The study of Seyfert 2 galaxies with and without infrared broad lines

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Abstract From the literature, we construct from literature a sample of 25 Seyfert 2 galaxies (S2s) with a broad line region detected in near infrared spectroscopy and 29 with NIR BLR which was detected. We find no significant difference between the nuclei luminosity (extinction-corrected [OIII] 5007) and infrared color $f_{60}/f_{25}$ between the two populations, suggesting that the non-detections of NIR BLR could not be due to low AGN luminosity or contamination from the host galaxy. As expected, we find significantly lower X-ray obscurations in Seyfert 2s with NIR BLR detection, supporting the unification scheme. However, such a scheme was challenged by the detection of NIR BLR in heavily X-ray obscured sources, especially in six of them with Compton-thick X-ray obscuration. The discrepancy could be solved by the clumpy torus model and we propose a toy model demonstrating that IR-thin X-ray-thick S2s could be viewed at intermediate inclinations, and compared with those IR-thick X-ray-thick S2s. We note that two of the IR-thin X-ray-thick S2s (NGC 1386 and NGC 7674) experienced X-ray transitions, i.e. from Compton-thin to Compton-thick appearance or vice versa based on previous X-ray observations, suggesting that X-ray transitions could be common in this special class of objects.

Key words: galaxies: active – galaxies: Seyfert – infrared: galaxies

1 INTRODUCTION

Spectropolarimetric observations have detected hidden broad emission line regions in many Seyfert 2 galaxies (i.e., Antonucci & Miller [1985]). This kind of S2s can be unified with Seyfert 1 galaxies (S1s) under the unification scheme (Antonucci [1993]), in which the key component is a dusty torus surrounding the nucleus, and different lines of sight (obscured by the torus or not) induce different apparent properties between S1 and S2. Strong evidence supporting the unified model also comes from X-ray observations, which show that most S2s are generally heavily obscured ($N_H > 10^{22}$ cm$^{-2}$) (Risaliti et al. [1999] Bassani et al. [1999]). However, only $\sim 50\%$ of S2s with spectropolarimetric observations show polarized broad emission lines (PBLs) in polarized spectra (e.g. Tran 2001). The visibility of PBLs was found to be dependent on many factors, including intrinsic AGN luminosity, infrared colors, nuclei obscuration, and likely more, and provides valuable information on the physical properties and geometry of the obscuration, scattering region, and the broad emission line region (e.g., Shu et al. 2007 and references therein).

Another efficient way to detect the hidden broad line regions in S2s is near-infrared (NIR) spectroscopy, due to the relatively smaller dust opacity in NIR than in the optical (e.g. see Gordon et al.
of 12 type 2 AGNs, Lutz et al. (2002) found all three objects with detected broad Br α. Detecting NIR broad emission lines in some (but not all) S2s (e.g., Goodrich et al. 1994; Veilleux et al. 1997a; Lutz et al. 2002), providing further support to the AGN unification model. By studying a sample of 12 type 2 AGNs, Lutz et al. (2002) found all three objects with detected broad Br α.

However, careful examinations of other factors which could affect the visibility of NIR BLR have not been performed, and better understanding of the relation between NIR and X-ray obscuration in Seyfert 2 galaxies demands larger samples. In this paper, we construct a large sample of S2s from literature with detected NIR broad emission lines (IRBL S2 hereafter) and those which were not detected (non-IRBL S2), and perform the first systematic comparison. Throughout this paper, we use the cosmological parameters $H_0 = 70$ km s$^{-1}$ Mpc$^{-1}$, $\Omega_m = 0.27$, and $\Omega_\Lambda = 0.73$.

## 2 SAMPLE AND STATISTICAL PROPERTIES

By searching the literature, we collected 25 IRBL S2s. We exclude intermediate Seyferts (Seyfert 1.8, Seyfert 1.9) which will otherwise bias our comparison of obscuration (see §3) since they were defined to be less obscured in the optical, and thus most of them are observable in the near infrared and X-ray. Most of these infrared broad lines are hydrogen recombination lines, i.e., Bracket and Paschen lines, except for one He I 10830 in NGC 1275. The sample and the detected NIR broad emission lines and widths are listed in Table 1. We also list the following in the table for each source: in Cols. (5-6) whether or not polarized broad emission lines were detected and their corresponding references; in Col. (7) IR flux density ratio $f_{\text{f}0\mu m}/f_{\text{f}20\mu m}$, where $f_{\text{f}0}$ and $f_{\text{f}20}$ are directly from NED except for Mrk 477 and 3C 223 whose values are interpollatively or extrapolatively obtained according to their infrared spectrum; column (8-9) X-ray absorption column density and references; column (10-12) reddening-corrected [O III] line flux, luminosity and references. For comparison, we list the sample of 29 non-IRBL S2s in Table 2. LINERs are excluded from the sample.

When calculating the luminosity of [O III] in Table 1 and Table 2, we have applied $F_{\text{cor}}^{\text{[O III]}} = F_{\text{obs}}^{\text{[O III]}}[(\log L_{\text{[O III]}}/\alpha/\beta)_{\text{obs}}/(\log L_{\text{[O III]}}/\alpha/\beta)_0]^{2.94}$ (Bassani et al. 1999) to correct the dust extinction to [O III], where $F_{\text{cor}}^{\text{[O III]}}$ is the extinction-corrected flux of [O III] 5007, and $F_{\text{obs}}^{\text{[O III]}}$ the observed flux of [O III] 5007 with intrinsic Balmer decrement of $(\log L_{\text{[O III]}}/\alpha/\beta)_0 = 3.0$.

### Table 1: Sample of Seyfert 2s with near-infrared broad lines.

| Source       | z  | Width | Ref. PBL Ref. | $f_{\text{f}0}/f_{\text{f}25}$ | $\log N_H$ | Ref. [O III] | $\log L_{\text{[O III]}}$ | Ref. |
|--------------|----|-------|---------------|-------------------------------|-------------|--------------|----------------------------|------|
| 3C 223       | 0.14 | Pao4100 | H96 ? ... | 0.26 22.88 C04 3.88 42.28 P07 |
| F13451+1232  | 0.12 | Pao2588 | V97b ? ... | 2.88 22.65 B04 2.79 42.02 A00 |
| F23498+2423  | 0.21 | Pao3027 | V97b ? ... | 8.51 ... 12.11 43.2 V99 |
| F13305-1739  | 0.148 | Pao2896 | V99 ? ... | 2.95 ... 361.96 44.33 V99 |
| IRAS 08311-2459 | 0.10 | Pao779 | M00 ? ... | 4.53 ... ... ... ... |
| IRAS 15462-0450 | 0.10 | Pao | M09 ? ... | 6.48 ... 6.15 42.19 V99 |
| NGC 6240     | 0.024 | Bro1800 | S08 ? ... | 6.48 24.13 P03 135 42.27 B99 |
| Arp 220      | 0.018 | Bro3300 | D87 ? ... | 13.01 22.48 C02 3.69 40.44 V99 |
| IRAS 14348-1447 | 0.083 | Pao2 >2500 | N91 ? ... | 11.48 21.48 P03 4.53 41.89 V99 |
| NGC 1386     | 0.0029 | Bry | R02 n M00 | 3.74 >24 L06 1020 41.27 S89 |
| NGC 7582     | 0.0052 | Bry3000 | R03 n H97 | 6.62 23.89 P07 369 41.36 S95 |
| Mrk 463E     | 0.057 | Paβ1794.Bry1070 | V97a y | Y96 1.35 23.51 B04 125 42.89 D88 |
| Mrk 477      | 0.058 | Bry1630 | V97a y T92 | 2.71 >24 B99 1240 43.62 D88 |
| NGC 2110     | 0.0078 | Paβ1204.Bry3127 V97a | y M07 | 4.92 22.48 E07 321 41.62 B99 |
| NGC 262, Mrk 348 | 0.015 | Paβ1850.Bry2500 V97a | y D88 | 1.54 23.20 A00 177 41.96 D88 |
| NGC 7674     | 0.029 | Pao3000,Bry3000 | R06 y | Y96 2.79 >24 B05a 193 42.57 D88 |
Bianchi et al. 2005a; B05b: Bianchi et al. 2005b; C02: Clements et al. 2002; C03: Churazov et al. 2003; C04: Croston et al. 2004; Ref. A00: Axon 2000; A06: Awaki et al. 2006; B99: Bassani et al. 1999; B03 Bellamy et al. 2003; B07: Bian et al. 2007; B05a: Bland-Hawthorn et al. 2005; B08: Bland-Hawthorn et al. 2008; Reunanen et al. 2002; R03: Reunanen et al. 2003; R06: Riffel et al. 2006; R94: Ruiz et al. 1994; S08: Sani et al. 2008; S95: Shemmer et al. 2008; S09: Shemmer et al. 2009; Storchi-Bergmann & Pastoriza 1989; T09:Teng et al. 2009; T01: Tran 2001; U00: Ueno et al. 2000; V97a: Veilleux et al. 1997a; V97b: Veilleux et al. 1997b; V99: Veilleux et al. 1999; W93: Warwick et al. 1993, MNRAS; Y96: Young et al. 1996; Y98: Young et al. 1998.

Notes: Col. (1): the source name; col. (2): the redshift; col. (3): the width of NIR broad lines. The letters and number denote the type of lines and their velocities (in unit of km s\(^{-1}\)), respectively; col. (4): the references for the observations of near-infrared broad lines; col. (5): whether have been observed optically polarized broad lines; col. (6): the references for the observations of polarized broad lines; col. (7): the ratio of the flux at 60 \(\mu\)m to the flux at 25\(\mu\)m; col. (8); (9): the hydrogen density by X-ray observations and their references, respectively; col. (10), (11), (12): the reddened corrected [O III] flux density (in units of \(10^{-14}\) erg cm\(^{-2}\) s\(^{-1}\)), [O III] luminosity (in units of erg cm\(^{-2}\) s\(^{-1}\)), and their references, respectively.

| Source        | z     | Width | Ref. | PBL Ref. | \(f_{60}/f_{25}\) | \(\log N_H\) | Ref. | \([O\;III]\) \(f\) | \([O\;III]\) \(L\) | Ref. |
|---------------|-------|-------|------|----------|-----------------|-------------|------|----------------|----------------|------|
| F20460+1925   | 0.18  | Pa2857| V97b | y        | Y96             | 1.55        | 22.40 B99 | 11.2 | 43.02 B99     |             |      |
| F23060+0505   | 0.17  | Pa2194| V97b | y        | Y96             | 2.69        | 22.92 B07 | 99.45| 43.92 B99     |             |      |
| F05189-2524   | 0.042 | Pa2619| V99  | y        | Y96             | 3.98        | 22.83 T09 | 130  | 42.74 L01     |             |      |
| IRAS 11058-1131| 0.055 | Pa7179| V99  | y        | Y96             | 2.4         | >24 U00   | 39.4 | 42.45 Y96     |             |      |
| Mrk 3         | 0.014 | ...   | H99  | y        | M90             | 1.34        | 24.13 B05b| 4610 | 43.27 M94     |             |      |
| Mrk 176       | 0.027 | Pa3129| R94  | y        | M83             | 2.96        | 23.88 G05 | 105  | 42.19 K78     |             |      |
| PKS 1549-79   | 0.15  | Pa1745| B03  | y        | S95             | 2.15        | ...       | 130  | 41.15 H06     |             |      |
| 3C 234        | 0.184 | Pa4100| H96  | y        | Y98             | 0.89        | 23.54 P08 | 20.9 | 43.3 P08      |             |      |
| NGC 1275      | 0.018 | He I 11.08\(\mu\)m |          |           | G01             | 2.11        | 21.08 C03 | 311  | 42.34 B99     |             |      |

Table 2: Sample of Seyfert 2s without the detection of near-infrared broad lines.
Notes: Col. (1): the source name; col. (2): the redshift; col. (3): the references for the observations of near-infrared broad lines; col. (4): whether have been observed optically polarized broad lines; col. (5): the references for the observations of polarized broad lines; col. (6): the ratio of the flux at 60\(\mu\)m to the flux at 25\(\mu\)m; col. (7), (8): the hydrogen density by X-ray observations, and their references, respectively; col. (9), (10), (11): the redden corrected [O III] flux density (in units of \(10^{-14}\) erg cm\(^{-2}\) s\(^{-1}\)), [O III] luminosity (in units of erg s\(^{-1}\)), and their references, respectively.

Ref. A91: Acker et al. 1991; A99: Alexander et al. 1999; A85: Antonucci& Miller 1985; B99: Bassani et al. 1999; B97: Bonatto et al. 1997; C06: Cappi et al. 2006; D88: Dahari & De Robertis 1988; D04: Deluit 2004; D03: Dennefeld et al. 2003; E04: Evans et al. 2004; G05: Guainazzi et al. 2005; H97: Heisler et al. 1997; I08: Itoh et al. 2008, PASJ; K78: Koski 1978; L05: Levenson et al. 2005; L06: Levenson et al. 2006; L01: Lumsden et al. 2001; L02: Lutz 2002; M06: Madejski et al. 2006; M00: Moran et al. 2000; M01: Moran 2001; M94: Mulchaey et al. 1994; N00: Nagao et al. 2000; N04: Nagao et al. 2004; O04: Ohno et al. 2004; O98: Oliva et al. 1998; P06: Pounds 2006; R06: Riffel et al. 2006; R99: Risaliti et al. 1999; R00: Risaliti et al. 2000; Sa07: Sazonov et al. 2007; S07: Shu et al. 2007; S08: Storchi-Bergmann & Pastoriza 1989; S95: Storchi-Bergmann et al. 1995; S97a: Sazonov et al. 2007; T05: Teng et al. 2005; T08: Teng et al. 2008; T91: Terlevich et al. 1991; T92: Tran et al. 1992; T01: Tran et al. 2001; V95: Veilleux et al. 1995; V97a: Veilleux et al. 1997; V97b: Veilleux et al. 1997; V99: Veilleux et al. 1999; X02: Xia et al. 2002; Y96: Young et al. 1996; Z06: Zhang J.S 2006.

In Figure 1 we plot the redshift distribution of both IRBL S2s and non-IRBL S2s. Most of the sources are located at redshift < 0.05, except for several IRBL S2s. K-S test shows that the redshift distributions of IRBL S2s and non-IRBL S2s are statistically different with a confidence level of 99.8%. We attribute this difference to the inhomogeneous nature of the samples (combined from literature).

Various studies had found higher detection rate of PBLs in S2s with higher AGN luminosity (see Shu et al. 2007 and references therein). To investigate whether the visibility of NIR broad emission lines in S2s depends on AGN’s intrinsic luminosity, we plot in Fig. 2 the histogram distribution of reddening corrected L_{[O III]} for IRBL S2s and non-IRBL S2s. We find a weak trend that non-IRBL S2s show lower L_{[O III]}, however the difference is statistically insignificant (K-S test shows the difference has only a confidence level of 90%).

Heisler et al. (1997) found that the visibility of PBL is related to the far-infrared colors and Seyfert 2s with warmer FIR colors (f_{60}/f_{25} < 4) are more likely to have hidden broad lines. Here we also investigate whether the visibility of NIR broad lines in S2s depends on FIR colors. We plot the distributions of FIR colors (f_{60\mu m}/f_{25\mu m}) of IRBL S2s and non-IRBL S2s in Fig. 3, and find no statistical difference between two populations.

The X-ray absorption column densities were collected from literature for two samples. Whenever available, we cite measurements based on Chandra/XMM data which have higher spatial resolution and higher spectral quality comparing with previous data. In Fig. 4 we plot the N_{H} distribution for IRBL S2 and non-IRBL S2, where we can clearly see weaker X-ray obscuration in IRBL S2s. K-S test shows that the difference in N_{H} between two populations is significant at 99% level.

3 DISCUSSION

3.1 IRBL S2s versus non-IRBL S2s

Comparing our samples of IRBL S2s with non-IRBL S2s, we find that while IRBL S2s have significantly higher redshift, their intrinsic AGN luminosity distribution is statistically consistent with non-IRBL S2. The consequence is that the non-detection of infrared broad emission lines in non-IRBL S2s, which are located at even lower redshifts, is not likely due to the detection limit of IR spectral observations. The similar distribution of FIR colors (f_{60}/f_{25}) in two populations and the smaller redshift in non-IRBL S2s (which suggests smaller contribution from the host galaxy for fixed slit width) also suggest that the non-detection of NIR broad emission lines could not be attributed to stronger host galaxy contamination.

Recent studies have suggested that the BLR might be absent in low luminosity and/or low accretion rate AGNs (e.g., Elitzur & Ho et al. 2009). However, the consistent intrinsic AGN luminosity in IRBL S2s and non-IRBL S2s suggest that the non-detection of NIR BLR in our sample was not due to intrinsic absence of BLR, but due to heavy obscuration.
Consistently, we find significantly higher X-ray obscuration in non-IRBL S2s, 66% of which are obscured with column density $> 10^{24} \text{ cm}^{-2}$, while the fraction for IRBL S2s is only 29%. This result is consistent with Lutz et al. (2002), which detected low X-ray absorption in IRBL S2s in a much smaller sample.

We also check the relation between the detection of NIR broad emission line and that of polarized broad emission line in Seyfert 2 galaxies. By matching our sample with spectropolarimetric observations in literature (see Table 1 and 2), we find that PBLs were detected in 14 out of 16 IRBL S2s with both NIR spectral and optical spectropolarimetric observations, but in a much smaller fraction (9 out of 24) of non-IRBL S2. This suggests that the visibility of BLR in NIR spectra and in polarized spectra is connected. Shu et al. (2007) found S2s with PBL have smaller X-ray obscuration. This pattern is consistent with our finding that S2s with NIR broad emission lines have lower X-ray obscuration.

### 3.2 Dust extinction versus X-ray obscuration

The optical dust extinction in AGNs ($E_{B-V}$ or $A_V$) has been compared with X-ray obscuring column densities by many studies, which yield rather large diversity in the observed dust-to-gas ratios. Particularly, Maiolino et al. (2001a) reported $E_{B-V}/N_H$ appears $\sim 3$ to $\sim 100$ times lower than Galactic
in various class AGNs, most of which are Seyfert 1s, quasars and intermediate Seyferts. Maiolino et al. (2001b) attributed the lower $E_{B-V}/N_H$ to several possible mechanisms, including dust distribution dominated by large grains (their most favorable model), metallicity higher than solar which would affect $N_H$ measurements through X-ray spectral fitting, low dust-to-gas ratio, geometry effect, etc (also see Wang & Zhang 2007). On the other hand, dust-to-gas ratio consistent with or even much higher than Galactic value were also reported. For instance, Wang et al. (2009) reported a dust-to-gas ratio consistent with Galactic value in the partially obscured Seyfert galaxy Mrk 1393, while much higher dust-to-gas ratios were reported in some AGNs which could be due to ionized absorber mixed with the dust (see Komossa 1999 for a review).

Taking the large diversity in the ratio of observed dust reddening to X-ray column density, we are not surprised to see significant number of IRBL S2s with large X-ray obscuration (e.g. those with $N_H > 10^{23}$ cm$^{-2}$ in Fig. 4), which were absent from the small sample of Lutz et al. (2002). The possible mechanisms proposed by Maiolino et al. (2001b) could also apply here. We note that the samples we presented are not uniformly selected, since various NIR observations were designed to search for various NIR broad emission lines with different detection limit. A more strict comparison between two populations requires direct measurements of NIR extinction for each detected NIR broad emission line, and lower limits to those non-detected, most of which were unavailable however from literature.

**Fig. 2** The distribution of $L_{[O III]}$ of IRBL S2s and non-IRBL S2s.
However, the detection of IR broad emission lines in those X-ray Compton-thick S2s (with $N_H > 10^{24}$ cm$^{-2}$) is still a puzzle, since the thick X-ray absorption is too large for the detection of NIR BLR (e.g. the detection of Br$\alpha$ implying $N_H < 10^{23}$ cm$^{-2}$ assuming a Galactic extinction curve, see Lutz et al. 2002). The discrepancy can not be solved even assuming a dust-to-gas ratio 10 times lower than Galactic. Dust dominated by large grains could not help either since dust with large grains has a much flatter extinction curve, and does not significantly alter the opacity in NIR (see Fig. 5 of Lutz et al. 2002).

3.3 IR-thin X-ray-thick S2s and their Spectral transitions

For six of IRBL S2 identified as Compton-thick in X-ray (NGC 1386, NGC 7674, Mrk 3, NGC 6240, Mrk 477, and IRAS 11058-1131), we refer them as IR-thin X-ray-thick Seyfert 2 galaxies hereafter. Below we discuss several possible explanations to the discrepancy between the detection of NIR broad lines and Compton-thick X-ray obscuration.

In the view of traditional unification model, this discrepancy can be ascribed to the different emission region of broad emission line and X-ray continuum. These sources could be viewed along the edge of the torus where the absorption along the line of sight to the central engine is still X-ray thick, while
that to the outer part of BLR at larger distances has much lower column density. In this scheme, the column density of the torus smoothly decreases from edge-on to face-on, and these sources (infrared-thin X-ray thick) can only be detected at intermediate inclination angle.

However, the geometry of the torus in AGN is still unclear. The recent view of the unification model has suggested that the obscuring torus is most likely clumpy, instead of smoothly distributed. The evidences come for instance from the IR SED fitting (e.g. Ramos Almeida et al. 2009), and the detection of rapid variation of X-ray absorption in Seyfert 2 galaxies (e.g. Risaliti et al. 2007). In this model, it’s much easier to understand the observed different opacities detected in IR and X-ray band: we could expect that BLR is mainly obscured by Compton-thin medium, with clumpy Compton-thick clouds mixing within it. The typical size of a single Compton-thick cloud must be much smaller than BLR, otherwise one would see consistent $N_H$ inferred from optical/NIR and from X-ray. Nevertheless, considering that NIR BLR have been detected only in a small fraction of Compton-thick S2s, IR-thin/X-ray-thick S2s must be viewed differently from those IR-thick/X-ray-thick ones. Comparing with IR-thick X-ray-thick sources, they could be at certain evolving stage or at intermediate inclination angle when/where the clumpy Compton-thick clouds do exist to block the central X-ray continuum with certain probability, but with too small filling factors to block the whole BLR. In Fig. 5 we present a cartoon diagram to demonstrate the toy model we proposed. If the model is right, we would expect X-ray absorption varia-

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**Fig. 4** The distribution of the hydrogen column densities of IRBL S2s and non-IRBL S2s.
tions in these IR-thin X-ray thick Seyfert 2 galaxies, due to the movement of the compact Compton-thick clouds.

Alternatively, the discrepancy could be due to the facts that IR and X-ray observations were not obtained simultaneously. For instance, sources with central engines fading off might be mis-classified as Compton-thin against their Compton-thin nature, because the observed X-ray spectra could be dominated by reflection component from a much larger scale due to the fading of the direct emission (e.g. Matt, Guainazzi & Maiolino 2003).

Both the later two models we presented above predict or require spectral transitions (i.e. from Compton-thin to Compton-thick or vice versa) for our IR-thin X-ray-thick S2s. By searching previous X-ray observations, we found X-ray spectral transitions in two out of six IR-thin X-ray-thick S2s (NGC 1386 and NGC 7674).

Risaliti et al. (2002) have studied NGC 1386 in X-ray and found it changed from Compton-thin ($N_{\text{H}} = 2.8 \times 10^{23} \text{ cm}^{-2}$) on Jan 25, 1995 to Compton-thick on Dec 10, 1996, which means that the timescale of variation is less than 2 years. This source likely remains Compton-thick till XMM observation in Dec. 2002 (Guainazzi et al. 2005).

Bianchi et al. (2005) reported the hard X-ray flux density of NGC 7674 decreased from $24 \times 10^{-12} \text{ erg cm}^{-2} \text{ s}^{-1}$ in 1977 (HEAO A-1) to $8 \times 10^{-12} \text{ erg cm}^{-2} \text{ s}^{-1}$ in 1989 (GINGA). BeppoSAX in 1996 and XMM-Newton in 2004 also observed this source, with much smaller hard X-ray flux density of 0.75 and $0.70 \times 10^{-12} \text{ erg cm}^{-2} \text{ s}^{-1}$, respectively. Bianchi et al. also presented a spectral transition between GINGA observations (1989) and BeppoSAX/XMM-Newton observations, from transmission-dominated to reflection-dominated. They argued it was likely due to the “switching-off of the central engine in NGC 7674, and the reflection-dominated spectra observed by BeppoSAX and XMM are the delayed emission (with $\sim 15$ years delay) from a reflector at larger distance (such as the inner surface of a torus) although they can not rule out the variation of absorption column density. Here we argue that the transition is more likely due to the variation in absorption based on two reasons: 1) the size of the inner torus radius in Seyfert galaxies is believed to be within several light weeks to several light months (see Suganuma et al. 2006), much smaller than that derived based on X-ray transition ($\sim 15$ years); this means the delayed reflection emission should disappear several months after switching-off and can not last $\sim 15$ years; 2) the broad emission line, which is produced at even smaller distance than the torus and should disappear even faster after switching-off, was detected in near-IR 6 years after the so-called “switching-off” (Riffel et al. 2006).

No X-ray transitions were reported in the rest four IR-thin X-ray-thick S2s. Note Turner et al. (1997) and Awaki et al. (2000) both reported the variability of hard X-ray flux in Mrk 3 within one year. More interestingly, recent Suzaku observation (Ikeda, Awaki & Terashima 2009) suggested Mrk 3 to be viewed at a particular inclination (along the edge of the torus). For NGC 6240, no X-ray transition is observed though there was a flux variability of $\sim 1.7$ factor from 1994 to 1998 (Ptak et al. 2003). Note NGC 6240 is well known because it contains a binary active galactic nucleus (Komossa et al. 2003). For Mrk 477 and IRAS 11058-1131, X-ray observations are rather limited. The available X-ray spectral parameters are from ASCA and BeppoSAX about 20 years ago for Mrk 477 and IRAS 11058-1131, respectively (Bassani et al. 1999; Risaliti et al. 2000).

We finally propose based on our toy model and above observational evidences that IR-thin X-ray-thick S2s are special type of X-ray-thick S2s. They could be viewed at an intermediate angle (i.e., along the edge of Compton-thick torus) comparing with IR-thick X-ray-thick S2s, and might have higher rate to show spectral transitions than other X-ray thick S2s. We note Guainazzi et al. (2005) detected only one transition out of 11 optically selected Compton-thick AGNs. Following up or monitor observations of this particular class of sources could bring valuable informations on the obscuration in AGNs.

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Fig. 5 A cartoon diagram demonstrates why we see IR-thin X-ray-thick S2s, and why they are special. While we observe the central X-ray source (plotted as black dot) through the dusty medium (large blue region) without intervening these Compton-thick clouds (small blue dots), we see them as IR-thin/X-ray-thin, otherwise as IR-thin/X-ray-thick. In the situation that the density (or sky coverage) of the Compton-thick clouds is too high that most of the BLR (red circle) could be blocked by the Compton-thick clouds, we see them IR-thick/X-ray-thick. Besides, such three situations might be an evolving effect, instead of an inclination effect as shown in this cartoon, i.e., the torus evolves with time, and the appearance of S2s depends on the evolving status of the torus, instead of inclination angle.
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