A UNIQUE X-RAY UNABSORBED SEYFERT 2 GALAXY: IRAS F01475-0740

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ABSTRACT

X-ray unabsorbed Seyfert 2 galaxies appear to have X-ray absorption column densities that are too low ($N_{\text{H}} < 10^{22} \text{ cm}^{-2}$) to explain the absence of broad emission lines in their optical spectra, challenging the standard active galactic nucleus (AGN) unification model. In this Letter, we report Suzaku exposure on the X-ray unabsorbed Seyfert 2 galaxy IRAS F01475-0740, in which a hidden broad-line region was detected through spectropolarimetric observation. The X-ray data show rapid and significant variations on timescales down to 5 ks, indicating that we are viewing its central engine directly. A newly obtained optical spectrum and previous optical/X-ray data suggest that state transition is unlikely in this source. These make IRAS F01475-0740 a very peculiar X-ray unabsorbed Seyfert 2 galaxy which can only be explained by absorption from materials with abnormally high dust-to-gas ratio (by a factor of $>4$ larger than Galactic). This is in contrast to most AGNs, which typically show dust-to-gas ratios $3\sim 100$ times lower than the Galactic.

Key words: galaxies: active – galaxies: Seyfert – X-rays: individual (IRAS F01475-0740)

Online-only material: color figures

1. INTRODUCTION

The active galactic nucleus (AGN) unification scenario has been successful in explaining different types of active galaxies (Antonucci 1993). In the unification model, type 1 and type 2 AGNs are believed to be intrinsically the same but viewed from different orientations, and the absence of broad emission lines (BELs) in type 2 AGNs is due to the obscuration by an optically thick structure (dusty torus) from our line of sight. The most convincing evidence supporting the unified model is the detection of polarized BELs in Seyfert 2 galaxies by spectropolarimetric observations (e.g., Antonucci & Olszewski 1985; Tran 2001). X-ray observations also support the unified scenario by detecting typically larger absorption column densities $N_{\text{H}} > 10^{23} \text{ cm}^{-2}$ in type 2 AGNs (e.g., Risaliti et al. 1999).

However, a fraction of Seyfert 2 AGNs were reported to show no or very low X-ray absorption (with $N_{\text{H}} < 10^{22} \text{ cm}^{-2}$; Panessa & Bassani 2002; Hawkins 2004; Brightman & Nandra 2008; Tran et al. 2011), apparently in contrast to the standard unification model. Possible explanations to these “X-ray unabsorbed Seyfert 2” galaxies include the following.

1. They appear “unabsorbed” in X-ray due to contamination from the host galaxy, or a scattering component (e.g., Shu et al. 2010).
2. Weak/absent broad-line regions (BLRs) in low-luminosity or low accretion rate sources (Nicastro & Elvis 2000).
3. State transitions and non-simultaneous X-ray and optical observations, i.e., the absence of BELs could be due to a very low state in the central engine (e.g., Gilli et al. 2000). X-ray absorption was also found to be varying rapidly in some sources (e.g., Maiolino et al. 2010).
4. Extremely high dust-to-gas ratio (or expressed as $E_{B-V}/N_{\text{H}}$ or $A_V/N_{\text{H}}$) compared with the Galactic value. However, this is in contradiction with the observations of Maiolino et al. (2001), who measured $E_{B-V}/N_{\text{H}}$ of $3\sim 100$ times lower than Galactic for obscured AGNs at intermediate and high luminosities.

IRAS F01475-0740 was identified as a Seyfert 2 galaxy at $z = 0.017666$ by Aguerio et al. (1996) with the 2.15 m CASLEO telescope in Argentina. Tran (2001) reported the detection of polarized BELs in IRAS F01475-0740, indicating the existence of a hidden BLR. IRAS F01475-0740 was identified as X-ray unabsorbed based on XMM-Newton observation. Guainazzi et al. (2005) announced that the X-ray spectra observed by XMM-Newton in 2004 showed low X-ray absorption ($N_{\text{H}} = 4.7^{+0.5}_{-0.3} \times 10^{21} \text{ cm}^{-2}$). As noted by Brightman & Nandra (2008), such a low X-ray absorption is insufficient to suppress the optical broad lines unless the absorber has an anomalously high dust-to-gas ratio. They instead proposed that IRAS F01475-0740 is heavily obscured and its X-ray “unabsorbed” appearance is due to a scattering component by the electrons which also scatter broad optical emission lines.

In this Letter, we present a new Suzaku observation on IRAS F01475-0740 taken in 2008 in which we detect significant and rapid X-ray variations on timescales down to 5 ks. Such rapid variations, which were not seen during previous XMM exposure, provide strong constraint to the X-ray absorption nature of IRAS F01475-0740.

2. SUZAKU DATA REDUCTION

IRAS F01475-0740 was observed with Suzaku on 2008 July 14 for a net X-ray Imaging Spectrometer (XIS) exposure time of 57.9 ks (ObsID 703065010). We reprocessed the XIS 0,1,3 data from the unfiltered event files. In this Letter, we focus on XIS data only since IRAS F01475-0740 was non-detected by the Hard X-ray Detector-PIN. All of the data reduction followed the standard procedure illustrated in the Suzaku reduction guide. The most recent calibration released on 2010 November 4 and the analysis software package HEASOFT 6.10 were used.

3 There was no useful data from XIS2 after 2006 November because of a charge leak that occurred, see http://legacy.gsfc.nasa.gov/suzaku/nra_info/suzaku_td.pdf
4 http://heasarc.gsfc.nasa.gov/docs/suzaku/analysis/abc/
We examined the XIS 0.4–2 keV and 2–10 keV images from cleaned event files and find no contamination from nearby sources. This is also confirmed in the XMM image. To extract XIS spectra, we combined the 3 × 3 and 5 × 5 modes for each CCD. The source spectra were extracted from circular regions with radius 3, and the background from larger circular regions excluding the source and avoiding the calibration sources in corners. The response and ancillary response files were finally created using xisrmfgen and xissimarfgen.

3. SPECTRAL FITTING AND RAPID X-RAY VARIATION

In this Letter, the spectra of XIS0 and XIS3 (both are front-illuminated) were always added with addspec and fitted simultaneously with the spectrum of XIS1 (back-illuminated). In the spectral fitting, we chose 0.4–10 keV band for XIS0+XIS3 spectrum and 0.4–8 keV band for XIS1 (due to its much lower effective area at higher energy). The 1.5–2.0 keV spectra were excluded because of calibration uncertainty due to the Si K edge (Koyama et al. 2007). Fitting errors are of 90% confidence level for one parameter ($\Delta \chi^2 = 2.71$). The adopted cosmological parameters are $H_0 = 70\, \text{km s}^{-1}\, \text{Mpc}^{-1}$, $\Omega_m = 0.73$, and $\Omega_\Lambda = 0.27$. During spectral fitting, the Galactic column density along the line of sight to IRAS F01475-0740 is always taken into account ($N_H = 2.32 \times 10^{20} \, \text{cm}^{-2}$; Dickey & Lockman 1990).

The 0.4–10 keV XIS spectra integrated over the whole observation are shown in Figure 1. The spectra were first fitted with an absorbed power law with $\Gamma = 2.23^{+0.08}_{-0.08}$ and $N_H = 73^{+6}_{-5} \times 10^{20} \, \text{cm}^{-2}$. An additional soft component (mekal in XSPEC with $kT = 0.36^{+0.08}_{-0.08} \, \text{keV}$) is statistically required. Such a soft component could be due to emission from the host galaxy or due to a soft excess from the AGN (also see Teng & Veilleux 2010). The narrow iron Kα line was non-detected, and we provide the upper limit in Table 1.

![Figure 1. Suzaku XIS (black for XIS0+XIS3 and red for XIS1) spectra of IRAS F01475-0740. The spectra were binned to 100 counts bin$^{-1}$. The data in 1.5–2.0 keV were excluded because of calibration uncertainty due to the Si K edge. The continuum model is an absorbed power law plus a soft mekal component.](image)

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

| Component | Suzaku | High State | Middle State | Low State | XMM-Newton$^e$ |
|-----------|--------|------------|--------------|-----------|---------------|
| $N_H^a$   | $73^{+6}_{-6}$ | $79^{+5}_{-5}$ | $64^{+13}_{-20}$ | $41^{+11}_{-9}$ | $40^{+4}_{-4}$ |
| $\Gamma$  | 2.23$^{+0.08}_{-0.08}$ | 2.28$^{+0.06}_{-0.07}$ | 2.12$^{+0.20}_{-0.23}$ | 1.96$^{+0.17}_{-0.36}$ | 2.04$^{+0.10}_{-0.09}$ |
| $F(0.5–2 \, \text{keV})^b$ | 5.67$^{+0.45}_{-0.40}$ | 7.50$^{+0.62}_{-0.64}$ | 5.03$^{+0.01}_{-1.12}$ | 2.37$^{+0.59}_{-2.43}$ | 2.77$^{+0.26}_{-0.33}$ |
| $F(2–10 \, \text{keV})^b$ | 18.4$^{+1.0}_{-1.6}$ | 24.6$^{+1.4}_{-1.4}$ | 16.3$^{+2.7}_{-7.1}$ | 6.65$^{+1.4}_{-3.73}$ | 7.70$^{+0.7}_{-1.1}$ |
| EW_{FeKα} (eV)$^d$ | $<64$ | $<58$ | $<510$ | $<503$ | 288$^{+27}_{-267}$ |
| $kT$ (eV)  | 0.30$^{+0.08}_{-0.08}$ | 0.30$^{\text{fixed}}_{\text{fixed}}$ | 0.30$^{\text{fixed}}_{\text{fixed}}$ | 0.30$^{\text{fixed}}_{\text{fixed}}$ | 0.11$^{+0.05}_{-0.15}$ |
| $\chi^2/dof$ | 194/161 | 108/112 | 13/18 | 19/15 | 131/152 |

Notes.

$^a$ Column density of the cold absorber in units of $10^{20} \, \text{cm}^{-2}$.

$^b$ Flux in units of $10^{-13} \, \text{erg cm}^{-2} \, \text{s}^{-1}$.

$^c$ The spectra of XMM-Newton PN/MOS are re-binned to 25 counts bin$^{-1}$.

$^d$ With line central energy fixed at 6.4 keV and width $\sigma$ at 0.02 keV.

We provide the upper limit in Table 1 to its equivalent width by fixing the line width $\sigma$ at 0.02 keV.

![Table 1. Best-Fit Spectral Parameters](image)
variations in both bands and in all three XIS detectors\(^5\) on timescales down to 5 ks. The amplitude of the variation is much larger than the background count rate, thus the rapid variation cannot be due to the variation in instrumental background.

To investigate for spectral variation, we extract X-ray spectra in three time intervals signed high/middle/low state in Figure 2. We fit them separately with the mekal component fixed to the best-fit model of the whole exposure, and the fitting results are given in Table 1. IRAS F01475-0740 was also observed by XMM-Newton in 2004 January. We reprocessed the spectra of PN and MOS as Guainazzi et al. (2005) and the fitting results with the same model are also included in Table 1. We note that XMM fluxes are consistent with Suzaku low state. We saw no significant variation in spectral shape (photon index or absorption) within Suzaku exposure or between Suzaku and XMM observations. This indicates that the rapid X-ray variation is intrinsic and cannot be attributed to variation in absorption as detected in several other sources (e.g., Risaliti 2010). Note that a rapid X-ray variation in IRAS F01475-0740 was also detected during ROSAT PSPC exposure on 1992 July 13. Pfefferkorn et al. (2001) found its ROSAT count rate in the 0.2–2 keV band decreased from 0.064 to 0.021 counts s\(^{-1}\) within 12.9 hr, with the amplitude of the variation similar to Suzaku data.

4. DISCUSSION

We first note that the rapid X-ray variation in IRAS F01475-0740 is unlikely due to contamination from a nearby X-ray source, which must have comparable but variable X-ray flux, and locate close to IRAS F01475-0740 by coincidence. The ROSAT PSPC image obtained in 1992 has better resolution (25\(^{\prime}\) at 1 keV) than Suzaku (1.6). On PSPC image we clearly see a single point source at the position of IRAS F01475-0740 without contamination from nearby sources within 4\(^{\prime}\). The XMM MOS images obtained in 2004 have the best spatial resolution (6\(^{\prime}\) FWHM) in X-ray available for IRAS F01475-0740. Although XMM data revealed no variation (Brightman & Nandra 2008), no nearby sources were detected within 4\(^{\prime}\), and IRAS F01475-0740 remained point-like during the exposure. These indicate that, if there is any nearby source which is responsible for the detected rapid variation during ROSAT and Suzaku observations, either its distance to IRAS F01475-0740 is too small (< 6\(^{\prime}\)) to be resolved by XMM MOS or it could be located at a larger distance (< 25\(^{\prime}\), still unresolvable with ROSAT PSPC though) but totally disappear during XMM exposure. The X-ray source number density with \(f_{2-10\text{ keV}}\) above 1 \(\times\) 10\(^{-12}\) erg cm\(^{-2}\) s\(^{-1}\) provided by the ASCA Large Sky Survey is 0.5 deg\(^{-2}\) (Ueda et al. 1999). This means that the possibility of having another X-ray bright source within 25\(^{\prime}\) of IRAS F01475-0740 by chance is 0.00015. The possibility further drops to 9 \times 10^{-6} for a distance of 6\(^{\prime}\). We also note that the observed luminosity \(L_{2-10\text{ keV}}\) varies from 1.7 to 0.5 \(\times\) 10\(^{42}\) erg s\(^{-1}\) during Suzaku exposure. Such luminosity is too high for an off-nuclear ultraluminous X-ray source (ULX) located in IRAS F01475-0740 (Liu & Mirabel 2005; Liu et al. 2006).

Wang & Zhang (2007) estimated a mass of 10\(^{7.55}\) \(M_\odot\) for the supermassive black hole (SMBH) in the nucleus of IRAS F01475-0740 (deduced from the mass of bulge). For such an SMBH, the observed timescale of rapid X-ray variation (5 ks) corresponds to ~ 70 \(r_g\) (\(r_g = 2GM/c^2\)). This is far smaller than the sizes of the BLR, the torus, and the region of scattering electrons.

The rapid and significant X-ray variation detected in IRAS F01475-0740 thus proves that we were viewing its central engine directly (without significant contribution to X-ray flux from the host galaxy), and the fitted small X-ray absorption column density is physical instead of polluted by emission from host galaxy or scattering/reflection component (e.g., Shu et al. 2010; Brightman & Nandra 2008). The small iron K\(\alpha\) EW and the X-ray to reddening-corrected [O \(\text{III}\)] flux ratio \((f_{2-10\text{ keV}}/f_{[\text{O}\text{III}]}) = 1-3\) are consistent with (e.g., do not oppose) its Compton-thin identity (Bassani et al. 1999). Note that based\(^5\) Fitting each light curve with a constant yields large \(\chi^2 > 230\) for 19 data bins.

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on the $f_{2-10keV}/f_{IR}$ versus $f_{[OIII]}/f_{IR}$ plot. Petrov (2009) also classified IRAS F01475-0740 as Compton-thin with X-ray emission dominated by the AGN process.

In Section 1, we have listed possible explanations for “X-ray unabsorbed Seyfert 2” galaxies. The first of them, i.e., due to contamination from host galaxy or scattering/reflection component in X-ray, can thus be ruled out based on the detected rapid X-ray variation. The second one, i.e., intrinsically weak/lack of BLR in low-luminosity or low accretion rate sources, is not applicable either. This is because that polarized BEL has been detected (Tran 2001). We further note that the luminosity and accretion rate of IRAS F01475-0740 (with $L_{2-10keV} = 0.5-1.7 \times 10^{42} \text{erg s}^{-1}$, $L_{[OIII]} = 5 \times 10^{41} \text{erg s}^{-1}$, and an Eddington ratio of 0.28) can be consistent with those type 2 AGNs with hidden BLR’s detected (Shu et al. 2007; Nicastro et al. 2003). Below we discuss the remaining two possibilities.

4.1. State Transition?

In this section we examine whether there were state transitions in IRAS F01475-0740. We obtained a new optical spectrum with the National Astronomical Observatories, Chinese Academy of Sciences (NAOC) 2.16 m telescope on 2010 July 21. The spectrum with a resolution of 9.6 Å is plotted in Figure 3, in which no broad components of the permit lines were detected.

The detected narrow Balmer decrement is consistent with de Grijp et al. (1992; the number in brackets is from de Grijp et al.): $\frac{H_\alpha}{H_\beta} = 7.21 \ (7.19)$. We convert the Balmer decrement to optical reddening using the formula of Ward et al. (1987): $A_V = 6.67 \times (\log(H_\alpha/H_\beta) - \log(2.85)) \text{mag}$, and obtained an optical extinction $A_V = 2.7$ for the narrow-line region. The reddening to the narrow-line region corresponds to an X-ray absorption column density of $N_{HI} \sim 6 \times 10^{22} \text{cm}^{-2}$ (assuming a Galactic dust-to-gas ratio with $A_V = 4.5 \pm 0.3 \times 10^{-22}N_{HI} \text{cm}^{-2}$; Gorenstein 1975). This indicates that the observed X-ray absorption is only sufficient for the reddening to the narrow-line region assuming a Galactic dust-to-gas ratio.

Alternatively, the absorber in IRAS F01475-0740 could be clumpy, and the low X-ray $N_{HI}$ could be due to lower column density holes in the absorber. However, this is unlikely since while the non-detection of BELs in optical spectra needs almost complete coverage of the absorber to the BLR, consistent low $N_{HI}$ detected by multiple X-ray observations requires the absorber to be quite clumpy (that we have higher chance to view the central engine in X-ray through low column density holes).

Spectral fitting to Suzaku data also indicates that partial covering absorption is statistically not required ($\Delta \chi^2 < 1$).

4.2. Abnormally High Dust-to-gas Ratio

The only remaining possibility is that the absorption material in IRAS F01475-0740 has an abnormally high dust-to-gas ratio. Based on the new optical spectrum we obtained with NAOC 2.16 m telescope, we derived an upper limit to the broad H$\alpha$ to narrow [N$\alpha$] 6583 line flux ratio of 0.14 (assuming the broad H$\alpha$ has an FWHM of 5000 km s$^{-1}$). This upper limit is 180 times lower than the typical value in Seyfert 1 galaxies (Osterbrock 1977). This requires an extra extinction of $A_V > 6.9$ (assuming a Galactic extinction curve) to the hidden broad-line region, in addition to $A_V = 2.7$ to the narrow-line region. Consequently, the dust-to-gas ratio in IRAS F01475-0740 is at least ~4 times larger than the Galactic.

However, such a high dust-to-gas ratio is rather unusual among AGNs. Maiolino et al. (2001) report that while $E_B-V/N_{HI}$ in low-luminosity AGNs (with $L_X \sim 10^{41} \text{erg s}^{-1}$) could be...

6 An Eddington ratio of 0.28 is estimated based on [O III] emission (see Wang & Zhang 2007). Assuming a 10–200 correction factor from 2 to 10 keV to bolometric luminosity (Luo et al. 2010), the Eddington ratio for this object is 0.4–8%.
several times higher than the Galactic, AGNs with $L_X > 10^{42}$ erg s$^{-1}$ have $E_{B-V}/N_H$ lower than Galactic by a factor of 3–100. Note that absorption in AGNs with the dust-to-gas ratio consistent with Galactic were also reported (e.g., Wang et al. 2009). It is interesting to note that the X-ray luminosity of IRAS F01475-0740 ($L_{2–10 keV} = 0.5–1.7 \times 10^{42}$ erg s$^{-1}$) is right on the border between low-luminosity sources with $E_{B-V}/N_H$ higher than Galactic and high-luminosity sources with $E_{B-V}/N_H$ lower than Galactic in Maiolino et al. (2001).

Brandt et al. (1996) proposed that a dusty warm absorber could exist in the quasar IRAS 13349+2438 to explain the lack of X-ray cold absorption in contradiction with strong optical reddening. Several similar cases were later reported (Komossa 1999). To examine whether the absorber in IRAS F01475-0740 is also ionized, we fit the Suzaku spectra with an ionized absorption model warmabs. We find that warm absorption is statistically not required. X-ray absorption edges due to ionized gas or dust were non-detected either in Suzaku or XMM spectra.

We finally note that IRAS F01475-0740 also appears peculiar in the infrared spectrum. It is the only Seyfert 2 galaxy with mid-IR silicate emission in the Spitzer sample of Hao et al. (2007). This makes it more like a type 1 AGN, suggesting smaller dust absorption opacity in IR compared with other Seyfert 2 galaxies. BELs are expected to be detectable in near-IR spectra for absorber with small column density (Lutz et al. 2002). Deep near-IR and optical spectra are essential to detect the reddened BEL and measure the abnormal dust extinction.

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