A characterization of the NGC 4051 soft X-ray spectrum as observed by *XMM*-Newton

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1. Introduction

It is commonly accepted that the center of active galaxies (Active Galactic Nuclei -AGNs) hosts a massive black hole (with a mass in the range $10^6 - 10^9$ M$_\odot$) accreting the surrounding material via the formation of a disk. How the energy released from the central engine interacts with the local environment and contributes to the history of the host galaxy is one of the crucial question of present astrophysical research. In this respect, while the mechanisms of energy output in the form of radiation and relativistic jets are quite well understood, it also seems that the outflowing winds have an important role in the overall energy budget. Although the origin of these winds is still controversial, at our present level of understanding the narrow-line regions, the inner part of an obscuring torus [1] and the black hole accretion disk [2] are all possible locations.

X-ray obscured AGNs (with an intrinsic column density $N_H \gtrsim 10^{22}$ cm^{-2}) are not completely dark in the soft X-ray band. High resolution *XMM*-Newton and Chandra observations revealed a complex spectrum dominated by emission lines from He-and H-like transitions of elements from carbon to neon as well as by L-shell transitions of Fe XVII to Fe XXI ions [3–6]. This gas, which shows the signature of a photoionization process [4,7], is sometimes referred to as a warm mirror.

In unobscured AGNs a modification of the output energy spectrum may also occur as a consequence of absorption by a warm ionized gas along the line of sight. The properties of these so called warm absorbers can be summarized as follows: i) average ionization parameter in the range $\log \xi = 0-3$, ii) total column density in the range $\log N_H = 21 - 22$ cm^{-2}, iii) outflow velocities of hundred of km s^{-1} (see e.g. [8]). Evidence of a multi-phase warm absorber gas was also recently reported for Mrk 841 ([9]).

In general, detecting warm mirror signatures is easier in sources in low flux states, because the emission features are not outshone by the continuum radiation. This was the case for the Seyfert 1 galaxy Mrk 335, whose soft X-ray spectrum resembled the spectra of obscured AGNs when the source was observed at low state ([10]), but does not show any evidence of a warm absorber in the high flux state ([11]).

The overall properties of the warm mirror (even if it is poorly constrained) and the warm absorber (as described above) are similar so that there is the possibility that they represent the same physical system. Conversely, the interplay between the warm absorber and warm mirror regimes is best studied in sources that display both components.

In this work, we examined in details the soft X-ray spectra of NGC 4051 as obtained by the *XMM*-Newton gratings. Each of the detected emission line (see Fig. 1) was fitted by a Gaussian profile in order to get the relative intensities among the features.

The results obtained from this phenomenological study allow us to highlight some considerations on the physical conditions of the X-ray emitting gas in NGC 4051. Indeed, a value of the G ratio higher than 4 is a strong indication of a photoionized gas. An estimate of the gas electron density n_e can be done when the other two line ratios L and R are taken into account. In the particular case of the O VII triplet line ratios quoted above, the electron density is constrained to be $n_e \lesssim 10^{10}$ cm^{-3} for a pure photoionized gas. Note however that the line intensities obtained from the phenomenological study described above do not account for a warm absorber, which is not taken into account in the model.

An additional constraint on the electron density value can be obtained noting that the *XMM*-Newton observation of NGC 4051 in its low state occurred ~ 20 days after the source entered this

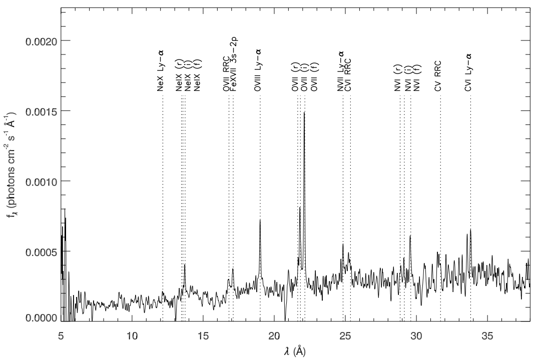

Figure 1. Fluxed RGS spectrum of NGC 4051 (low state). The first order spectra of the two RGS cameras were combined and the resulting spectrum smoothed with a triangular kernel. The identified lines are labeled with the corresponding ion transition name and vertical dashed lines (the big dips at $\simeq 13$ Åand $\simeq 21$ Åin this plot are due to CCD gaps).

regime. Because the O VII triplet line intensity is consistent with that measured during high flux states, it is believed that the recombination time of the O VII is larger than 20 days,thus implying (for a gas temperature of $\simeq 10^4$ K) a more stringent constraint on the electron density of $n_e \lesssim 10^5$ cm^{-3}.

A deeper analysis has been performed by using the photoionization code Cloudy ([12]). We assumed a plane parallel geometry with the central engine shining on the inner face of the cloud surrounding the NGC 4051 black hole with a flux density depending on the ionization parameter U. Assuming the standard AGN continuum described above, we generated a grid of reflected spectra from a photoionized nebula, varying the ionization parameter $\log U$, the electron density $\log n_e$ and the total column density $\log N_H$. The free parameters spanned the ranges $\log U$=[-1.0,4.0]; $\log(n_e/\mathrm{cm}^3) = [2, 12]$ and $\log(N_H/\mathrm{cm}^2)$=[19,24] in steps of 0.1 dex, respectively. Additive and multiplicative fits tables were generated to account for both the emission and absorption features.Our final model can be described by the formula $phabs * mtab(n_e, N_H, U) * \{\sum atab(n_e, N_H, U)\}$. We recursively increased the number of Cloudy additive components until this operation resulted in a statistically significant improvement of the fit quality. The analysis carried out in this paper allowed us to identify two ionization states for the line emitting gas and one warm absorber medium. It is interesting to note that

- The X-ray emitting region can be placed at a distance of $r \gtrsim 0.05$ pc. - We found a lower limit of the warm absorber distance $\simeq 0.02$ pc, i.e. at least a factor 10 larger than that measured in the high state flux.

We address the reader to the original paper ([13]) for further details on the analysis.

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