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A search for electron-scattered wings in Hα in Seyfert-1 galaxies

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Summary. Spectra were obtained of a dozen bright Seyfert-1 galaxies to search for the presence of ultra-broad wings in Hα, caused by electron scattering in the hypothetical hot intercloud medium. The spectra, which covered the wavelength range from 5300 Å to 8750 Å, were carefully calibrated to obtain the accurate continuum shape. In no case ultra-broad wings of the type expected from electron scattering were found, although significantly broader wings are detected than in previous data. Synthesized spectra were used to estimate the sensitivity of the survey for electron scattered wings. The results can be converted into a lower limit on the temperature of 7 10^7 K, and an upper limit of 0.15 on the electron scattering optical depth.

Key words: galaxies: active – galaxies: Seyfert – lines: profile – spectroscopy

1. Introduction

The strong and broad emission lines in type 1 Seyfert galaxies and quasars are emitted from the inner parsec of these objects. The lines have a typical velocity width of a couple of thousand km s^{-1}. They are emitted by a large number of high density clouds ($n_e \sim 10^{10}$ cm^{-3}), that are energised by a strong non-stellar continuum source. The geometry of this broad lines region (BLR) is poorly known; ingredients of the presently most popular models are radially outflowing clouds (Blumenthal and Mathews, 1975; Capriotti et al., 1979) and an accretion disk (Osterbrock, 1978; van Groningen, 1983).

In almost all models there is a need for a much hotter medium ($T > 10^7$ K). In cloud models this medium is required to stabilise the clouds against evaporation (McKee and Tarter, 1975; see however Perry and Dyson, 1985; Collin-Souffrin et al., 1988). For accretion disk models there is the basic problem of how to transport the photons from the central continuum source onto the disk. A hot corona surrounding the disk, that has some optical depth for electron scattering provides a plausible mechanism for this transport. The physics of the hot medium (HM) and its equilibrium with the dense material has been studied in detail by Krolik et al. (1981). These authors demonstrate that gas exposed to the non-stellar continuum radiation field can settle down in a two-phase equilibrium with the temperature of the HM being of order 10^{7-9} K.

Up to now there is no direct observational evidence for the existence of the HM, simply because it has very few observational consequences. Its expected X-ray luminosity is only a small fraction of the observed X-ray luminosity and hence difficult to identify. As pointed out by Shields and McKee (1981) a considerable electron scattering optical depth may lead to an observable wing under strong emission lines. Such a wing would have a full width at half maximum (FWHM) of 20000 $\hat{T}_7^{1/2}$ km s^{-1}, where $\hat{T}$ is the temperature of the HM in units of 10^7 K. The intensity of the wing relative to the unscattered line is roughly equal to the Thomson optical depth, if the latter is less than about unity.

The best place to look for such wings is around the strong Hα emission line. It has a large equivalent width, typically ~500 Å, and it can be observed with accurate, linear detectors. For Hα the FWHM of the wings at 10^7 K corresponds to ~430 Å, i.e. an optical depth of 0.1 results in wings that rise 10% above the continuum. In reality, however, the HM may be much hotter and the wings correspondingly broader and weaker, so their detection may be very difficult.

In this paper we report on an unsuccessful attempt to detect electron scattered wings in a sample of a dozen bright Seyfert-1 galaxies. The data are of excellent S/N ratio and special care was taken throughout the data reduction procedure to get a very accurate relative flux calibration. The data reduction is discussed in Sect. 2, and the results are presented in Sect. 3. The implications of the absence of ultra-broad wings are discussed in Sect. 4.

2. Observations and data reduction

Low resolution spectra with high signal-to-noise ratios of a sample of 13 bright Seyfert-1 nuclei were obtained at the Isaac Newton Telescope at La Palma, Spain[1]. The Intermediate Dispersion Spectrograph was used to take spectra of the region encompassing Hα (5300–8750 Å). A 150 grooves/mm grating was used in first order, giving a dispersion of 270 Å/mm at 5500 Å. The 235 mm camera was used with a front-illuminated GEC CCD as detector. The projected slit width was 1.5 arcsec, yielding a resolution of ~10 Å. All observations were made with the slit at the parallactic angle to minimize the effects of atmospheric differential refraction. Each object was integrated twice for typically 1000 s to

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[1] The Isaac Newton Telescope is operated on the island of La Palma by the Royal Greenwich Observatory at the Spanish Observatorio del Roque de Los Muchachos of the Instituto de Astrofisica de Canarias

1989A&A...211..318V

Table 1. Journal of the observations

Object	Dwell time (s)	Airmass	Seeing (″)
3C120	2000	1.15	1.5
NGC3227	1500	1.01	1.0
Akn 120	2000	1.23	1.2
Akn 202	2500	1.05	1.5
Mkn 6	2750	1.50	>2.0
Mkn 9	2500	1.17	1.0
Mkn 79	5000	1.10	2.0
Mkn 231	800	1.28	1.0
Mkn 335	1600	1.30	1.5
Mkn 374	2500	1.15	2.0
Mkn 376	2000	1.07	2.0
Mkn 618	2000	1.34	2.0
Mkn 704	2000	1.02	1.0

achieve the required S/N without saturating the detector in the peak of Hα. Table 1 presents a log of the observations.

Several times a night the spectra of the "standards" HD 84937 and G 191 B2B were obtained, in order to establish an accurate flux calibration. To determine the relative sensitivity of the individual pixels, the spectrum of a tungsten lamp, projected on the inside of the dome, was taken every night. A neon-argon arc spectrum was recorded after each object scan to obtain the wavelength calibration.

The seeing fluctuated between 1 and > 2 arcsec during the run, while photometric conditions broke down quite often because of intervening cirrus clouds.

The data frames were corrected in a standard way for the contributions of the bias and the preflash. They were also divided by a normalized flat field frame in order to correct for pixel-to-pixel sensitivity variations. The wavelength calibration was performed with a second order polynomial, using about 15 lines yielding a rms value of the residuals of ~0.3 Å. Cross-correlation of spectra taken at different times showed a drift of typically several tenths of a pixel.

To extract the 1 dimensional spectra from the data frames, a modified version of the algorithm described by Horne (1986) was used. This method results in a spectrum of photometric quality, i.e. no flux is lost anywhere in the spectrum, as was shown by Horne (1986) and by several tests performed by us. The algorithm also offers a convenient way of rejecting cosmetic flaws (like cosmic ray hits) and of correcting for moderate misalignment between the spectrum and the CCD columns.

The spectral region between 6800 and 8800 Å is contaminated by atmospheric absorption. To correct for this, we constructed normalized atmospheric absorption templates from trailed observations of bright stars. By dividing an object spectrum with such a template, the absorption bands should disappear. However, the small bulk shift motions, mentioned earlier, caused some oscillating features in the regions containing the deepest and steepest troughs (e.g. the A-band of O_2 at ~7600 Å). These shifts usually amounted to a few tenths of a pixel. The shift of the template was measured by cross-correlating the absorption features in the object spectrum and the template. After correcting the template the division gave only minor residuals for ~5 pixels at the region of the A-band.

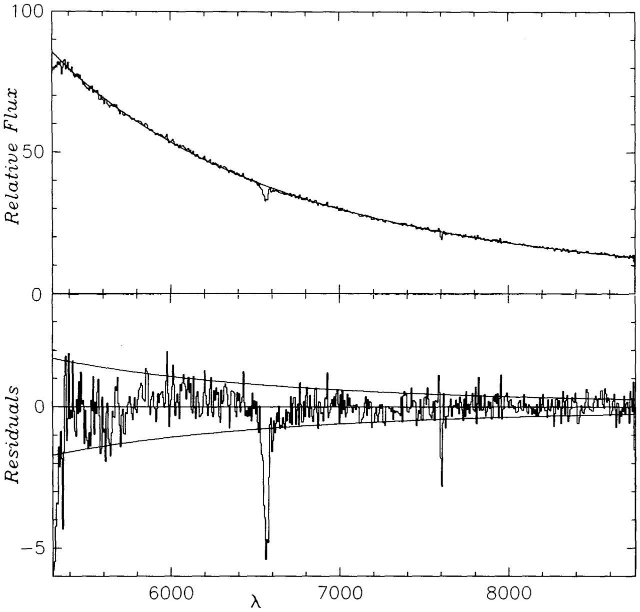

Fig. 1. Upper: The spectra of the flux calibration star G 191 B2B calibrated with HD 84937. This shows that the spectrum of G 191 B2B is extremely well represented by a power-law ($f_\lambda \propto \lambda^{-3.77}$). Lower: The residuals after subtracting the power-law fit. The two outer solid lines represent deviations of −2% and +2%

Special attention was payed to the relative flux calibration. This step is of crucial importance for the quality of the resulting spectra. The use of inaccurate flux data from the literature can introduce spurious low frequency ripples in the continua, which can be easily mistaken for electron scattered wings.

We observed the standard stars HD 84937 (sp = sdF; Oke and Gunn, 1983) and G 191 B2B (sp = DAwk; Oke, 1974) twice a night. Furthermore the BL Lac object OJ 287, which was in a high state at the time, was observed on two nights. Its featureless power-law spectrum can be used to constrain the shape of the detector response. The power-law nature of the continua of G 191 B 2 B and OJ 287 was confirmed by dividing their unprocessed raw spectra. The result should be another power-law, as indeed was the case.

The tabulated flux data of G 191 B2B by Oke (1974) shown severe deviations from a power-law in the red part of the spectrum ($\lambda > 7000$ Å). As already indicated by the quoted high statistical errors, these data are inadequate for calibrating a spectrum with the desired 1 to 2% accuracy.

The flux data for HD 84937 from Oke and Gunn (1983) were found to meet our requirements on accuracy. To demonstrate this, Fig. 1 displays the spectrum of G 191 B2B, flux calibrated with HD 84937. There are only minor deviations from the expected power-law; they are less than 2% everywhere (apart from some stellar absorption from Hα and an A-band residual). In principle, the firmly established power-law nature of G 191 B2B could be used to further constrain the wavelength-dependent sensitivity of the detector. The high quality of our spectra and of the flux data of HD 84937 do not justify the extra effort.

The absolute calibration, i.e. the overall flux level, is significantly affected by light losses due to cirrus clouds, and to seeing and guiding errors. Because of this, the absolute flux level is not very reliable.

1989A&A...211..318V

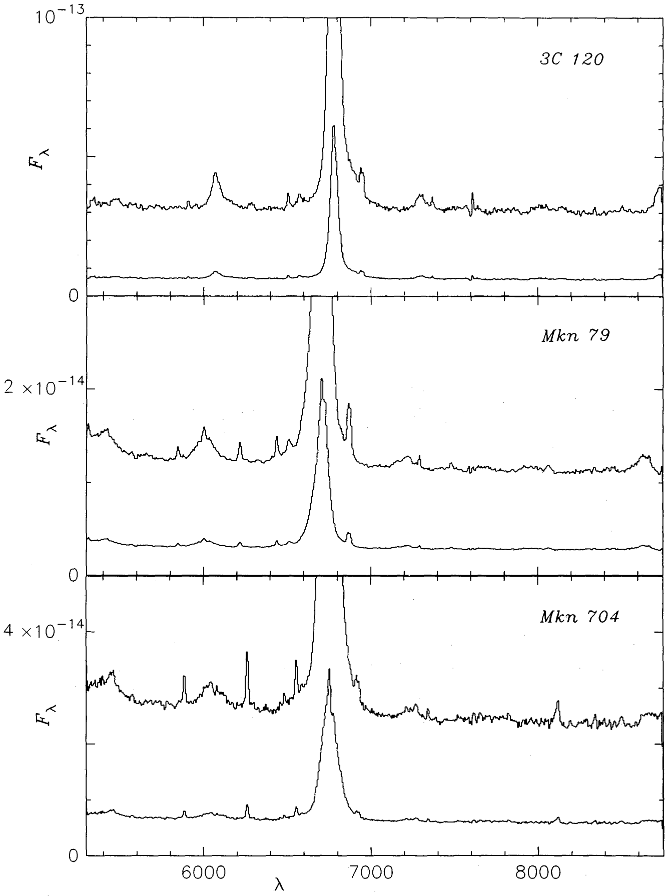

Fig. 2. Example spectra of three objects in the sample. The abcissa gives the wavelength in Ångströms; ordinates are the observed flux density in erg cm^{-2} s^{-1} Å^{-1}, and refer to the lower spectrum in each panel. The upper spectra have been blown up by factors of 5,4 and 4 respectively. The data have been rebinned to 6 Å/bin

3. Results

Despite our accurate calibration methods, we did not detect ultra-broad wings in any of the Seyfert-1 galaxies in our sample. Although we find Hα emission at as much as 15000 km s^{-1} away from the line centre, these wings are not of the type expected from electron scattering. The basic reason for this is that a full width of 30000 km s^{-1} corresponds to a temperature of the HM of 5 10^6 K. A medium of this temperature is thermally unstable and can therefore not act as the confining medium (Krolik et al., 1981). The implications of the absence of broad wings are discussed in the following section. Here we will concentrate on the other characteristics of the observed spectra.

Figure 2 displays the observed spectra of three of the objects in the sample. In 3 C 120, the broad lines have a prominent red wing, visible both in Hα and He I λ 5876. In both Mkn 79 and Mkn 704 the extreme wings are strongly blue asymmetric. This blue wing must be partly caused by multiplet 74 of Fe II (i.e. Phillips, 1978), since it is also seen in other strong Fe II emitters (Mkn 374 and Akn 120).

We have measured the full width of the Hα line at 50% (FWHM), 10% (FW10) of the peak intensity and at zero intensity (FWZI). Here, the peak of the broad components was used, after correcting the observed profiles for the contributions of the narrow Hα and [N II]. (No attempt was made to correct for the above-mentioned contribution of Fe II in the blue wing of Hα). Table 2 lists the measured widths and compares them with other measurements in the literature. It is clear that in general the FWHM and FW10 agree very well with the earlier data; no doubt the deviations are the result of both measuring errors and actual profile variations. The FWZI of our spectra always greatly exceed previous measurements. This difference is certainly the result of the high S/N and the accurate calibration of the continuum. The increase in the FWZI ranges from 40% in Mkn 374 (one of the lower S/N spectra) to more than a factor 2 in a number of objects. These results stress the fact that the FWZI should never be used

Table 2. Line width parameters

	FWHM (km s^{-1})		FW10% (km s^{-1})		FWZI (km s^{-1})	
Object	INT	Others	INT	Others	INT	Others
3C 120	2350	2000[1,a]	5700		28500	15000[1,a]
NGC 3227	3520[b]	2400[1]	7490		21600	11600[1]
Akn 120	5260	5300[2]	9880	9400[2]	28300	20000[2]
Akn 202	2400	1800[4]	5200		17800	
Mkn 6	6070		14100		27100	
Mkn 9	2970		6800		22900	
Mkn 79	3920	4000[3]	9020	8430[3]	26700	17400[3]
Mkn 231	2700		8400		[c]	
Mkn 335	1470	1120[3]	4180	3520[3]	21800	9500[3]
Mkn 374	3620	3200[3]	9150	10260[3]	20200	14600[3]
Mkn 376	4800	4900[1]	9860		30700	20200[1]
Mkn 618	2740	2100[1]	6370		21300	8700[1]
Mkn 704	5860	5230[3]	11000	12700[3]	27300	12700[3]

[1] Osterbrock (1977); [2] de Bruyn and van Groningen (1989); [3] Osterbrock and Shuder (1982); [4] Grandi (1980)
[a] Average of Hα and Hβ
[b] Narrow line correction uncertain
[c] Continuum level too uncertain

Table 3. Broad line ratios with respect to Hα

Object	He I λ5876	He I λ7065	O I λ8446
3C120	0.053	0.024	–
NGC3227	0.068	0.015	0.021
Akn120	0.048	0.017	–
Akn202	0.061	0.016	0.022
Mkn6	–	0.010	0.026^a
Mkn9	0.055	0.018	–
Mkn79	0.048	0.021	0.025
Mkn231	–	–	–
Mkn335	0.043	0.024	0.025
Mkn374	0.088	–	–
Mkn376	0.052	0.015	–
Mkn618	0.070	0.022	–
Mkn704	0.034	0.016	0.020:

^{a} Blended with Ca II λ8498 (Persson, 1988)

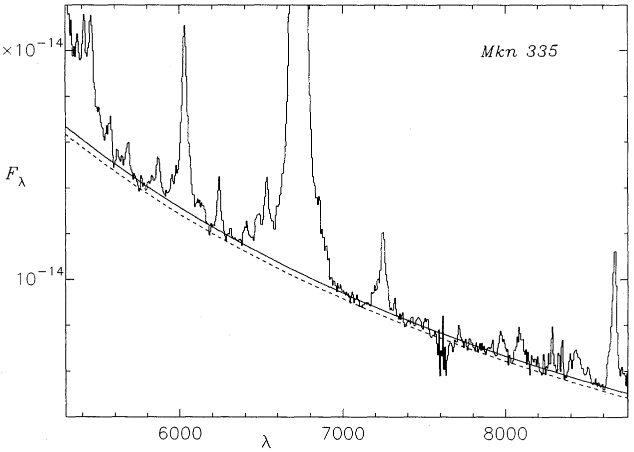

Fig. 3. The observed spectrum of Mkn335, demonstrating the problems with detecting ultrabroad wings. Two continua have been drawn, differing by only 1.2%. Using the lower continuum, one might identify a wing in Hα with a width >800 Å, while the upper yields no such wing

for statistical studies; in particular not when using a sample with large differences in S/N and resolution.

In Table 3 we have collected the line strength measurements of He I λ5876 and λ7065 and O I λ8446. Note that in all cases where the O I flux is not listed, it is shifted beyond the red end of the spectrum at 8750 Å. In general our measurements of the He I lines agree well with previous data (e.g. Osterbrock, 1977; Feldman and McAlpine, 1978). There is apparently no correlation between the fluxes of the two lines. The O I λ8446 line was first studied systematically in Seyfert galaxies by Grandi (1980), who found a large dispersion in the O I/Hα ratio. From Table 3 it is clear that our data do not confirm this large spread: in fact, the ratio always lies between 0.020 and 0.026. For two of the four objects that the samples have in common, there is a large discrepancy. In Akn202 Grandi finds an upper limit on the O I/Hα ratio of 0.005, while we find it to be 0.022. In Mkn79 the corresponding numbers are <0.003 and 0.025 (see also Fig. 2). In NGC3227 the O I/Hα ratio is lower than found by Grandi; 0.021 vs. 0.038. In Mkn335 both measurements agree on a ratio of 0.025. In view of the high quality of both data sets we feel that we have found evidence that the O I/Hα ratio in some objects must be highly variable.

4. Discussion

As already stated, conspicuous ultra-broad wings under Hα do not show up in our data. In this section we discuss the limits that can be set on the strength and the width of these wings. With no obvious wings visible a major concern is the determination of the actual continuum level in the spectra. To demonstrate what the effect is of a small change in the continuum level, we drew in Fig. 3 two power-laws in the spectrum of Mkn335. Their mutal spacing is only 1.2%. Clearly, the lower continuum could accomodate a very extended wing with a FWHM of over 800 Å and $F_{\rm wing}/F_{\rm line}>0.1$. On the other hand, using the upper continuum one finds no broad wing at all.

So it appears that to make a strong quantitative statement about the non-existence of electron scattered wings is out of the question. To test the sensitivity of the data for wings of various shapes, we used a semi-quantitative approach. For this purpose we constructed synthetic spectra since they allow full control over the different spectral components and avoid distraction by unnecessary detail. The basic ingredients, the power-law continuum, the emission lines and noise, were taken to resemble the mean properties of our 6 best spectra. The following input parameters were used: the slope of the power-law continuum $\alpha=-0.5$ ($f\lambda\propto\lambda^{\alpha}$), EW(H$\alpha$) = 520 Å, S/N = 120 in the continuum around Hα and the FWHM of the unscattered Hα equal to 3000 km s^{-1}. The strengths of the emission lines (both forbidden and permitted) relative to Hα were collected from the literature. The shape of the electron scattered wing was taken from Shields and McKee (1981): $F(x)\propto\exp(-x^2)/(1+2.6|x|+0.96x^2)$, where x is a scaled frequency shift, $x=(m_{\rm e}c^2/8k\hat{T})^{1/2}(\Delta v/v)$. This profile has a FWHM of 20000 $\hat{T}_7^{1/2}$ km s^{-1}, for an optically thin medium.

The detectability of the wings was then probed by varying the wing strength and full width, and was expressed in terms of “clear”, “doubtful” or “no” detection. The results of this procedure are resumed in Fig. 4. In the area above the hatched region the wings would have been readily detectable in our spectra. The hatched area represents the parameter space for which wing detection would have been marginal. On the left hand side (log (FWHM) < 2.3) confusion with the proper broad lines hinders the identification of the electron scattered wings.

To convert these observational constraints into constraints on the physical parameters of the BLR (i.e. $\hat{T}$ and $\tau_{\rm es}$) the following relations were used. For the case of a homogeneous, hot medium the optical depth is given by: $\tau_{\rm es}\sim\sigma_T\hat{n}_{\rm e}R\sim\sigma_T n_{\rm e}(T/\hat{T})$R, where pressure equilibrium between the hot medium and the clouds is assumed. For low optical depths, $F_{\rm wing}/F_{\rm line}$ is directly related to $\tau_{\rm es}$, and $\hat{T}$ to the FWHM of the wings. Using the relations given by Shields and McKee (1981) and adopting $T=10^4$ K results in:

$$F_{\rm wing}/F_{\rm line}=n_{10}R_{-2}\left(\frac{\rm FWHM}{240\,\text{Å}}\right)^{-2}.$$

Here n_{10} is the cloud density in units of 10^{10} cm^{-3} and R_{-2} the radius of the BLR in units of 0.01 pc. This relation is also drawn in Fig. 4, for a number of values of the product $n_{10}R_{-2}$. Note that for the higher optical depths this relation deviates from a straight line due to non-linearity and multiple scattering (see Shields and McKee, 1981).

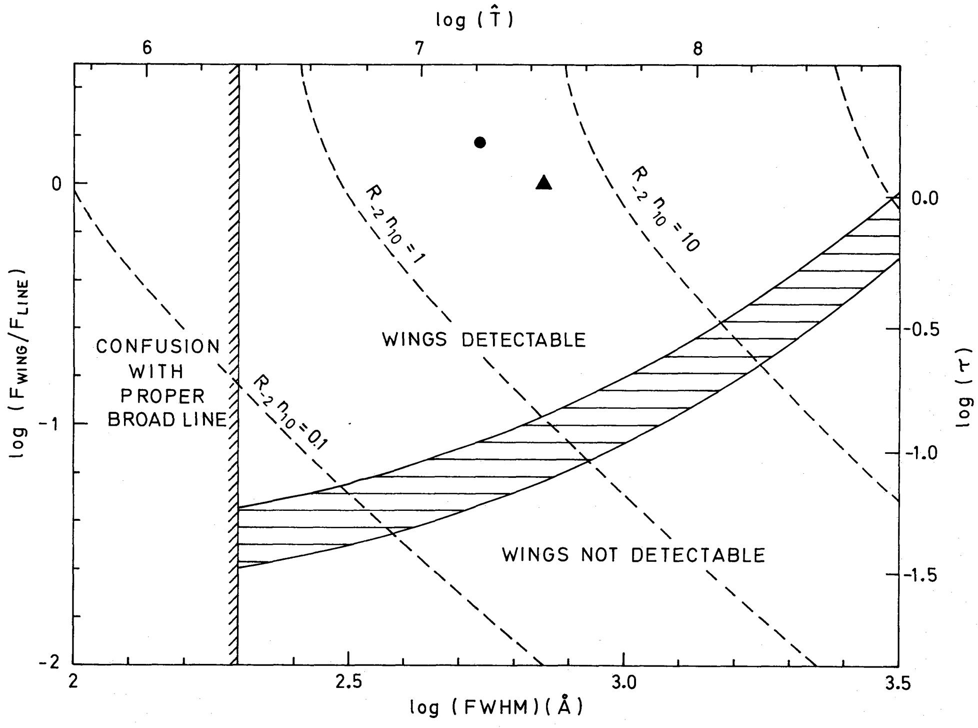

Fig. 4. Plot of the FWHM of the electron scattered Hα-wings versus the ratio of the wing flux to unscattered flux. Tests with synthesized spectra show that wings above the hatched region would have been readily detected with the present data. The hatched region represents the more doubtful detections. To the left scattered wings would be confused with the proper broad line component. The product of the BLR radius and the cloud density is constant along the deashed lines: Seyferts lie between $n_{10} R_{-2} = 1$ and 10 (see text). We find that all objects in the sample must lie below the dashed region, resulting in an upper limit on the electron temperature of 7 10^7 K. The positions of 3C 120 (▲) as obtained from X-ray observations and B 340 (●) from optical data have been marked (see text). Note that the temperature scale at the top is only correct for low values of τ_{es}

A characteristic value of the product $n_e R$ for the objects in our sample may be obtained in several ways. Variability measurements of some sample objects and of Seyferts of comparable luminosity yield a typical size of the BLR of 0.03 to 0.1 pc (Peterson et al., 1985; Peterson, 1987; Clavel et al., 1987). Combining this with the canonical BLR density of $10^{9.5}\,\mathrm{cm}^{-3}$ then yields $n_{10} R_{-2} = 1-3$. Another way of estimating R is to use the value of the ionization parameter (as obtained from photoionization calculations). This results in a somewhat higher value: $n_{10} R_{-2} = 3-10$. These values lead to the following constraints on the temperature and optical depth of the HM when no ultrabroad wings are detected (cf. Fig. 4). For $n_{10} R_{-2} = 1$ one finds $\hat{T} > 4\ 10^7$ K and $\tau_{\mathrm{es}} < 0.1$, while for $n_{10} R_{-2} = 10$ the limits are $> 1.5\ 10^8$ K and < 0.25 respectively.

These limits on the temperature of the HM are inconsistent with recent estimates of the Compton equilibrium temperature by Mathews and Ferland (1987). Hence our observations support the view of Mathews and Ferland that if the HM exists, it must be heated by other processes such a shocks, cosmic rays and radio frequency heating (Krolik et al., 1981).

We have also marked the position of B 340 in Fig. 4, using the Hα-wing parameters found by Shields and McKee (1981). From this it is clear that wings 20 × fainter than those of B 340 still would fall within our detection limit. So it seems that either B 340 is a very exceptional object or that the wings in Baldwin's (1975) data are spurious. Clearly, these data badly need confirmation by higher quality spectra. Petre et al. (1984) found evidence for a thermal component in the X-ray spectrum of 3C 120. The best spectral fit to the data yields a temperature of $\sim 10^7$ K and an emission measure of $\sim 2\ 10^{66}\,\mathrm{cm}^{-3}$. Such a medium, in pressure equilibrium with the broad line clouds and spherically distributed, would have an optical depth of about unity. Such a large value of τ_{es} is certainly excluded by the present observations. It therefore seems that the X-ray emitting gas and the BLR are not spatially coincident and that the X-ray emission cannot come from the HM.

Thus we can state that the detection of the hot medium in the BLR through optical spectroscopy, is extremely hard, even with the availability of high S/N and carefully calibrated data. However, such data can be used successfully to constrain the physical properties of the HM.

Detection of a HM and reliable measurements of its temperature will remain very difficult. In the near future the high resolution spectroscopy of Fe-lines and edges in the 1–10 keV range with satellite experiments, like AXAF (Holt, 1987), seems to be a promising method.

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References

Baldwin, J.A.: 1975, *Astrophys. J.* **201**, 26
Blumenthal, G.R., Mathews, W.G.: 1975, *Astrophys. J.* **198**, 517
de Bruyn, A.G., van Groningen, E.: 1989, *Astron. Astrophys.* (in press)
Capriotti, E., Foltz, C., Byard, P.: 1979, *Astrophys. J.* **230**, 681
Clavel, J., Altamore, A., Boksenberg, A., Bromage, G.E., Elvius, A., Pelat, D., Penston, M.V., Perola, G.C., Snijders, M.A.J., Ulrich, M.H.: 1987, *Astrophys. J.* **321**, 251
Collin-Souffrin, S., Dyson, J.E., McDowell, J.C., Perry, J.J.: 1988, *Monthly Notices Roy. Astron. Soc.* **232**, 539
Feldman, F.R., MacAlpine, G.M.: 1978, *Astrophys. J.* **221**, 486
Grandi, S.A.: 1980, *Astrophys. J.* **238**, 20

Holt, S.S.: 1987, *Astrophys. Letters. Comm.* **26**, 61

Horne, K.: 1986, *Publ. Astron. Soc. Pacific* **98**, 609

Krolik, J.H., McKee, C.F., Tarter, C.B.: 1981, *Astrophys. J.* **249**, 422

Mathews, W.G., Ferland, G.J.: 1987, *Astrophys. J.* **323**, 456

McKee, C.F., Tarter, C.B.: 1975, *Astrophys. J.* **202**, 306

Oke, J.B.: 1974, *Astrophys. J. Suppl. Ser.* **27**, 21

Oke, J.B., Gunn, J.E.: 1983, *Astrophys. J.* **266**, 713

Osterbrock, D.E.: 1977, *Astrophys. J.* **215**, 733

Osterbrock, D.E.: 1978, *Proc. Natl. Acad. Sci.* USA **75**, 540

Osterbrock, D.E., Shuder, J.M.: 1982, *Astrophys. J. Suppl. Ser.* **49**, 149

Perry, J.J., Dyson, J.E.: 1985, *Monthly Notices Roy. Astron. Soc.* **213**, 665

Persson, S.E.: 1988, *Astrophys. J.* **330**, 751

Peterson, B.M.: 1987, *Astrophys. J.* **312**, 79

Peterson, B.M., Meyers, K.A., Capriotti, E.R., Foltz, C.B., Wilkes, B.J., Miller, H.R.: 1985, *Astrophys. J.* **292**, 164

Petre, R., Mushotzky, R.F., Krolik, J.H., Holt, S.A.: 1984, *Astrophys. J.* **280**, 499

Phillips, M.M.: 1978, *Astrophys. J. Suppl. Ser.* **38**, 187

Shields, G.A., McKee, C.F.: 1981, *Astrophys. J. Letters* **246**, L 57

van Groningen, E.: 1983, *Astron. Astrophys.* **126**, 363