Coronal Lines from BLR, NLR, and ENLR

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Abstract. We discuss kinematical evidence that highly ionised ("coronal") lines are emitted from gas sharing the same velocity field as BLR, NLR and ENLR. A close correlation between ionisation potential, 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 ionisation 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 ionisation 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 ionisation potentials may be used to probe the transition regime between the 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 ionisation mechanism. Although photoionisation is usually advocated as the dominant mechanism of ionisation in BLR and NLR plasma, recent modelling and observations of extended NLRs suggest a possible contribution from auto-ionising shocks (see Bicknell, this volume). Studies of forbidden high-ionisation lines (FHILs) may add important information on this issue (see Penston et al., 1984 and Oliva, this volume). With ionisation 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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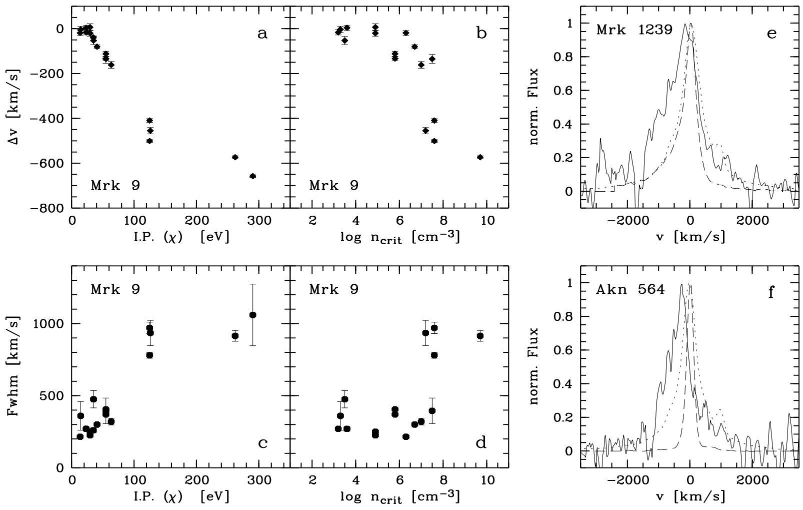

Figure 1. Panels a-d show correlation between line widths and blueshift with ionisation potential and critical density in Mrk 9. Panels e and f compare profiles of coronal lines ([Fe XI, full), BLR lines (Hα, dotted), and NLR lines ([O III], dashed) in Akn 564 and Mrk 1239.

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). 17 sources were observed at least two times during three spectroscopic runs. Spectra of moderate resolution (200 km), 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 in Erkens et al. Although our spectra did not show any significant variations of the profiles or line fluxes from any of the highly ionised forbidden lines, some FHILs clearly changed with respect to those observations reported in the literature.

We confirm earlier reports of correlations between line widths and χ and critical densities (n_{crit}). Even stronger correlations are found between the blueshift of the lines and χ and n_{crit}. Examples are shown in Figure 1 a-d, illustrating the correlations for the Seyfert 1 galaxy Mrk 9. Both, blueshift and line width are better correlated with χ but the detailed parametrisation 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 Figure 1, comparing the profiles of [O III], Hα and a forbidden high ionisation line in 2 sources.

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

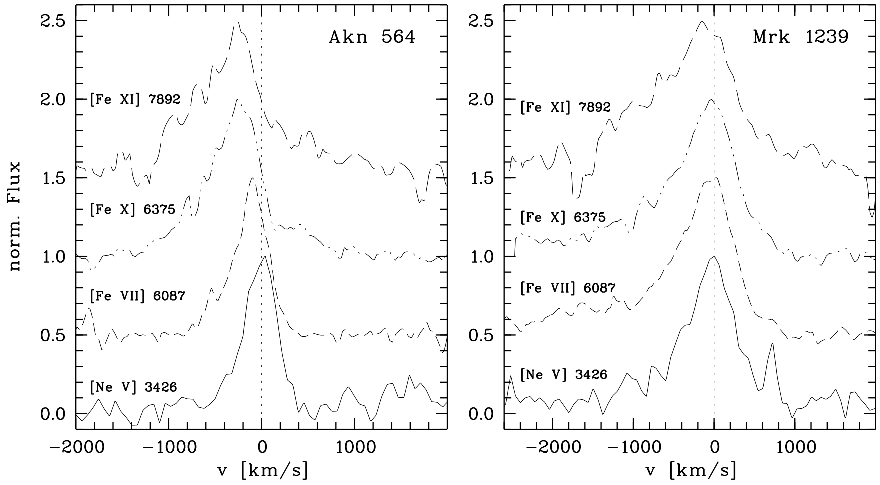

Figure 2. The comparison of line profiles of several FHILs in Akn 564 and Mrk 1239 illustrates the variation of line width and position with ionisation potential.

3. Decelerating outflows

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

We used the line ratio of [Fe VII] 3759/6087 Å 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 ionisation 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 ionisation mechanisms.

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

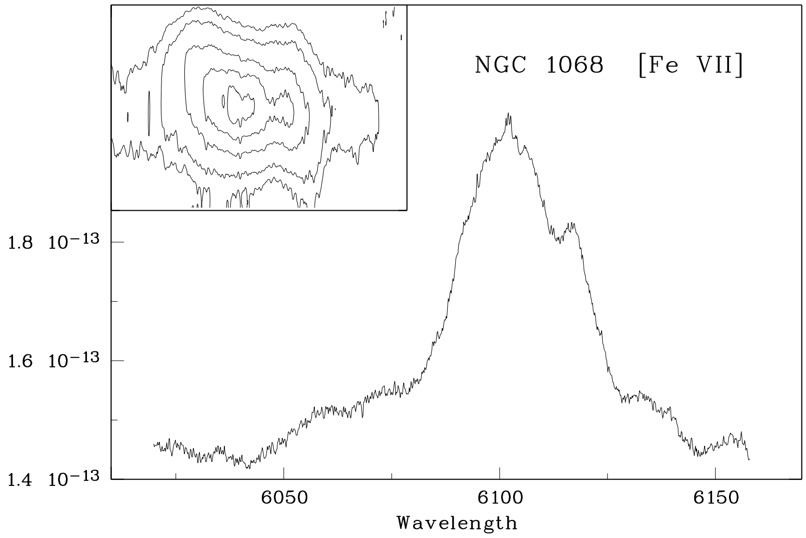

Figure 3. The line profile of [Fe VII] 6081 Å in NGC 1068, averaged over the central 3". The inset gives contours to the l-v distribution, clearly indicating the spatial offsets of different contributions.

vidual components is also illustrated in the spatially integrated spectrum of the [Fe VII] 6081 Å 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 ionisation in special circumstances may contribute to the ionising 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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