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The Variabilities of the Soft and Hard X-ray Components of NGC 7314 and NGC 7582 and the Distribution of Absorbing Matter in Type II AGNs

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Abstract ASCA observations of the two Type II AGNs, NGC 7314 and NGC 7582, show clear variations in the broad X-ray band (0.4–10 keV) on short timescales $\sim 10^4$s. Spectral analysis indicates that they both have an absorbed hard X-ray component and an unabsorbed soft "excess" component. To clarify the origin of the latter, we made a cross-correlation analysis of the two components. The results show that, for NGC 7314, the soft X-ray variability is proportional to that of the hard X-ray component. This indicates that the active nucleus of NGC 7314 must be partially covered and so the soft emission is a "leaking" of the variable hard component. For NGC 7582, there is no detectable variability in the soft component, although there is a definite one in the hard component. This indicates that the variable nucleus of NGC 7582 must be fully blocked by absorbing matter, and the soft emission is most likely the scattered component predicted by the AGN unified model.

Key words: galaxies: individual (NGC 7314, NGC 7582) — galaxies: X-rays — galaxies: variabilities

1 INTRODUCTION

The unified AGN model (Antonucci et al. 1993) always contains a broad line region (BLR) and a central engine, i.e., a super-massive black hole plus an accretion disk and the difference between the spectral characteristics of type I and type II AGNs is explained as due to our viewing angle: if we observe the system through the putative torus, then we see a type II AGN; if not, then a type I. However, even among type II AGNs, the distribution of absorbing matter along the line of sight may be different for different galaxies because the geometry and density distribution of the different tori may be different. X-ray is an effective means for probing the absorbing matter, because not only all emission above a few keV can penetrate the torus, but

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also the spectral components with different variabilities in the X-ray band come from different emission regions.

The X-ray spectra of type II AGNs generally comprise two power-law components: a soft one and a hard one (Turner et al. 1997), separated by the "break" energy which is around several keV depending on the specific value of the absorption column density along the line of sight for the particular individual galaxy. The hard component on the average has a very similar slope to type I AGNs (Nandra et al. 1997), so it is likely that, in this case, the intrinsic emission from the active nucleus has gone through the putative torus, as predicted by the unified model. In the standard AGN paradigm (e.g. Mushotzky 1993), the soft power-law component is thought to be produced either as a "leakage" of the direct emission through a partial covering of the active nucleus, or as a reprocessed or scattered emission in regions far-away from the active nucleus. Two models, labelled "partial covering" and "scattering", have thus been proposed to explain the origin of the observed soft excess (e.g., Turner et al. 1997). Unfortunately, these two models are numerically equal (see Section 3) and the spectral fit alone cannot tell which scenario is at work in any given galaxy, but this is very important for our understanding of the intrinsic structure, including the pattern of absorbing matter in the line of sight.

In this paper, we propose to diagnose the physical origin of the soft X-ray emission through a cross-correlation analysis of the variations in the soft and hard X-ray bands. For some type II sources where the hard component representing the direct emission can be observed, it should vary as in type I AGNs (Nandra et al. 1997). As for the soft component, it can be either variable or not, depending on their physical origin. Generally, the variations are largely smeared out in the reprocessed or scattered X-ray emissions. Thus, we can deduce whether or not the soft component comes mainly from the same origin as the hard component. Likewise, different variability characteristics may indicate different emission models.

From a well studied ASCA sample of Seyfert II galaxies (Turner et al. 1997), we found that two objects, NGC 7314 and NGC 7582, both of which also belong to the small class of the so-called narrow emission line galaxies (NELGs), appear to have relatively bright and variable X-ray luminosities, so they are selected as the targets in the present study.

2 OBSERVATIONS AND DATA REDUCTION

NGC 7314 and NGC 7582 were observed twice with the ASCA satellite. The first time was on November 14, 1994 for NGC 7582 and November 20, 1994 for NGC 7314, with the two SIS instruments operating in a mixture of Bright and Faint 2-CCD modes. The second was on November 20–22, 1996 for NGC 7582 and May 18–19, 1996 for NGC 7314, with both Solid-state Imaging Spectrometers, SIS-0 (S0) and SIS-1 (S1) operating in 1-CCD Faint mode.

All the data were selected from periods of high and medium telemetry rates. The SIS data were screened using the following criteria: a) data was not taken in the region of the South Atlantic Anomaly, b) the angle between the field of view and the edge of the bright and dark earth exceeded 25° and 5°, respectively, and c) the cutoff rigidity was greater than 4 GeV c^{-1}. After the selection, we further discarded the data if d) there were any spurious events taking place or if the dark frame error appeared abnormal. More details concerning the performance and instrumentation of ASCA have been reported in separate papers (ASCA satellite: Tanaka et al. 1994; SIS: Burke et al. 1991).

The resulting effective exposures of the observation in 1996 are $\sim$ 41400 s for NGC 7582 and $\sim$ 42800 s for NGC 7314. For the SIS data in mixture mode obtained in 1994, the data was treated in BRIGHT (including converted FAINT data) mode, and the resulting effective exposures of the data are $\sim$ 22500 s for NGC 7582 and $\sim$ 38800 s for NGC 7314. For the purpose of this study, we have chosen the dataset obtained in 1996 for both objects.

The ASCA data of NGC 7582 and NGC 7314 did not suffer contamination from any confusing sources. The source counts were extracted from circulars regions of radius $\sim$ 3 arcmin. The background was extracted from source-free regions on the same detectors.

3 SPECTRAL ANALYSIS

We use the combined SIS(0/1) spectra in the energy range of 0.4–10 keV for the two galaxies. The spectra were so grouped that each energy channel contains at least 20 counts, so as to allow the application of minimizing techniques. Spectral analysis was performed using the XSPEC (11) program.

As shown in Figure 1, the X-ray spectra of the two galaxies are modelled with a single power-law absorbing model. The residuals of the fitting clearly indicate the presence of significant "excess" emission that dominates the spectrum below $\sim$ 2 keV for NGC 7582, and $\sim$ 1 keV for NGC 7314. At higher energies, significant residuals at around $\sim$ 6.4 keV indicate the presence of an iron Kα line feature in both galaxies. Considering the physical picture of the unified AGN scheme, we might expect the overall spectrum to be complex and a single power law inadequate: we might see a certain fraction of the (power-law like) primary continuum through heavy obscuration by the putative torus, superimposed with components that represent an indirect central continuum scattered into our line-of-sight, and/or a leakage of the central continuum through a non-uniform (e.g., partially covering) absorber. In addition, hot gas due to starburst activity or in the host galaxy might also make a contribution to the soft X-ray emission. With the observed data it should be possible to explore models of varying degrees of complexity. For the origin of the soft X-ray emission there are several models.

a) Partial Covering Model. In this model, the un-absorbed power law component, which might explain the soft excess, represents a fractional "leakage" of the continuum from a partially obscured central X-ray source. The following expression is then used for fitting the data:

$$I(E) = A[(1-f)E^{-\alpha} + e^{-\sigma(E)N_H}E^{-\alpha}]\,,$$

where σ(E) is the energy dependent photon-electric cross-section and N_H is the intrinsic absorption column density; the absorbed power-law component with photon index α mimics the partially obscured central X-ray source and f is the percentage covering factor; the first power-law represents the "leakage" of the intrinsic continuum, factored by the fraction $(1-f)$.

b) Scattering Model. This model consists of the sum of two power-laws with the same photo index but different absorptions and normalizations. One power law is a direct component absorbed by a highly intrinsic column density, and the other is a scattered component which is free from intrinsic absorption. The "non-absorbed" or scattered continuum mimics the soft excess. This interpretation is supported by the unified model of AGNs (Antonucci 1993), which predicts that the direct continuum of Seyfert galaxies is strongly obscured by a thick torus (Ghisellini et al. 1994), while a part of the nuclear emission is scattered by free electrons surrounding the broad-line region (e.g., Antonucci, Miller 1985; Awaki et al. 1991). Accordingly, the fitting formula here reads,

$$I(E) = A_2E^{-\alpha} + A_1e^{-\sigma(E)N_H}E^{-\alpha}\,.$$

c) Thermal Models, for example: Bremsstrahlung or a Raymond-Smith Model (RS). In these models, it is assumed that the soft X-ray emission is produced by an optically thin, hot plasma associated with the host galaxy, e.g., starburst activities.

Note that although physically very different, models a and b are numerically equal. The normalization ratio of the two power-law components corresponds to the covering factor, $1-f = A_2/A_1$. Thus, the spectral analysis alone cannot distinguish which one of the two is at work.

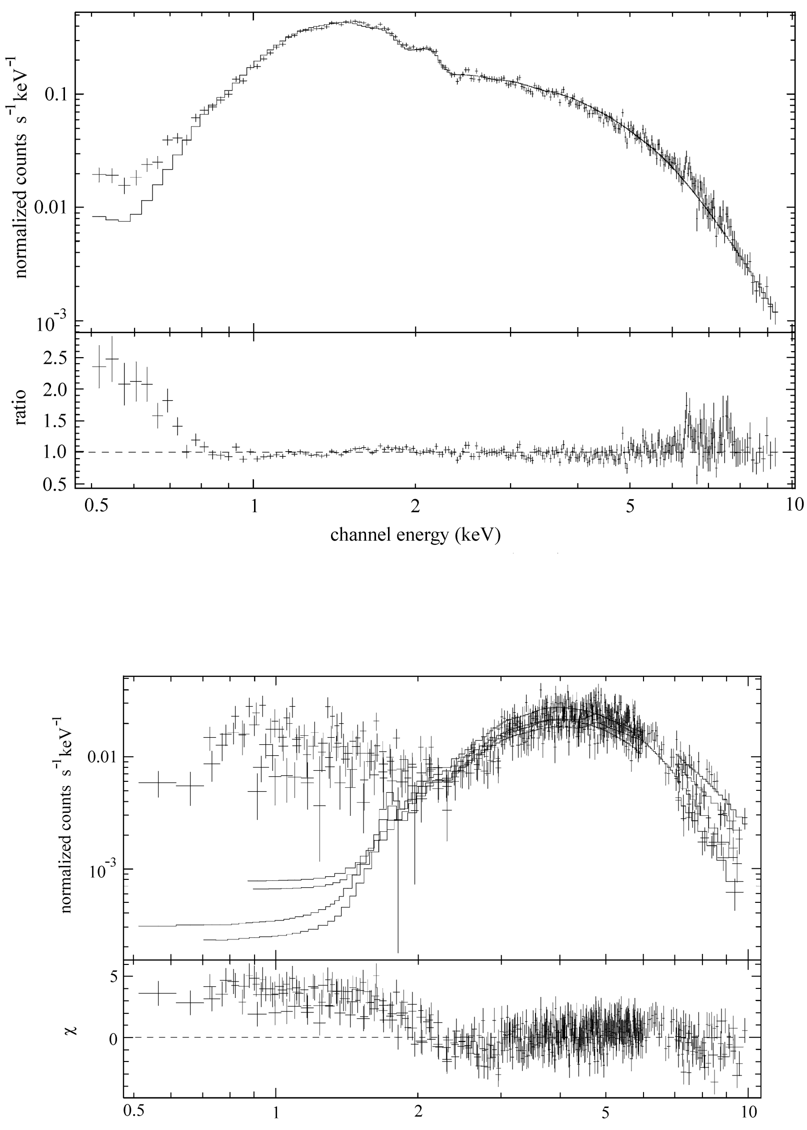


Fig. 1 Folded spectrum of NGC 7582 (upper panel) and NGC 7314 (bottom panel), fitted with one powlaw model. We can see strong soft excess remains after fitting for both galaxies.

From the spectral analysis given in Xue et al.(1998), the best-fit model for NGC 7582 is either a or b, plus c. We applied the same modelling to NGC 7314. The best-fit model we found is the scattering or partial covering plus the RS model: the model parameters are listed in Table 1, and the spectral fit is shown in Figure 2. From the parameters, we can see that for both NGC 7314 and NGC 7582, the thermal component is not the dominant one for the soft emission. The soft emission mainly comes either from partial leakage or from scattering. Although the partial covering and scattering models are numerically equal in the fitting, they imply very different variabilities: in the partial covering model the soft component is expected to show the same rapid variation as the direct continuum; whereas in the scattering scenario it is expected to show no sign of variability. Thus we can differentiate the two physical scenarios by an analysis of the time variations.

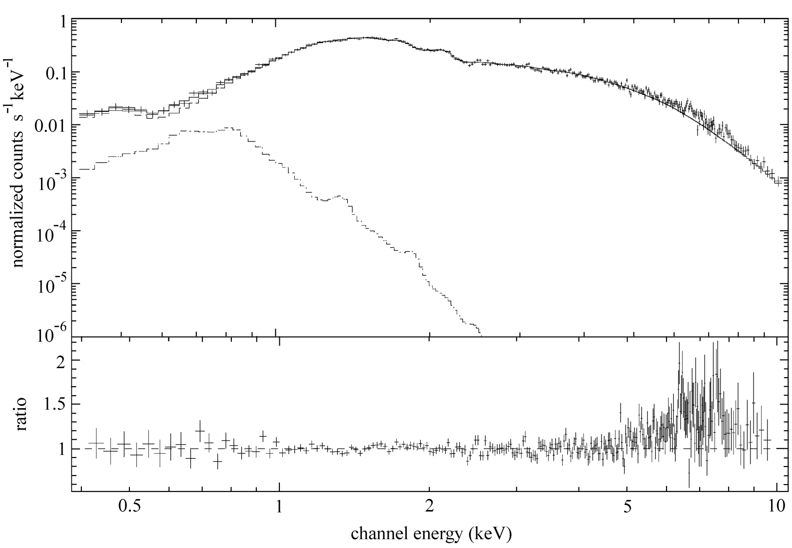


Fig. 2 Folded spectrum of NGC 7314, fitted with the model of "partial covering power-law + Raymond-Smith". The best-fit parameters of this model and flux measurements are listed in table 1 and table 2.

Table 1 The Best Spectral Fit Parameters (Observations in 1994) Partial Covering / Scattering + Raymond-Smith

Dataset	kT [keV]	Abundance [solar]	$N_{\rm H}$ [10^{22} cm^{-2}]	Γ	$A_{\rm s}/A_{\rm p}^{\rm a}$ %	$A_{\rm RS}/A_{\rm s}^{\rm b}$ %	χ^2_ν/d.o.f
NGC 7582	$0.79^{+0.07}_{-0.09}$	$1.4^{+0.5}_{-0.4}$	$12.4^{+0.06}_{-0.08}$	$1.52^{+0.09}_{-0.07}$	$3.3^{+0.3}_{-0.4}$	14^{+5}_{-6}	1.22/162
NGC 7314	$0.19^{+0.08}_{-0.1}$	$1.0^{+0.7}_{-0.8}$	$0.84^{+0.04}_{-0.04}$	$1.90^{+0.06}_{-0.04}$	$2.3^{+0.8}_{-0.8}$	35^{+8}_{-10}	1.01/157

[a] $A_{\rm s}/A_{\rm p}$ = (normalization of the scattered component at 1 keV)/(normalization of the primary continuum at 1 keV)

[b] $A_{\rm RS}/A_{\rm s}$ = (normalization of the RS component at 1 keV)/ (normalization of the scattered component at 1 keV)

4 TIME ANALYSIS

The light curves of each observation were extracted for the SIS spectral instruments in XSELECT (V1.3), with 5760 s (~ 1 satellite orbit) binnings. Then, the same instrumental-type data, SIS 0 and SIS 1 were combined to improve the signal-to-noise ratio. We divided the light curve of each galaxy into the soft and hard bands. Considering that the absorption by the torus is proportional to the column density in the line of sight, for different column densities we have different "break" energies between the soft and hard bands. For NGC 7314 with a given column density about 0.8×10^{22} cm^{-2}, we define the soft band to be $0.4 \sim 1$ keV, while for NGC 7582, whose column density is about 1×10^{23} cm^{-2}, the soft range is $0.4 \sim 2$ keV.

The light curves in the soft and hard bands of the two galaxies are displayed in Figure 3. We find that for both NGC 7314 and NGC 7582, the hard band light curve is significantly variable on a time scale around $\sim 10^4$ s. As for the soft band light curves, the χ^2 probability for the null hypothesis is $\sim 12\%$, and the RMS variation is $\sim 59\%$ for NGC 7314. In contrast, for NGC 7582 there is almost no variability (the χ^2 probability is $=\sim 67\%$). To clarify the relationship between the soft and hard bands, we made a correlation analysis of the soft and hard variations. We found that there is a strong correlation (correlation coefficient ~ 0.7) for NGC 7314, and no correlation for NGC 7582 (correlation coefficient ~ 0.2).

It is worth noting that, since the RS component has a thermal origin and has no relation with the hard component, the variabilities of the RS component and the hard component are not correlated. So, the thermal component will have an effect on the correlation coefficient between the soft and hard variabilities. However, as the thermal emission is not a dominant component, its effect is negligible.

5 DISCUSSION

In the unified AGN model, the pattern of absorbing matter in the line of sight is closely related with the putative torus. First, the absorbing matter is thicker if we look at the central source through the torus than if we look at it directly. Secondly, for different type II AGNs, the line of sight may be inclined at different angles to the central plane, so intercepting different amounts of absorbing matter. Lastly, even for a same viewing angle, the column density encountered may be different for different galaxies, for the torus may have a "patchy" structure, composed of a number of individual, moving dust clouds.

The difference in the soft vs. hard X-ray variabilities between NGC 7314 and NGC 7582 can be explained by a difference in the viewing angle and/or in the structure of the torus. The column density from the spectral fitting is about one order of magnitude greater in NGC 7582 than in NGC 7314. The soft X-ray component in NGC 7314 mainly comes from a leakage of the central source emission; In contrast, for NGC 7582, there is almost no soft component coming from the leakage. It appears that the central source in NGC 7582 is almost fully obscured. The difference between NGC 7314 and NGC 7582 may therefore be explained by two factors. First, although both galaxies belong to type II AGNs and NELGs, the line of sight is inclined at different angles to the plane of the torus in the two cases. Second, the "thickness" of the torus in the two galaxies is different even when viewed from the same angle.

We also compared the two observational runs. The best-fit parameters for NGC 7582 are given in Xue et al.(1998), and those for NGC 7314 for the model of partial covering plus RS are listed in Tables 1 and 2. From a comparison of the confidence contour levels in the spectral slope vs. the intrinsic absorption column density plot of the two observational runs (see Figure 4), we see that there is a clear change in the absorption column of NGC 7582 during the 2-year interval, while there is no such change in NGC 7314. According to the “patchy” torus interpretation, the change in NGC 7582 (Xue et al. 1998) is due to different individual clouds coming into the line of sight during the two year interval.

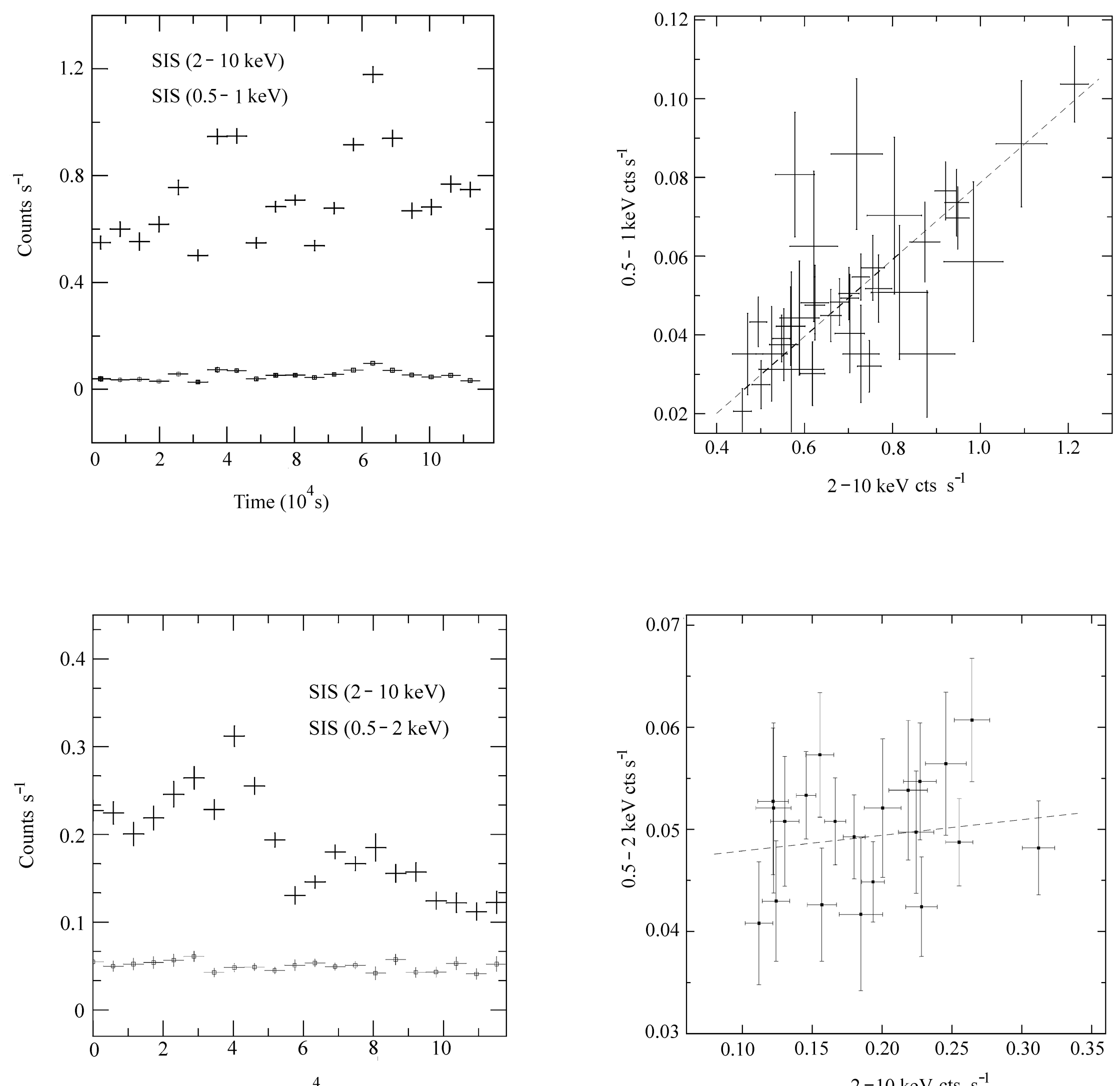


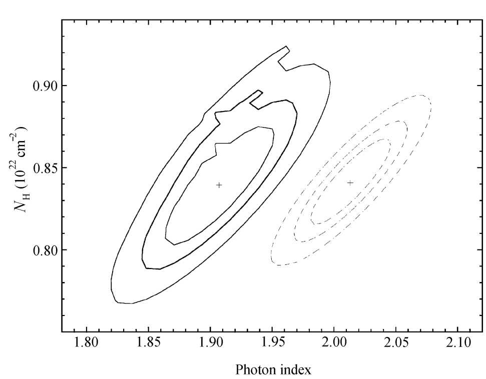
Fig. 3 Comparison of the soft versus hard X-ray variabilities in NGC 7314 and NGC 7582. The hard and soft X-ray lightcurves, as well as the their correlation analysis are shown in the upper panels for NGC 7314, and in the bottom left panels for NGC 7582. A significant correlation exists between the soft and hard X-rays variabilities in NGC 7314, whereas there is none such a correlation in NGC 7582.

Table 2 Flux and Luminosity for the Best-Fit Model of NGC 7314

Dataset	Observed Flux [10^{-13} erg cm^{-2}s^{-1}]			Intrinsic Luminosity† [10^{40} erg s^{-1}]
	0.5–1 keV	2–10 keV	0.5–10 keV	0.5–10 keV♯
1994	$7.64^{+0.27}_{-0.22}$	376^{+27}_{-35}	456^{+32}_{-38}	745^{+45}_{-50}
1996	$4.74^{+0.24}_{-0.21}$	233^{+36}_{-32}	279^{+40}_{-36}	428^{+50}_{-44}

† The absorption corrected. ♯ Assuming $H_0 = 50$ km s^{-1}Mpc^{-1} and $q_0 = 0.5$.

From a comparison of the iron Kα line in the two galaxies, we find that, for NGC 7582, the Kα line is relatively narrow ($\sigma \sim 0.15$ keV), while for NGC 7314, it is much broader. From the analysis in Yaqoob et al.(1996) the Kα line in NGC 7314 is about $5 \sim 7$ keV and it has a more extensive red wing than in NGC 7582. By checking the data shown in Fig. 1, we can find that it also has a more extensive blue wing. The rapid variable component is also found in the Kα line of NGC 7314. Since the broad and variable Kα line is closely related to the accretion disk of the central nucleus, the difference also suggests the "partial covering" in NGC 7314, i.e., we may detect more direct emission from the central source. The comparison also indicates a difference in the pattern of absorbing matter in the line of sight for the two galaxies.



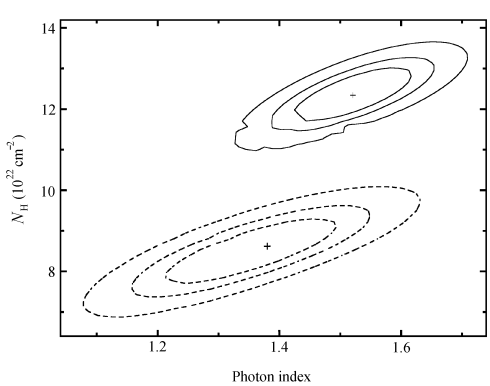


Fig. 4 Confidence contour levels (68%, 90% and 99%) for the spectral slope vs. the intrinsic absorption column density. The upper panel is for NGC 7314, and the bottom is for NGC 7582. The comparison of two observation is shown in one figure for two galaxies respectively. We can see the intrinsic absorption evidently changed in NGC 7582 during the 2-year interval, but in NGC 7314 there is no important variation.

6 CONCLUSIONS

From a cross-correlation analysis of spectral components, we have found that in NGC 7314 the soft band of X-ray has the same variability as the hard band, which means the soft band mainly comes from the same emission source (warm accretion. In contrast, in NGC 7582, the soft band is almost constant in time, which indicates that the soft band and the hard band come from different processes. We can pattern the absorbing matter in the two galaxies accordingly: for NGC 7314 the central source is only partially obscured, while for NGC 7582 the central source is almost completely obscured. Assuming the so called Compton scattering thin regime where the column density is not too large, the high energy X-ray can penetrate the torus, and the variability analysis can be effectively used to figure out the pattern of absorbing matter (in the line of sight) in type II AGNs. It has been shown that in the simple AGN unification model, the inclination factor alone cannot fully account for the diverse properties of type II AGNs and that at least we need to consider a torus with some complex structure.

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