficiency could also be lower than the value we used in Section 2 due to the Doppler beaming effect.

We speculated on the origin of the magnetic flux necessary to trigger the inversion event and show that a very high flux-to-mass ratio is necessary. The ratio is much higher than what is expected from molecular clouds or a tidally disrupted star. If the flux is provided by an internal stochastic dynamo we would expect these events of full destruction of the corona to be rare because it would take a long time to develop such large flux inversions stochastically (Begelman & Armitage 2014). Relatively long intervals between inversion events are also likely if the flux first has to accumulate out to large radii in the MAD. In any case, these events should always be accompanied by a significant dip in L_X that seems unrelated to the UV/optical light curve like in 1ES 1927+654. However, they could also happen in a different regime of accretion rate than in 1ES 1927+654 and the change in the UV/optical luminosity might be more moderate in certain cases. This emphasizes the need to monitor X-rays as well as the optical flux in changing-look events.

Radio-loud objects, which are the AGN most likely to host a jet powered by the BZ effect and possibly a MAD, are prime candidates for undergoing similar events. These could exhibit a short-term interruption in the jet (possibly visible at milliarcsecond or higher resolutions) and a change in radio loudness associated mainly with an increase in the UV/optical emission.

With our scenario, we have attempted to explain the broad features of the changing-look event in 1ES 1927+654. However, there remain interesting additional features to explain such as the hardening of the X-rays as they brighten during the dip and the extreme variability of ≈2 dex over time-scales of hours near the dip. Explaining these behaviors may require a better understanding of the origin of X-ray emission in AGN.

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DATA AVAILABILITY

The underlying data are available in the article.

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