# VOSPEC AND HIGH-RESOLUTION X-RAY LINE CATALOGUES

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## ABSTRACT

X-ray data with high-resolution in the spatial and energy domains are crucial to derive the geometrical distribution and the physical properties of gas and dust surrounding Active Galactic Nuclei (AGN). We present in this paper *CIELO-AGN*, the first catalogue of ionised emission lines detected in the soft X-ray spectra of a sample of 69 nearby obscured AGN. This catalogue has been implemented according to an IVOA Data Model, and can be accessed through VO-compatible applications. The results extracted from CIELO support the scenario, whereby the active nucleus is responsible for the X-ray "soft excess" almost ubiquitously observed in nearby obscured AGN via photoionization of circumnuclear gas.

Key words: Virtual Observatory.

## 1. INTRODUCTION

Gas and dust in the innermost kilo-parsec around core supermassive black holes in Active Galactic Nuclei (AGN) play a key role in the AGN phenomenological appearance. AGN structure models are crucial in our understanding of the accretion processes ultimately responsible for the tremendous energy output in these objects. In its most extreme versions, they postulate that the bulk of orientation effects in AGN are due to either an azimuthally-symmetric static and compact pc-scale dusty gas systems (the "torus" of the standard Seyfert Unification scenarios; Antonucci & Miller, 1985; Antonucci, 1993), or to high-velocity gas outflows, originating from instabilities in the accretion disk and pushed outwards by the AGN radiation pressure (Elvis, 2000). It is likely that these two systems coexist, and their nature and origin are intimately linked (Elitzur, 2006).

X-rays represent a privileged bandpass where one can study the properties of AGN nuclear matter. Gas and dust leave clear spectral signatures in AGN X-ray spectra, either through absorption features - narrow-band atomic transitions, or continuum photoelectric obscuration - or through reprocessing of the nuclear primary continuum. In both cases, observations with the highest possible resolution, both in the spatial and in the energy domain, are crucial. In this paper, we will concentrate on clues on AGN structure models, obtained by studying reprocessing features. Since the study of reprocessing features is best carried on in AGN, where the primary continuum radiation is suppressed by large obscuration, we will focus on this class of sources.

## 2. HIGH-RESOLUTION IN THE SPATIAL DOMAIN

In the *spatial* domain the sub-arcseconds resolution of the *Chandra* optics led to the discovery of soft X-ray extended emission on scales as large as hundreds of parsecs in several nearby obscured AGN (Smith & Wilson, 2001; Yang et al., 2001; Sako et al., 2000; Bianchi et al., 2006). The soft X-ray morphology is remarkably well correlated with the Narrow Line Regions (NLRs), as traced by higher resolution HST O[III] images (see e.g. Fig. 1). The observed optical to X-rays Spectral Energy Distributions are consistent with AGN photoionization, provided that the ionisation parameter remains almost constant across the whole X-ray emission extension. This implies an electronic density radial profile $n_e \propto r^{-\beta}$, with $\beta \simeq 1.8$–$2.0$, confirming independent outcome of optical line ratio diagnostics (Kraemer et al., 2000; Bradley et al., 2004; Collins et al., 2005).

## 3. HIGH-RESOLUTION IN THE ENERGY DOMAIN

Thanks to the unprecedented sensitivity and *energy* resolution of the grating detectors on-board *Chandra* and XMM-Newton, it is now possible for the first time to perform true spectroscopy of the reprocessed emission. Soft X-ray spectra in obscured AGN are dominated by He- and H-like transitions of metals from Carbon to Nitrogen, as well as by L-shell transitions from FeXVII to FeXXI (Sako et al., 2000; Sambruna et al., 2001; Kinkhabwala et

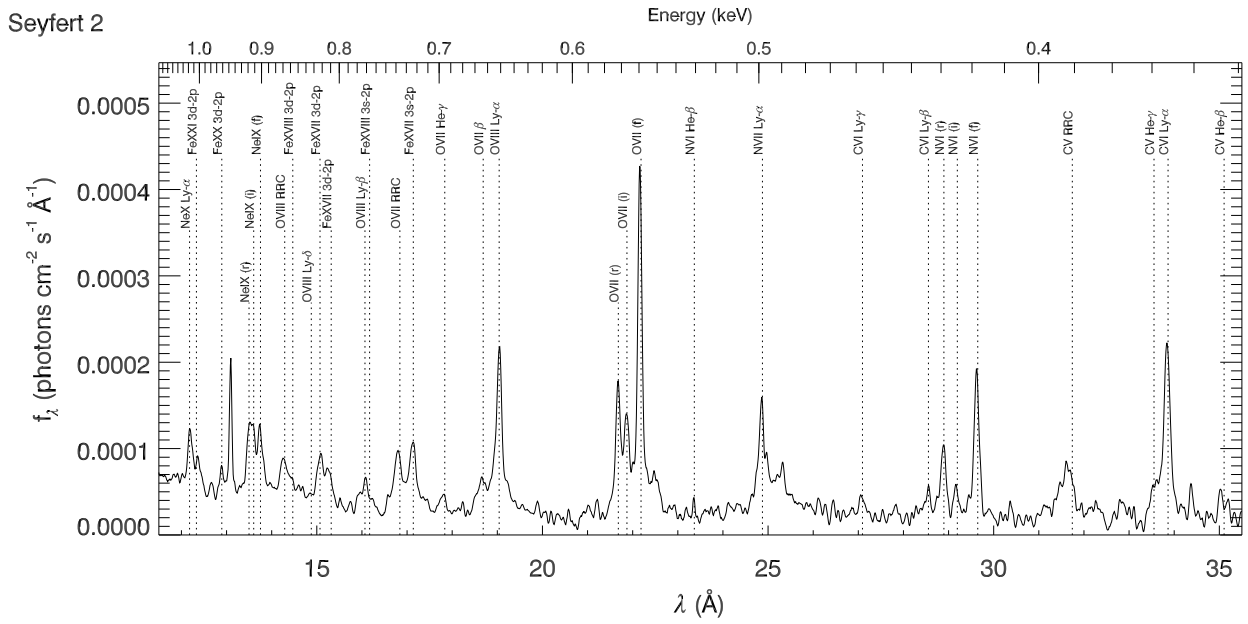


*Figure 2. Stacked XMM-Newton/RGS fluxed spectra of 33 objects included in CIELO-AGN, whose total counts in the soft X-ray band are between 250 and 2500. The total exposure time is about 2 Ms. Spectra of the two RGS cameras have been merged and smoothed with a 5-channels wide triangular kernel for illustration purposes only. The positions of the line transitions measured in CIELO-AGN are labelled.*

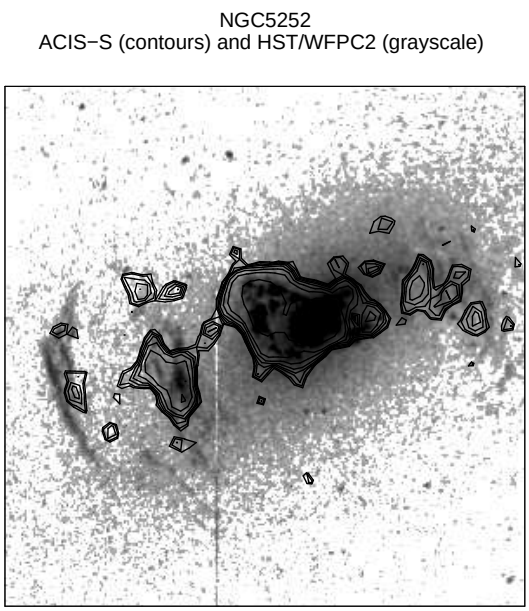


*Figure 1. Soft X-ray (0.2-2 keV) ACIS/Chandra image of NGC 5252 (contours), superposed to the HST/WFC2 O[*III*] filter image (greyscale). The dimensions of the image are 30'x30'.*

al., 2002). The detection of narrow Radiative Recombination Continua (Liedahl et al., 1995) features, the large intensity ratio between the forbidden component of the OVII Ly-$\alpha$ triplet and the OVIII Ly-$\alpha$, and the large integrated line luminosity ($L \gtrsim 10^{40}$ erg s$^{-1}$) indicate again that the AGN radiation field is the most likely culprit for the gas ionisation balance (Guainazzi & Bianchi, 2006). This conclusion can be achieved only through measurements at the highest possible spectral resolution currently available. In Fig. 2 we show the stacked spectrum of the sources with most counts in our catalogue, taken with the high-resolution RGS cameras ($E/\Delta E \sim$300; der Herder et al., 2001). Despite of the much larger collecting area of the EPIC cameras, their moderate energy-resolution ($E/\Delta E \sim$15; Strüder et al., 2001) irremediably blurs line features. Indeed, the CCD soft X-ray spectra of obscured AGN can be equally well fit by different scenarios (Turner et al., 1997; Guainazzi et al., 1999), some of them totally ruled out by the high-resolution spectroscopic measurements (Brinkman et al., 2002).

## 4. CIELO-AGN: A HIGH-ENERGY ASTRONOMY VO-COMPLIANT RESOURCE

### 4.1. The catalogue

The spectroscopic results on a sample of 69 obscured AGN observed by XMM-Newton have been compiled in **CIELO-AGN** (*Catalogue of Ionised Emission Lines in Obscured AGN*, Guainazzi & Bianchi, 2006). The

main conclusions of this study can be summarised as follows: a) narrow Radiative Recombination Continua are detected in about 36% of the objects in our sample (in 26% their intrinsic width is $< 10$ eV); b) higher order transitions are generally enhanced with respect to pure photoionization, indicating that resonant scattering plays an important role in the ionization/excitation balance. These results support the scenario, whereby the active nucleus is responsible for the X-ray "soft excess" almost ubiquitously observed in nearby obscured AGN via photoionization of circumnuclear gas. They confirm on a statistical basis the conclusions drawn from the detailed study of the brightest spectra in the sample. Furthermore, we propose a criterion to statistically discriminate between AGN-photoionized sources and starburst galaxies, based on intensity of the forbidden component of the OVII He-alpha triplet (once normalized to the OVIII Ly-alpha) coupled with the integrated luminosity in He-like and H-like oxygen lines.

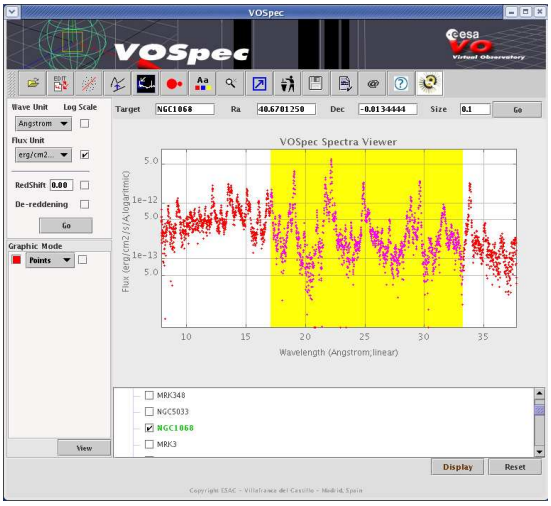


*Figure 3. Main* vospec *window. The XMM-Newton/RGS spectrum of NGC 1068 (retrieved through a Simple Spectral Access Protocol compliant server), is shown.*

### 4.2. The VO implementation

CIELO-AGN has been implemented in compliance to a Virtual Observatory data model, which is being developed in the framework of the International Virtual Observatory Alliance: the *Atomic and Molecular Data Model* (Dubernet et al., 2007). The Model is organised around the concept of LINE, defined as the results of a transition between two states. This definition encompasses also free-bound transitions. Each transition is defined through the pair of LEVELS between which it occurs. In turn the LEVELS are characterised by the attributes of the SPECIES to which they belong, and by one (or more) QUANTUMSTATE. The latter is characterised by a proper set of QUANTUMNUMBERS. Any processes which modify the intrinsic properties of a LINE (monochromaticity, laboratory wavelength etc.) is described through the attributes of the PROCESS class, which allows also to describe the nature of the process responsible for the line generation. The class ENVIRONMENT allows server providers to list physical properties of the line-emitting/absorbing plasma, derived from the properties of the line emission/absorption complex. The present Line Data Model does not explicitly address non-electromagnetic transitions.

The corresponding access protocol (*Simple Line Access Protocol*, SLAP; (Salgado et al., 2007)) has been implemented in the Spectral Energy Distribution ESA visualisation tool vospec (Osuna et al., 2006). This allows the interactive identification of line features on spectra retrieved through Simple Spectra Access compatible servers (Fig. 3). Along with CIELO-AGN, other databases of atomic and molecular lines have been implemented as SLAP servers, such as the NIST database of atomic transitions (Fig. 4).

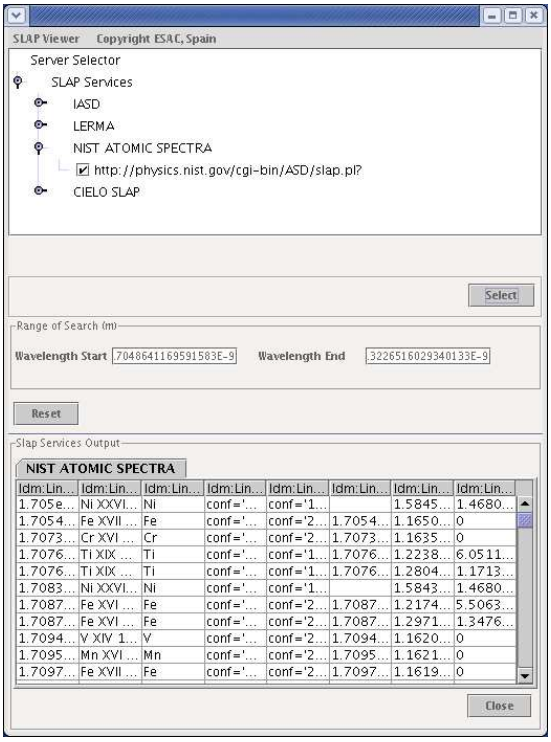


*Figure 4. The list of NIST Atomic and Molecular Database transitions in the RGS bandpass, accessed through a SLAP call within* vospec.

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