Astron. Astrophys. 177, 42–50 (1987)

ASTRONOMY
AND
ASTROPHYSICS

Geometry of the mass-outflows around broad absorption line QSOs and formation of the complex Lyα + N v Line profile

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Received September 30, accepted November 26, 1986

Summary. In order to further elucidate the question whether all quasars are affected by the broad absorption line (BAL) phenomenon, we investigate in the present work the possibility that observed BAL profiles are formed in spherically symmetric expanding atmospheres. We first show that the small residual intensity and/or large equivalent width reported for some absorption troughs (C IV, Si IV, etc.) may very well be reproduced by the resonance scattering of line photons across spherically symmetric BAL regions, taking into account the possible effects due to turbulence, occultation and/or electron collisions. Reanalyzing the distributions of the N v emission peak ratio, i.e. N v/I_c, observed in representative samples of BAL and non-BAL QSOs, we confirm that the N v emission strength appears to be generally higher in the spectrum of BAL quasars. Furthermore, using Sobolev-type approximations for the transfer of line radiation in spherically expanding envelopes, we find that an overall good agreement can be achieved between the theory and the observed attenuation of the Lyα emission-line, the observed enhancement of the N v emission strength and the possible presence of a shoulder-like feature in the red wing of the N v emission profile. All these results are certainly consistent with the view that BAL and non-BAL QSOs form two distinct classes of quasars.

Key words: lines: profile – quasars: mass loss

1. Introduction

Blueshifted broad absorption lines (BALs) are seen in the spectrum of as much as 3 to 10 percent of the total number of moderate-to-high redshift quasars discovered on objective prism plates (Hazard et al., 1984). Nevertheless, it is still unclear how much observational biases affect the true distribution of BAL QSOs in space and time (Turnshek, 1986). The level of ionization observed for the BALs is appreciably high (cf. C IV, N v and O VI resonance lines) and the Doppler velocity shifts involved are of the order of 0.1 *c*, up to 0.2 *c*. We refer the reader to the review papers by Weymann et al. (1981), Weymann and Foltz (1983) and Turnshek (1984b) for a more detailed description of the BAL characteristics.

Whereas there is little doubt that the BALs are intrinsic to the quasars, there is not yet a general agreement on which mechanism(s) are responsible for the ejection and observed ionization of the outflowing gas (cf. Weymann et al., 1985). The same indetermination applies to the type of geometry characterizing the BAL region (BALR) giving rise to the observed P Cygni-like profiles. The first models accounting for these were based on the scattering of line photons in spherically symmetric expanding envelopes (Scargle et al., 1970, 1972; Grachev and Grinin, 1975; Surdej and Swings, 1981). In the remainder, we shall refer to these as to the "*standard*" models. However, several discrepancies between the theory and observations were invoked by various authors and resulted in crediting jet-, fan- and/or disk-like geometries at the prejudice of the previous models (cf. Junkkarinen et al., 1983; Junkkarinen, 1983; Turnshek, 1984b; etc.). In Sect. 2, we present arguments which lend support to the view that the claimed discrepancies are only apparent and that somewhat improved "*standard*" models remain physically viable.

Except for the case of the N v emission (see the different conclusions reached by Turnshek, 1984b and Hartig and Baldwin, 1986), it is well established that the emission-line properties of BAL QSOs are different from those of non-BAL QSOs (see e.g. Lyα, C IV, C III], Fe II, etc.). In Sect. 3, we have reanalyzed the distributions of the N v peak intensity-normalized to the nearby continuum-for two samples of BAL and non-BAL QSOs. In agreement with Turnshek (1984b, 1986), we find that the N v emission strength is generally higher in the spectrum of BAL QSOs.

These observational results are certainly consistent – although not necessarily demonstrative – with the view that BAL and non-BAL QSOs form two distinct classes of quasars.

Furthermore, using Sobolev-type approximations for the transfer of line radiation in spherically symmetric envelopes, we show in Sect. 4 that an overall good agreement can be achieved between the theory and the main characteristics of the complex Lyα + N v line profile observed in the spectrum of BAL quasars. The resonance line scattering of Lyα photons by N^{4+} ions provides one more independent argument in favour of the BALRs being intrinsic to the BAL QSOs.

General conclusions and a discussion form the last section.

2. Geometry of the BALRs

Scargle et al. (1970, 1972) were the first to interpret the formation of BAL profiles as due to the resonance scattering of line photons in spherically symmetric expanding envelopes. Particularizing

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★ Also, Chercheur qualifié au Fonds National de la Recherche Scientifique (Belgium)

★★ Also, Aspirant au Fonds National de la Recherche Scientifique (Belgium) this "*standard*" model to the case of an outward-decelerating atmosphere, Grachev and Grinin (1975) and Surdej and Swings (1981) have shown that a fairly good agreement could be achieved between the theory and the C IV and Si IV P Cygni-like profiles observed in the spectrum of PHL 5200.

However, as more BAL QSOs were discovered and spectroscopically investigated, various authors claimed that the basic predictions of "*standard*" models were incompatible with the observations (cf. Junkkarinen, 1980, 1983; Turnshek, 1981, 1984b, etc.). The most often quoted discrepancies were that:

i) on the average, the equivalent width $EW_{\rm abs}$ of the blue-shifted absorption component of a BAL profile is substantially larger than the equivalent width $EW_{\rm em}$ of the scattered emission-line; and that

ii) the residual intensity observed in some highly saturated absorption troughs can be unusually small (i.e. $E(X)/E_c \simeq 0$, where $E(X)$ denotes the flux emitted by the expanding atmosphere at a given frequency X; E_c being the flux radiated by the central source).

As a consequence, alternative models involving jet-, fan- and/or disk-like geometries were proposed. According to such models, the intrinsic fraction of QSOs which are undergoing the BAL phenomenon is equal to the observed fraction divided by the covering factor of the BALR (Weymann et al., 1985). This implies that BAL gas could be present around most, if not all QSOs.

In the remainder of this section, we show that both observational constraints (i) and (ii) might be accounted for after several improvements of the "*standard*" model have been made. Indeed:

a) Until recently, most of line profile calculations were entirely based on the Sobolev escape probability method (cf. Castor and Lamers, 1979). Under the assumption of pure resonance scattering of line photons, this class of models essentially produces profiles such that $EW_{\rm em}/EW_{\rm abs} \sim 1$ and $E(X)/E_c \neq 0$ over the whole frequency interval. The importance of *turbulence* in expanding atmospheres has led various authors to abandon Sobolev-type theories and to work out solutions of the transfer equation in the comoving frame of the fluid (Mihalas et al., 1975; Bastian et al., 1980; Hamann, 1981a; Schönberg, 1985a; Hempe and Schönberg, 1986). As the ratio between the stochastic and macroscopic velocities of the flow gets higher, the resulting P Cygni profiles are characterized by smaller values of $EW_{\rm em}/EW_{\rm abs}$ as well as a larger frequency interval over which $E(X)/E_c \simeq 0$ (see Hamann, 1980, 1981b; Bertout, 1985; Schönberg, 1985b; Lamers et al., 1986).

Let us further note that:

b) The ratio $EW_{\rm abs}/EW_{\rm em}$ also scales up with the importance of the *occultation* of the expanding atmosphere by the central core (cf. Drew and Giddings, 1982). This effect is particularly important for the case of outward-decelerating envelopes (see Surdej and Swings, 1981).

c) If the escape probability (β_{12}^1) of a line photon is sufficiently small compared to its destruction probability (ε_{12}) by a *collisional de-excitation* and if the electron temperature of the expanding atmosphere is lower than the diluted radiation temperature, the resulting BAL profile will just appear to be made of a dark trough (Surdej, 1979a).

Because the "*standard*" model with the above improvement(s) (a) and/or possibly (b) and (c) allows one to account for the main observed characteristics of BAL profiles and since it is really the most simple model that physical self-consistency permits, we believe that spherically symmetric BALRs still constitute attractive and physically viable models. As we point out in the next sections, such models also provide a good explanation for the complex Lyα + N V line profile observed in the spectrum of BAL QSOs.

3. Emission-line properties of BAL QSOs

With the aim of further exploring the question of whether all quasars might be expelling matter at very high velocities, Turnshek (1984b) and Hartig and Baldwin (1986) have sought to compare the emission-line (EL) properties of BAL QSOs to those of non-BAL, i.e. "normal", QSOs. If the distribution of the EL properties were the same in the two groups of quasars, it would give further support to the view that all quasars undergo the BAL phenomenon. However, it is well established that the EL properties of BAL QSOs are different from those of non-BAL QSOs. Indeed:

i) On the average, the strength of the C IV emission-line is weaker for BAL QSOs (Turnshek, 1984b; Hartig and Baldwin, 1986).

ii) Both Fe II and Al III emissions appear to be stronger in the spectra of BAL QSOs (Wampler, 1986), specially in those which display well detached absorption troughs (Hartig and Baldwin, 1986).

iii) It is also very likely that the larger width reported by Turnshek (1984b) for the C III] λ 1909 emission-line in the spectra of BAL QSOs is at least partially caused by unusually strong Al III λ 1857 emission and by blends of Fe II and Fe III lines near $\lambda \sim 1900$ Å (Hartig and Baldwin, 1986).

iv) Of particular interest is the weakness or absence of both Lyα emission and blue-shifted absorption in most BAL QSOs (Hazard et al., 1984).

As far as estimates of the N V emission strength are concerned, Turnshek (1984b, 1986) and Hartig and Baldwin (1986) reach different conclusions. Turnshek finds that the N V emission is stronger for BAL QSOs rather than Hartig and Baldwin report a similar strength for both classes of QSOs. The latter authors have used approximately 15 quasars in each class; the non-BAL ones being taken from a single source. In order to further elucidate this discrepancy, we have extended the comparison of the N V emission strength to larger samples of quasars. We have selected four samples of non-BAL quasars (Osmer and Smith, 1976; Baldwin and Netzer, 1978; Smith et al., 1981 and Young et al., 1982) resulting in a total number of 52 objects for which reasonably good spectra have been published. We have similarly searched the literature for all BAL QSOs having a Lyα + N V line profile that was recorded with a sufficiently good signal to noise ratio. Table 1 lists 26 such members for which an estimate of the N V peak intensity, normalized to the nearby continuum (i.e. N V$/I_c$), has been made. For both classes of quasars, the peak intensity of N V was simply measured above an hand-drawn continuum. However, because the ratio of the Lyα to N V strength (i.e. Lyα/N V) is much higher in the spectra of non-BAL QSOs than in those of BAL QSOs, the red wing of Lyα may seriously contaminate the N V$/I_c$ measurements of the former QSOs. It is clear that there will result a systematic overestimate of the N V$/I_c$ ratio measured for the non-BAL QSOs.

We have illustrated in Fig. 1a the normalized distributions of the N V$/I_c$ measurements obtained for the 52 non-BAL and 26 BAL QSOs (cf. Table 1). Let us first point out that with the possible exception of the data by Smith et al. (1981), the individual

Table 1. List of the 26 BAL QSOs for which an estimate of the N v/I_c ratio has been made. The BAL QSOs in italics refer to those which show the presence of a shoulder-like effect in the red wing of their N v emission-line profile

BAL QSO	N v/I_c	References
0104 + 315	2.6	12
0128 − 367	2:	17
0134 − 376	3.8	17
0324 − 407	2.2	11, 13
0333 − 380	1.6	5
0335 − 336	2:	5
0856 + 172	1.5:	1, 5
0903 + 173	1.8	1, 5
1011 + 091	2:	5, 15
1232 + 134	2.6	16
1246 − 057	2.3	6
1303 + 308	1.5	10
1309 + 056	3.2	10, 14
1336 + 135	2.8	5
1413 + 117	4.2	15
1414 + 089	2.4	5, 8
1504 + 106	2.1	5
2239 − 411	3.7	2
2241 − 370	2.9	2
UM 139	2.9:	3
MCS 141	2.9	7
MCS 232	1.5	7
MCS 253	2.9	9
MCS 275	1.7	7
PHL 5200	3.3	4, 21
RS 23	3.6	3

Notes to Table 1: (:) Uncertain measurement, (1) Turnshek, 1981, (2) Clowes et al., 1979, (3) Junkkarinen, 1980, (4) Junkkarinen et al., 1983, (5) Hazard et al., 1984, (6) Boksenberg et al., 1978, (7) Turnshek et al., 1980, (8) Foltz et al., 1983, (9) Shaver et al., 1982, (10) Turnshek et al., 1984, (11) Whelan et al., 1979, (12) Stocke et al., 1984, (13) Baldwin and Smith, 1983, (14) Young et al., 1982, (15) Drew and Boksenberg, 1984, (16) He et al., 1984, (17) Arp, 1984

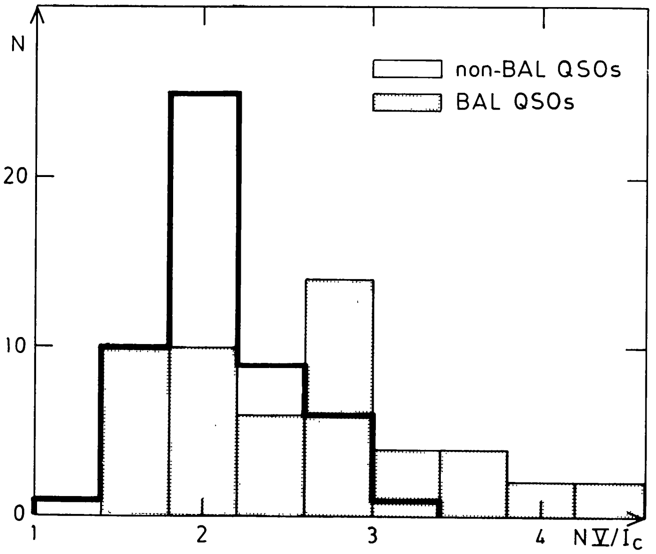

Fig. 1a. Normalized distributions of the N v/I_c measurements determined for the 52 non-BAL and 26 BAL QSOs (see text)

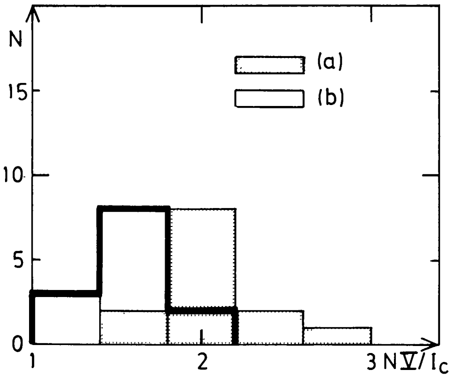

Fig. 1b. Referring to the sample of non-BAL quasars published by Young et al. (1982), this figure represents the N v/I_c distributions derived from the N v emission peak being measured from just above the continuum (a) as well as from the extrapolated red wing of the Lyα emission-line (b)

distributions of N v/I_c were found to be essentially the same for the four selected samples of non-BAL QSOs. Within the measurement uncertainties, Smith et al. (1981) also found that their estimates of the N v strength were somewhat different from those previously determined by Osmer and Smith (1976) for the same objects. *It is clear from Fig. 1a that the distribution of N v/I_c is markedly different between BAL and non-BAL QSOs.* We see that the N v/I_c ratio is generally higher for BAL QSOs than the overestimated value measured for the other quasars. In order to roughly estimate how much our measurements of N v/I_c are overestimated for the non-BAL QSOs, we have made new measurements of the NV intensity peak from just above the extrapolated red wing of the Lyα emission-line. Due to the better resolution as well as signal to noise ratio of the spectra published by Young et al. (1982), we have only performed these new measurements for this sample. Both the distributions of the corrected and uncorrected N v/I_c measurements are reproduced in Fig. 1b. We clearly see from this figure that all values of N v/I_c referring to non-BAL QSOs might have been overestimated in Fig. 1a by as much as a factor 2. This is in agreement with independent estimations made by Osmer and Smith (1977). Therefore, we safely concur with Turnshek (1984b) that the observed N v peak intensity is appreciably higher in the spectrum of BAL than in that of non-BAL QSOs.

4. Formation of the complex Lyα + N v line profile

One of the most outstanding features observed in the spectrum of high redshift BAL QSOs is the complex Lyα + N v line profile: the Lyα emission and blueshifted absorption are unusually weak and/or absent (Hazard et al., 1984) whereas the N v emission-line plus associated P Cygni-type absorption are generally well developed (cf. Sect. 3). Furthermore, because the velocity width of the N v BAL trough is usually larger than the velocity separation between Lyα and N v, it was soon suggested that the BALR must be located beyond the Lyα EL region (cf. Lynds, 1966). Further arguments supporting this view have been given by Weymann and Foltz (1983). One then naturally expects that the resonance line scattering (RLS) of Lyα photons by the receding N^{4+} ions in a spherically symmetric envelope can account for both the attenuation of Lyα and the enhancement of the N v emission lines.

We have performed profile calculations along these lines, making use of the Sobolev approximation (Sobolev, 1947; Castor, 1970) for treating the radiative interactions between the N^{4+} ions and the underlying continuum plus Lyα photons. Since the resulting Lyα + N v line profiles depend to some extent on both the adopted geometry and line formation mechanism, it is very likely that they should provide a useful diagnostic tool. At the end of this section, we compare the main characteristics of the theoretical line profiles with those observed in representative spectra of BAL QSOs.

4.1. Expression of the complex Lyα + N v line profile

Because we do not intend to perform here accurate fittings of individual Lyα + N v line profiles but rather to delineate their main characteristics, we shall adopt in the following a model that is as simple as possible. We first consider that the resonance line transitions of N v at $\lambda\lambda$ 1238.8, 1242.8 Å can be modelized by a two-level atom that scatters photons in accordance with a complete redistribution in frequency and direction. We also assume that the central source which emits the continuum and Lyα photons is point-like with respect to the size of the outward-accelerating BALR. Under such approximations and following Surdej (1979b), it is straightforward to establish that the expression $E(X)/E_c$ of the complex Lyα + N v line profile as a function of the dimensionless frequency X takes the form

$$\frac{E(X)}{E_c} = \int_{-1}^{\mathrm{Min}(-|X|,\,X_{\min})} (1+\xi(X'))\,\frac{(1-\exp(-\tau^r_{12}(X')))}{|2X'|}\,P(X',X)\,dX' + \begin{cases}(1+\xi(X))\cdot\exp(-\tau^r_{12}(X)) & \text{if } X\in[-1,X_{\min}],\\ (1+\xi(X)) & \text{if } X\in[X_{\min},1],\end{cases} \tag{1}$$

$\xi(X)$ representing the Lyα emission profile normalized to the continuum at the frequency X and where

$$X' = -v(L)/v_\infty\,, \tag{2}$$

$$X = X'\cdot\cos(\theta)\,, \tag{3}$$

$$X_{\min} = -v_0/v_\infty\,, \tag{4}$$

and

$$P(X',X) = \frac{1-\exp(-\tau_{12}(X',X))}{\tau_{12}(X',X)}\cdot\frac{1}{\beta^1_{12}(X')}\,. \tag{5}$$

We briefly recall hereafter the physical meaning of the different quantities appearing in the previous relations. v_0 (resp. v_∞) denotes the initial (resp. terminal) radial velocity $v(L)$ of the flow, L being the radial distance expressed in source radii units. $\tau_{12}(X', X)$ (resp. $\tau^r_{12}(X')$) represents the fictive line opacity evaluated at a distance $L(X')$ along a direction making an angle θ(resp. $\theta = 0$) with respect to the radial direction. These quantities are related as follows:

$$\tau_{12}(X',X) = \tau^r_{12}(X')\Big/\left(\mu^2\left(1-\frac{d\ln L}{d\ln|X'|}\right)+\frac{d\ln L}{d\ln|X'|}\right), \tag{6}$$

with

$$\mu = \cos(\theta)\,. \tag{7}$$

$\beta^1_{12}(X')$ stands for the usual escape probability of a line photon emitted along any direction in the expanding medium

$$\beta^1_{12}(X') = \int_0^1 \frac{1-\exp(-\tau_{12}(X',X'\mu))}{\tau_{12}(X',X'\mu)}\,d\mu\,. \tag{8}$$

4.2. Numerical applications

By means of Eq. (1), it is straightforward to compute Lyα + N v line profiles under various physical conditions. For convenience, we adopt the velocity law

$$X' = X_{\min} + (1 + X_{\min})(1/L - 1) \tag{9}$$

and the opacity distribution

$$\tau^r_{12}(X') = \tau_0(1 + X')^\gamma\,, \tag{10}$$

with $X_{\min} = -0.01$, τ_0 and γ being free parameters. We further assume that the unabsorbed Lyα emission-line is adequately fitted by a gaussian profile

$$\xi(X') = A\cdot\exp\left(-\left(\frac{X'-X_L}{\sigma_X}\right)^2\right), \tag{11}$$

where A represents the Lyα emission peak intensity, $X_L < 0$ corresponds to the ratio of the velocity separation between Lyα and N v ($\sim -6000\,\mathrm{km\,s^{-1}}$) to v_∞ and σ_X is related to the FWHM of the gaussian profile via the relation

$$\mathrm{FWHM} \simeq 1.665\sigma_X\cdot v_\infty\,. \tag{12}$$

Values of $A \sim 3$ and FWHM $\sim 4000\,\mathrm{km\,s^{-1}}$ are typical for Lyα emission-lines observed in the spectrum of non-BAL QSOs. Therefore, we have adopted similar values for the computed Lyα + N v line profiles illustrated in Fig. 2. In this figure, the full line represents the Lyα + N v line profile $E(X)/E_c$ according to Eq. (1), the dotted line corresponds to the underlying emission function $1 + \xi(X)$, the dashed line depicts the N v line profile that would be observed in the absence of Lyα – N^{4+} interactions (set $\xi(X) = 0$ in Eq. (1)) and, finally, the dotted-dashed line illustrates the contribution of Lyα photons to the N v emission profile (see next section).

4.3. Discussion

First of all, we wish to point out that the calculations illustrated in Fig. 2 consist of representative Lyα + N v line profiles, whose main characteristics-discussed hereafter-are not significantly altered for other choices of the physical parameters.

As expected, the most important consequences of the interactions between the Lyα photons and the N^{4+} ions are:

i) An attenuation of the Lyα emission-line. The absorption of Lyα may be partial (Fig. 2a) or complete (Fig. 2b) depending on the strength of the N v line opacity,

ii) An appreciable enhancement of the N v emission strength. We recall that both these spectral features are commonly observed in the spectrum of BAL QSOs (cf. Sect. 3). Furthermore,

iii) A shoulder-like feature is usually apparent on the red wing of the N v emission profile (cf. Figs. 2a and b).

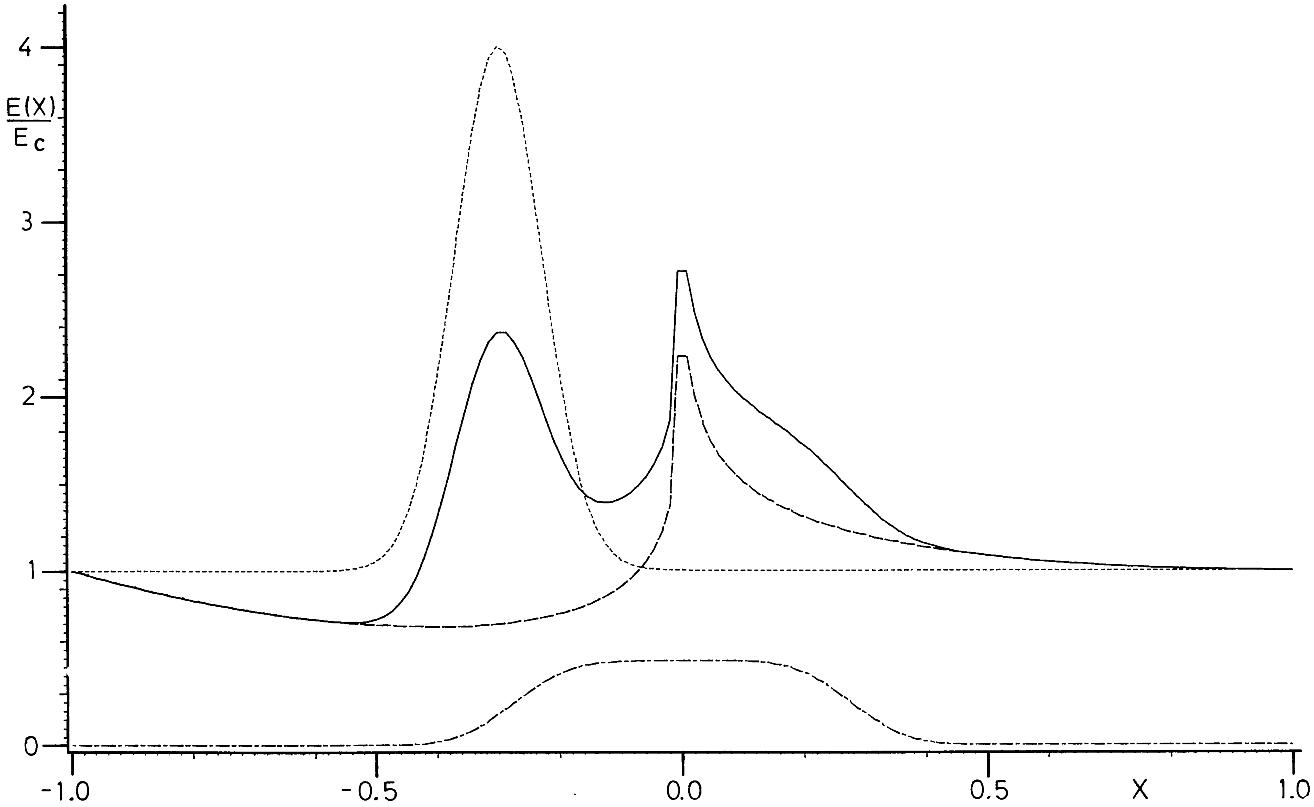

Fig. 2a. Computed Lyα + N v line profile for the choice of the parameters $\tau_0 = 1.0$, $\gamma = 1.0$, $X'_L = -0.30$ and $\sigma_X = 0.1$.
In this and the next figures, the full line represents $E(X)/E_c$ versus X according to Eq. (1), the dotted line corresponds to the underlying emission function $1 + \xi(X)$, the dashed line depicts the N v line profile that would be observed if there were no Lyα $-$ N^{4+} interactions and the dotted-dashed line illustrates the contribution of Lyα photons to the N v emission profile (cf. Eqs. (13) and (14))

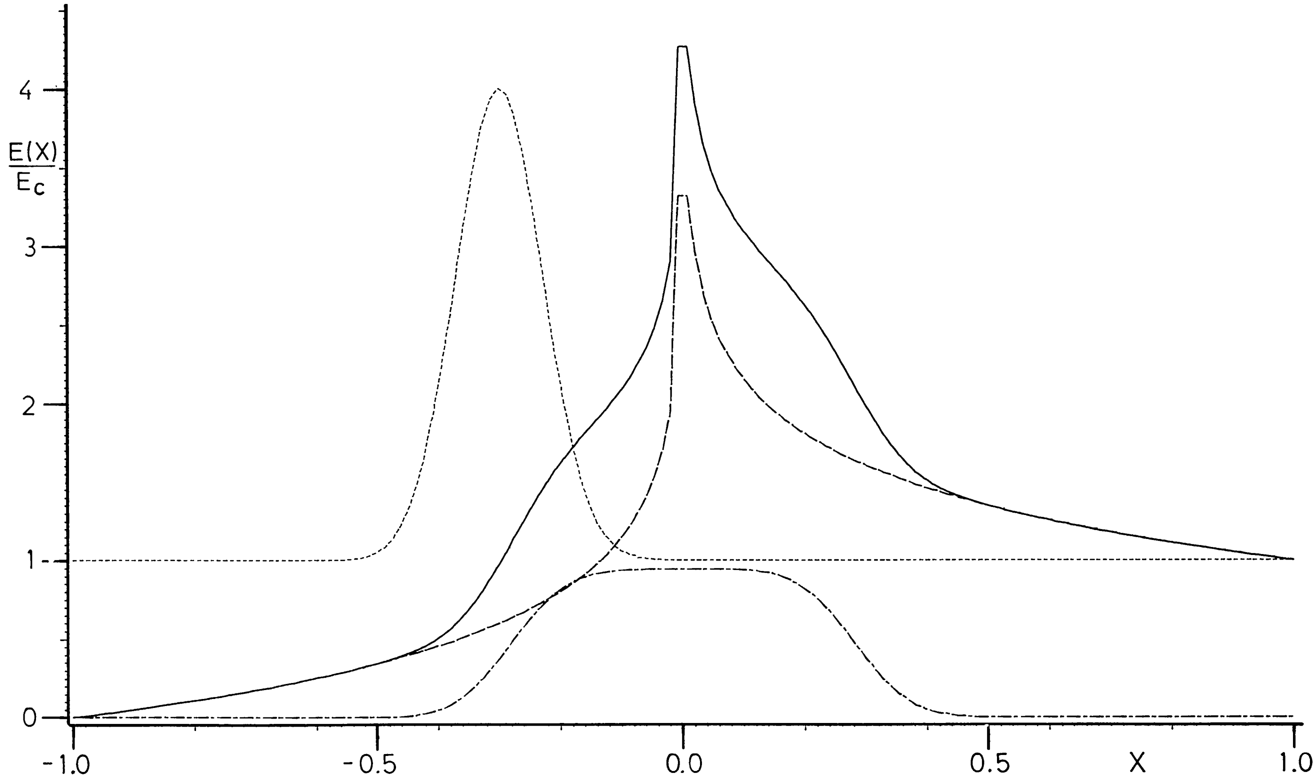

Fig. 2b. Computed Lyα + N v line profile for the choice of the parameters $\tau_0 = 10.0$, $\gamma = 0.1$, $X'_L = -0.30$ and $\sigma_X = 0.1$

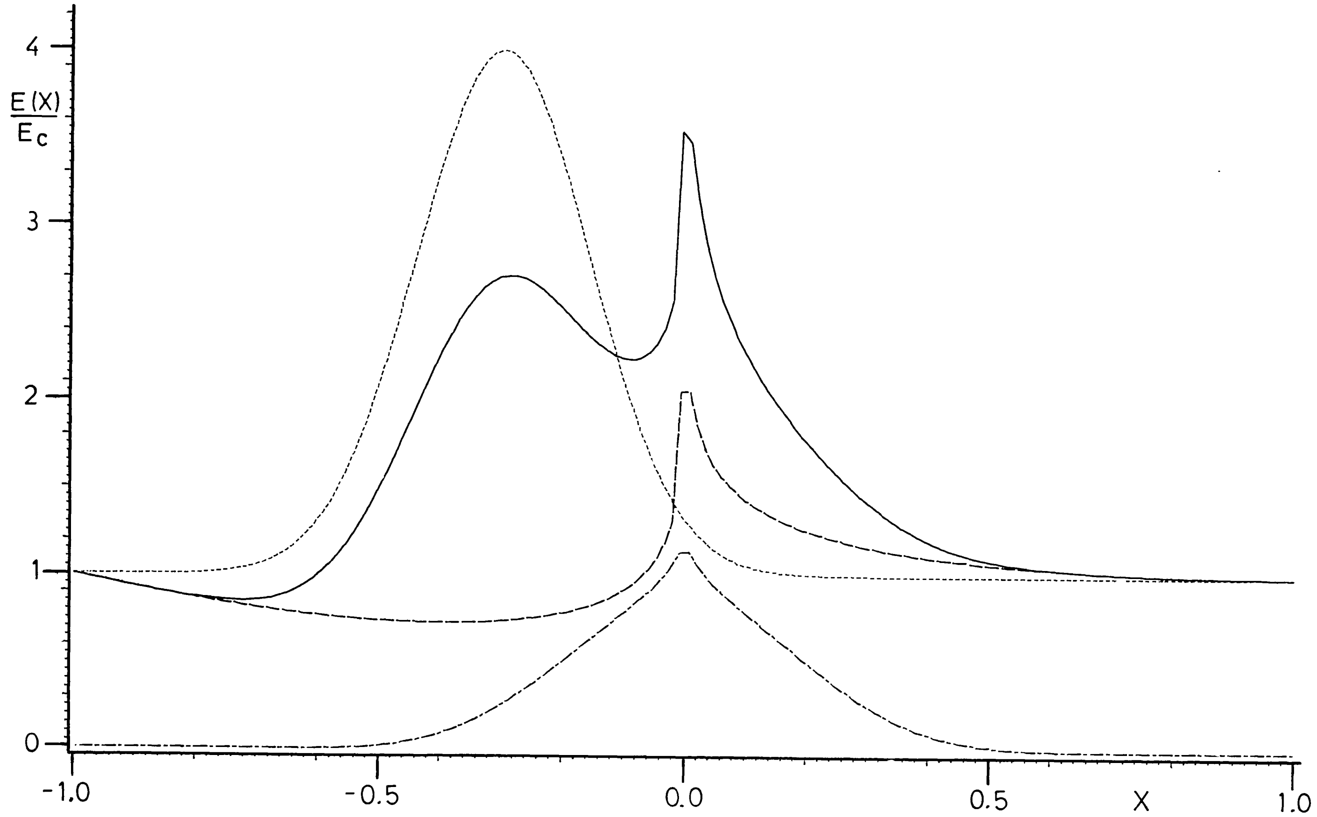

Fig. 2c. Computed Lyα + N V line profile for the choice of the parameters $\tau_0 = 0.8$, $\gamma = 1.0$, $X'_L = -0.30$ and $\sigma_X = 0.2$

There is some good evidence that such an asymmetry is detected in an appreciable number ($\gtrsim 25\%$) of BAL QSO spectra (see the BAL QSOs in italics in Table 1). We believe, for instance, that the tentatively identified Si II λ 1263 emission-line in the spectrum of PHL 5200 (Junkkarinen et al., 1983), Q 2240.9-3702 (Clowes et al., 1979), Q 1413 + 117 (Drew and Boksenberg, 1984), etc. could be due to this shoulder-like effect. We shall discuss this point in Sect. 5.

Now, we should like to give further physical insight on the effects responsible for the main characteristics i), ii) and iii) of theoretical Lyα + N V line profiles described above. Considering that the intensity of the Lyα emission-line centered at X_L drops to negligible values at frequencies $X_L - 2\sigma_X \lesssim X \lesssim X_L + 2\sigma_X$, it is clear that most of Lyα photons will be scattered by the N^{4+} ions within a shell bounded by the radii $L(X'_{\rm inner} = X_L + 2\sigma_X)$ and $L(X'_{\rm outer} = X_L - 2\sigma_X)$. This directly accounts for the attenuation of the Lyα emission-line observed in BAL QSO spectra (cf. the feature i) above). Furthermore, it is straightforward to establish that, within the frequency interval $X \in [X'_{\rm inner}, -X'_{\rm inner}]$, the contribution $E(X)_{{\rm Ly}\alpha}/E_{\rm c}$ of Lyα photons scattered from the shell $[L(X'_{\rm inner}), L(X'_{\rm outer})]$ to the emission-line profile $E(X)/E_{\rm c}$ is expressed by

$$E(X)_{{\rm Ly}\alpha}/E_{\rm c} = \int_{X'_{\rm outer}}^{X_{\rm inner}} \xi(X') \frac{(1 - \exp(-\tau^r_{12}(X')))}{|2X'|} P(X', X)\, dX'. \quad (13)$$

Because for $|X| < -X'_{\rm inner}$ the redistribution function $P(X', X)$ is only very slightly dependent on the frequency X, the contribution $E(X)_{{\rm Ly}\alpha}/E_{\rm c}$ appears to be nearly constant in the frequency interval $X \in [X'_{\rm inner}, -X'_{\rm inner}]$. Outside this range, we find that

$$E(X)_{{\rm Ly}\alpha}/E_{\rm c} = \int_{X'_{\rm outer}}^{{\rm Max}(-|X|, X'_{\rm outer})} \xi(X') \frac{(1 - \exp(-\tau^r_{12}(X')))}{|2X'|} P(X', X)\, dX' \quad (14)$$

is a function which rapidly decreases to zero as $|X| \to -X'_{\rm outer}$ (see the dotted-dashed lines in Fig. 2). The superposition of the rectangular emission profile $E(X)_{{\rm Ly}\alpha}/E_{\rm c}$ to the contribution

$$E_{\rm c}(X)/E_{\rm c} = \int_{-1}^{{\rm Min}(-|X|, X_{\rm min})} \frac{(1 - \exp(-\tau^r_{12}(X')))}{|2X'|} P(X', X)\, dX' \quad (15)$$

due to the continuum source photons scattered across the whole expanding envelope provides a very good account for both the enhancement of the N V emission strength (cf. ii) above) and the shoulder-like feature located near the frequency $-X'_{\rm inner}$ in the red wing of the N V emission profile (cf. iii) above). As it might be expected, a symmetric shoulder-like feature is also apparent at the frequency $X'_{\rm inner}$ whenever the Lyα emission-line is strongly absorbed (cf. Fig. 2b).

The simple quantitative interpretation of the above spectral characteristics i), ii) and iii) clearly demonstrates that these are general properties of the spherically symmetric model plus resonance line scattering (RLS) and not artefacts caused by the particular choice of a velocity and/or opacity distribution(s), of the point-like source approximation, of the two-level atom model, etc. However, we can easily foresee that these spectral characteristics will vanish whenever the N v optical depth gets too small in the frequency interval $X' \in [X'_{\mathrm{outer}}, X'_{\mathrm{inner}}]$. One also expects that for appreciably large widths of the Lyα emission-line, the scattering of Lyα photons will take place across the whole expanding envelope resulting in a contribution $E(X)_{\mathrm{Ly}\alpha}/E_c$ that is more sharply peaked near $X = 0$. While the N v emission peak will be strengthened, the shoulder-like feature will almost completely disappear (see Fig. 2c).

5. Conclusions

We have pointed out in the present work that a spherically symmetric expanding BALR in which the resonance scattering of line photons is consistently treated with the possible effects due to turbulence, occultation, collisions, etc. may very well account for the observed characteristics of P Cygni-like profiles in the spectra of BAL QSOs. If, on the contrary, one assumes that all quasars do have BALRs covering only a small fraction of the continuum source, "*ad-hoc*" geometries as well as physical mechanisms must be introduced in order to explain the observed BAL profiles as well as the different emission-line properties existing between BAL and "*apparently*" non-BAL QSOs.

In this context, we have established that alike the cases for the C IV, Lyα, C III], Al III, Fe II, Fe III, etc. emission-lines (Turnshek, 1984b; Hartig and Baldwin, 1986) the distribution of the N v emission peak, i.e. N v$/I_c$, is markedly different between BAL and non-BAL QSOs. In the framework of the Sobolev approximation, we have applied the "*standard*" model in order to simulate complex Lyα + N v line profiles. This simple model has allowed us to directly interpret the observed enhancement of the N v emission strength as well as the attenuation of the Lyα emission-line in the spectra of BAL QSOs. Furthermore, the prediction that a shoulder-like feature should be present in the red wing of the N v emission and its possible detection in the spectrum of at least 7 BAL QSOs[1] seem to indicate that the tentative identification of Si II λ 1263 emission in those spectra is very doubtful. Indeed, any other low ionization broad emission-line (cf. Si II λ 1556, etc.) has ever been reported with the presence of Si II λ 1263 in BAL QSO spectra (Junkkarinen et al., 1983; Clowes et al., 1979; Drew and Boksenberg, 1984). In addition, Si II λ 1263 has never been detected as a very conspicuous emission-line in the spectrum of non-BAL QSOs (see e.g. Baldwin, 1977). We believe that improved Lyα + N v theoretical line profiles including the finite structure of the N v resonance doublet as well as the possible effects due to turbulence, etc. should be compared with observations before more definite statements can be made. We actually develop such an improved "*standard*" model at the Liège Institute of Astrophysics (Surdej and Hutsemékers, 1987).

Recalling that the velocity structure of BALs ranges from smooth (P Cygni-type) to complex absorptions and that, for some BAL QSOs, the absorption troughs appear to be well detached from the central emission-lines, it is interesting to mention that Turnshek (1984a) and Hartig and Baldwin (1986) report a possible correlation between BAL and EL properties: BAL QSOs exhibiting detached troughs with observable velocity structure often have weaker and/or broader high excitation emission-lines (e.g. C IV, Si IV). Since detached absorption troughs may directly be simulated, as a first approximation, by setting $\xi(X') = 0$ and $-1 < X_{\mathrm{min}} \ll -0.01$ in Eq. (1), we find that the "*standard*" model also predicts weaker and broader emission-lines for such profiles (cf. Fig. 3). The net effect of adding some turbulence then results in better separating the blueshifted BAL from the broader and weaker emission-line (Surdej and Hutsemékers, 1986).

Considering:

i) that the improved "*standard*" model provides a good description of the observed high ionization C IV, Si IV, etc. line profiles (see Sect. 2);

ii) the whole set of differences existing between the EL properties of BAL and non-BAL QSOs (Turnshek, 1984b; Hazard et al., 1984; Hartig and Baldwin, 1986; see Sect. 3);

iii) that the "*standard*" model accounts very well for the main observed characteristics of the complex Lyα + N v line profile (see Sect. 4); and

iv) the fact that there seems to exist a correlation between the width, the strength of emission-line profiles and the velocity structure of the absorption troughs (see above), we conclude that it is highly plausible and natural to assume that BAL and non-BAL QSOs form two distinct classes of quasars. Furthermore, the possibility that the formation of a BALR results from the progressive destruction of a "*normal*" broad emission-line region (BELR) deserves some special attention. Indeed, Blumenthal and Mathews (1979) have proposed that the optically thick emission-line clouds giving rise to a "*normal*" emission line spectrum could, under certain circumstances, be radiatively expelled from the central non thermal source. As they accelerate away, these clouds expand and become optically thin in the Lyman continuum, producing broad absorption features in the high excitation lines due to resonance scattering. No Mg II absorption can however be formed. In such a scenario, BAL QSOs with smooth absorption troughs adjacent to the emission (cf. the spectra of RS 23, H 1413 + 113, PHL 5200, etc.) would represent objects in the early phase of the BAL phenomenon, the BALR and BELR being partially coexistent. BAL QSOs exhibiting detached troughs with observable velocity structure and weak, broad high excitation emission-lines (cf. the spectra of Q 0932 + 501, Q 1308 + 308, H 1414 + 090, etc.) would correspond to a more advanced stage of the BALR. It is also likely that if turbulence results from thermal instabilities occurring in an initially smooth flow, the relevant line profiles will show a more complex absorption structure and a weaker emission component, just as it is observed. If the general trend of the proposed scenario is correct, one would expect to observe marked differences between the properties of the narrow emission line region (NELR) pertaining to these two extreme classes of BAL QSOs and, more generally, to BAL and non-BAL QSOs. The lack of observable [O III] emission in the spectrum of several low redshift BAL QSOs (Turnshek, 1986) could, for instance, be an observational proof of the non-existence of a NELR whenever a BALR is present.

Acknowledgements. We thank both Mrs M. Macours-Houssonloge and Mrs J. Bosseloirs for typing the manuscript and drawing the figures.

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[1] It is likely that the shoulder-like feature is present in more BAL QSO spectra. However, the poor quality of some published spectra (bad S/N, insufficient spectral resolution) as well as the existence of physical complications (overlapping between the N v emission profile and the Si IV BAL, etc.) often prevent one from detecting it.

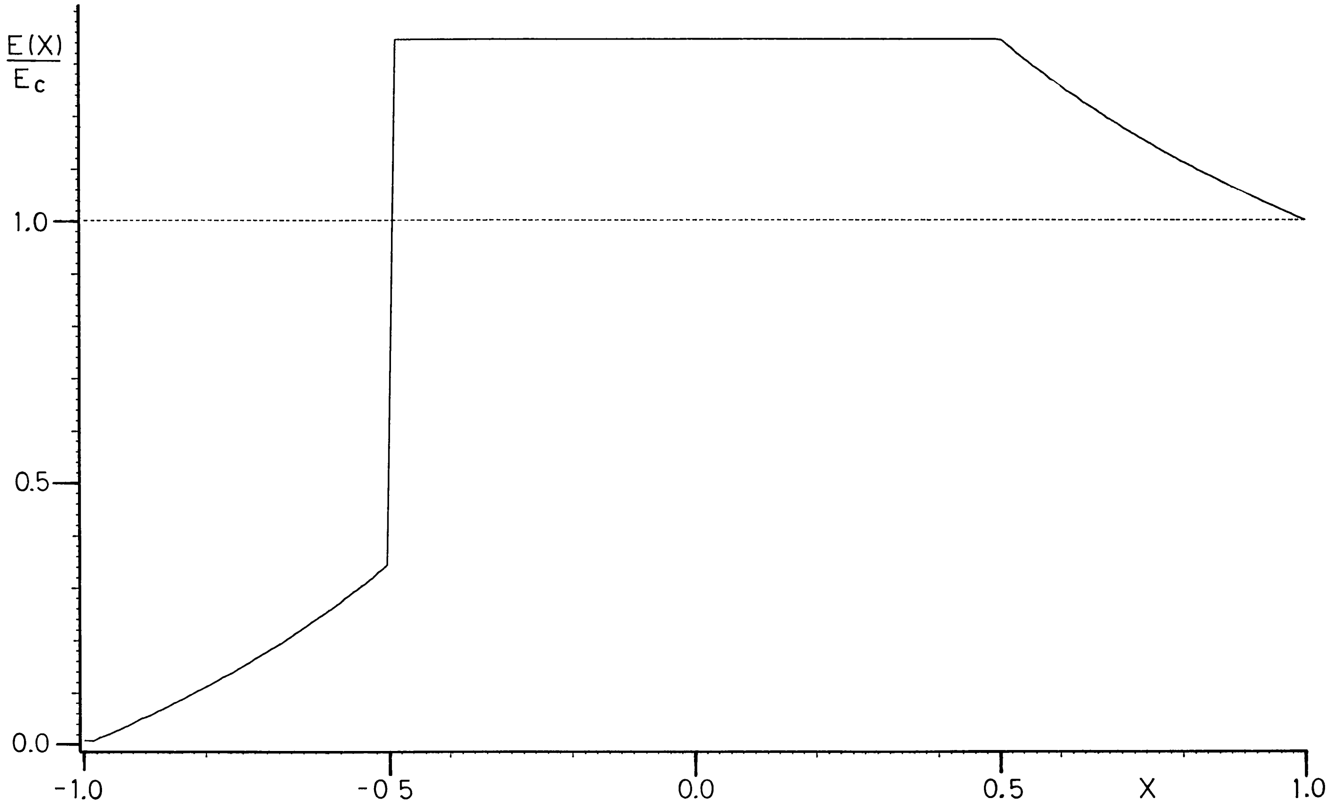

Fig. 3. Setting $\xi(X')=0$, $X_{\min}=-0.50$, $\tau_0=10.0$ and $\gamma=0.1$ in Eq. (1), the resulting profile consists of a well detached absorption through cutting the blue wing of a broad and weak emission-line (compare with the N V profile given in Fig. 2b)

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Note added in proof: Optical imaging of the low redshift BAL QSO 1411 + 442 has led Hutchings (1986, preprint presented at the IAU Symposium No. 121) to conclude that "the BAL phenomenon is not connected with a highly inclined disk system, or with nuclear extinction".