Studying the X-ray/UV Variability of Active Galactic Nuclei with data from Swift and XMM archives

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Many efforts have been made in understanding the underlying origin of variability in Active Galactic Nuclei (AGN), but at present they could give still no conclusive answers. Since a deeper knowledge of variability will enable to understand better the accretion process onto supermassive black holes, here we present preliminary results of the first ensemble structure function analysis of the X-ray variability of samples of quasars with data from Swift and XMM-Newton archives. Moreover, it is known that UV and X-ray luminosities of quasars are correlated and recent studies quantified this relation across 5 orders of magnitude. In this context, we present here some preliminary results on the X-ray/UV ratio from simultaneous observations in UV and X-ray bands of a sample of quasars with data from XMM-Newton archive.

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I. INTRODUCTION

Active Galactic Nuclei (AGN) show flux variations over the entire electromagnetic spectrum. Indeed, variability was one of the first recognized properties of quasars. The variations appear to be aperiodic and have variable amplitude. Although variability plays a key role in constraining the size of the central engine of AGN, its physical origin remains substantially unknown. Many mechanisms have been proposed to explain optical observations, such as supernova explosions, star capture, gravitational microlensing or disk instabilities. Some indication on the nature of variability can be obtained from the analysis of the power spectrum, or the structure function, of single-band lightcurves. Besides the study of individual lightcurves, ensemble properties of statistical quasar (QSO) samples can provide further constrains on the origin of variability.

Rapid X-ray variability is a hallmark of AGN. X-ray short time scale (10^3 – 10^5 s) variability provides evidence that the emission comes from a compact region around the central supermassive black hole. Whereas theoretical studies [1] provide an explanation of the optical-UV radiation from a steady, optically thick, accretion disk, they cannot explain the X-ray emission. In recent years consensus has grown on a standard scenario where UV thermal photons from the disk are Comptonized by hot (T ~ 100-200 keV) electrons in an optically thin corona. This scenario accounts, to a first approximation, for the observed power-law spectrum with a high energy cut-off, and it can also produce the so-called Compton reflection component, including emission lines, with different assumptions about the geometry of the X-ray emitting corona. However, a self-consistent theory of X-ray emission is still missing, and even the global distribution of the radiated energy between X-rays and optical bands, as a function of the total emitted power, is still a subject of debate. This is because the origin of the hot corona and its geometry is far from clear. Magnetic flares, clumpy disks and aborted jets are among the suggested mechanisms to heat the corona (see e. g. [2]. All of these mechanisms are associated with variable and clumpy structures, thus variability itself may provide clues to identify the most appropriate model.

In the optical bands the ensemble analysis on large optical samples (25,000 objects) was made possible by the Sloan Digital Sky Survey (SDSS), and provided a characterization of the dependence of optical variability on luminosity, redshift, wavelength and time delay [3], [4]. A similar analysis has not yet been performed in the X-ray, and now becomes possible thanks to the relatively wide field-of-view of typical X-ray instrumentation, such as those on-board XMM-Newton and Swift satellites, which allow to retrieve field data from individual pointed observations. Two available databases are suitable for this analysis, i.e. the Second XMM-Newton serendipitous source catalogue (XMMSSC) [5], and the Swift XRT Serendipitous Source Catalog [6]. The former is limited, by orbital constraints, to long time scale (several months)
variations and suffers for rather sparse sampling. On the contrary the Swift database provides a sampling at intermediate time-scales (hours to a few months) for a number of objects sufficient to calculate an ensemble SF. To build an ensemble SF of the AGN, it is necessary to ascertain the AGN nature of the X-ray serendipitous sources, excluding possible X-ray emitting stars or galaxies, and to know the redshifts of the sources in order to group all the individual flux variations of different objects in bins of rest-frame time lag. Here we present preliminary results of an X-ray variability analysis of two samples of quasars with optical spectra in the SDSS: we used archival data from the Swift and XMM serendipitous source catalogs to perform a study of the ensemble X-ray variability. We used a structure function (SF) analysis to express a curve of growth of variability with time lag. The index of the power law portion of the SF contains important information on the variability mechanism and could be used to put constraints on emission models. We also merged the data from the two datasets to obtain a combined Swift-XMM SF [see 7, for details].

Moreover, it is known that UV and X-ray luminosities of quasars are correlated and recent studies quantified this relation across 5 orders of magnitude (e. g. [8] and [9]). Such studies inform ongoing efforts to understand the structure and the physics of quasars nuclear regions, providing constraints on models of physical associations between UV and X-ray emissions. Since UV photons are generally thought to be radiated from the accretion disk whereas X-rays are produced in the disk corona, the UV/X-ray luminosity relation is an indication of the balance between accretion disks and their coronae. In this context, we present here some preliminary results on the X-ray/UV relation from simultaneous observations in UV and X-ray bands of a sample of quasars with data from XMM-Newton archive [see [10, for details].

II. X-RAY VARIABILITY

A. Struction Function (SF)

The ensemble statistic on a large sample of objects together with the spread in rest-frame time, caused by the redshift distribution of the sample, allows an accurate characterization of variability through the study of the dependence of the ensemble structure function (SF):

$$SF(\tau) = \sqrt{\frac{\pi}{2}}\left[\log F(t + \tau) - \log F(t)\right]^2 - \sigma_n^2$$

on luminosity, redshift, time lag $\tau$ and wavelength, where $\sigma_n$ is the contribution of the noise to the r.m.s. logarithmic flux changes and the angular brackets indicate the ensemble average over appropriate bins of time lag and $F$ is the flux [3, 11].

B. Data

The Swift mission was specifically designed to sample the X-ray afterglow of gamma-ray bursts (GRBs) on time scales from hours to months. A catalog of serendipitous X-ray sources in the deep fields centered on GRBs (The Swift-XRT GRB Deep Field Serendipitous Survey)
FIG. 2: Ensemble Structure Function (SF), in the rest-frame, for the XMM sample. The Figure shows both the noise subtracted SF (blue line) and noise unsubtracted SF (black line). The photometric noise was evaluated in the first bin and subtracted in quadrature [11] to obtain the noise subtracted (blue line) SF. The black dots are the contributions to the SF from the individual source lightcurves. The dashed line is the linear fit of the SF.

is being completed at ASDC [6]. These observations make up an unbiased X-ray survey since GRBs explode at random positions in the sky. To date the catalog contains ~ 7000 serendipitous sources with fluxes down to ~ $10^{-15} \text{erg cm}^{-2} \text{s}^{-1}$ in the 0.5-10 keV band and ~ 800 down to $5 \times 10^{-14} \text{erg cm}^{-2} \text{s}^{-1}$. We cross-correlated this catalog with the spectroscopic catalog provided by the SDSS, Data Release 7 [12], in order to build a sample of confirmed quasars. We found 27 confirmed quasars with enough sampling (at least, 100 photons in the lightcurve) to be used in the following SF analysis. Hereafter, we will refer to this sample as Swift sample.

To have a second confirmed quasars sample, we cross-correlated the repeated X-ray observations in the updated incremental version 2XMMi of the Second XMM-Newton Serendipitous catalogue (XMMSSC) with the SDSS Quasar Catalog, Fifth Data Release [13]. This results in 272 quasars. Hereafter, we will refer to this sample as XMM sample. The 2XMMi catalogue contains information for 192,000 serendipitous XMM sources, 27,000 of which possess lightcurves and time-dependent spectra.

C. Data Analysis and Results

Figure 1 shows the results from the SF analysis on the Swift sample, whereas Figure 2 shows the results from the SF analysis on the XMM sample. The figures show both the noise subtracted SF (blue line in both figures) and noise unsubtracted SF (red line in Figure 1) black line in Figure 2 and 3. The photometric noise dominates the first bin and was subtracted in quadratu-
ture [11] to obtain the noise subtracted (blue line) SFs. The red and black dots are the contributions to the SF from the Swift and XMM individual source lightcurves, respectively. The linear fits of the SFs give the slopes $\beta = 0.11 \pm 0.03$ (Swift sample) and $\beta = 0.17 \pm 0.02$ (XMM sample).

Figure 3 shows the results from the SF analysis on the combined Swift-XMM datasets. The linear fit of this combined SF gives a slightly flatter slope ($\beta = 0.08 \pm 0.02$) than in the two separated samples. The slope of the SFs can be related to the slope $\alpha$ of the power spectrum (PDS) [see for details 14, $\alpha = 1 + 2\beta$]. We found that the slopes of the SFs are consistent with the PDS slopes computed on single object lightcurves ($1 \lesssim \alpha \lesssim 2$), although smaller than the average PDS slope ($\alpha_m = 1.55$) [15].

III. X-RAY/UV RATIO

A. The dataset

We used TOPCAT to build a sample of objects with simultaneous UV-X-ray observations, matching the Second XMM-Newton Serendipitous catalogue XMMSSC with the XMM-OM Serendipitous Ultra-Violet Source Survey (SUSS), a catalog of UV sources serendipitously detected by the Optical Monitor on board XMM-Newton. Among them we selected a sample of confirmed quasars in the SDSS Quasar Catalog, Fifth Data Release [13]. The sample consists of 209 radio-quiet quasars with no Broad Absorption Line (BAL). Among them 44 quasars have repeated observations (up to 9).

B. Data analysis and preliminary results

The relationship between the X-ray and optical/UV luminosity of AGN is usually described by the slope of an hypothetical power law between 2500 Å and 2 keV rest-frame, $\alpha_{ox} = 0.3838 \log(L_X/L_{UV})$, where $L_{UV}$ and $L_X$ are the specific luminosities at 2500 Å and 2 keV, respectively. The XMM-OM SUSS catalog provides for each source one or more specific fluxes (up to 6). We computed an Optical-UV SED for each source. The results are plotted in Figure 4. We used these SEDs to evaluate $L_{UV}$, whereas we estimated $L_X$ from the integrated flux in the band 4 (2-4.5 KeV), available in the XMMSSC catalog. Details on the calculation of the specific luminosities will be found in [10]. Figure 5 shows the $\alpha_{ox} = L_{UV}$ anticorrelation in our sample. The dashed line represents the linear fit of the data, giving $\alpha_{ox} = (-0.200 \pm 0.013) \log L_{UV} + (4.440 \pm 0.390)$. The slope is steeper than those provided by [8, 17], but it is in good agreement with the recent results from [9]. We found the scatter in the data to have the same order of magnitude reported by [9].

IV. CONCLUSIONS

We produced the first ensemble SFs of AGN in the X-ray band using data from the Swift and
FIG. 5: The Figure shows the $\alpha_{\text{ox}} - L_{UV}$ anticorrelation. Black open circles refer to sources with single-epoch data, whereas colored data refer to sources with multiepoch observations. The blue line represents the linear fit of the data.

XMM-Newton archives. The slopes of the ensemble SFs are consistent with those provided by PDS analyses, although flatter than the average value found in [15].

We presented the first attempt to use simultaneous UV and X-ray observations to study the $\alpha_{\text{ox}} - L_{UV}$ relation using XMM-Newton observations. We found a steeper slope than many precedent works [e.g. 8, 17], but in agreement with a recent study [9]. Since the scatter in the data has the same order of magnitude reported by [8], we could suppose that variations within a same object and from object to object are more important than the simultaneity of the X-ray/UV data.

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