A POSSIBLE ULTRA STRONG AND BROAD Fe Kα EMISSION LINE IN SEYFERT 2 GALAXY IRAS 00521-7054

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ABSTRACT

We present XMM-Newton spectra of the Seyfert 2 Galaxy IRAS 00521-7054. A strong feature at ~6 keV (observer’s frame) can be formally fitted with a strong (EW = 1.3 ± 0.3 keV in the rest frame) and broad Fe Kα line, extending down to 3 keV. The underlying X-ray continuum could be fitted with an absorbed power law (with Γ = 1.8 ± 0.2 and N_H = 5.9^{+0.7}_{-0.6} × 10^{22} cm^{-2}) plus a soft component. If due to relativistically smeared reflection by an X-ray illuminated accretion disk, the spin of the supermassive black hole (SMBH) is constrained to be 0.97^{+0.03}_{-0.13} (errors at 90% confidence level for one interesting parameter), and the accretion system is viewed at an inclination angle of 37° ± 4°. This would be the first type 2 active galactic nucleus reported with strong red Fe Kα wing detected which demands a fast rotating SMBH. The unusually large EW would suggest that the light bending effect is strong in this source. Alternatively, the spectra could be fitted by a dual-absorber model (though with a global χ^2 higher by ~6 for 283 dof) with N_H1 = 7.0 ± 0.8 × 10^{22} cm^{-2} covering 100% of the X-ray source, and N_H2 = 21.7^{+5.6}_{-5.4} × 10^{22} cm^{-2} covering 71%, which does not require an extra broad Fe Kα line.

Key words: galaxies: active – galaxies: Seyfert – X-rays: individual (IRAS 00521-7054)

Online-only material: color figures

1. INTRODUCTION

The broad Fe Kα fluorescent emission line in active galactic nuclei (AGNs), first clearly detected by ASCA (Tanaka et al. 1995), provides an important tracer for probing the physical conditions and geometrical distribution of matter in the vicinity of a supermassive black hole (SMBH). The line is believed to be from the accretion disk by reflecting the illuminating X-ray continuum, and the unique broad and skewed (toward the red) line profile is a consequence of the relativistic Doppler effect (e.g., Fabian et al. 1989; Laor 1991). Such broad Fe Kα emission lines have been detected in a significant number of AGNs (Nandra et al. 1997, 2007; Wang et al. 1999; Fabian et al. 2002; Miller 2007; Guainazzi 2010; de la Calle Pérez et al. 2010). More interestingly, in a few sources the red wing of the Fe Kα emission line appears too broad to be produced from accretion disk surrounding Schwarzschild black holes (Wilm et al. 2001; Fabian et al. 2002; Patrick et al. 2011b). In these cases, assuming the accretion disk extends to the innermost stable circular orbit (ISCO; determined by the spin of the black hole), fast rotating Kerr black holes are required, for which the accretion disk could extend closer to the horizon thus stronger gravitational redshift could be produced (Reynolds & Fabian 2008). Therefore, the Fe Kα line profile enables astronomers to measure the spin of SMBHs, which is otherwise extremely difficult or even impossible (Reynolds & Nowak 2003). Till now, rotating SMBHs have been claimed in a number of type 1 AGNs (e.g., Brenneman & Reynolds 2006, 2009; Patrick et al. 2011b; Brenneman et al. 2011). However, strong debates exist on the nature of the ultra broad red wings, challenging the base of such measurements. An alternative scenario is that the observed broad and skewed line profile is artificial due to continuum curvature produced by more complex absorption (e.g., partial covering ionized absorber; Reeves et al. 2004; Miller et al. 2008, 2009; Turner & Miller 2009). Although various efforts have been made to distinguish two scenarios, including performing spectral fitting over wider bands to better determine the absorption and the underlying continuum (Patrick et al. 2011a), studying bare Seyferts with no or very weak warm absorption (Patrick et al. 2011b), and monitoring the lag between reflection component and the continuum (Fabian et al. 2009), a clear picture has not been obtained.

Meanwhile, type 2 AGNs could provide a different insight into the nature of broad Fe Kα emission. According to unification model, type 2 AGNs are viewed at higher inclination angle comparing with type 1 sources. Furthermore, while ionized absorption, which plays the key role in the alternative scenario to the broad Fe Kα line, is common in type 1 AGNs (e.g., Reynolds 1997), X-ray absorption in type 2 sources is dominated by cold matter. Till now, broad Fe Kα lines were detected only in a few type 2 AGNs (see Guainazzi et al. 2010 for a summary of broad Fe Kα line detections in obscured AGNs, mostly type 1.8 and 1.9 sources; Iwasawa et al. 1996; Dewangan et al. 2003; Shu et al. 2010a). However, neither of the Fe Kα line red wing in these type 2 AGNs is broad enough to demand a rotating SMBH.

IRAS 00521-7054 is a Seyfert 2 galaxy at z = 0.0689. In this Letter we present new XMM-Newton observation on IRAS 00521-7054 taken in 2006, in which we detect an ultra strong and broad Fe Kα line. In Section 2, we describe the XMM-Newton observations and data reduction. Section 3 provides our detailed spectral fitting to the continuum and the emission line, followed by discussion in Section 4.

2. DATA REDUCTION

IRAS 00521-7054 was observed with XMM-Newton twice in 2006 in Prime Full Window mode. The durations of the two exposures were 17.3 ks (on 2006 March 22) and 14.2 ks (2006 April 22), respectively. We reduced the raw data with the XMM-Newton Scientific Analysis System (SAS; Gabriel et al. 2004) version 10.0.0. The exposures were processed using the SAS pipeline “epchain” and “emchain.” We filtered the event files to include only those events with XMM-Newton-SAS quality flag FLAG==0 (#XMMEA_EM) for PN (MOS1 and MOS2), and
extracted single- and double-pixel events (PATTERN ≤ 4) for PN, and single- to quadruple-pixel events (PATTERN ≤ 12) for MOS1 and MOS2. After excluding high background intervals, the net exposures for two observations are 5.7 ks and 7.9 ks for PN, and 7.4 ks and 11.0 ks for MOS, respectively. Source spectra were extracted from circles with radius of 30″ for PN, and 40″ for MOS centered on the source position. For both PN and MOS data, the background events were extracted from source-free areas on the same chip using four circular circles with a combined area four times larger than the source region. We note that adopting different background regions would not alter any scientific results presented in this Letter. The response matrix and ancillary response file were generated using the RMFGEN and ARFGEN tools with the SAS software. The extracted net source count rate is ~0.26 counts s⁻¹ for PN, and ~0.08 counts s⁻¹ for MOS, thus the exposures are free from the pile-up effect.

3. SPECTRAL FITTING

We examined the light curves of each exposure, and found no significant variation within or between two exposures. Through a preliminary spectral fitting, we also found no spectral variations between two observations. We therefore combined the spectra from two exposures to increase the S/N ratio in the spectra, and obtained one composite PN spectrum and one MOS spectrum (co-added from MOS1 and MOS2). Both spectra were binned to have at least 20 counts per bin to allow the use of χ² statistics with XSPEC V12.6.0. All fitting errors are of 90% confidence level for one parameter (Δχ² = 2.71), if not otherwise stated. The adopted cosmological parameters are H₀ = 70 km s⁻¹ Mpc⁻¹, ΩΛ = 0.73, and Ωm = 0.27. During spectral fitting, the Galactic column density along the line of sight to IRAS 00521-7054 is always taken into account (N_H = 4.44 × 10²⁰ cm⁻²; Dickey & Lockman 1990).

In Figure 1, we present XMM-Newton spectra of IRAS 00521-7054 for both PN and the summed MOS1 and MOS2 data. It can be seen that the MOS data are consistent with the PN data within the statistical errors. We first fit the 0.5–10 keV spectra with an absorbed power law plus an extra soft component. The soft component could be scattered emission of the intrinsic X-ray continuum, or from the host galaxy. We find that either a power law free from intrinsic absorption (with Γ = 2.4 ± 0.5), a blackbody (with T = 0.21 ± 0.03 keV), or a bremss plasma emission could provide adequate fit to the soft component, and these models are statistically indistinguishable based on current data. Hereafter, we simply choose a blackbody model to fit the soft component. We note that choosing different soft component models would not alter the fitting results in this Letter. This simple continuum model provides a poor fit to the data, with χ² = 368.3 for 287 degrees of freedom. The data to model ratio plot (Figure 1(b)) shows that there is clear residual emission between 3 and 7 keV that could be interpreted as the existence of a relativistic Fe Kα emission line. We then exclude data bins between 3 and 7 keV to fit the continuum and present the plot of data to best-fit model ratio in Figure 1 (panel c) to demonstrate the line profile.

The line appears rather broad, and the red wing extends to as low as 3 keV. We then add a relativistic disk line model (laor in XSPEC; Laor 1991) to fit the broad line (see Figure 1), and the fitting is significantly improved (Δχ² = 58 for four more free parameters). The best-fit line and continuum parameters are listed in Table 1. During the fit, we fixed the line energy at 6.4 keV in the source rest frame, since it is otherwise poorly constrained by the data. The small best-fit inner radius (R_in = 1.8_{-0.8}^{+0.7} r_g) suggests that the central SMBH is fast rotating (fitting with a diskline model for a non-rotating SMBH instead yields larger χ², Δχ² = 9). Furthermore, the line EW is remarkably large (EW = 1.3 ± 0.3 keV in the rest frame). The best-fit inclination of the disk is 37°. Since narrow Fe Kα cores are often seen in the X-ray spectra of AGNs (Yaqoob & Padmanabhan 2004; Shu et al. 2010b, 2011), we added a narrow Gaussian line (with central energy fixed at 6.4 keV in the rest frame, and line width at zero, i.e., unresolved by XMM-Newton PN and MOS spectra) to the fit, and found that such a narrow component is not statistically required in addition to the broad component (Δχ² < 1, EW < 56.0 eV). The reflection component from neutral material, in addition to the underlying power law (pexrav in XSPEC; Magdziarz & Zdziarski 1995), is not statistically required either (Δχ² = 0 and R < 0.8). The normalization of which thus has little effect on the broad Fe Kα line intensity.

We also apply a self-consistent model (kerrconv × reflionx; Brennan & Reynolds 2006; Ross & Fabian 2005) to fit the broad line (see Figure 2), and the best-fit parameters are presented in Table 1. The fitting also suggests that the central SMBH is rotating, with α = 0.97_{-0.13}^{+0.03}. This model produces similar residual χ²/dof compared with the simple laor line model (310.13/283 versus 311.54/280), and consistent

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1 Fitting spectra from two exposures simultaneously yields results consistent with that presented in this Letter, but is rather computer time consuming while adopting complex models.
continuum is fitted with a power law plus a soft blackbody and emissivity index

to the dual-absorber model does not change the underlying continuum caused by more complex absorption.

Below we apply different absorption models to the spectra without including an additional broad emission line component.

We then adopted a dual cold absorber model (with NHI covering 100% of the central X-ray source, and NH2 partially covering the continuum). Interestingly, the dual-absorber model fits the spectra much better (χ2/dof = 319.09/285), however it is still statistically worse than the laor line model (Δχ2 = 9).

In Figure 3(b), we can still see clear residuals at ~6 keV in the data to model ratio plot, compared with the residuals of the best-fit laor and reflionx models (see Figures 3(d) and (e)). Adding a reflection component (pexrav) and/or a narrow Gaussian at 6.4 keV to the dual-absorber model does not change the produced χ2. Replacing either one or both of the cold absorbers with ionized absorption yields consistent results and best-fit ionization parameters at zero, indicating that more complex warm absorption models do not improve the fitting. The best-fit parameters of the dual-absorber model are NHI = 7.0 ± 0.8 × 1022 cm−2 with unit coverage, and NH2 = 21.7 ± 5.6 × 1022 cm−2 with a covering factor f = 0.71 ± 0.06. We also note that the best-fit power-law slope (Γ = 2.8 ± 0.1) appears considerably steep, greater than that of 99.7% of AGNs in a large XMM-Newton sample (Scott et al. 2011).

We note that in our dual-absorber model, all element abundances are fixed to the solar values. By adopting the zvphabs model in XSPEC, we tried to fit the spectra by allowing the

with a spin of α = 0.97 ± 0.03. This is the first measurement of SMBH spin in a type 2 AGN.

4.1. Alternative Models

In this sub-section we investigate whether such an ultra strong and broad Fe Kα line could in fact be due to curvature in the underlying continuum caused by more complex absorption. Below we apply different absorption models to the spectra without including an additional broad emission line component.

A single warm absorber (absori in XSPEC), a partially covering warm absorber, or a partial covering cold absorber model can be easily ruled out because of the much larger χ2 reduced (Δχ2 > 50, compared with the laor line model).

Table 1

Best-fit Parameters of Three Spectral Models

| Number | Model Parameters | Model 1 | Model 2 | Model 3 |
|--------|------------------|---------|---------|---------|
| 1      | zblackbody: KT (keV) | 0.21±0.03 | 0.21±0.03 | 0.21±0.03 |
| 2      | zphabs: Column density, NHI (cm−2) | 5.9±0.6 × 1022 | 6.4±0.1 × 1022 | 7.0±0.8 × 1022 |
| 3      | zpowerlw: Photon index, Γ | 1.8±0.2 | 2.5±0.1 | 2.8±0.1 |
| 4a     | laor: Line energy (keV) | 5.99±0.06 | 5.99±0.06 | 5.99±0.06 |
| 4b     | laor: Emissivity index, q | 3.7±0.4 | 3.7±0.4 | 3.7±0.4 |
| 4c     | laor: Inclination, θ (degrees) | 37±6 | 37±6 | 37±6 |
| 4d     | laor: Inner radius (r) | 1.8±0.7 | 1.8±0.7 | 1.8±0.7 |
| 4e     | laor: Outer radius (r) | 400±400 | 400±400 | 400±400 |
| 5a     | kerrconv: Emissivity index, q | 3.4±0.4 | 3.4±0.4 | 3.4±0.4 |
| 5b     | kerrconv: Inclination, θ (degrees) | 37±4 | 37±4 | 37±4 |
| 5c     | kerrconv: Spin parameter, Ω | 0.99±0.03 | 0.99±0.03 | 0.99±0.03 |
| 5d     | kerrconv: Inner radius, rISCO | 0.00±0.00 | 0.00±0.00 | 0.00±0.00 |
| 5e     | kerrconv: Outer radius, rISCO | 400±400 | 400±400 | 400±400 |
| 6a     | reflionx: Iron abundance | 3.4±1.3 | 3.4±1.3 | 3.4±1.3 |
| 6b     | reflionx: Photon index, Γ | Tied to param3 | Tied to param3 | Tied to param3 |
| 6c     | reflionx: Ionization parameter, ξ (erg cm−2 s−1) | 16.2±2.0 | 16.2±2.0 | 16.2±2.0 |
| 7a     | zpcfabs: Column density, NHI (cm−2) | 21.7±5.6 × 1022 | 21.7±5.6 × 1022 | 21.7±5.6 × 1022 |
| 7b     | zpcfabs: Covering fraction, f | 0.71±0.06 | 0.71±0.06 | 0.71±0.06 |

χ2/dof | 310.13/283 | 311.54/280 | 319.09/285

Figure 2. XMM-Newton spectra of IRAS 00521-7054 with the best-fit reflionx model (Model 2 in Table 1).

(A color version of this figure is available in the online journal.)

4. DISCUSSION

We present the detection of an ultra strong and broad Fe Kα line in Seyfert 2 galaxy IRAS 00521-7054. The X-ray continuum is fitted with a power law plus a soft blackbody emission. The observed 0.5–2 keV and 2–10 keV fluxes are 3.8 × 10−14 erg cm−2 s−1 and 2.4 × 10−12 erg cm−2 s−1, respectively. The absorption corrected 2–10 keV rest-frame luminosity is 3.9 × 1043 erg s−1. The Fe Kα line is rather strong with EW = 1.3 ± 0.3 keV, larger than most broad Fe Kα lines detected in other AGNs (with typical EW of several 100 eV). Spectral fitting suggests that the SMBH in IRAS 00521-7054 is rotating
Fe and Ni abundance to be free parameters, which could likely produce better fit to the strong edge feature at $\sim 7$ keV in the spectra. We found that an overabundance of Fe/Ni (by a factor of $\sim 2.6$) could slightly improve the fit ($\Delta \chi^2 = 2.5$), but is not statistically required, thus the abundance of Fe/Ni cannot be well constrained. This model, however, yields a flatter power-law index ($\Gamma = 2.3^{+0.6}_{-0.5}$), consistent with most AGNs. Figure 3(c) shows the data to model ratio plot for this model, in which weak residuals at $\sim 6$ keV are still visible, compared with the laor and reflionx model. This model (by allowing the Fe and Ni abundance to be free parameters) is still statistically slightly worse than the laor line model (the difference of $\chi^2$ is 6.5 with the same degrees of freedom).

We note that, while the relativistic reflection scenario yields formally a slightly better fit than the double absorption scenario we have presented in this Letter, only follow-up observations with higher spectral resolution and/or larger sensitive energy bandpass would allow us to discriminate between them.

4.2. The Nature of the Ultra Strong Fe Kα Line

Spectral fitting to the broad Fe Kα line suggests that the accretion system is viewed at an intermediate inclination angle of $37^\circ \pm 4^\circ$, in agreement with studies of other type 2 AGNs (Guainazzi et al. 2010). It is interesting to note that Frogel & Elias (1987) reported the detection of broad Hα emission line (with full width at zero intensity of $> 6000$ km s$^{-1}$) in its optical spectrum. This suggests that IRAS 00521-7054 is a Seyfert 1.9 galaxy, consistent with the intermediate inclination angle obtained through X-ray spectral fitting.

The measured broad line shows superb large line EW ($1.3 \pm 0.3$ keV in the rest frame, fitted with a laor line), much larger than most of those previously detected in either type 1 or type 2 AGNs. This is, however compared a different situation with large narrow Fe Kα line EW ($> 1$ keV) reported in Compton-thick AGNs (see Levenson et al. 2006; Liu & Wang 2010). In Compton-thick AGNs, the large Fe Kα line EW is due to strong attenuation to the underlying continuum, and the narrow Fe Kα line, which is produced at a much larger scale compared with the continuum, suffers little or no obscuration. In IRAS 00521-7054, there exists only moderate obscuration to the continuum. Furthermore, the detected Fe Kα line is ultra broad and is believed to be from the innermost region of the accretion disk, thus strong attenuation (if there is any) could not enlarge the line EW.

Theoretical calculations have shown that reflection from a constant density slab which is illuminated with a power-law spectrum could produce the Fe Kα line with EW no larger than $\sim 800$ eV (e.g., Ballantyne et al. 2002). One possible explanation for the observed large EW in IRAS 00521-7054 is the light bending effect. Fabian & Vaughan (2003) reported a similar large line EW (1.4 keV if fitted with a laor line) in MCG 6-30-15 during a low-flux interval, and it can be simply attributed to the strong light bending effect which could (with the X-ray continuum source located closer to the central SMBH) yield weaker observed flux in continuum, but almost constant reflection component. We note that the fitted emissivity index $q$ (see Table 1) is also consistent with that reported in MCG 6-30-15 during a low-flux interval ($3.3 \pm 0.3$). However, it is still puzzling that the line EW in IRAS 00521-7054 remains stably large during two XMM-Newton exposures, while such large EW was rather rare in other AGNs and was only detected in low-flux state in MCG 6-30-15 (Fabian & Vaughan 2003), and in 1H0707-495 (Fabian et al. 2009; Zoghbi et al. 2010; de la Calle Pérez et al. 2010) and IRAS13224-3809 (Ponti et al. 2010).

The reflionx model also yields an overabundance of iron (Fe/solar = $3.4 \pm 1.3$). We note that a similar overabundance in iron was also reported in other AGNs (e.g., Ballantyne et al. 2003; Risaliti et al. 2009; Patrick et al. 2011b). The best-fit spin of the SMBH is $\alpha = 0.97^{+0.03}_{-0.13}$ (90% confidence level), suggesting that the black hole may be maximally spinning.
However, a Schwarzschild solution is still consistent with the data if the 99% confidence level uncertainties are considered (see Figure 4). Higher S/N spectra are therefore desired to understand the nature of the ultra strong and broad Fe Kα line in IRAS 00521-7054.

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