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Coronal Lines from the BLR, NLR, and ENLR

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Abstract. We discuss kinematical evidence that highly ionized ('coronal') lines are emitted from gas sharing the same velocity field as the BLR, NLR, and extended NLR. A close correlation between ionization potential and line width and blueshift with respect to systemic velocity suggests a hot outflow being responsible for the emission of coronal lines. This outflow is probably connected to the warm absorber observed in X-rays and the outflowing radio plasma. The high degree of ionization is dominantly due to photons from the blue bump but contributions from shocks are indicated in at least some of the sources observed.

1. Introduction

Correlations between the widths of forbidden lines and the ionization potentials of the corresponding transitions have been revealed in several samples of Seyfert galaxies. This led to the speculation that the lines of very high ionization potentials may be used to probe the transition regime between the narrow-line region (NLR) and the broad-line region (BLR), providing an important tool for kinematical studies of this transition region (Appenzeller & Östreicher, 1988).

A second important aspect is the ionization mechanism. Although photoionization is usually advocated as the dominant mechanism of ionization in BLR and NLR plasma, recent modeling and observations of extended NLRs suggest a possible contribution from auto-ionizing shocks (see Bicknell et al., this volume). Studies of forbidden high-ionization lines (FHILs) may add important information on this issue (see Penston et al. 1984 and Oliva, this volume). With ionization potentials (χ) in the range of 50–350 eV, they sample the entire range of photon energies provided by the big blue bump, which is inaccessible to direct studies, and may serve as a calorimeter to the flux of this most important component in the broad band spectral energy distribution of radio-quiet AGN.

Both of these issues are studied in an independent but complementary way with modern X-ray instrumentation. A combination of the results from X-ray spectroscopy and studies of FHILs will lead to significant advances in our understanding of the hot outflows from radio-quiet AGN.

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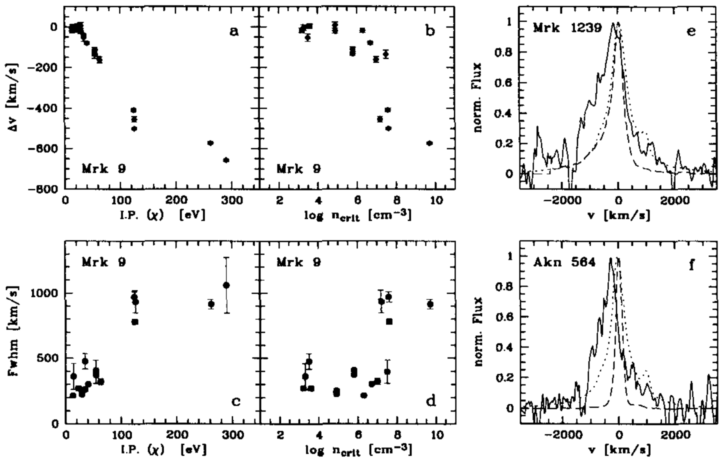

Figure 1. Panels a-d show correlation between line widths and blueshift with ionization potential and critical density in Mrk 9. Panels e and f compare profiles of coronal lines ([Fe XI, full), BLR lines (Hα, dotted), and NLR lines ([O III], dashed) in Akn 564 and Mrk 1239.

2. Statistical Investigations

In order to study the kinematical characteristics of the coronal-line emitting plasma, we carried out a statistical study of AGN which were previously known to emit strong coronal lines (Erkens et al., in preparation). Seventeen sources were observed at least two times during three spectroscopic runs. Spectra of moderate resolution (200 km s^{-1}), covering the entire optical wavelength range (320–1100 nm), were taken with an average total integration time of 4.5 hours. Data-reduction procedures are described in detail by Erkens et al. Although our spectra did not show any significant variations of the profiles or line fluxes from any of the highly ionized forbidden lines, some FHILs clearly changed with respect to those observations reported in the literature.

We confirm earlier reports of correlations between line width and χ and critical density n_{crit}. Even stronger correlations are found between the blueshift of the lines and χ and n_{crit}. Examples are shown in Fig. 1, illustrating the correlations for the Seyfert 1 galaxy Mrk 9. Both blueshift and line width are better correlated with χ but the detailed parameterization of the correlation varies throughout the sample. Line widths of coronal lines (we studied [Ne V], [Fe VII], [Fe X], and [Fe XI] in particular) are always significantly larger than those of [O III] and reach or exceed those of permitted lines in one third of the sources. Examples are given in panels e and f of Fig. 1, comparing the profiles of [O III], Hα, and a forbidden high-ionization line in two sources.

The close match of line widths of the most highly ionized lines ([Fe XI]) and the Balmer lines suggests that FHILs originate partly from a volume sharing the same velocity field as the central BLR.

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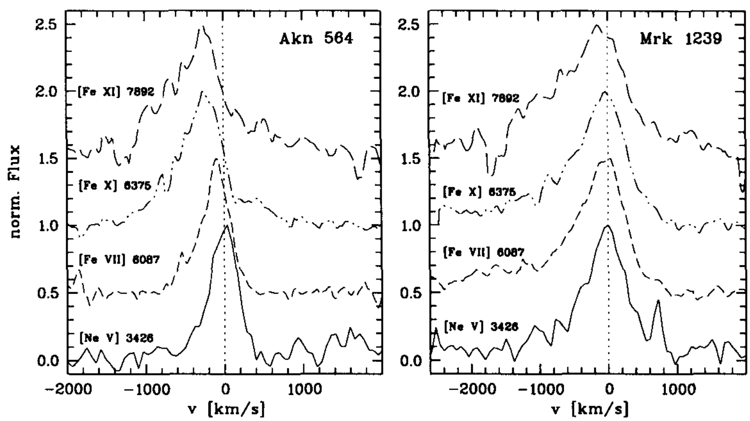

Figure 2. The comparison of line profiles of several FHILs in Akn 564 and Mrk 1239 illustrates the variation of line width and position with ionization potential.

3. Decelerating Outflows

A smooth transition to the narrower profiles of less highly ionized species (e.g., [Fe VII]) which are similar to the profiles emitted from the more extended NLR illustrates the stratification throughout the transition region (Fig. 2). The obvious blueshift of all FHIL indicates radial motion throughout this transition region and the correlation of blueshift with ionization potential (decreasing towards the lower-ionization species which are emitted from the more extended NLR) suggests that the FHIL are emitted from a decelerating hot outflow.

We used the [Fe VII] $\lambda3759/\lambda6087$ line ratio to derive temperatures in the FHIL zone of several 10^4 K. In a few cases, temperatures of 10^5 K are derived, indicating that shock ionization may be an important contributor. This is also indicated by the large [Fe XI]/[Fe X] ratio observed in those sources. Detailed comparisons with model calculations require special care. In all cases with sufficient S/N, the line profiles indicate a multi-component nature of the line profiles, suggesting that the total flux of different lines may be emitted from several separate regimes which each might have different physical conditions.

In a few nearby Seyfert galaxies, it is possible to separate individual regimes spatially as well. Many of the spatially resolved NLRs are associated with the weak radio jets observed in those galaxies. In some cases, the close association suggests jet–NLR interactions which need to be taken into account when studying the ionization mechanisms.

We have taken long-slit spectrograms of high resolution and S/N to study the spatially extended NLR of NGC 1068 (Wagner & Dietrich 1996; Dietrich & Wagner, in preparation). Emission from [Fe VII] is clearly spatially extended, as illustrated from the inset of Fig. 3. The contribution from individual components

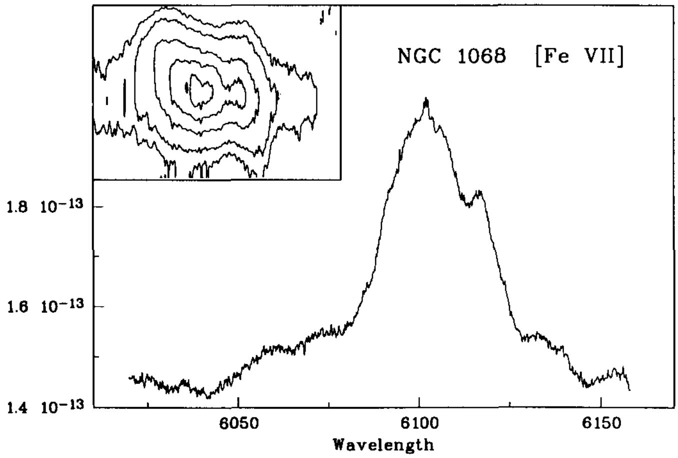

Figure 3. The line profile of [Fe VII] $\lambda 6081$ in NGC 1068, averaged over the central 3″. The inset gives contours to the l-v distribution, clearly indicating the spatial offsets of different contributions.

is also illustrated in the spatially integrated spectrum of the [Fe VII] $\lambda 6081$ line. The broad base is confirmed from independent high S/N observations, and can be seen in other lines of [Fe VII] as well.

The stratification of the plasma emitting coronal lines in velocity space suggests that the FHILs are emitted by a hot outflowing component. The temperatures reach up to 10^5 K and shock ionization in special circumstances may contribute to the ionizing photons in special cases. The outflow originates from close to the BLR and may extended into the spatially resolvable parts of the NLR. The close association of radio jets and NLR suggests that the latter is physically related to the radio outflows. Line profile studies are of particular relevance for the kinematics of these outflows.

The total line strengths show a close correlation with the spectral index observed in the soft X-ray regime. This correlation is discussed in more detail in Erkens et al. (in preparation), and may be explained as a physical association of the warm absorbers seen in the high-energy end of the X-ray spectral range accessible with *ROSAT* and the FHIL-emitting plasma.

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