Investigating the origin of the Fe emission lines of the Seyfert 1 galaxy Mrk 205.

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ABSTRACT

We have investigated the nature and origin of the Fe K emission lines in Mrk 205 using observations with Suzaku and XMM-Newton, aiming to resolve the ambiguity between a broad emission line and multiple unresolved lines of higher ionization. We detect the presence of a narrow Fe Kα emission line along with a broad band Compton reflection hump at energies $E > 10$ keV. These are consistent with reflected emission of hard X-ray photons off a Compton thick material of $N_{\text{H}} \geq 2.15 \times 10^{21}$ cm$^{-2}$. In addition we detect a partially covering ionized absorption with ionization parameter $\log(\xi / \text{erg cm}^{-1}) = 1.9^{+0.1}_{-0.5}$ column density $N_{\text{H}} = (5.6^{+2.0}_{-1.9}) \times 10^{22}$ cm$^{-2}$ and a covering factor of $0.22^{+0.09}_{-0.06}$. We detect the presence of emission arising out of ionized disk reflection contributing in the soft and the hard X-rays consistently in all the observations. We however, could not definitely ascertain the presence of a relativistically broadened Fe line in the X-ray spectra. Using relativistic reflection models, we found that the data are unable to statistically distinguish between the scenarios when the super-massive black hole is non-rotating and when it is maximally spinning. Using the disk reflection model we also find that the accretion disk of the AGN may be truncated at a distance $6R_G < R < 12R_G$, which may suggest why there may not be any broad Fe line. The Eddington rate of the source is low ($\lambda_{\text{Edd}} = 0.03$), which points to an inefficient accretion, possibly due to a truncated disk.

Key words: galaxies: individual Mrk 205–galaxies: Seyfert–galaxies: active–galaxies: kinematics and dynamics.

1 INTRODUCTION

The most well accepted scenario of X-ray spectral emission in active galactic nuclei (AGN) is that of an optically-thin and hot ($T \sim 10^9$ K) corona (Haardt & Maraschi 1993; Haardt et al. 1994) upscattering the seed UV photons emitted from the accretion disk (Shakura & Sunyaev 1973) around the central super-massive black hole (SMBH), resulting in a power law spectrum. It is also believed that the X-ray photons from the corona are reflected off the cold neutral matter (poplarly called torus) as well as the ionized accretion disk to produce fluorescent emission lines of Fe of various ionic stages. The relatively higher abundance of Fe coupled with a higher fluorescent yield, makes the Fe Kα emission line the most prominent and ubiquitous of all emission lines in the X-ray spectra of AGN.

The FeKα line was detected for the first time by Mushotzky et al. (1978) using OSO-8 observations of Centaurus-A. With the advent of the latest generation X-ray telescopes such as XMM-Newton, Suzaku and Chandra, the presence of the Fe Kα line in AGN X-ray spectra has been found to be almost ubiquitous (Fukazawa et al. 2011). The neutral Fe Kα emission line with a rest frame energy of 6.4 keV, arising out of the distant reflection off neutral medium (torus) is mostly narrow ($\sigma \lesssim 100$ eV) and is associated with a Compton reflection hump peaking at energies $> 10$ keV. On the other hand when the X-ray coronal photons are reflected off the ionized accretion disk, the rest frame energy of the Fe Kα emission line may shift to higher energies ($6.40 < E < 6.96$ keV). In addition to that, if the reflection happens from the inner regions of the accretion disk where the matter is in relativistic motion around the SMBH, the emitted Fe Kα line profile becomes broad and skewed with a red wing extending towards lower X-ray energies due to gravitational redshift and transverse Doppler redshift (see e.g., Fabian et al. 1989). These relativistic Fe Kα emission lines sometimes originate within a few gravi-
tational radii from the central object and hence serve as important probes of the physical processes taking place in the inner most regions of the AGN (de La Calle Pérez et al. 2010; Wilkins & Fabian 2011; Fabian et al. 2014). Thus both the narrow and broad Fe Kα emission lines in the X-ray spectra give us important clues to the hitherto spatially unresolved inner regions of AGN in the vicinity of the SMBH. However, some authors have cautioned that warm absorbers and/or neutral absorbers with sufficiently high column density may modify the $3 - 7$ keV energy range of the X-ray spectra of AGN, mimicking a broad relativistic Fe Kα line with a red wing (see e.g., Reeves et al. 2004; Miller et al. 2008; Turner & Miller 2009). Similarly, a blend of the helium and hydrogen-like iron at $6.7 - 6.9$ keV can be misinterpreted as a broad diskline profile detected at high inclination, particularly in spectra at moderate (CCD) energy resolution (Yaqoob et al. 2003; Longinotti et al. 2007).

de La Calle Pérez et al. (2010) studied the nature of the relativistically broadened Fe Kα emission line in a sample of 31 Type-1 AGN. The authors found that the occurrence probability of a broad Fe Kα emission line is $\sim 36\%$ with an average equivalent width of $\sim 100$ eV. The average accretion disk inclination detected in the AGN was $28 \pm 5^\circ$. A recent sample study on the narrow Fe Kα emission line and its link with molecular torus was carried out by Ricci et al. (2014). The authors detected the line ubiquitously in a sample of 24 AGN. More interestingly, with simultaneous mid-infra-red (MIR) studies they found that the narrow Fe Kα line is produced by the same material that is responsible for the MIR emission in AGN, implying that the molecular torus is an important reprocessor of the AGN primary emission.

Mrk 205 is a nearby ($z = 0.071$) low luminosity radio quiet quasar with an intriguing Fe Kα emission line complex. Reeves et al. (2001) studied this source with XMM-Newton and detected a narrow Fe Kα as well as a moderately broad (rms width $\sigma = 300$ eV) Fe Kα emission lines at $6.4$ keV and $6.7$ keV respectively, in the rest frame. The authors suggested that the broad line arises from X-ray reflection off the surface of a highly ionized accretion disk, while the narrow component is due to the reflection of X-ray photons off a distant neutral matter, possibly the torus. However, the authors could not affirmatively distinguish whether the ‘broadened line’ did originate from a relativistic accretion disk, or it’s a blend of higher ionization Fe emission lines. A similar study of Mrk 205 carried out by Page et al. (2003) using XMM-Newton observations found that the Fe K emission lines do not present any strong evidence for reprocessing in the inner, relativistic parts of accretion disks. Patrick et al. (2012) studied the Suzaku spectra of the source and could not detect any broad Fe emission line. Using the same Suzaku observation Iso et al. (2016) detected a partially covering ionized absorber which mimics a relativistically broadened Fe line. The detection and origin of the broad Fe Kα emission line of Mrk 205 is therefore still a matter of debate.

In recent years there has been a rapid development in our understanding of the broad Fe Kα line in terms of relativistic disk reflection models such as relsill (García et al. 2013) which consistently models the broad Fe K feature along with the soft X-ray excess ($< 2$ keV) and the hard X-ray bump ($> 10$ keV) due to disk reflection. Moreover, more sophisticated models for reprocessing by optically thick cold matter have been developed, such as MYTorus (Murphy & Yaqoob 2009) which consistently models the narrow Fe Kα emission line with the Compton reflection hump at $E > 10$ keV. Thus, spectral coverage in the $10 - 30$ keV energy band is highly important to break the degeneracy between the broad Fe Kα lines and blend of higher ionization Fe Kα and other Fe lines. With the availability of the Suzaku broadband spectral data for the source Mrk 205, and with the recent physical models, we are now critically poised to investigate the origin of the iron complex in Mrk 205 in detail. In this paper we carry out a detailed X-ray spectral analysis of the source Mrk 205 using Suzaku and XMM-Newton telescopes focussing on the origin of the narrow and the broad Fe K emission lines using realistic broad band models, and shedding light on the reprocessing medium around the SMBH.

The paper is arranged as follows: Section 2 describes the observation and data reprocessing. Section 3 lists the steps taken in the spectral analysis. Section 4 discusses the results followed by conclusions in Section 5.

## 2 OBSERVATION AND DATA REPROCESSING

Mrk 205 was observed by XMM-Newton on two occasions in 2000 and 2006 for 15 ks and 100 ks respectively, and once by Suzaku in 2010 for 101 ks. See Table 1 for details and the short notation of the observation ids. The Suzaku reprocessing and spectral extraction were carried out following the steps described in Laha et al. (2018) and Ghosh et al. (2016). There is no pile up in the XIS spectra of the source. We extracted the hard X-ray spectral data using the HDX- PINXBPI tool from the PIN cleaned events and the pseudo-event lists generated by the AEPipeline tool. See Ghosh et al. (2016) for a description of the methods involved in extracting the PIN spectrum. The EPIC-pn data from XMM-Newton were reduced using the scientific analysis system (SAS) software (version 15) with the task epchain and using the latest calibration database. We used EPIC-pn data because of their higher signal to noise ratio as compared to MOS in the Fe-K energy band, our region of interest. For filtering and spectral extraction we followed the methods described in Laha et al. (2014).

The Suzaku XIS and the PIN spectra were grouped by a minimum counts of 200 and 20 per energy bin, respectively, using the command gppha in the HEASOFT software. The XMM-Newton spectra were grouped by a minimum of 20 counts per channel and a maximum of five resolution elements using the command specgroup in SAS. The XSPEC (Arnaud 1996) software was used for spectral analysis. All errors quoted on the fitted parameters reflect the 90% confidence interval for one interesting parameter, corresponding to $\Delta \chi^2 = 2.7$ (Lampton et al. 1976).

## 3 DATA ANALYSIS

Figure 1 right panel shows the extrapolation of a powerlaw model in the $4 - 5$ keV energy band to the whole sensitive band pass of the Suzaku instruments. We clearly find the presence of a soft X-ray excess (at $E < 2$ keV), an Fe line complex (at $6 - 7$ keV) and a hard X-ray excess ($E > 10$ keV) in the residuals. Figure 1 left panel shows the hardness ratio (HR) lightcurve of Mrk 205 for the Suzaku observation, where the HR is the ratio of the flux in the hard ($2.3 - 10$ keV) and soft ($0.6 - 1.7$ keV) energy band. We find that the HR does not show any significant variation during the observation. Hence, we used time averaged Suzaku spectra in this work. In this study, we used two sets of models to fit the broad band Suzaku as well as XMM-Newton spectra. 1. The baseline phenomenological models and 2. The physical models, which we discuss below.

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3.1 The phenomenological models

We used a set of phenomenological models to describe the continuum as well as the discrete components in the X-ray spectra of Mrk 205. The sole purpose of this exercise is to identify the features that are present in the broad band spectra which can serve as a motivation for the use of specific physical models in the next section. The baseline phenomenological model consists of a neutral Galactic absorption (tbabs), a neutral absorption intrinsic to the host galaxy (ztbabs), a multiple blackbody component, which is used to model the soft X-ray excess (diskbb, Mitsuda et al. 1984), and the coronal emission described by a power law. For the discrete emission features, we used the diskline model (Fabian et al. 1989) to describe the broad Fe line, and a Gaussian profile for the narrow Fe emission line.

We fixed the column density of tbabs to the Galactic value of $3 \times 10^{20}$ cm$^{-2}$ (Dickey & Lockman 1990). We detected an intrinsic neutral absorption column for all the XMM-Newton observations. Interestingly we did not detect any neutral absorption column excess of the Galactic column in the Suzaku spectra. An addition of the ztbabs model resulted no improvement in the fit ($\Delta \chi^2/\text{dof} = 2/1$) in the Suzaku spectra. Table 2 lists the best fit parameters and also the fit statistics achieved using the phenomenological models. We also list the improvement in statistics ($\Delta \chi^2/\text{dof}$) for each spectra on addition of the discrete emission line models to assess the statistical significance of the model. An energy-independent multiplicative factor was used to account for the relative normalizations of different instrument responses.

In XSPEC notation the baseline model reads as: constant $\times$ tbabs $\times$ ztbabs $\times$ diskbb $\times$ diskline $\times$ pexrav $\times$ Gaussian $+$ pexrav. The same model was used for the EPIC-observations.

We detected a narrow Fe Kα emission line at $\sim 6.4$ keV rest frame, for all of the Suzaku and XMM-Newton observations. A Gaussian profile fit to the narrow line in Suzaku yielded an equivalent width of $60^{+13}_{-11}$ eV, with an improvement in the fit by $\Delta \chi^2/\text{dof} = 101/3$, which reflects a $> 99.99\%$ confidence in the detection of the emission line (Lampton et al. 1976). For XMM-Newton observations a similar fit yielded equivalent width values of $49 \pm 19$ eV, $35 \pm 15$ eV, $66 \pm 14$ eV and $10 \pm 3$ eV, with an improvement in the fit by $\Delta \chi^2 = 13, 26, 24$ and $32$ for xmm101, xmm201, xmm301 and xmm501 respectively (see Table 2).

To account for the neutral reflection from distant neutral material, we used the model pexrav (Magdziarz & Zdziarski 1995), in the Suzaku spectra only, due to availability of data beyond 10 keV. The pexrav incident powerlaw slope was tied to the primary powerlaw slope ($\Gamma$). The pexrav angle could not be constrained and hence was tied to the diskline inclination. The model pexrav in the Suzaku spectra improved the fit significantly with a $\Delta \chi^2 = 50$ and we obtained a best fit relative reflection fraction of $R = 1.69^{+0.31}_{-0.22}$.

Apart from a narrow emission line, a broad Fe emission line was also detected in the Suzaku spectra which was fitted with a diskline model, which improved the fit by $\Delta \chi^2 = 37$ for three parameters of interest, with the rest frame line energy $E = 6.36^{+0.31}_{-0.32}$ keV. The Fe abundance of the diskline model was fixed to that of the solar value. A similar fit with the diskline model for the XMM-Newton observations resulted in relatively weak improvements in statistics, $\Delta \chi^2 = 17, 5, 0$ and 18 for xmm101, xmm201, xmm301 and xmm501 respectively, clearly indicating that a broad emission line is not required for the observations xmm201 and xmm301. In the Suzaku spectra, the diskline inclination could be constrained to $22^{+9}_{-3}$ degrees, and this value was fixed for the XMM-Newton observations, because we do not expect it to vary on human timescales.

The baseline model gives a good description to the Suzaku as well as XMM-Newton spectra (see Figure 2). The powerlaw photon index $\Gamma$ remains consistent ($\sim 1.9$) for all the observations within errors, similar to those obtained by previous studies (Reeves et al. 2001; Page et al. 2003). Two diskbb models were needed to fit the soft X-ray excess in the XMM-Newton datasets with electron temperatures of $\sim 0.07$ keV and $\sim 0.24$ keV. For Suzaku only one diskbb component was necessary with an electron temperature of $\sim 0.14$ keV.

Previous study of the source Mrk 205 using Suzaku observation (Iso et al. 2016) has detected the presence of partially ionized cloud which could mimic the presence of a broad Fe K emission line (see for e.g., Inoue & Matsumoto 2003). We fitted the Suzaku spectra with a partially covering ionized absorber model (zxpabs) and removed the diskline from the baseline model and found that the fit improves by $\Delta \chi^2 = 14$ compared to the baseline model fit described earlier. This implies a possibility that the broad line is an artifact of a high column density partially covering ionised absorber. We investigate this matter further with physical models in the next section.

3.2 The physical models

We used a set of physical models to describe the continuum and the discrete components in the Suzaku and XMM-Newton X-ray spectra of Mrk 205. The narrow Fe Kα emission line along with the Compton reflection of hard X-ray photons off cold material is modeled with MYTorus (Murphy & Yaqoob 2009; Yaqoob 2012). The soft X-ray excess, the powerlaw, the broad Fe emission line (if any) and the reflection of hard X-ray photons off ionized accretion disk are modeled with relxill (version 1.2.0, Garcia et al. 2014). The MYTorus inclination angle and the normalisation of the individual components were left free to vary. The photon index $\Gamma$ in MYTorus was tied with the primary power law component of the relxill model. The latest version of relxill model self consistently includes the relativistic broadening of the Fe K emission line along with the soft X-ray excess emission and the relativistic hard X-ray emission at $E > 10$ keV. The relxill model assumes a lamp-post geometry of scattering, whereby the hard X-ray emitter (corona) irradiates the accretion disk from the top, and the hard X-ray pho-tons get Compton scattered from the accretion disk. In the model relxill, the accretion disk is assumed to be an optically thick slab of gas and the reflection emissivity from the accretion disk depends on its radius as a powerlaw $E(r) \propto r^{-q}$, where $E$ is the emissivity of the gas due to reflection, and $q$ is the emissivity index. In Newtonian geometry, the emissivity index is $q = 3$. In the general relativistic high gravity regime the inner emissivity profile steepens to higher values (Wilkins & Fabian 2011). The model relxill assumes that the transition from relativistic geometry to Newtonian geometry happens at a break radius $r_{br}$. Thus in our fits, the emissivity index of the accretion disk at $r < r_{br}$ have values ranging from $3 < q < 10$, while at $r > r_{br}$ the index is fixed to 3. Recent studies of the accretion disk emission using the model relxill (Ghosh et al. 2016; Tomsick et al. 2018; Ghosh et al. 2018; Jiang et al. 2018) have found that the emissivity index in the relativistic regimes can take up values as large as $8 - 10$. For all the observations we have added a partially covering ionized absorption model zxpabs to account for any absorption along the line of sight. For MYTorus the equatorial column density and the inclination angle between the observers line of sight and the symmetry axis of...
the torus is allowed to vary freely. The inclination angles of the 
\textit{relxill} and \textit{MYTorus} models are united and separate, because they 
are entirely two different reprocessing media and are treated as separate 
quantities. For the \textit{XMM-Newton} observation the inclination of \textit{MYTorus} is not well constrained possibly due to non-coverage of > 10 keV spectrum.

Table 3 lists the best fit model parameters along with the best 
fit statistics for \textit{Suzaku} and \textit{XMM-Newton} observations. For the 
\textit{Suzaku} spectra we have carried out two separate fits in order to 
ascertain if the data prefers a broad Fe line or not. In the first case 
we have kept the inner radius of the relativistic reflection model 
fixed to the inner circular stable orbit for a non rotating black hole 
\((R_{\text{in}} = 6R_{\text{g}})\). In the second case, we fixed the inner radius to 
that of a maximally spinning black hole \((R_{\text{in}} = 1.23R_{\text{g}})\). For the \textit{XMM-Newton} observations similar exercises have been done but 
we report only the Schwarzschild case because we do not find any 
difference in the quality of fit between the two scenarios. Figures 3 
and 4 show the data, the best fit physical models and the residuals 
for the \textit{Suzaku} and the \textit{XMM-Newton} observations. To test if the partially 
ionized absorption is needed by the data using the physical 
models, we removed the model \(\text{zxbabs+zxipcf}\) from the fit and tested 
the two cases of maximally spinning and non-spinning black hole. 
The fit statistic for the non-spinning case in the \textit{Suzaku} observa-
tion is 845/735, while for maximally spinning case is 836/735 re-
spectively. Both the fits are worse compared to those when the pa-
tially covering ionized absorber model is included, implying that 
the model is statistically required by the data.

We also tested for the case when the soft X-ray excess could be described by intrinsic disk-comptonization of the ac-
ercretion disk photons emitted in the UV. The model \texttt{optxagnf} 
(\textit{Done et al. 2012}) assumes that the gravitational energy released 
in the accretion disk powers the disk emission in UV, the soft 
X-ray excess and the power law emission. The broadband model in \texttt{XSPEC} notation we used to fit the \textit{Suzaku} spectra is 
\((\text{tbabs+zxipcf+\text{optxagnf+MYTorus}})\). The fit resulted 
in a statistic \(\chi^2/\text{dof} = 900/735\) (with positive residuals in the 
soft X-ray region) which is worse than the best fit model obtained 
with the baseline model above. This may indicate that the spectra 
needs a further disc reflection model to describe the soft excess. We added the model \texttt{relxill} to the current fit and the fit improved to \(\chi^2/\text{dof} = 808/727\). The fit is comparable to that 
found using the physical model mentioned above. We have used only the 
Schwarzschild case for the reflection model here, as we have al-
ready checked that the data are insensitive to the spin of the black 
hole. We carried out the same exercise for the \textit{XMM-Newton ob-
servations} and found similar results. Table 4 lists the best fit param-
eters obtained using this model. We discuss these results in the next 
section.

4 RESULTS AND DISCUSSION

We have carried out an X-ray spectral analysis of the Seyfert 1 
galaxy Mrk 205 using the observations from \textit{Suzaku} and \textit{XMM-
Newton} telescopes. Previous studies by \textit{Reeves et al. (2001)} and 
\textit{Page et al. (2003)} could not affirmatively confirm the presence of 
broad Fe K\alpha emission line and the authors proposed that the higher 
ionization broad line could also be a blend of several higher ion-
ization Fe K emission lines, mimicking a broad feature. In this 
study, for the first time, using broad band spectra \((0.5 - 30 \text{ keV})\) 
from \textit{XMM-Newton} and \textit{Suzaku} and physical models such as \texttt{relxill}, 
we investigate the presence of a broad Fe K\alpha emission line in the 
source Mrk 205.

The super massive black hole at the center of the galaxy 
Mrk 205 has a mass \(10^{8.32\pm 1.0} \times M_\odot\) (\textit{Tombesi et al. 2012; 
Kara et al. 2016}). The \(2 - 10 \text{ keV}\) unabsorbed luminosity of Mrk 205 is \(L_{2-10 \text{ keV}} = 10^{45.9} \text{ erg s}^{-1}\). Using the bolometric cor-
rection factor of \(\kappa = 20\) (\textit{Vasudevan & Fabian 2007}), we find that 
the bolometric luminosity of the AGN is \(L_{\text{bol}} \sim 10^{45.10} \text{ erg s}^{-1}\), 
which implies an Eddington rate of \(\lambda_{\text{Edd}} = 0.03\). Below we dis-
cuss the main results in context to the origin of the narrow and 
broad Fe emission lines and the properties of the X-ray reprocess-
ing media in the vicinity of the SMBH.

4.1 Origin of the narrow Fe K\alpha emission line

The \textit{Suzaku} X-ray spectra of Mrk 205 shows the presence of a narrow 
Fe K\alpha emission line with an equivalent width of \(\sim 60 \text{ eV}\), which 
is typical of nearby Seyfert galaxies. This fluorescent emission 
line is believed to arise when the hard X-ray photons from the 
corona get reflected from high column-density neutral mate-
rial in the vicinity of the SMBH, possibly the torus. \textit{Ricci et al.} 
(2014) in a multiwavelength study of the narrow Fe K\alpha emission 
line found that the line originates from a neutral material possibly 
located in the molecular torus. The authors claim that most of the 
narrow Fe K\alpha emission is produced by the same material which 
is also responsible for emission in the mid-infrared. \textit{Fukazawa et al.} 
(2011) studied the X-ray spectra of a sample of AGN with \textit{Suzaku}. 
They found a strong correlation between the equivalent width of the 
narrow Fe K\alpha emission line and the neutral absorption column den-
sity in the range \(10^{23} - 10^{25} \text{ cm}^{-2}\), indicating that the Fe K\alpha 
line is emitted by the Compton thick reprocessing medium around the 
SMBH. For absorption column densities below \(10^{23} \text{ cm}^{-2}\) there 
was no dependence of the Fe K\alpha equivalent width on the column. 
In Mrk 205 we find that the \textit{MYTorus} model, which models the narrow 
Fe K\alpha emission line simultaneously with the Compton hump 
(peaking at \(\sim 20 \text{ keV}\)) has a best fit reflection column density of 
\(\geq 2.15 \times 10^{24} \text{ cm}^{-2}\). This result corroborates the fact that the neu-
tral Fe K\alpha emission line of Mrk 205 arises from the Compton-thick 
torus.

4.2 Is there a broad Fe line in the X-ray spectra?

\textit{Reeves et al. (2001)} detected a broad Fe K\alpha emission line for the 
source Mrk 205 with \textit{XMM-Newton} spectra, however, the authors 
were skeptical about the nature of the emission line. The best fit rest 
frame line energy of the broad line measured was \(6.7 \text{ keV}\) which 
\(\text{is not consistent with that of other broad line profiles measured in} 
\text{Seyfert-1 galaxies (Nandra et al. 1997)}, \text{where the line peaks at} 
\text{around } 6.4 \text{ keV and the bulk of the line flux is redshifted below this} 
\text{energy. The authors also discussed the possibility of a large incli-
nation angle of the disk } \sim 75 - 90\text{ degrees, but it would mean that} 
\text{the source is nearly edge-on, defying the optical classification of it} 
\text{being a Seyfert 1 galaxy. Another possibility could be that the inner} 
\text{accretion disc being too highly ionized, the red wing of the broad} 
\text{Fe K\alpha emission line is suppressed. The authors also proposed an} 
\text{alternative scenario whereby the apparent broad emission line is} 
\text{due to the blend of several high ionization Fe lines near } 6.7 \text{ keV.} 
\text{It is common to find ionized emission lines in Seyfert 2 spectra} 
\text{arising from warm electron scattering regions, but the equivalent} 
\text{widths of such lines are much smaller in case of Seyfert 1 galaxies.} 
\text{More recent comprehensive sample study on broad Fe K\alpha emission} 

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lines (de La Calle Pérez et al. 2010) have detected broad Fe Kα emission line peaking at ~ 6.4 keV with a substantial flux in the red wing of the profile.

For the observation xmm101, same as the one studied by Reeves et al. (2001) and Page et al. (2003), we detect an Fe emission line at 6.84$^{+0.14}_{-0.15}$, consistent with the previous studies, using simple Gaussian fits. To test the presence of a broad emission line arising out of inner-accretion-disk reflection of a spinning black hole we used the relativistic reflection models. We created two sets of models to fit the Suzaku and XMM-Newton observations. One with the inner circular stable orbit fixed to value as obtained for a non rotating black hole (i.e, $R_{in} = 6R_{G}$). In the second case, we fixed the inner radius to that of a maximally spinning black hole ($R_{in} = 1.23R_{G}$). Table 3 shows the best fit parameters for the physical model, and we find that both the models result in equally good fit. The results indicate two possible scenarios: 1. Either the broad Fe line is indeed not present or 2. The data are not sensitive enough to detect them.

4.3 Is the disk truncated for this source?

As discussed above, the Suzaku and XMM-Newton observations pointed out that the data cannot distinguish between the two scenarios: a rapidly spinning and a non-spinning black hole. This may imply that we are viewing a truncated accretion disk whose inner radius lie further out ($> 6R_{G}$). In the Suzaku observation we have carried out a test to check how far the inner radius of the disk extends in order to produce simultaneously the soft X-ray excess and the hard excess. We set the inner radius in the Schwarzschild case to $> 20R_{G}$, and froze the inner emissivity index to the Newtonian value, $q_{1} = 3$. We measured the range of the inner radius and found an upper limit of $< 12R_{G}$. We therefore conclude that the inner radius of the accretion disk may have been truncated at a larger distance in the range 6$R_{G} < R < 12R_{G}$. We note however, that the truncation radius is not very significantly large, implying that the relativistic effects could still be present and the disk reflection model is required by the data. This is also corroborated by the fact that we did not get a good fit when we used disk Comptonization model ($\text{Optxagnf}$) to fit the data, and the fit improved radically upon the addition of a disk reflection model ($\text{relxill}$). The truncation of the disk is also supported by the fact that the Eddington rate of the source is low ($\lambda_{\text{Edd}} = 0.03$), implying that the black hole is not feeding efficiently.

5 CONCLUSIONS

We have carried out an extensive X-ray spectral analysis of the local Seyfert-1 galaxy Mrk 205, investigating the anomalous hard X-ray emission of the source Mrk 205 as shown by previous studies. We used the broad band spectra from XMM-Newton and Suzaku for our investigation. We list the main conclusions below:

- The X-ray spectra of Mrk 205 is typical of local Seyfert galaxies, with power law photon index $\Gamma \sim 1.90$, a soft-excess, an Fe line complex and a hard X-ray excess. The soft excess possibly arise from the ionized accretion disk, as it could be described simultaneously with the hard X-ray excess. A fit with intrinsic disk comptonization model ($\text{optxagnf}$) did not result in a good fit.
- The origin of the narrow Fe Kα emission line is possibly due to the reflection of hard X-ray photons off the neutral molecular torus with a column density of $\geq 2.15 \times 10^{24}$ cm$^{-2}$, implying a Compton thick reflector.
- We detect a partially covering ionized absorption with ionization parameter $log(\xi/\text{erg cm s}^{-1}) = 1.9^{+0.1}_{-0.15}$, column density $N_{H} = (5.6^{+2.0}_{-1.9}) \times 10^{22}$ cm$^{-2}$ and a covering factor of $0.22^{+0.06}_{-0.09}$.
- We conclude that we cannot affirmatively confirm the presence of a broad line. The data quality is not sensitive enough to detect the broad line. However, we confirm that disk reflection component is statistically required by all the spectra.
- We found that the accretion disk may be truncated at a larger distance from the SMBH, $6R_{G} < R < 12R_{G}$, as obtained from broad band Suzaku observation, confirming the fact we do not detect any broad Fe emission line. This is supported by the fact that the Eddington rate of the source is low ($\lambda_{\text{Edd}} = 0.03$).
Table 1. The X-ray observations of Mrk 205.

| Satellite   | Observation id | Short id | Date of obs | Net exposure |
|-------------|----------------|----------|-------------|--------------|
| XMM-Newton  | 0124410101     | xmm101   | 07-05-2000  | 15 ks        |
|             | 0401240201     | xmm201   | 18-10-2006  | 28 ks        |
|             | 0401240301     | xmm301   | 20-10-2006  | 29 ks        |
|             | 0401240501     | xmm501   | 22-10-2006  | 43 ks        |
| Suzaku      | 705062010      |          | 22-05-2010  | 101 ks       |
| Nustar\(^1\) | 60160490002    |          | 20-06-2017  | 20 ks        |

\(^1\) Due to insufficient signal to noise ratio of the Nustar observation in the FeK band, the data were not used for analysis in this paper. See Appendix A for details of the spectra and fit.
Investigating the origin of the Fe emission lines of the Seyfert 1 galaxy Mrk 205.

Figure 1. Left: Background subtracted XIS lightcurve of Mrk 205 in the 0.6−1.7 keV energy band (top panel), 2.3−10 keV (middle panel) and the hardness ratio (bottom panel) for the Suzaku observation of Mrk 205. Note that the hardness ratio does not vary significantly during the 101 ks observation. Right Top panel: The 4.0−5.0 keV Suzaku spectra of Mrk 205 fitted with an absorbed powerlaw and the rest of the 0.6−50.0 keV dataset extrapolated. Bottom panel: The broadband residuals from the fit above, showing the presence of soft X-ray excess, an Fe line complex and a hard X-ray excess (at E > 10 keV). The X-axis represents observed frame energy.

Figure 2. The Suzaku spectra of Mrk 205 along with the best-fit baseline phenomenological models. Note that there is some excess visible in the PIN data after obtaining the best fit, which could be due to the relativistic disk reflection hump which is not modeled in the spectra. We have used a diskline profile to describe the broad Fe Kα emission line. See Section 3 for details. The X-axis represents observed frame energy.
Figure 3. Left: The Suzaku spectra of the source Mrk 205 with the best-fit physical models and residuals, as described in Section 3. Right: The best fit physical models to the Suzaku spectra of Mrk 205. The relxill model describing simultaneously the soft X-ray excess, the broad Fe Kα emission line and the relativistic reflection hump in the hard X-rays is plotted in red dotted line. The MYTorus model which describes the narrow Fe Kα, and Ni emission lines along with the Compton hump due to distant neutral reflection is plotted in blue dotted line. The final best fit model is plotted in black solid line. The X-axis represents observed frame energy.

Figure 4. Top Left: The XMM-Newton spectra (id: xmm101) of the source Mrk 205 with the best-fit physical model and residuals, as described in Section 3. Top Right: Same as left, except for the obsid: xmm201, bottom Left: Same as top left, except for the obsid: xmm301, bottom Right: Same as top right, except for obsid: xmm501
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Table 2. The best fit parameters of the baseline phenomenological models for the *Suzaku* and *XMM-Newton* observations of Mrk 205.

| Models    | Parameter | Suzaku | xmm101 | xmm201 | xmm301 | xmm501 |
|-----------|-----------|--------|--------|--------|--------|--------|
|          | $N_H \times 10^{20} \text{ cm}^{-2}$ | 3.0 (f) | 3.0 (f) | 3.0 (f) | 3.0 (f) | 3.0 (f) |
|          | $\Gamma$ | $1.97^{+0.01}_{-0.01}$ | $1.72^{+0.05}_{-0.03}$ | $1.94^{+0.05}_{-0.06}$ | $1.90^{+0.02}_{-0.06}$ | $1.94^{+0.03}_{-0.02}$ |
|          | $T_{\text{in}}$ (keV) | $0.07^{+0.01}_{-0.01}$ | $0.08^{+0.01}_{-0.01}$ | $0.11^{+0.01}_{-0.01}$ | $0.09^{+0.01}_{-0.01}$ | $0.03^{+0.01}_{-0.01}$ |
|          | $\Delta N_{\text{ztbabs}}$ | $2.42^{+2.80}_{-2.50}$ | $7.7^{+2.10}_{-1.50}$ | $0.4^{+0.60}_{-0.40}$ | $1.56^{+0.71}_{-0.49}$ | $0.5^{+0.71}_{-0.49}$ |
|          | $E_r$ (keV) | $6.36^{+0.31}_{-0.32}$ | $6.84^{+0.15}_{-0.14}$ | $< 6.36^{+0.31}_{-0.32}$ | $6.36^{+0.31}_{-0.32}$ | $6.36^{+0.31}_{-0.32}$ |
|          | $\beta$ | $< -5.97$ | $< -2.58$ | $< -2.51$ | $< -3.2$ | $< -3.2$ |
|          | $R_{\text{in}}$ (r$_g$) | $< 9.79$ | $< 578$ | $< 9.79$ | $< 578$ | $< 9.79$ |
|          | Incl (°) | $22^{+6}_{-3}$ | $< 58$ | $< 30$ | $< 30$ | $< 30$ |
|          | $\Delta \chi^2/\text{dof}$ | $37/5$ | $17/5$ | $5/5$ | $0/5$ | $18/5$ |
| Narrow-Gauss | $E_r$ (keV) | $6.38^{+0.15}_{-0.29}$ | $6.36^{+0.09}_{-0.14}$ | $6.36^{+0.25}_{-0.19}$ | $6.39^{+0.58}_{-0.80}$ | $6.58^{+0.49}_{-0.10}$ |
|          | $\Delta \chi^2/\text{dof}$ | $23/3$ | $13/3$ | $26/3$ | $24/3$ | $32/3$ |

$\Delta \chi^2$ improvement in statistics upon addition of the corresponding discrete component.

The model *pexrav* was used only for *Suzaku* observation as it had broad band spectra necessary for constraining the parameters.

The inclination angle of *pexrav* is tied to the inclination angle of the diskline as it could not be constrained independently.
### Table 3. Best fit parameters for observations of Mrk 205 with the physical models.

| Component     | parameter          | Suzaku Without Spin | Suzaku With Spin | xmm101 Without Spin | xmm101 With Spin | xmm201 Without Spin | xmm201 With Spin | xmm301 Without Spin | xmm301 With Spin | xmm501 Without Spin | xmm501 With Spin |
|---------------|--------------------|---------------------|------------------|---------------------|------------------|---------------------|------------------|---------------------|------------------|---------------------|---------------------|
| Gal. abs.     | $N_{\text{H}}$\text{($10^{20}$ cm$^{-2}$)} | 3.0 (f)             | 3.0 (f)          | 3.0 (f)             | 3.0 (f)          | 3.0 (f)             | 3.0 (f)          | 3.0 (f)             | 3.0 (f)          | 3.0 (f)             | 3.0 (f)             |
| szxpcf        | $N_{\text{H}}$\text{($10^{22}$ cm$^{-2}$)} | $5.6^{+2.0}_{-1.0}$ | $5.1^{+2.0}_{-1.0}$ | < 0.06              | 48.3$^{+22.0}_{-29.0}$ | 16.5$^{+30.5}_{-5.2}$ | 23.3$^{+25.3}_{-4.4}$ |
|               | log$\xi$ (erg s$^{-1}$) | $1.9^{+0.1}_{-1.0}$ | $1.9^{+0.1}_{-1.0}$ | $-1.6^{+0.2}_{-0.4}$ | < 0.52          | < 0.03              | < 0.53          |
|               | $C_{\text{mfracs}}$ | $0.22^{+0.09}_{-0.08}$ | $0.22^{+0.11}_{-0.07}$ | $0.65^{+0.21}_{-0.26}$ | $0.34^{+0.17}_{-0.11}$ | $0.28^{+0.11}_{-0.15}$ | $0.22^{+0.13}_{-0.08}$ |
| resxill       | $A_{\text{res}}$ | 1(f)               | 1(f)             | 1(f)               | 1(f)             | 1(f)               | 1(f)             | 1(f)               | 1(f)             |
|               | log$\xi$ (erg cm s$^{-1}$) | $1.23^{+0.28}_{-0.26}$ | $1.32^{+0.79}_{-0.79}$ | $1.29^{+0.10}_{-0.25}$ | $0.30^{+0.06}_{-0.23}$ | $0.40^{+0.34}_{-0.22}$ | $0.38^{+0.34}_{-0.20}$ |
|               | $\Gamma$ | $2.19^{+0.05}_{-0.04}$ | $2.19^{+0.07}_{-0.07}$ | $2.13^{+0.04}_{-0.04}$ | $2.39^{+0.02}_{-0.02}$ | $2.36^{+0.09}_{-0.09}$ | $2.27^{+0.01}_{-0.01}$ |
|               | $n_{\text{res}}$\text{($10^{-5}$)h} | $5.52^{+0.14}_{-0.30}$ | $5.30^{+0.42}_{-0.62}$ | $2.50^{+0.04}_{-0.04}$ | $8.55^{+0.13}_{-1.53}$ | $7.90^{+0.09}_{-0.33}$ | $8.78^{+0.36}_{-0.36}$ |
|               | $q_{\text{1}}$ | 6(pegged)           | 3.3$^{+0.7}_{-0.9}$  | 6(pegged)           | 6(pegged)        | 6(pegged)           | 6(pegged)        |
|               | $q_{\text{2}}$ | 3(f)               | 3(f)             | 3(f)               | 3(f)             | 3(f)               | 3(f)             |
|               | $a$ | 0 (f)               | 0.99 (f)          | 0 (f)              | 0 (f)            | 0 (f)              | 0 (f)            |
|               | $R$(ref$IFrac$) | $1.0^{+0.3}_{-0.3}$  | $1.5^{+0.8}_{-0.8}$  | $0.5^{+0.2}_{-0.2}$  | $0.73^{+0.22}_{-0.17}$ | $0.50^{+0.22}_{-0.20}$ | $0.51^{+0.24}_{-0.12}$ |
|               | $R_{\text{cos}}$ (rg) | 6(f)               | 1.3(f)           | 6(f)               | 6(f)             | 6(f)               | 6(f)             |
|               | $R_{\text{in}}$ (rg) | 10(f)              | 10(f)            | 10(f)              | 10(f)            | 10(f)              | 10(f)            |
|               | $R_{\text{out}}$ (rg) | 400(f)             | 400(f)           | 400(f)             | 400(f)           | 400(f)             | 400(f)           |
|               | $i$(degree) | $31^{+5}_{-6}$       | $32^{+11}_{-8}$   | $31(f)$            | $31(f)$          | $31(f)$            | $31(f)$          |
| MYOrusL       | $s$(degree) | < 48                | 48(f)            | 48(f)              | 48(f)            | 48(f)              | 48(f)            |
|               | norm (10$^{-3}$) | $7.4^{+2.2}_{-2.2}$  | $8.2^{+2.6}_{-2.2}$ | < 6.2              | $12.5^{+7.7}_{-7.7}$ | $7.4^{+5.9}_{-5.3}$ | < 7.4            |
| MYOrusS       | NH(10$^{24}$ cm$^{-2}$) | > 2.15             | > 5.80           | 10.0(*)            | 10.0(*)          | 10.0(*)            | 10.0(*)          |
|               | norm (10$^{-3}$) | $3.30^{+2.50}_{-0.22}$ | $3.16^{+2.51}_{-0.30}$ | $35.8^{+21.1}_{-3.3}$ | $87.3^{+4.4}_{-40.4}$ | $32.0^{+47.4}_{-13.8}$ | $58.7^{+22.7}_{-7.1}$ |
|               | $\chi^{2}$/dof | 818/732             | 816/732          | 241/206            | 334/237         | 322/241            | 399/248          |

Notes: (f) indicates a frozen parameter. (*) indicates parameters are not constrained.

(a) $n_{\text{res}}$ represent normalization for the model resxill
Table 4. Best fit parameters for observations of Mrk 205 with the physical models.

| Component | parameter | Sazukawa Without Spin | xmm101 Without Spin | xmm201 Without Spin | xmm301 Without Spin | xmm501 Without Spin |
|-----------|-----------|------------------------|----------------------|----------------------|----------------------|----------------------|
| Gal. abs. | \( N_{\text{H}} (10^{20} \text{cm}^{-2}) \) | 2.8 (f) | 2.8 (f) | 2.8 (f) | 2.8 (f) | 2.8 (f) |
|          | \( N_{\text{H}} (\times 10^{22} \text{cm}^{-2}) \) | 4.9\pm2.1 | < 5.1 | < 0.06 | < 2.08 | > 4.7 |
|          | \( \log T_{\text{eff}} \) (erg cm s\(^{-1}\)) | 1.9\pm0.2 | -1.4\pm2.0 | -1.6 | < -0.52 | > 1.5 |
|          | \( C_{\text{Fe} \text{frac}} \) | < 0.30 | 0.28\pm0.11 | < 0.20 | < 0.4 | > 0.6 |
| oxagnf   | \( M_{\text{oxg}} \) | 2.1(f) | 2.1(f) | 2.1(f) | 2.1(f) | 2.1(f) |
|          | \( d \) (Mpc) | 308(f) | 308(f) | 308(f) | 308(f) | 308(f) |
|          | \( R_{\text{Fe}} \) (GeV) | 1.1\pm0.1 | 0.1(+) | 0.4\pm0.3 | 0.4\pm0.3 | 0.11\pm0.10 |
|          | \( kT_\text{Fe} \) (keV) | 0.32\pm0.02 | 0.26(+) | 0.48\pm0.12 | 0.54\pm0.52 | 0.51\pm0.15 |
|          | \( \tau \) | > 5.5 | 9.9(+) | > 6.2 | > 4.3 | > 9.4 \pm 0.9 |
|          | \( r_\text{e} (r_g) \) | 9.9\pm6.8 | 6.1(+) | 9.3\pm8.8 | 9.0\pm3.8 | 16(+) |
|          | \( a \) | 0(f) | 0(f) | 0(f) | 0(f) | 0(f) |
|          | \( f_{\text{Fe}} \) | 0(f) | 0(f) | 0(f) | 0(f) | 0(f) |
|          | \( \Gamma \) | 2.04(f) | 1.93(f) | 2.15(f) | 2.16(f) | 2.10(f) |
| relsill  | \( A_{\text{Fe}} \) | 1(f) | 1(f) | 1(f) | 1(f) | 1(f) |
|          | \( \log \) (erg cm s\(^{-1}\)) | 0.45\pm0.41 | 3.01\pm0.11 | 0.70\pm0.49 | 0.70\pm0.26 | 0.70\pm0.16 |
|          | \( \Gamma \) | 2.04\pm0.05 | 1.93\pm0.06 | 2.15\pm0.10 | 2.16\pm0.12 | 2.11\pm0.02 |
|          | \( n_{\text{e}}(10^{-5}) \) | 5.18\pm0.30 | 2.27\pm0.62 | 5.18\pm0.04 | 4.89\pm1.53 | 6.48\pm0.02 |
|          | \( q_{\text{l}} \) | 3.5\pm2.7 | 6(pegged) | 4.6\pm4.5 | > 4.1 | > 3.9 |
|          | \( \alpha \) | 0(f) | 0(f) | 0(f) | 0(f) | 0(f) |
|          | \( R_{\text{relfrac}} \) | 0.3\pm0.3 | 0.3\pm0.2 | 0.5\pm0.3 | 0.5\pm0.2 | 0.5\pm0.1 |
|          | \( R_{\text{Fe} \text{frac}} \) | 6(f) | 6(f) | 6(f) | 6(f) | 6(f) |
|          | \( R_{\text{e} \text{Fe} \text{frac}} \) | 12\pm3 | > 10(f) | 19(*) | 15\pm9 | < 24(f) |
|          | \( R_{\text{e} \text{Fe} \text{frac}} \) | 400(f) | 400(f) | 400(f) | 400(f) | 400(f) |
|          | \( s(\text{degree}) \) | 4\pm7 | 18\pm8 | 19\pm10 | 13\pm11 | 20(pegged) |

**MYTorusL**
- \( \alpha(\text{degree}) \) | < 60 | < 60 | < 60 | < 60 | < 60 |
- norm \( (10^{-3}) \) | 2.4\pm2.2 | 2.4(f) | 2.4(f) | 2.4(f) | 2.4(f) |

**MYTorusS**
- \( \text{NH}(10^{24} \text{cm}^{-2}) \) | > 2.15 | 10(pegged) | 10(pegged) | 10(pegged) | 10(pegged) |
- norm \( (10^{-3}) \) | 0.30\pm0.20 | 0.30(f) | 0.30(f) | 0.30(f) | 0.30(f) |

Notes: (f) indicates a frozen parameter. (*) indicates parameters are not constrained. (a) in units of \( 10^7 M_\odot \); (b) \( n_{\text{e}} \) reprent normalization for the model relsill.

\( \chi^2/\text{dof} \) | 805/727 | 240/204 | 325/235 | 310/239 | 405/246

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**Investigating the origin of the Fe emission lines of the Seyfert 1 galaxy Mrk 205.**

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**MN000 000, 1–77 (2013)**
APPENDIX A: THE NUSTAR OBSERVATION

In this section we discuss the Nustar observation (ob- sid:60160490002) of this source and show why this observation is not suitable for our work, and hence, not used. Mrk 205 was observed by Nustar for ~20 ks on June 20, 2017. The data were reprocessed using the HEASoft command nupipeline and subsequent spectra for the two instruments FPMA and FPMB were obtained. The source regions were selected using circular regions of 35 arc-sec radius centred at the centroid of the source coordinates obtained from NED (NASA Extragalactic Database). The background regions were selected using circles of same radius on the same CCD but away from the source. The net counts of the spectra obtained are ~ 3.5 × 10^7 for each of the detectors, FPMA and FPMB. The spectra were grouped by a minimum signal to noise ratio of three. Figure A1 shows the spectra in the energy range 4 – 40 keV fitted with a simple powerlaw absorbed by the Galactic column. We found that the spectra is fitted well by this simple model with a $\chi^2$/dof = 376/396 ~ 0.95. The best fit powerlaw slope of $\Gamma = 1.84 \pm 0.06$, similar to the slope we detected in Suzaku and XMM-Newton spectra. The Nustar spectra is over-modeled even with a simple absorbed powerlaw. We added a Gaussian profile at 6.4 keV to model the narrow FeK emission line and the fit improved only by a $\Delta \chi^2 = 8$ for three parameters of interest. In addition, the normalisation of the Fe line could not be constrained. We therefore, do not use the Nustar spectra in our analysis due to lack of statistics in detecting the Fe-Kα discrete spectral features and also the broad Compton hump at ~20 keV.

In future we propose to obtain a deeper view of the source with Nustar.

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MNRAS 000, 1–77 (2013)
Figure A1. The NuStar FPMA (in red) and FPMB (in black) spectra of the source Mrk 205. The spectra were grouped by a minimum signal to noise ratio of three. Top Panel: The spectra with the best fit model (a simple powerlaw absorbed by the Galactic column). The best fit statistic is $\chi^2/\text{dof} = 376/396 \sim 0.95$. Bottom Panel: The residuals of the spectra after the fit. See Appendix A for details. The X-axis represents observed frame energy.