Highlights on Spanish Astrophysics IX, Proceedings of the XII Scientific Meeting of the Spanish Astronomical Society held on July 18 – 22, 2016, in Bilbao, Spain. S. Arribas, A. Alonso-Herrero, F. Figueras, C. Hernández-Monteagudo, A. Sánchez-Lavega, S. Pérez-Hoyos (eds.)

Unveiling the physics of AGN through X-ray variability

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Abstract

Although variability is a general property characterizing active galactic nuclei (AGN), it is not well established whether the changes occur in the same way in every nuclei. The main purpose of this work is to study the X-ray variability pattern(s) in AGN selected at optical wavelengths in a large sample, including low ionization nuclear emission line regions (LINERs) and type 1.8, 1.9, and 2 Seyferts, using the public archives in *Chandra* and/or *XMM–Newton*. Spectra of the same source gathered at different epochs were simultaneously fitted to study long term variations; the variability patterns were studied allowing different parameters to vary during the spectral fit. Whenever possible, short term variations from the analysis of the light curves and long term UV flux variability were studied. Variations at X-rays in timescales of months/years are very common in all AGN families but short term variations are only found in type 1.8 and 1.9 Seyferts. The main driver of the long term X-ray variations seems to be related to changes in the nuclear power. Other variability patterns cannot be discarded in a few cases. We discuss the geometry and physics of AGN through the X-ray variability analysis.

1 Introduction

Historically, active galactic nuclei (AGN) were classified as type 1 when broad Balmer permitted lines are detected in their optical spectra, while they are of type 2 when only narrow lines are detected. Using the relative intensity of the broad and narrow lines, these nuclei can also be classified as intermediate Seyferts as type 1.2, 1.5, 1.8, or 1.9 AGN, the latter having the weaker broad component [13].

The unified model (UM) of AGN [1] tries to accommodate all objects hosting an AGN within the same scenario. While this works for most Seyfert galaxies, the UM is not able to explain the characteristics of, e.g., low ionization nuclear emission line region nuclei (LINER), that were first classified in the optical using diagnostic diagrams, which allows differentiating between Seyfert and LINER [6].

Variability is a property that characterizes AGN at all wavelengths, found for Seyferts in the sixties in the optical, and in the seventies at X-rays [14]. For LINERs, however, the first clear evidence was reported long afterwards at UV frequencies [12]. At X-rays, a few studies have been performed showing that variability is common in LINERs [15, 18, 5]. Because of the much smaller effect of obscuration than at other wavebands – therefore allowing to reach closer to the AGN – we study the variability of these sources at X-ray frequencies. These variations are though to be produced by intrinsic changes of the nuclear power source or by clouds that intersect the line of sight of the observer.

Here we study the variability of these AGN families and compare their properties using a systematic and homogeneous methodology. From this analysis we can differentiate between intrinsic or extrinsic variations and obtain information about the inner structure of AGN.

2 Sample and data reduction

We used the LINERs from the Palomar sample [11] and the sample from [4], and the Seyferts 1.8, 1.9 and 2 from the Véron Cetty & Véron catalogue [17]. We made use of all the publicly available *XMM–Newton* and *Chandra* data and selected those targets with more than one date of observation for the same nucleus. The final sample contains 17 LINERs, 15 Seyfert 1.8/1.9, and 26 Seyfert 2.

Chandra and *XMM–Newton* data were reduced in a systematic, uniform way using standard software analysis packages. Details on the sample selection and reduction can be found in [7, 8, 9].

3 Methodology

XSPEC[1] was used for the spectral fitting. The detailed methodology can be found in [7, 8], a brief summary is provided in the following:

Individual spectral anaysis: Firstly, we selected the best fit model for each data set individually. Six different models were used to fit the data; a thermal model (MEKAL in XSPEC, ME), a power law model (PL) or a composite model using these two simple models (2PL, MEPL, ME2PL, and 2ME2PL). The $\chi^2/d.o.f$ and F-test were used to select the simplest model that best represents the data.

Simultaneous spectral analysis: We simultaneously fitted the spectra for each object with the same model, which was selected from the individual analysis. For each galaxy,

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[1] http://heasarc.nasa.gov/xanadu/xspec/

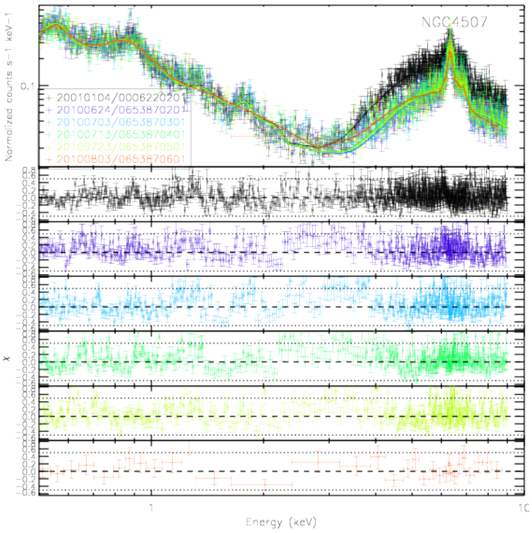

Figure 1: Example of the simultaneous fitting from the NGC 4507 spectra in six epochs with *XMM–Newton* data using the 2ME2PL model. The best fit results in $Norm_2$ and N_{H2} as the variable parameters (SMF2 was used). The legend shows the date (yyyymmdd) and the obsID. The residuals are shown from the second row on.

the initial values for the parameters were set to those obtained for the spectrum with the largest number counts. The simultaneous fit was made in three steps:

0. SMF0 (Simultaneous fit 0): The same model with all parameters linked to the same value to fit every spectra of the same object was used, i.e., representing non-variable sources.
1. SMF1: Using SMF0 as the baseline, we let one parameter (N_{H1}, N_{H2}, Γ, $Norm_1$, $Norm_2$, and kT) vary one-by-one. The best fit was selected as that with the χ^2_r closest to unity that improved SMF0 (using the F-test).
2. SMF2: Using SMF1 as the baseline for this step (when SMF1 did not fit the data well), we let two parameters vary, the one that varied in SMF1 along with any of the other parameters of the fit. The χ^2_r and F-test were again used to confirm whether the fit is improved.

An example of the simultaneous fitting for NGC 4507 is shown in Fig. 1, where six spectra were fitted with the 2ME2PL; the best-fit used SMF2 with the normalization of the power law, $Norm_2$, and the column density, N_{H2}, as the parameters varying.

Flux variability: X-ray luminosities were calculated from the best-fit models in the soft (0.5–2 keV) and hard (2–10 keV) energy bands. UV data from the OM onboard *XMM–*Newton were used when available (simultaneously with X-ray data). In both cases, we assumed an object to be variable when $L_{max} - L_{min} > 3 \times \sqrt{(err(L_{max}))^2 + (err(L_{min}))^2}$.

Short timescale variability: We calculated the normalized excess variance, $\sigma^2_{\rm NXS}$, for each light curve segment with 30-40 ksec following prescriptions in [16].

Compton-thickness: The sources were classified as Compton-thick[2] candidates following the criteria in [2]. Sources showing transitions from Compton-thick to Compton-thin

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[2] Sources with $N_H > 1.5 \times 10^{24} cm^{-2}$.

in different observations were classified as changing-look candidates.

4 Results and discussion

In the following, we summarize the results obtained for the three AGN families separately:

LINERs: Short-term variations are not reported in X-rays. Long-term X-ray variations were analyzed in 13 out of 17 LINERs[3]; about half of them showed variability (8 out of the 13). At UV frequencies, most of the nuclei with available data are variable (five out of six). Thus, 14 LINERs are analyzed at UV and/or X-rays, 11 of which are variable at least in one energy band[4]. This means that variability on long-timescales is very common in LINERs. These X-ray variations are mainly driven by changes in the nuclear power (eight sources), while changes in absorptions are found only for one source (NGC 1052). We do not find any difference between type 1 and 2 LINERs, neither in the number of variable cases, nor in the nature of the variability pattern. We find indications of an anticorrelation between the slope of the power law and the Eddington ratio. The study of LINERs can be found in [7, 8].

Seyfert 2: Short-term variability at X-rays was studied in ten cases, but variations are not detected. From the 25 analyzed sources, 11 show long-term variations; eight (out of 11) are Compton-thin, one (out of 12) is Compton-thick, and the two changing-look candidates are also variable. The main driver for the X-ray changes is related to the nuclear power (nine cases), while variations at soft energies or related to absorbers at hard X-rays are less common, and in many cases these variations are accompanied by variations in the nuclear continuum. At UV frequencies, only NGC 5194 (out of six sources) is variable, but the changes are not related to the nucleus. The study of Seyfert 2 can be found in [9].

Seyfert 1.8/1.9: X-ray short-term variations are detected in six out of the eight studied sources. X-ray long-term variability is found in all the 15 nuclei. None of the sources are classified as Compton-thick candidates, and two of them are classified as changing-look candidates. The main variability pattern is related to intrinsic changes in the sources, which are observed in ten nuclei. Changes in the column density are also frequent, as they are observed in six nuclei. Variations at soft energies are detected in five sources. Variations at UV frequencies are detected in seven out of the nine sources where data were available. The results of this study are in preparation.

The main results of our study of the AGN families are summarized in Table 1. Short-term X-ray variations are detected in Seyfert 1.8/1.9 but not in Seyfert 2 nor LINERs, whereas long-term X-ray variations are common in all the groups. The latter variations are mainly related to changes in the hard nuclear continuum in all cases (i.e., $Norm_2$ is responsible). Changes in the absorption are also observed in Seyfert 1.8/1.9 and 2, but are rather uncommon in LINERs, where these changes were detected only in one source. Variations at soft energies (i.e., in $Norm_1$ or N_{H1}) are only detected in Seyfert 1.8/1.9. At

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[3] We could not analyze the remaining four due to a high fraction of extranuclear contamination in *Chandra* data.

[4] Note that none of the three objects that do not vary in X-rays have available UV data

Table 1: Main results on the variability analysis.

	Seyfert 1.8/1.9	Seyfert 2	LINER
Short-term X-ray	Yes	No	No
Long-term X-ray	Yes	Yes	Yes
Variable	$Norm_2$, N_{H2}	$Norm_2$	$Norm_2$
parameters	$Norm_1$	N_{H2}	(N_{H2} in one case)
Long-term UV	Yes	No	Yes

UV frequencies, variability is detected in LINERs and Seyfert 1.8/1.9 but not in Seyfert 2.

We conclude that the long-term X-ray variations may occur similarly in LINERs, Seyfert 1.8, 1.9 and 2. However, differences are found when comparing the different groups. On one hand, the acccretion mechanism might be different for LINERs and Seyferts; based on the anticorrelation between the spectral index and the Eddington ratio in LINERs, the accretion in these sources could be inefficient, on the contrary to the efficient accretion in Seyferts. In any case, the X-ray variations seem to occur similarly independently of the accretion mechanism. Our results are also suggestive of Seyfert 2s having an obstructed view of the inner parts of the AGN, whereas its view might be unobstructed in LINERs, based on their UV variability. This might be in agreement with theoretical works claiming the disappeareance of the broad line region (BLR) and the torus at low accretion rates [3]. A more detailed comparison between the properties of LINERs and Seyfert 2 can be found in [10].

On the other hand, our results are also suggestive of Seyfert 1.8/1.9 having an unobstructed view of the nucleus, based on the short-term and soft X-ray and UV variations observed in these sources. This behaviour is also observed in Seyfert 1 galaxies, thus we propose that Seyfert 1.8/1.9 are more likely Seyfert 1s. A study on the X-ray and UV variability of Seyfert 1s is needed for a proper comparison. A comparison between the properties of Seyfert 1.8/1.9 and 2 is under preparation.

Acknowledgments

This work was financed by MINECO grant AYA 2010-15169, AYA 2012-39168-C03-01, AYA 2013-42227-P, Junta de Andalucía TIC114 and Proyecto de Excelencia de la Junta de Andalucía P08-TIC-03531. This research made use of data obtained from the *Chandra* Data Archive provided by the *Chandra* X-ray Center (CXC), and from from the *XMM*-Newton Data Archive provided by the *XMM*-Newton Science Archive (XSA).

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