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NEAR INFRARED (0.8–2.3 μM) CORONAL LINES IN ACTIVE GALACTIC NUCLEI

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RESUMEN

Se presenta un análisis de las líneas coronales (CLs) emitidas en la región del IR cercano (0.8 a 2.3 μm) para una muestra de 54 galaxias activas. Se encuentra que las CLs tienden a aparecer más en las galaxias de tipo 2 (Ty2) que de tipo 1 (Ty1). La presencia casi en igual porcentaje de ciertas CLs para ambos tipos de galaxias puede indicar que la parte interna del toroide no es una fuerte región emisora de las mismas. Una correlación entre el FWHM y el potencial de ionización tiende a observarse en objetos del tipo NLS1, mientras que para galaxias Ty2 y "nomales" del Ty1 la correlación sólo se presenta para un cierto número de objetos. También se observa que existe una débil correlación entre la luminosidad de los rayos X suaves y la luminosidad de las CLs más conspicuas.

ABSTRACT

An analysis of Coronal Lines (CLs) emitted in the near IR (0.8 a 2.3 μm) is presented for a sample of 54 active galaxies. It is found that CLs are prone to appear more in Type 2 galaxies than in Type 1. The existence of some energetic CLs almost in equal percentage for both type of objects could indicate that the inner face of the torus is not a strong emission region of CLs. It is observed that the majority of NLS1 galaxies tend to present a correlation between the FWHM and the ionization potential; however that correlation holds in less than half of the Type 2 and "Normal" Type 1 galaxies. Finally, it is also observed a weak correlation between the soft X-ray luminosity (0.1–2.4 keV) and the luminosity of the most conspicuous CLs.

Key Words: galaxies: active — galaxies: nuclei — X-rays: galaxies

1. INTRODUCTION

Some active galactic nuclei (AGN) display in their spectra coronal lines (CLs), i.e., emission lines arising from forbidden transitions of excited states of highly ionized species ($h\nu_{ion} \geq 100$ eV). There have been a lot of controversy about the possible location of the emission of the CLs in active galaxies. Regions such as the torus, close or in part of the broad line region (BLR), narrow line region (NLR) and extended narrow line region (ENLR) have been proposed as locations for the formation of CLs. Detection of these lines is an indicator of the existence of very energetic processes occurring in the AGN. Hence the study of CLs is fundamental to understand the ionization structure and excitation mechanisms of the emitting gas.

Displacements of the peak position of the coronal line profiles relative to the laboratory wavelengths as well as the determination of the size of the coronal emitting region can provide clues about the location and kinematics of the high ionization emission gas. It is known that optical CLs tend to be broader than low ionization forbidden lines (Phillips & Osterbrock 1975) as well as their centroid position blueshifted with respect to other emission lines (Grandi 1978). This is interpreted as the emission region being located nearer to the central engine than the NLR and probably being associated to outflows. Related with this is the correlation found between the ionization potential (IP) necessary to create the ionized specie and the line width reported for some Seyfert galaxies (Wilson 1979). The current paradigm places the CLR somewhere between the NLR and the BLR. However, some authors speculate that the torus could be a CLs emitter. Pier & Voit (1995) suggest that the inner face of the torus is a natural place to produce CLs. Some observations tend to give support to this description (Muruyama & Taniguchi 1998). However, due to the relatively few CLs present in the optical region (almost all ions of Fe) these results are not conclusive.

With the development of high-sensitive detectors in the near infrared region (NIR), observations of a significant number of active galaxies has now been possible (Giannuzzo, Rieke, & Rieke 1995;

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Erkens, Appenzeller, & Wagner 1997; Prieto & Viegas 2000; Lutz et al. 2002; Rodríguez-Ardila et al. 2002; Reunanen, Kotilainen, & Prieto 2003; Riffel, Rodríguez-Ardila, & Pastoriza 2006). Thus, additional CLs have been added up to the list (i.e., [S VIII], [S IX], [Fe XIII], [Si VI], [Si VII], [Si IX], [Si X], [Ca VIII]) allowing a revision of previous findings and a more consistent analysis of a complex emitting region not yet understood.

Here we present preliminary results of a compilation of CLs published to date in the NIR (0.8–2.3 μm). From the study of this database we draw information about the most likely location of the CLs as well as to explore the effect of the soft X-ray in the luminosity of the CLs.

2. SELECTION OF THE SAMPLE

The sample of AGN for this work was selected from the galaxies investigated by Riffel, Rodríguez-Ardila, & Pastoriza (2006). It is composed by 47 Seyferts and quasars observed in the wavelength interval 0.8–2.3 μm and collected using cross-dispersed spectroscopy at IRTF. In addition, we include in our analysis a sub-sample of active galaxies with published data on CLs covering a similar wavelength interval as our main sample (Oliva et al. 1994; Maiolino et al. 1998; Marconi et al. 1996; Oliva & Moorwood 1990; Rodríguez-Ardila et al. 2002; Rodríguez-Ardila, Contini, & Viegas 2005; Mazzalay & Rodríguez-Ardila 2006). An effort was made in order to set up the sample as uniform as possible. In total it is constituted by 54 galaxies: 36 of Type 1 (Ty1) and 18 of Type 2 (Ty2). Of the former type, 19 galaxies ($\sim$ 50 %) are classified as of the subtype narrow-line Seyfert 1 (NLS1).

3. RESULTS

We found that from the 54 galaxies that constitute the sample, 19 do not show CLs (35 %); 5 show one CL, 5 show two, 8 show three, 4 show four, 7 show five, 4 show six, none shows seven and two show eight. Some of them indeed show clear and conspicuous coronal emission. Figure 1 shows the percentage in number of galaxies (for each Ty1 and Ty2) where coronal emission is detected. The abscissa axis goes from the lower ionization potential (IP) at the left ([Ca VIII], 127.7 eV) up to the higher IP detected at the right ([S XI], 447.1 eV). It is observed that Ty2 galaxies are prone to show more CLs that Ty1 galaxies except for [Fe XIII] λ1.0747 μm. Emission by [Si VI] λ1.9640 μm and [S VIII] λ0.9913 μm is observed in 60–70% of Ty2 galaxies while in Ty1 galaxies is reduced to $\sim$ 50%. [S IX] λ1.252 μm and [Si X] λ1.4301 μm are frequently observed too, but in a lower percentage that ranges from 35–50%. Emission by [Ca VIII] λ2.3213 μm, [S XI] λ1.9196 μm, [Fe XIII] λ1.0747 μm and [Al IX] λ2.0450 μm is less frequently observed in the sample.

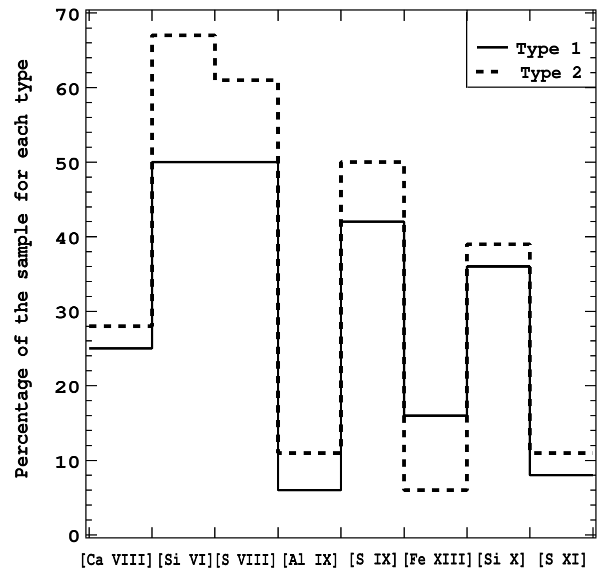

Fig. 1. Percentage of the entire sample of galaxies constituting the sample (discriminated as Ty1 and Ty2 objects) vs. the ionization potential (IP, χ) required for the indicated coronal line. Values of the IP are (in eV): Ca^{+7}: 127.7; Si^{+5}: 166.8; S^{+7}: 280.9; Al^{+8}: 284.6; S^{+8}: 328.2; Fe^{+12}: 330.8; Si^{+9}: 351.1 and S^{+10}: 447.1.

Lines that demand more energy ([Si X] λ1.4301 μm and [S XI] λ1.9196 μm, which require 351 and 447 eV respectively), are present almost in the same percentage for both type of galaxies. Since some authors have suggested that the inner edge of the torus is an appropriate place for producing CLs, it could be expected that these lines would tend to be more detectable in Seyfert 1 than in Seyfert 2 galaxies, according to unified models. Our results seems to rule out the hypotheses of prominent coronal emission on the inner face of the torus and tend to support a more extended region for emission of CLs, which is supported by recent observations (Rodríguez-Ardila et al. 2006).

In order to establish if there is a correlation between line width and IP, we measured the FWHM of the most conspicuous CLs in the galaxy sample. We found that in narrow line Seyfert 1 galaxies (NLS1) 8 out of 11 objects display such a correlation. For normal Ty1 and Ty2 objects the situation is rather different: more than half of each type of objects do not show a correlation between the FWHM and IP.

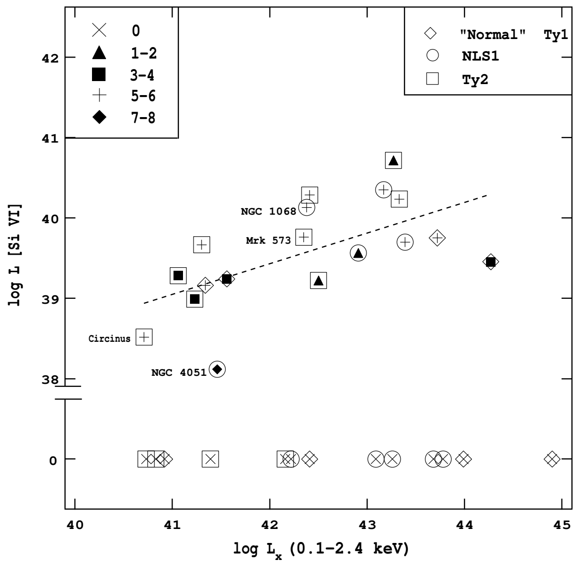

Fig. 2. Luminosity of [Si VI] $\lambda 1.964\,\mu$m (erg s^{-1}) versus the soft X-ray luminosity (erg s^{-1}). The labels at the top left correspond to the number of CLs detected. The dashed line represents a linear fit to all the values.

We also explored the relationship between the luminosity of the soft X-rays (0.1–2.4 KeV) and the luminosity of [Si VI] $\lambda 1.964\,\mu$m and [S VIII] $\lambda 0.9913$ μm. The reason to select this band is because a significant number of active galaxies in our sample have data published in this region. Moreover, the "ROSAT band" corresponds to the interval in energy required to produce S^{+7} and Si^{+5} (0.28 and 0.17 keV respectively). Figure 2 displays [Si VI] $\lambda 1.964\,\mu$m luminosity versus soft X-ray luminosity integrated over 0.1–2.4 keV corrected for absorption. The plot suggests that the emitting CLs galaxies have a correlation between the quantities involved (linear correlation index of 0.602), which is to be expected if the CLs emission is influenced by photoionization. A similar correlation (figure not showed) was found for the luminosity of [S VIII] $\lambda 0.9913$ μm. Furthermore, Figure 2 suggests that Ty2 AGN tend to be more luminous in [Si VI]$\lambda 1.964\,\mu$m than Ty1 AGN ("normal" Ty1 and NLS1) with respect to a similar X-ray luminosity.

Also Figure 2 tells us that the amount of coronal emission detected in each object is independent of its soft X-ray luminosity. Clearly, no evident connection exists between the quantity of soft X-ray displayed by an AGN and the occurrence of CLs in it. We conclude that the mechanism that turns an AGN into a CL-emitter is not related to its soft X-ray emission although if these lines are present, their strength correlates with that of the soft X-rays.

4. SUMMARY

For a sample composed of 54 AGN, we have found that NIR CLs tend to appear more in Ty2 than in Ty1 galaxies: the result is more significant for the most conspicuous CLs ([Si VI] $\lambda 1.964$ μm and [S VIII] $\lambda 0.9913$ μm). Observation of [Si X] $\lambda 1.4301$ μm and [S XI] $\lambda 1.9196$ μm in almost equal percentages for both Ty1 and Ty2 objects could indicate that, under the grounds of the unified models, the emission region do not seems to be spatially situated in the interior of the torus; instead, our data indicate that it is spatially extended. We found that the relationship between the FWHM and IP is not straightforward as far as the NIR CLs are concerned. In NLS1 galaxies they tend to be correlated but in most "normal" Ty1 and Ty2 do not. We also found a weak correlation between luminosity of [Si VI] $\lambda 1.964$ μm and [SVIII] $\lambda 0.9913$ μm and the soft X-ray luminosity. This indicates that both the soft and hard X-rays have a contribution to the heating of the gas that provides the excitation of the ionized species.

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