Simultaneous *NuSTAR* and *XMM-Newton* 0.5-80 keV spectroscopy of the Narrow Line Seyfert 1 galaxy SWIFT J2127.4+5654


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ABSTRACT

We present a broad band spectral analysis of the joint *XMM-Newton* and *NuSTAR* observational campaign of the Narrow Line Seyfert 1 SWIFT J2127.4+5654, consisting of 300 ks performed during three *XMM-Newton* orbits. We detect a relativistic broadened iron Kα line originating from the innermost regions of the accretion disc surrounding the central black hole, from which we infer an intermediate spin of \( a = 0.58^{+0.11}_{-0.17} \). The intrinsic spectrum is steep (\( \Gamma = 2.08 \pm 0.01 \)) as commonly found in Narrow Line Seyfert 1 galaxies, while the cutoff energy (\( E_c = 108^{+11}_{-10} \) keV) falls within the range observed in Broad Line Seyfert 1 Galaxies. We measure a low-frequency lag that increases steadily with energy, while at high frequencies, there is a clear lag following the shape of the broad Fe K emission line. Interestingly, the observed Fe K lag in SWIFT J2127.4+5654 is not as broad as in other sources that have maximally spinning black holes. The lag amplitude suggests a continuum-to-reprocessor distance of about 10 – 20 \( r_g \). These timing results independently support an intermediate black hole spin and a compact corona.

Key words: Galaxies: active - Galaxies: Seyfert - Galaxies: accretion - Individual: SWIFT J2127.4+5654

1 INTRODUCTION

According to the commonly accepted paradigm, luminous Active Galactic Nuclei (AGN) are believed to host a su-
The gravitational radius is defined as $r_{\text{in}}$ in some bright quasars. A half-light radius of the corona of X-ray microlensing experiments confirm that it is compact; its geometry. Recent works suggest that most of the emission arises from within $r_{\text{in}} \lesssim 6 r_g$, where $r_g \equiv GM/c^2$. Eclipses of the X-ray source have also placed constraints on the size of the hard X-ray emitting region: $r_{\text{in}} \lesssim 30 r_g$ in NGC 1365 (Risaliti et al. 2005; Maiolino et al. 2016; Brenneman et al. 2012), $r_{\text{in}} \lesssim 11 r_g$ in SWIFT J2127.4+5654 (Sanfrutos et al. 2013).

Recently, X-ray reverberation around accreting black holes has also revealed that the corona is compact. On short timescales, the variability associated with the primary continuum is found to lead the variability associated with the soft excess and the broad iron K spectral features. These time delays are short (e.g. tens of seconds in 1H0707-465, which has a black hole mass of $\sim 2 \times 10^6 M_\odot$; Kara et al. 2013), suggesting that the light travel time between the continuum emitting corona and the reprocessing region is small, within $\sim 10 r_g$. The first detection of X-ray reverberation was found between the continuum and the soft excess (Fabian et al. 2000). In this work, the soft excess was shown to be associated with the broad iron L emission line which peaks at $\sim 0.8$ keV. Since then, reverberation lags associated with the soft excess and the iron K emission line have been discovered (Zoghbi et al. 2012; De Marco et al. 2013; Kara et al. 2013), and all reveal that the X-ray emission is coming from very small radii. In this paper, we explore the frequency-dependent time lags in SWIFT J2127.4+5654 that are associated with the soft excess and the broad iron K line.

**Figure 1.** From the top to the bottom, NuSTAR FPMA+B and XMM-Newton EPIC-Pn light curves in the 3-80 keV, 2-10 keV and 0.5-2 keV energy bands are shown. The ratio between 0.5-2 keV and 2-10 keV EPIC-Pn light curves is shown in the bottom panel, straight and dashed lines indicate mean and standard deviation, respectively.

In addition to these geometric constraints, cutoff energies in several bright Seyfert galaxies have been measured with hard X-ray satellites in the past, such as BeppoSAX (Dadina et al. 2007; Perola et al. 2002) and INTEGRAL (Panessa et al. 2011; de Rosa et al. 2012; Molina et al. 2013). Current measurements of cutoff energies range between 50 and 300 keV and require spectra extending above 50 keV for better constraints, due to the contribution from complex spectral components (such as reflection from the accretion disc and from distant material) to the broad band spectral shape.

Narrow Line Seyfert 1 galaxies (NLS1) are a class of AGN whose spectra show peculiar emission-line and continuum properties. They are considered to be Eddington limit accretors (Boroson & Green 1992), and so systematically host smaller black hole masses than Broad Line Seyfert 1 galaxies (Komossa & Xu 2007, and references therein). The primary defining criteria of these objects are the width at half-maximum (FWHM) of the Balmer emission lines in their optical spectra ($\lesssim 2000$ km s$^{-1}$) and the relative weakness of the $[OIII]$ emission at $\lambda 5007$ (Osterbrock & Pogge 1984). Past X-ray analyses have shown their very variable continua, on time scales of hours (Ponti et al. 2012). The X-ray spectra of these objects show very steep slopes, between $\Gamma = 2.1 - 2.5$ (Boller et al. 1996; Brandt et al. 1996, 1997).
The Nuclear Spectroscopic Telescope Array (NuSTAR: Harrison et al. 2013) is the first high energy focusing X-ray telescope on orbit, ~100 times more sensitive in the 10–80 keV band compared to previous observatories covering these energies, enabling the study of steep spectrum objects at high energies with high precision.

SWIFT J2127.4+5654 (A.K.A. IGR J21277+5656, z=0.0144) was classified as a NLS1 galaxy on the basis of the observed FWHM of the Hα emission line (~1180 km s⁻¹; Halpern 2006). It has been first detected with Swift/BAT in the hard X-rays (Tueller et al. 2003). The source was detected in the hard band with INTEGRAL/IBIS and an averaged spectrum was obtained by Malizia et al. (2008) in the 17-100 keV band by summing the available on-source exposures (and therefore emission states), resulting in a steep spectrum, in the range Γ = 2.4 – 3. The authors also discussed a single epoch optical spectrum: the NLS1 classification was confirmed and a black hole mass of 1.5 x 10⁷ M☉ was inferred. The Swift/XRT data were analyzed by the same authors together with the INTEGRAL/IBIS averaged spectrum and the presence of a spectral break or of an exponential cutoff in the range of 30–90 keV was suggested (Panessa et al. 2011). SWIFT J2127.4+5654 was then observed in 2007 with Suzaku for a total net exposure of 92 ks, a L₁/Ledd = 0.18 and a Γ = 2.06 ± 0.03 were measured (Miniutti et al. 2009). A relativistically broadened Fe Kα emission line was detected, strongly suggesting that SWIFT J2127.4+5654 is powered by accretion onto a rotating Kerr black hole, with an intermediate spin value of a = 0.6 ± 0.2. This result has been also confirmed by Patrick et al. (2011) and in a recent work, using a ~130 ks long XMM-Newton observation (Sanfrutos et al. 2013). The Fe Kα shape has been also interpreted in terms of reprocessing in a Compton-thick disc-wind (Tatum et al. 2012), which would require super-Eddington luminosities (Reynolds 2012).

We present, in the following, results from a simultaneous NuSTAR and XMM-Newton observational campaign performed in November 2012. Taking advantage of the unique NuSTAR energy window, we cover the 0.5–80 keV energy bandwidth. The paper is structured as follows: in Sect. 2 we discuss the joint NuSTAR and XMM-Newton observations and data reduction, in Sect. 3 and 4 we present the spectral and lags analyses, respectively. We discuss and summarize the physical implications of our results in Sect. 5 and 6.

2 OBSERVATIONS AND DATA REDUCTION

2.1 NuSTAR

NuSTAR (Harrison et al. 2013) observed SWIFT J2127.4+5654 simultaneously with XMM-Newton with both Focal Plane Module A (FPMA) and B (FPMB) starting on 2012 November 4 for a total of ~340 ks of elapsed time. The Level 1 data products were processed with the NuSTAR Data Analysis Software (NuSTARDAS) package (v. 1.1.1). Cleaned event files (level 2 data products) were produced and calibrated using standard filtering criteria with the nupipeline task and the latest calibration files available in the NuSTAR calibration database (CALDB). Both extraction radii for the source and background spectra are 1.5 arcmin. Custom good time intervals files were used to extract the FPMA and FPMB spectra simultaneously with the three XMM-Newton orbits. After this process, the net exposure times for the three observations were 77 ks, 42 ks and 42 ks, for a total Signal-to-Noise Ratio (SNR) of 215, 235 and 186 for the FPMA and 209, 234 and 186 for the FPMB, between 3 and 80 keV. The background-subtracted count rates are 0.631±0.003, 0.798±0.004 and 0.889±0.005 counts/s for the FPMA, and 0.604±0.003, 0.785±0.003 and 0.876±0.005 counts/s for the FPMB, between 3 and 80 keV (Fig. 1).

No significant variability is observed in the ratio between the 5-10 and 60-keV count rates (see Fig. 2) during any of the three exposures, suggesting that spectral variabili-
ity in the NaSTAR bandpass during these observations is only weak.

The three pairs of NaSTAR spectra were binned in order to over-sample the instrumental resolution by at least a factor of 2.5 and to have a SNR greater than 3σ in each spectral channel. The cross-calibration constant between the two instruments is consistent with 2% in the three orbits.

2.2 XMM-Newton

SWIFT J2127.4+5654 was observed by XMM-Newton (Jansen et al. 2001) for ~300 ks, starting on 2012 November 4, during three consecutive revolutions (OBSID 0693781701, 0693781801 and 0693781901) with the EPIC CCD cameras, the PN (Strüder et al. 2001) and the two MOS (Turner et al. 2001), operated in small window and medium filter mode. Data from the MOS detectors are not included in our analysis since they suffered strongly from photon pileup. The extraction radii and the optimum time cuts for flaring particle background were computed with SAS 12 (Gabriel et al. 2001), operated in small window and medium filter mode. Data from the MOS detectors were not included in our analysis since they suffered strongly from photon pileup. The extraction radii and the optimum time cuts for flaring particle background were computed with SAS 12 (Gabriel et al. 2001) via an iterative process which leads to a maximization of the SNR, similar to the approach described in Piconcelli et al. (2004). The resulting optimal extraction radius is 40 arcsec and the background spectra were extracted from source-free circular regions with a radius of about 50 arcsec.

After this process, the net exposure times were 94 ks, 94 ks and 50 ks for the EPIC-Pn, with 0.5-10 keV count rates of 5.411 ± 0.007, 6.498 ± 0.008 and 7.787 ± 0.013 counts/s for the three orbits (Fig. 1), respectively. The observation naturally divides into low, medium and high flux states. The 2-10 keV flux of the source during the third orbit (high flux state) is consistent with the one observed by Suzaku in 2007 (Miniutti et al. 2009). Spectra were binned in order to over-sample the instrumental resolution by at least a factor of 3 and to have no less than 30 counts in each background-subtracted spectral channel. This allows the applicability of χ² statistics. We do not include the 1.8-2.5 keV energy band due to calibration effects associated with the Si/Au edge (Smith et al. 2013).

3 SPECTRAL ANALYSIS

The adopted cosmological parameters are H₀ = 70 km s⁻¹ Mpc⁻¹, Ωm = 0.73 and ΩΛ = 0.27, i.e. the default ones in xspec 12.8.1 (Arnaud 1996). Errors correspond to the 90% confidence level for one interesting parameter (Δχ² = 2.7), if not stated otherwise.

We started our analysis fitting the medium flux state spectrum with a power law absorbed with only the Galactic column density (7.65 × 10²¹ cm⁻²; Kalberla et al. 2005) between 2-4 keV and 7.5-10 keV. In Fig. 3 the broad band data-to-model ratio is shown (the continuum is modeled with a Γ = 1.89 power law) and both a broad iron Kα line and a strong Compton hump are clearly visible.

3.1 EPIC PN spectral analysis

A phenomenological fit is applied in the 3-10 keV range to the three spectra, with a baseline model composed by a power law and four Gaussian lines, to reproduce the broad and narrow components of the Fe Kα emission line and the Fe XXV Kα, Fe XXVI Kα lines at 6.7 keV and 6.966 keV, respectively. We left the normalization of the power law free to vary between the three orbits, to include intrinsic flux variations of the source. The fit is good (χ²/dof=331/321=1.03) and no strong residuals are present; results are presented in Table 1. Comparing the 2013 observation with the old Suzaku one, it is interesting noting that the broad component of the iron line (σ = 0.25+0.17−0.12 keV) is less prominent and the Equivalent Width of the narrow Fe Kα in the last orbit (the one comparable in flux with the Suzaku observation) is consistent with the one reported in Miniutti et al. (2009).

We then simultaneously fitted the 0.5–10 keV EPIC-Pn spectra from the three orbits with a more physical model, leaving the normalizations of the primary power law and of the disc reflection component free to vary, to take into account the flux variations of the source. When we use a model composed of an absorbed power law and cold distant reflection the fit is not good (χ²/dof=549/457=1.86) and strong residuals around the iron Kα band are present.

We then added a relativistically blurred reflection component arising from an ionized accretion disc and a further absorber at the distance of the source (Sanfrutos et al. 2013). We used xillver for both cold and ionized re-
reflection (García et al. 2013) and RELCONV for relativistic smearing (Dauser et al. 2013). The inclusion of a blurred reflection component in the model greatly improves the fit ($\chi^2$/dof=507/451=1.12). The addition of two emission lines at 6.7 keV (Fe XXV Kα, actually a triplet) and at 6.966 keV (Fe XXVI Kα), with fluxes consistent with the ones reported in Table 1, marginally improves the fit $\chi^2$/dof=498/449=1.11. Replacing the intrinsic neutral absorber with an ionized one, we find an upper limit to the ionization state of $\log \xi \leq -0.54$, leading to no improvement of the fit. The photon index of the primary continuum is steep ($\Gamma = 2.11 \pm 0.01$), as commonly found for NLS1 galaxies and no strong residuals are present throughout the energy band, with the exception of a feature in the spectrum from the third orbit around $\sim 0.8$ keV which is not attributable to any known spectral feature (Fig. 1). The excess in the soft energy band, shown in Fig. 3, is a combination of the steep primary continuum and the blurred ionized reflection, no additional components to the model described above are needed. We find an intermediate value for the black hole spin ($a=0.5 \pm 0.2$), in good agreement with the value measured by Suzaku, values for the emissivity and inclination of the disc are consistent with previous analyses (Miniutti et al. 2004). Best fit parameters are presented in Table 2. When we leave the column density of the neutral local absorber and the photon indices of the primary continua free to vary between the three spectra a marginal improvement of the fit ($\chi^2$/dof=481/445=1.07) is found, with no variations from combined best fit parameters.

3.2 Broad band spectral analysis

We then included the six 3–80 keV NuSTAR (FPMA and FPMB) spectra in our analysis, extending the spectral coverage up to 80 keV. We left the cross-calibration constants between XMM and NuSTAR free to vary. A photon index of $\Gamma = 2.08 \pm 0.01$ is found, in agreement with previous Suzaku observations (Miniutti et al. 2004). We get a best fit $\chi^2$/dof=1907/1567=1.21 and strong, structured residuals can be seen above $\sim 20$ keV (Fig. 5 left panel), suggesting the presence of a high energy cutoff.

![Figure 4. EPIC-Pn 0.5-10 keV best fit and residuals with a model where blurred relativistic reflection is taken into account, no structured residuals are seen.](image)

<table>
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<th>Table 2. Best fit parameters for reflection and absorption models. Column densities are in $10^{21}$ cm$^{-2}$ units, disc inclination angles are in degrees, ionization parameters $\xi$ are in erg cm s$^{-1}$ units, Fe abundance is with respect to the solar value and cutoff energy $E_\text{c}$ is in keV units. Power law normalizations are in ph cm$^{-2}$ s$^{-1}$ keV$^{-1}$ at 1 keV and $q$ is the adimensional parameter for the disc emissivity. The subscript $p$ indicates that the parameter pegged at its minimal allowed value.</th>
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<th>Table 3. Best fit fluxes and luminosities in different energy intervals. Fluxes are in $10^{-11}$ erg cm$^{-2}$ s$^{-1}$ units and are observed. Luminosities are in $10^{43}$ erg s$^{-1}$ units and are corrected for absorption. We calculated $L_{\text{bol}}$ from the 2-10 keV luminosity, applying the relation of (Marconi et al. 2004) for the bolometric corrections (this factor is also consistent with the lowest bolometric correction for this accretion rate presented in Vasudevan &amp; Fabian 2009). A value for the black hole mass of $1.5\times10^7$ M$\odot$ has been used (Malizia et al. 2008).</th>
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Therefore, we substituted the primary power law with the cutoff model in XSPEC and tied the values of the cutoff energies to the ones of the reflection components. The fit greatly improves ($\Delta \chi^2 = 174$, for one additional degree of freedom), a $\chi^2$/dof=1733/1566=1.11 is found and no strong residuals are present in the whole energy band (Fig. 5 right panel). Best fit parameters can be found in Table 2 and fluxes, luminosities and Eddington ratios in Table 3. The cross-calibration factors between the PN and the FPMA, FPMB detectors are $K_{\text{FPMA}} = 1.045 \pm 0.007$.

\footnote{1} A test version of XILIVER has been used, where the cutoff energy is a variable parameter.
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\[ \text{data and folded model} \]

\[ \text{SWIFT J 2127.4+5654: Best fit} \]

**Figure 5.** Left panel: broad band fit of the NuSTAR and XMM spectra with a model that does not take into account the high energy cutoff. Clear residuals can be seen above \( \sim 20 \) keV. Right panel: broad band XMM + NuSTAR best fit when a cutoff energy is properly modelled.

\[ \Delta \chi^2 = 2.30, 6.17 \text{ and } 11.83 \text{ contours (corresponding approximately to } 68\%, 95\% \text{ and } 99.7\% \text{ confidence levels) for the cutoff energy } E_c \text{ and photon index } \Gamma \text{ (left panel) and for the cutoff energy and the blurred ionized reflection fraction in the second orbit (right panel).} \]

\[ \text{Confidence contours: Chi–Squared} \]

\[ \text{Parameter: PhoIndex} \]

\[ \text{Parameter: HighECut (keV)} \]

\[ \text{Parameter: reflfrac} \]

\[ \text{Parameter: Ecut (keV)} \]

\[ \text{Confidence contours: Chi–Squared} \]

\[ \chi^2/\text{dof}=1756/1570=1.11 \]

and \( K_{\text{FPMB}} = 1.074 \pm 0.007 \). We measure a cutoff energy \( E_c=108^{+11}_{-10} \text{ keV and } \Gamma = 2.08 \pm 0.01 \): Fig. 6 (left panel) presents the contour plot of photon index versus cutoff energy. In order to estimate the relative strength of the Compton hump (arising from both distant and blurred ionized reflection components) with respect to the primary continuum, we followed a method similar to the one described in Walton et al. (2013) for NGC 1365, using the relative normalizations of the reflection (modeled with PEXRAV, with the inclination angle and iron abundance fixed to best fit values) and of the power law components, above 10 keV. We find values of \( R_1 = 1.5 \pm 0.2 \), \( R_2 = 1.6 \pm 0.2 \) and \( R_3 = 1.1 \pm 0.2 \) for the three sets of spectra, respectively.

Thanks to the NuSTAR+XMM broad band view, the degeneracy between the contribution from the ionized and the cold reflector can be broken, using recent X-ray disc reflection models that include relativistic blurring and a direct measure of \( R \). We substituted the blurred ionized reflection and primary components in the broad band best fit model for RELXILL (a model that includes both relativistic effects and reflection from an accretion disc, Garcia et al. 2013). The reflection fraction \( R \) has been left to vary between the three orbits. The overall fit is good (\( \chi^2/\text{dof}=1756/1570=1.11 \)) and no differences from best fit parameters presented in Table 2 are found. The contribution of the blurred reflection component from the disc to the total reflection fraction in the three orbits is \( R_{\text{disc}}^1 = 1.1 \pm 0.1, R_{\text{disc}}^2 = 1.2 \pm 0.1 \) and \( R_{\text{disc}}^3 = 0.9 \pm 0.1 \). The contour plot of the cutoff energy \( E_c \) and the \( R_{\text{disc}}^2 \) parameter is shown in Fig. 6, right panel. If we consider a lamp-post geometry and use RELXILLLP (with spin and inclination parameters fixed to their best-fit values) we find an height of the X-ray source of \( 25 \pm 10 \ r_g \), consistent with the estimates discussed in Sect. 5.

Once a best fit is obtained we try to reproduce the primary continuum (modeled with CUTOFFPL in XSPEC so far) with a more physical model where the electron energy \( (kT_e) \) and the coronal optical depth (\( \tau \)) can be disentangled, using different geometries. Photon index and cutoff energy are fixed to their best fit values in the reflection components. We
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5 DISCUSSION

We analyzed the NuSTAR+XMM spectrum of the NLS1 galaxy SWIFT J2127.4+5654. A relativistic reflection component is found in proximity of an intermediate spin Kerr black hole ($a=0.58^{+0.11}_{-0.12}$), confirming past Suzaku results (Miniutti et al. 2004, Patrick et al. 2011) and providing a very accurate measurement of the intermediate black hole spin of this source, thanks to the broad (0.5-80 keV) spectral coverage. Fig. 7 shows the different components of the model, including the primary continuum, the relativistic blurred reflection of the disc and the emission from distant, neutral matter. The contribution from the blurred ionized reflection arising from the accretion disc to the total reflection fraction has been measured and it is described in Sect. 5.2. The values obtained are similar to those estimated for other type 1 AGN in Walton et al. (2013). Fig. 10 shows the goodness-of-fit as a function of the black hole spin: the broader spectral coverage with respect to past analyses allows us to rule out a maximally spinning black hole with a significance $>5\sigma$, and a non-rotating Schwarzschild black hole ($a=0$) is rejected with a significance $>3\sigma$. We find that the accretion disc parameters (disc emissivity and inclination angle) are in agreement with the ones discussed in the past and the steep emissivity ($\epsilon \propto r^{-6.7}$) suggests that the Fe emission arises from the innermost regions of the disc (see Miniutti & Fabian 2004, for a more detailed description of the light bending model). Other physical interpretations have been recently discussed for the joint XMM and Suzaku analysis of Fairall 9 (Lohfink et al. 2012). The intermediate black hole spin we measure carries information about the accretion history of the source, and a value of $0.6-0.7$ suggests a scenario where the black hole mass in SWIFT J2127.4+5654 is due to a recent black hole merger (see Volonteri et al. 2005, Berti & Volonteri 2008, for a de-
Figure 8. *Left panel:* The frequency-dependent lag between 0.3–1 keV and 1–5 keV. A positive lag indicates that the hard band lags behind the soft band. We see a hard lag at \( \nu < 3.5 \times 10^{-5} \) Hz, and zero lag above that frequency. Poisson noise begins to dominate the power spectrum at \( \nu \sim 5 \times 10^{-4} \) Hz. (The blue hash shows the frequency range explored for the lag-energy spectrum in the left panel of Fig. 9). *Right panel:* The frequency-dependent lag between the 3–5 keV and 5–8 keV bands. The hard lag extends up to \( 3 \times 10^{-4} \) Hz. (The red hash shows the frequency range for the lag-energy spectrum in the right panel of Fig. 9).

Figure 9. *Left panel:* The lag-energy spectrum for low frequencies, \( \nu < 3.5 \times 10^{-5} \) Hz (corresponding to the frequency range shown in blue hash in Fig. 8). The lag increases steadily with energy. *Right panel:* The lag-energy spectrum for frequencies \( \nu = [3.5-30] \times 10^{-5} \) Hz (the red hash in the right panel of Fig. 8). This shows little lag between the continuum and soft excess, and a sharp increase in the lag at > 5 keV.

tailed discussion of the different cases) and Volonteri et al. (2007) for a description of the morphology dependent spin evolution.

The high data quality above 10 keV, thanks to the unique NuSTAR spectral coverage, permits us to measure a cutoff energy \( E_c = 10^{8.11}_{0} \) keV with unprecedented accuracy, marginally consistent with prior INTEGRAL results where a cutoff energy of \( 49^{+17}_{-11} \) keV (Panessa et al. 2011) was measured. Using a Comptonization model to reproduce the spectral shape of the primary continuum we find values
of kT_e=68^{+37}_{-32} keV and τ = 0.35^{+0.35}_{-0.19} with a slab geometry and kT_e=53^{+28}_{-26} keV and τ = 1.35^{+1.03}_{-0.67} with a spherical geometry. The power law continuum is an estimate of the power dissipated in the corona and it is ~ 57% of the total 3-80 keV luminosity (L_{bol}^{3-80}=1.92 \times 10^{43} \text{ erg s}^{-1} for the second orbit, Table 3). This represents ~ 7.5% of the bolometric luminosity of the source (L_{bol} \sim 2.6 \times 10^{44} \text{ erg s}^{-1}).

The electron plasma temperatures agree with the ones found in Brenneman et al. (2014) for the Broad Line Seyfert 1 galaxy (BLSy1) IC 4329A, but the lower values for τ in SWIFT J2127.4+5654 suggest a different geometry in the corona. Indeed, NLS1 galaxies are high rate accreting objects with low black hole masses (McLure & Jarvis 2004; Bian & Zhang 2004; Netzer & Trakhtenbrot 2007). The lower optical depth might indeed explain why the relativistic reflection in this object (~ 33% of the total 3-80 keV luminosity) is more prominent than in IC 4329A, where the power law continuum component is higher, being ~ 87% of the total 5-79 keV luminosity.

SWIFT J2127.4+5654 shows significant lags over a wide range of frequencies. X-ray time lags are largely agreed to be caused by two separate processes: by the light travel time between the X-ray source and the ionized accretion disc and by mass accretion rate fluctuations that get propagated inwards on the viscous timescale and cause the soft coronal emission from large radii to respond before the harder coronal emission at smaller radii. When we measure the lag at a particular frequency, we are measuring the average time lag, and so if both effects are contributing to the lag at a particular frequency, it can be difficult to disentangle which process is responsible for the lag. In sources with a large soft excess that is dominated by relativistically blurred emission lines (i.e. 1H0707-495 and IRAS 13224-3809), we can easily disentangle these two effects by looking at the lag between ~ 0.3 – 1 keV and ~ 1 – 4 keV. In these sources, we find that at low frequencies, the hard band lags the soft (due to dominating propagation lags) and at high frequencies, the soft band lags the hard (due to greater reverberation between corona and accretion disc). For SWIFT J2127.4+5654, the 0.3–1 keV to 1–5 keV frequency-dependent lag shows the typical hard lag of ~ 1000 s at frequencies below 3.5 \times 10^{-5} Hz (left panel of Fig. 5). It does not show an obvious soft reverberation lag, and this likely because the soft excess is not very strong, due to absorption or because of low iron abundance. However, we can look for reverberation signatures at higher energies, where there the Fe K line is strong, and there is little absorption. The frequency-dependent lag in the right panel of Fig. 5 shows the 5-8 keV lagging behind the 3-5 keV band up to higher frequencies of ~ 3 \times 10^{-4} Hz. While some of this lag is likely due to propagation effects (i.e. below 3.5 \times 10^{-5} Hz), the high frequency lag (3.5 – 30 \times 10^{-5} Hz) is likely caused by reverberation, where the emission from the Fe K line centroid (5-8 keV) lags behind the continuum or red wing of the line (3-5 keV).

The lag-energy spectra support this hypothesis (Fig. 9). The low-frequency lag-energy spectrum below 3.5 \times 10^{-5} Hz shows a nearly featureless spectrum, increasing with energy (indicative of intrinsic propagation lags in the corona), while the higher frequencies (ν = [3.5 – 30] \times 10^{-5} Hz) have a different shape. There is still little contribution from the soft excess, but we see a large increase in lag at 5 keV, also where we see the red wing of the Fe K line. The lag does not decrease above 8 keV, as is often seen in Fe K reverberation lags, and this could be an effect of the inclination of the disc (Cackett et al. 2013), or just too low statistics to confirm a decrease in the lag.

In principle, the amplitude of the lag reflects the light travel time between the primary X-ray source and the accretion disc, and can give an estimate of the size of the corona (Wilkins & Fabian 2013). However, it is important to take dilution into account before converting the time delay to a physical distance. For example, at 6.5 keV, the ionised reflection component contributes to ~ 30 per cent of the entire variable emission (i.e. not including the cold reflection component), while the continuum contributes to remaining 70 per cent. Therefore the intrinsic lag will be diluted by 70 per cent, since 70 per cent of the emission comes from the direct continuum. Furthermore, the reference band to which we measure the lag at each energy is also effected by dilution. It is composed of roughly 10 per cent reflection and 90 per cent power law. If the intrinsic lag in SWIFT J2127.4+5654 is 1000 s, then, including all the effects of dilution, the observed lag at 6.5 keV is ~ 200 s (which is close to what we observe). Given the lower reflection fraction at soft energies below 1 keV, the observed lag should be closer to 50 s, which is also consistent with what we see in the right panel of Fig. 5. Assuming an intrinsic lag of 1000 s puts the X-ray source at a height of ~ 13 r_g above the disc, for a black hole mass of 1.5 \times 10^7 M_\odot (Malizia et al. 2008).

The high-frequency lag-energy spectrum (ν = [3.5 – 30] \times 10^{-5} Hz) shows that the Fe K lag profile is not very broad. Importantly, this timing result is independent of the spectral results, which also shows the emission line is not broad. All other sources with Fe K reverberation lags have a maximally spinning black hole, and show Fe K reverberation lags as low as 3–4 keV. This source only shows a reverberation lag at above 5 keV, as expected for a larger inner radius. This is very strong evidence for an intermediate black hole spin.
6 SUMMARY
We presented a NuSTAR+XMM broad band (0.5-80 keV) spectral analysis of the joint observational campaign in 2012 of SWIFT J2127.4+5654. The main results of this paper can be summarized as follows:

- thanks to the broader spectral coverage with respect to past analyses, a relativistic reflection component is found in proximity of an intermediate spin Kerr black hole \((\alpha=0.58^{+0.12}_{-0.17})\), a maximally spinning black hole can be ruled out with a significance > 5\(\sigma\) and a non-rotating Schwarzschild black hole is rejected with a significance > 3\(\sigma\);
- the high data quality above 10 keV allowed us to measure a cutoff energy \(E_c=108^{+11}_{-10}\) keV with unprecedented precision;
- the high-frequency lag-energy spectrum shows an Fe K reverberation lag. Unlike other maximally spinning black holes that have broad Fe K lags, SWIFT J2127.4+5654 has a narrower lag profile, which independently suggests an intermediate spin black hole.

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