Astron. Astrophys. 96, 242–253 (1981)

ASTRONOMY AND ASTROPHYSICS

Decelerated Flows of Matter around the Quasars PHL 5200 and RS 23*

J. Surdej[1,**,***] and J. P. Swings[2]

[1] European Southern Observatory, ESO c/o CERN, CH-1211 Geneva 23, Switzerland
[2] Institut d'Astrophysique, Université de Liège, Avenue de Cointe 5, B-4200 Cointe-Ougrée, Belgium

Received December 12, 1979; accepted August 8, 1980

Summary. In the framework of the Sobolev approximation, we performed line profile calculations in order to simulate the P Cygni-like profiles observed for the resonance doublets of C IV and Si IV in the spectrum of the quasar PHL 5200 and of C IV in that of RS 23.

Taking into account the structure of the resonance doublets ($^2S_{1/2} - ^2P^0_{1/2,3/2}$) and the non-local transfer of line photons in an outward-decelerating envelope, we show that a good agreement between the theory and the observations is achieved for symmetrically spherical outward-flows decelerated in the gravitational field of the central quasars.

Adopting the value $R^* = 0.05$ pc for the quasi-stellar radius of PHL 5200, the extensions $r^{\text{C IV}}_{\max} \simeq 20$ pc and $r^{\text{Si IV}}_{\max} \simeq 2$ pc of the envelopes in which the P Cygni profiles of C IV and Si IV are formed are then deduced. Furthermore, the central mass of PHL 5200 is found to be $M \simeq 5.8\ 10^8\ M_\odot$ and the corresponding rate of mass-loss superior to $0.02\ M_\odot$/yr.

Finally, an evolutionary scheme linking these two peculiar objects to other known mass-losing ones (Q 0932+501, Q 1246 −057, etc.) and to the numerous narrow-line absorption quasars is proposed.

Key words: mass loss – PHL 5200 and RS 23 – quasars – radiative transfer

1. Introduction

The analysis and interpretation of line profiles observed in the spectrum of quasars present much interest. Indeed, spectroscopic observations of a great number of them have revealed that their redshift measured from the positions of the absorption line components (Z_a) is generally smaller than the one determined from the positions of the emission lines (Z_e). This observational fact naturally led to curiosity about the origin of the absorption components: are they due to absorption of the quasi-stellar continuum in clouds situated at cosmological distances from the quasar ("cosmological hypothesis")? Or are they associated with an ejection of matter intrinsic to the quasar itself ("intrinsic hypothesis")?

This latter hypothesis is supported by the fact that for some quasars the redshifts Z_a and Z_e are correlated via a function depending only on atomic data such as the rest wavelengths of certain resonance lines and/or continuum edge (see, for instance, Bahcall et al., 1968; Burbidge et al., 1968; Burbidge and Burbidge, 1975; Boksenberg, 1977). The mechanisms ("line-locking" and/or "edge-locking") leading to such a configuration of the redshifts Z_a and Z_e have been emphasized by Milne (1926) and have later been adapted to the field of quasars, namely by Mushotzky et al. (1972), Scargle (1973), and Burbidge and Burbidge (1975).

Further arguments in favour of the intrinsic hypothesis are given by the observation of a continuity between the redshifts Z_a and Z_e associated with the absorption and emission components of the resonance doublets of C IV, Si IV, and N V and the Ly α line in the spectra of the quasars PHL 5200 (Lynds, 1967; Burbidge, 1968, 1969; Lynds, 1972; Boksenberg, 1977) and RS 23 (Burbidge, 1970). Indeed, the profiles resulting from the superposition of these individual components are strikingly similar to the P Cygni profile of type I as classified by Beals (1955). Solid arguments in favour of the intrinsic hypothesis for these lines should, however, be provided by a quantitative agreement between the observations and the results of the model adopted for describing the mass-loss phenomenon. Furthermore, in the best case, one can expect to derive from such a confrontation some physical and/or geometrical parameters characterizing the quasars and their envelopes. In this paper we propose such an approach for the quasars PHL 5200 and RS 23. We shall also briefly discuss the aspect of the P Cygni-like profiles observed recently in the spectra of the quasars Q 1246−057 (Osmer and Smith, 1977; Boksenberg et al., 1978) and Q 0932+501 (Notni et al., 1979).

In Sects. 2 and 3 we present for the quasars PHL 5200 and RS 23, respectively, the observational data, the results of theoretical attempts by previous authors and by ourselves to explain the P Cygni profiles for the resonance doublets of C IV and Si IV, and the determination of some basic physical and geometrical parameters characterizing the quasar plus envelope system.

Section 4 is devoted to a brief discussion concerning the aspect of the P Cygni-like profiles in the spectrum of the quasars Q 1246−057 and Q 0932+501.

Finally, an evolutionary scheme locating PHL 5200 and RS 23 in the general context of quasars is proposed in the last section, as well as some general conclusions.

Send offprint requests to: J. Surdej

* Partly based on observations collected at the European Southern Observatory, ESO, La Silla, Chile

** Also, Aspirant au Fonds National de la Recherche Scientifique (Belgium)

*** Present address: Institut d'Astrophysique, B-4200 Cointe-Ougrée, Belgium

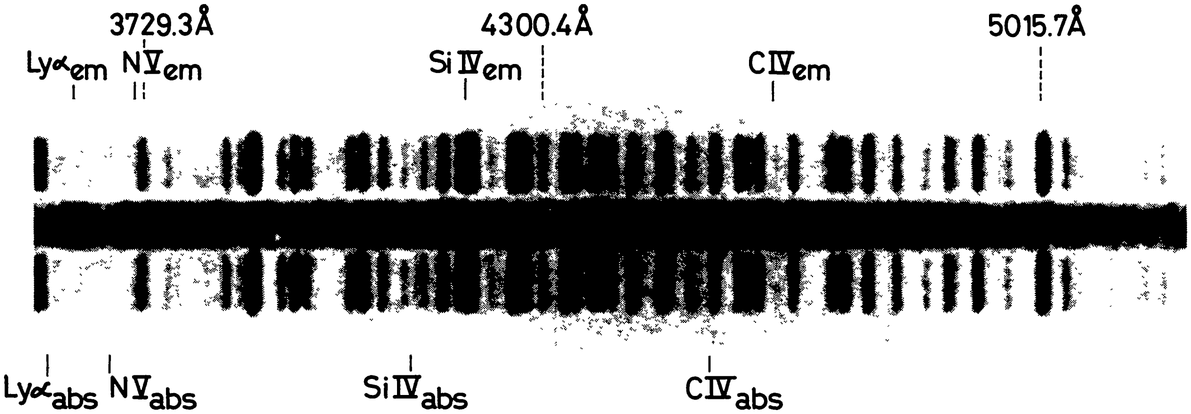

Fig. 1. Spectrogram of PHL 5200 recorded with the Boller & Chivens spectrograph (dispersion: 171 Å/mm) attached to the Cassegrain focus of the 3.6 m ESO telescope (July, 1978)

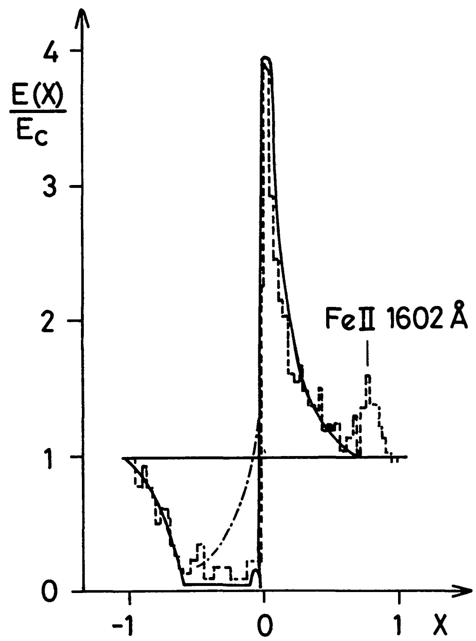

Fig. 2. Comparison between the profiles calculated (full line) and observed (dashed line) for the resonance doublet of C IV in the spectrum of PHL 5200 (see text). The dot-dashed line represents a portion of the profile calculated by Scargle, Caroff and Noerdlinger (1970, 1972) by means of an A.E envelope

2. PHL 5200

A. Observations

The quasi-stellar object PHL 5200 (Q 2225−055, 4 C−5.93, see Scheuer and Wills, 1966; $m_b=18^m_.45$) has been observed spectroscopically for the first time by Lynds (1967) at Kitt Peak National Observatory. Lynds reports: "The most prominent features in the spectrum of PHL 5200 are three wide absorption bands (about 100–150 Å in width) apparently associated with emission features which are located at their sharp borders. The three emission features involved may be identified with the resonance lines N V λ 1240, Si IV $\lambda\lambda$ 1394 and 1403, and C IV λ 1549."

Lynds finds that the redshift of PHL 5200 determined from the positions of the emission lines is $Z_e=1.981$, and that if one interprets these line profiles as formed in expanding media, the maximal velocity $v_{\max}$ observed from the shortest extent of the P Cygni absorption component, on a wavelength scale, amounts to 10,000 km s^{-1} in the rest frame of the quasar.

Burbidge (1968, 1969) confirms these remarkable features of the spectrum of PHL 5200, and she suspects a slight variability, on a time scale of about one year, of the P Cygni absorption profile for the resonance lines of Si IV around the redshift values $Z_a=1.891$ and $Z_a=1.950$.

We have reproduced in Fig. 1 a spectrogram of PHL 5200 recently obtained at the Cassegrain focus of the 3.6 m ESO telescope (Boller and Chivens spectrograph; dispersion: 171 Å/mm; exposure time: 1 h 45 min). Unfortunately the noise of the photocathode, appearing on the spectrum through the strong and non-uniform background, did not allow us to record intensity tracings of the interesting P Cygni profiles. However, we confirm the redshift value $Z_e=1.981$ and the fact that the maximal expansion velocities measured from the line profiles of C IV and Si IV are the same and are equal to $v_{\max}=10{,}000\pm200$ km s^{-1}. In deriving this value, we naturally considered that the maximal expansion velocity v_i, observed at the shortest wavelength extent of the P Cygni absorption component, results from the relation

$$v_i=-(v_{\max}+\Delta v_{23}), \tag{1}$$

where the quantity Δv_{23} represents the separation of the two upper atomic levels (2 and 3) of the given resonance doublet, expressed in terms of Doppler velocities (for instance $\Delta v_{23}=498$ km s^{-1} for C IV and $\Delta v_{23}=1939$ km s^{-1} for Si IV).

Scargle et al. (1970, 1972) have reproduced intensity tracings for the line profiles of C IV and Si IV, observed by Burbidge (1968, 1969) in the spectrum of PHL 5200. In Figs. 2 and 3, the dashed lines represent these observed line profiles, normalized to the quasi-stellar continuum level.

B. Previous Models

In the context of the Sobolev approximation (Sobolev, 1947, 1958), Scargle et al. (1970, 1972), Lucy (1971), and van Blerkom

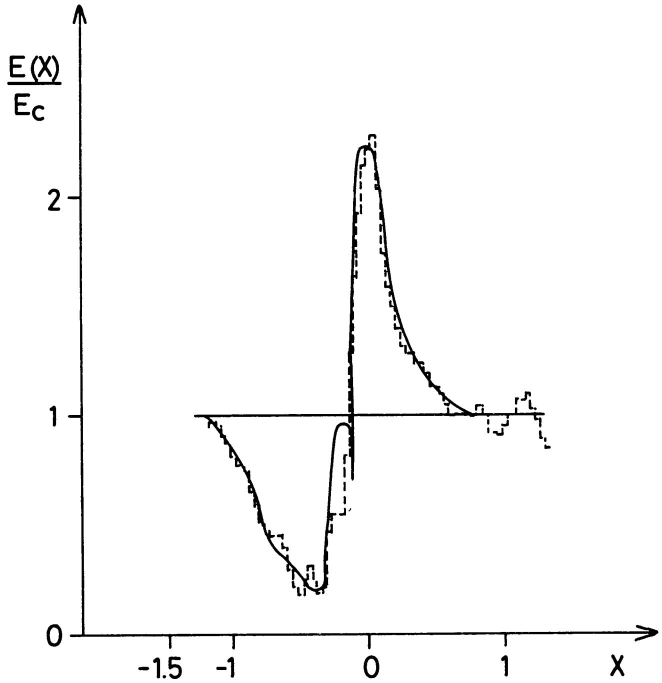

Fig. 3. Comparison between the profiles calculated (full line) and observed (dashed line) for the resonance doublet of Si IV in the spectrum of PHL 5200 (see text)

(1973) have tried to interpret quantitatively the line profiles observed in the spectrum of PHL 5200 via models of outward-accelerating envelopes (later referred to as A.E envelopes). The basic assumptions appearing in their works are the following: a spherically symmetric envelope is accelerated outwards around a central point-like object (Scargle et al., 1970, 1972) and of finite dimensions (Lucy, 1971; van Blerkom, 1973). Because the equivalent widths of the observed emission and absorption line components are almost equal, these authors adopt the additional hypothesis that the destruction probability ε (cf. Mihalas, 1970) of a line photon by collisional de-excitation is equal to zero. Furthermore, Lucy (1971) and van Blerkom (1973) suppose that the scattering of the line photons is coherent in a frame moving with the fluid, whereas Scargle et al. (1970) use an exact function for treating the redistribution of the spectral radiation in frequencies and directions (see also Caroff et al., 1972).

While Scargle et al. succeeded in their calculations to account for the profile of the emission component observed for C IV, they could not fit the abrupt transition between the P Cygni absorption and emission components (see the dot-dashed line in Fig. 2). The line profiles calculated by Lucy (1971) and van Blerkom (1973) differ mainly from the preceding one in that the maximal intensity of the emission component is smaller by about a factor of two. The different fictive opacity τ_{12} and velocity $v(r)$ distributions adopted by these authors, and the fact that Scargle et al. have neglected the finite dimensions of the quasi-stellar core, suffice to explain these deviations. Lucy (1971) concludes that the A.E envelope is probably not spherical and that only a stream of gas, exactly directed towards the observer, could explain the abrupt transition between the P Cygni absorption and emission components observed for the resonance lines of C IV.

Concerning the profile calculated for Si IV, Scargle et al. have reached a better agreement with the observations, but the distribution they adopted for the fictive opacity τ_{12} seems very unlikely: across the radial distance of the whole envelope, this function shows three discrete maxima and four discrete minima! Furthermore, let us stress that none of these authors has taken into account the structure of the resonance doublets of C IV and Si IV in calculating the transfer of spectral line radiation throughout the A.E envelopes. They approximated the two transitions of a resonance doublet to a single one described by a two-level atom model.

More recently, Grachev and Grinin (1975) have calculated for a two-level atom model, line profiles formed in outward-decelerating envelopes (later referred to as D.E envelopes) in order to simulate the observed line profile of C IV. The radial velocity field they adopted is given by the following relation:

$$v(r)=v_\infty(1+GR^*/r)^{1/2}, \quad (2)$$

which describes the motion of the fluid, initially ejected at the quasi-stellar surface with a velocity v_0 and subsequently decelerated by the gravitational field of the central nucleus to the terminal velocity v_∞. In that relation R^* stands for the radius of the central source, r for the radial distance at which is evaluated the velocity $v(r)$, and G is the decelerating parameter defined by

$$G=(v_0/v_\infty)^2-1. \quad (3)$$

The agreement reached by Grachev and Grinin between their calculations and the observed line profile for C IV is now quite remarkable. However, in their determination of the degree of excitation of the atoms at a given point $\boldsymbol{r}$ in the envelope, Grachev and Grinin supposed that the value of the source function S'_{12} included in the term of radiative coupling between distant atoms is given by the value of the source function calculated at this same point [see their Eqs. (20) and (21)]. This semi-local approximation used for treating the transfer of line photons in D.E envelopes results in overestimating (resp. underestimating) the true degree of excitation of the atoms near (resp. far from) the central source and this, in turn, influences of course the exact shape of the calculated line profile. Furthermore, Grachev and Grinin admitted in their formalism the restrictive hypothesis that at every point in the expanding medium the envelope is optically thick ($\tau_{12} \gg 1$) to the spectral line radiation. This, and the fact that they neglected the structure of the resonance doublet, did not enable them to calculate the line profile observed for Si IV and make their approach questionable. Let us also mention that these authors did not give any indication relative to the size $r_{max}^{C\,IV}$ of the D.E envelope in which is formed the line profile calculated for C IV.

C. *Proposed Model*

In a series of papers (Surdej, 1977, 1978a, 1979a, referred to below as Papers I, II, III, respectively) one of us has generalized the Sobolev approximation in order to treat the transfer of line radiation for a two-level atom model in outward-decelerating envelopes. We have shown there, by means of self-consistent calculations, the effects of the radiative interactions between distant atoms on the behaviour of the source function S_{12} throughout the medium, and the dependence of the calculated line profiles on the physical and geometrical parameters of the model. This theory is well suited to the study of line profiles formed by the scattering of photons in a single resonance line transition.

If we now consider a resonance doublet transition, we expect that this two-level atom model will still accurately describe the transfer of line radiation as long as the relative separation Δv_{23} of the two upper levels is very small in comparison with the maximal expansion velocity $v_{\max}$ of the medium. In practical calculations, this simplification is performed by assigning to the "fictive" single resonance transition $1 \leftrightarrows (2, 3)$ an oscillator strength f'_{12} equal to the sum of the oscillator strengths f_{12} and f_{13} specific to each of the single resonance transitions $1 \leftrightarrows 2$ and $1 \leftrightarrows 3$.

One can also imagine the other extreme case in which the relative separation Δv_{23} of the two upper levels is greater than or equal to twice the maximal expansion velocity $v_{\max}$ of the medium. In that case the resonance doublet profile will simply result as formed by the superposition of the two individual profiles corresponding to the two distinct line transitions $1 \leftrightarrows 2$ and $1 \leftrightarrows 3$. Indeed, the Doppler effects throughout the expanding medium are too small to shift the frequency ν_{12} (resp. ν_{13}) of a photon emitted at a point R in the line transition $1 \leftrightarrows 2$ (resp. $1 \leftrightarrows 3$) to the frequency ν_{13} (resp. ν_{12}) of the other line transition at a distinct point R'. Thus, if $\Delta v_{23} \gtrsim 2\, v_{\max}$, the two-level atom model applied independently to each of the single resonance transitions still enables one to calculate the resulting resonance doublet profile. In summary, one can say that it is justified to use the two-level atom model in order to analyse observed line profiles in the cases where the dimensionless quantity ΔX_{23} defined by

$$\Delta X_{23} = \Delta v_{23} / v_{\max} \tag{4}$$

is smaller than the corresponding spectral resolution of the observations or greater than 2.

If, in the frame of the fixed observer, we choose to define the frequency interval $X \in [X_i, X_f]$ [see relations (4) and (5) in Paper III] in which is formed a resonance doublet profile such that the central frequency $X=0$ corresponds to the unshifted position of the red component ($\nu = \nu_{12}$) of the doublet, we readily find that the extreme frequencies X_i and X_f associated with the photons emitted at a "local frequency"[1] $\nu_L \simeq \nu_{13}$ and $\nu_L \simeq \nu_{12}$, respectively, by those atoms approaching and receding from the observer with the maximal expansion velocities $v_{\max}$ and $-v_{\max}$, have the values $X_i = -[(\nu_{13}/\nu_{12}) + \Delta X_{23}]$ and $X_f = 1$. Since $\nu_{13}/\nu_{12} \simeq 1$, the frequency interval in which is formed a resonance doublet profile is given with a good approximation by

$$X \in [-1 - \Delta X_{23}, 1]. \tag{5}$$

The spectral resolution (dispersion: 375 Å/mm) of the line profiles (see Figs. 2 and 3) observed by Burbidge (1968, 1969) being equivalent to a frequency resolution $\Delta X \simeq 0.05$, and because the relative separation of the two upper levels for the resonance doublets of C IV and Si IV amounts [see relation (4)] to $\Delta X_{23} = 0.05$ and $\Delta X_{23} = 0.20$, respectively, it can be concluded that it is necessary to include the structure of the resonance doublets ($^2S_{1/2} - {}^2P^0_{1/2,3/2}$) in order to simulate and analyse the line profiles of C IV and Si IV observed in the spectrum of PHL 5200.

This conclusion led us to study the behaviour of the source functions S_{12} and S_{13} associated with each of the single line transitions $1 \leftrightarrows 2$ and $1 \leftrightarrows 3$ of a resonance doublet, the behaviour of the radiative forces due to the scattering of line photons, and the dependence of the resonance doublet profiles on the geometrical and physical parameters of the medium (A.E and D.E envelopes).

1 We recall (cf. Magnan, 1973) that the local frequency of a photon emitted or passing at a given point is the frequency seen by an observer moving with the medium at that point

A report of this work (Surdej, 1979b) is now published (Surdej, 1980, later referred to as Paper IV), and we shall quote here the most important results and conclusions relevant to the formation of the P Cygni-like profiles in the spectrum of PHL 5200.

D. Description and Results of the Proposed Model

First of all, let us expose the basic assumptions of the model: in the framework of the Sobolev approximation (cf. Paper I), we consider spherically expanding envelopes in which the level populations ($i=1$, 2, and 3) of the given ion have reached a steady state. We assume a complete redistribution in directions and frequencies for an emitted photon in the frame of a moving atom. Although in most of the applications we adopted the constancy of the ionization balance across the envelope when the only source of excitation is due to the pure resonance scattering of line photons, the model can also account for ionization distributions and the effects of thermal excitation by collisions, if these are specified. Furthermore, we considered for simplicity that the quasi-stellar core, of finite dimensions, radiates continuously like a black body at temperature T and with an intensity I_c constant over the frequency interval $X \in [-1 - \Delta X_{23}, 1]$.

Let us immediately point out that it is only for the case of D.E envelopes (cf. Grachev and Grinin, 1975) that we could simulate the abrupt transition observed between the P Cygni absorption and emission components in the resonance doublet profile of C IV (see the dashed line in Fig. 2). Therefore, in the following we shall only concentrate on the formation of line profiles in D.E envelopes.

An observer situated at a given point R in a D.E envelope and moving with the fluid sees, along the radial direction, a general state of contraction of the medium, whereas along an axis perpendicular to it the envelope presents a general state of expansion. Consequently, for the case of a three-level atom model (resonance doublet) embedded in a D.E envelope, there exist in addition to a radiative coupling between distant atoms emitting and absorbing photons of the same local frequency (cf. Papers I and II), two new types of radiative coupling corresponding to the emission of photons with a local frequency $\nu'_L \simeq \nu_{13}$ (resp. $\nu''_L \simeq \nu_{12}$) by atoms situated at points R' (resp. R'') and which can interact with atoms situated at a fixed point R with a local frequency $\nu_L \simeq \nu_{12}$ (resp. $\nu_L \simeq \nu_{13}$). It is easy to deduce that the geometrical locus (R, R') [resp. (R, R'')] of the points R' (resp. R'') with respect to a fixed point R is determined by the condition that the relative velocity between the moving atoms at points R' (resp. R'') and R is $v'_s - v_s = \Delta v_{23}$ (resp. $v''_s - v_s = -\Delta v_{23}$). We have illustrated in Fig. 4 the geometrical loci (R, R') (dashed lines) and (R, R'') (dot-dashed lines) with respect to the fixed point R, chosen such that $r = 2\, R^*$, for the values of the parameters $G=10$, $\Delta X_{23} = 0.1$, and $r_{\max} = 5\, R^*$. One also recognizes in that figure the geometrical locus (R, R''') (full line) of the distant points R''' with respect to R, and such that $v'''_s - v_s = 0$ (cf. Fig. 5 in Paper I). One can now better understand the physical mechanisms leading to the determination of the excitation degree (cf. S_{12}, S_{13}) of the atoms in the upper levels 2 and 3. For instance, the value of the source function S_{12} evaluated at a fixed point R depends on the intensities of the spectral radiation emitted with a local frequency $\nu'_L \simeq \nu_{13}$ at points R', with a local frequency $\nu'''_L \simeq \nu_{12}$ at points R''' and with a local frequency $\nu_L \simeq \nu_{12}$ in the neighbourhood of R. One sees that the radiative transfer in a D.E envelope appears fairly complex. A detailed report concerning the solution of this problem is included in Paper IV.

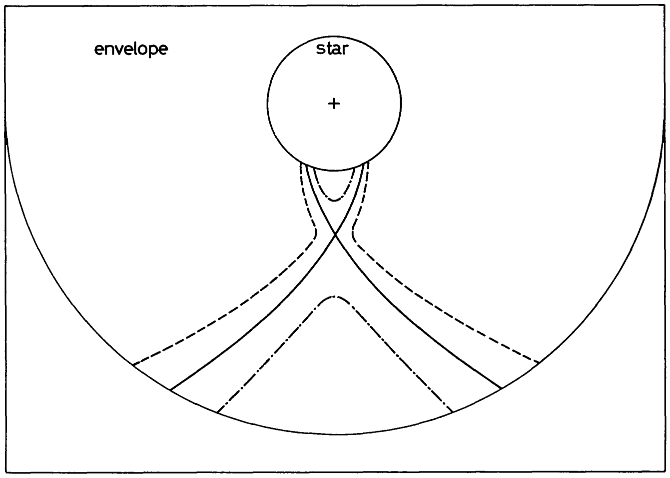

Fig. 4. Geometrical loci (R, R') (dashed line), (R, R'') (dot-dashed line), and (R, R''') (full line) with respect to the fixed point $R(L=2)$ for the values of the parameters $G=10$, $\Delta X_{23}=0.10$, and $L_{\max}=5$

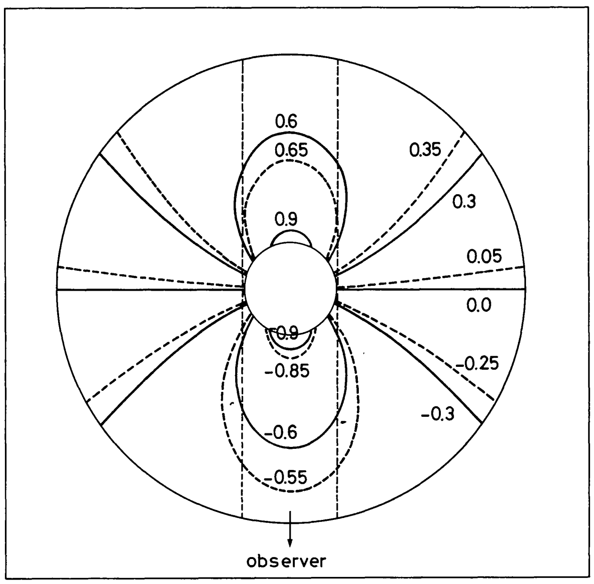

Fig. 5. Surfaces of equal frequencies $X=-0.85$, -0.55, -0.25, 0.05, 0.35, 0.65, and $Y=X+\Delta X_{23}$ in a D.E envelope for the values of the parameters $G=10$, $\Delta X_{23}=0.25$, and $L_{\max}=5$

Thus, supposing for the time being that the source functions S_{12} and S_{13} as well as the fictive opacities τ_{12} and τ_{13} [cf. relation (12.2) in Paper I] associated with the radiative transitions $1 \leftrightarrows 2$ and $1 \leftrightarrows 3$ have been determined throughout the whole space of the envelope, one can easily deduce the expression $E(X)/E_c$ for the resonance doublet profile in the frequency interval $X \in [-1-\Delta X_{23}, 1]$. This approach is in fact essentially the same as the one followed when establishing the expression $E(X)/E_c$ for a single resonance line (see Chapt. 4 in Paper III). Indeed, the expression $E(X)/E_c$ for the resonance profile represents merely the total amount of spectral energy $E(X)$, defined per frequency and solid angle units, radiated by the medium towards a fixed observer, and which has been normalized to the flux E_c of the quasi-stellar continuum integrated over the surface of the central core of the quasar. The quantity $E(X)$ is then given by the integration of the sum of the monochromatic intensity functions $I_{12}(X)$ and $I_{13}(Y=X+\Delta X_{23})$, implicitly space-defined, over a plane perpendicular to the line of sight:

$$E(X)=\int\int_{\Sigma}[I_{12}(X)+I_{13}(Y=X+\Delta X_{23})]\,d\sigma. \qquad (6)$$

In the frame of a fixed observer, $I_{12}(X)$ and $I_{13}(Y)$ account, respectively, for the specific intensities of line radiation emitted, with a local frequency $\nu_L \simeq \nu_{12}$ and $\nu'_L \simeq \nu_{13}$ along a direction parallel to the line of sight, by those parts of the envelope presenting a constant Doppler shift equal to

$$\left.\begin{array}{l} X=-v_s/v_{\max} \\ \text{and} \\ Y=-v'_s/v_{\max} \end{array}\right\} \qquad (7)$$

where v_s and v'_s represent the velocity of the envelope at the corresponding points with respect to the observer. We solved this set of equations for different values of the frequency $X \in [-1-\Delta X_{23}, 1]$, and the resulting "surfaces of equal frequencies X and $Y=X+\Delta X_{23}$" as seen by a fixed observer are illustrated respectively by the dashed and full lines in Fig. 5 for the case of a D.E envelope with $G=10$, $\Delta X_{23}=0.25$, and $r_{\max}=5\,R^*$.

Recalling the dependence of the line profiles formed in D.E envelopes for a single line transition on the behaviour of the surfaces of equal frequency X (cf. Paper III), one can immediately conclude that, to some extent, this dependence will still be valid for resonance doublet profiles since, except for a retardation equal to ΔX_{23}, the behaviour of the surfaces of equal frequency X and $Y=X+\Delta X_{23}$ is essentially the same.

We shall now summarize the essential characteristics of resonance doublet profiles formed in D.E envelopes. Being aware of the fact that the resonance doublet profiles can appear as formed by a single or double P Cygni profile, our conclusions are the following:

(i) The violet wing of the second, or unique, P Cygni absorption component always reaches smoothly the level of the quasi-stellar continuum up to the frequency $X_i=-1-\Delta X_{23}$ corresponding to the greatest velocity v_i observed on the resonance doublet profile. The knowledge of the relative separation Δv_{23} of the upper levels therefore enables the *maximal expansion velocity* v_0 to be deduced [see relation (1) with $v_{\max}=v_0$].

(ii) The sharp cut-off of the red wing of the emission component occurs at the frequency X_c defined by

$$\left.\begin{array}{l} X_c=\{[1-\sin^2(\theta_a)]\,[1+G\sin(\theta_a)]/(1+G)\}^{1/2}, \\ \text{with} \\ \sin(\theta_a)=-1/3\,G+[1/3+(1/3\,G)^2]^{1/2}, \end{array}\right\} \qquad (8)$$

and which corresponds to the total occultation of the corresponding surface of equal frequency by the quasi-stellar core. The location of this frequency X_c on the observed resonance doublet profile thus provides a direct *determination of the decelerating parameter G*.

(iii) The abrupt transition between the first, or unique, P Cygni absorption component and the first, or unique, emission line component takes place at the frequency X_t defined by

$$X_t=-\frac{(1+G/L_{\max})^{1/2}}{(1+G)^{1/2}}, \qquad (9)$$

which is associated with the closed surface of equal frequency which intersects the line of sight at the point $r_{\max}=L_{\max}R^*$. The location of the frequency X_t on an observed resonance doublet profile and the knowledge of the decelerating parameter G allows us to estimate *the maximal extension L_{max} of the envelope.*

(iv) If the conditions

$$\left.\begin{array}{l}\Delta X_{23} > X_c + X_t,\\ \text{and/or}\\ \Delta X_{23} > X_0,\\ \text{with}\\ X_0 = (1+G/L_{max})\Big/\left[(1+G)\left(1+\frac{3}{2}\frac{G}{L_{max}}\right)\right]^{1/2}\end{array}\right\} \quad (10)$$

are verified, the P Cygni absorption and/or emission components are resolved into two distinct components, and the composite line profile itself appears also resolved into a double P Cygni profile. Let us notice that X_0 is the frequency at which the open surfaces of equal frequency X transform themselves into closed ones. Whereas the maximum of the first emission component takes place at the central frequency $X=0$ if the medium is optically thick and at a frequency $X \in]X_t, 0[$ if $\tau_{12} \lesssim 1$, the maximum for the second emission component is observed at a frequency $X \in]X_t - \Delta X_{23}, -\Delta X_{23}[$.

E) Analysis and Calculation of the Resonance Doublet Profiles for C IV *and* Si IV

We measured the spectrum obtained for PHL 5200 (see Fig. 1) and determined the velocities (defined in the rest frame of the quasar!) corresponding to the locations v_i of the P Cygni absorption component that is the most displaced towards the short wavelengths, v_c of the sharp cut-off of the red wing of the emission line, and finally v_t of the abrupt transition between the P Cygni absorption and emission components. These velocities measured with respect to the maximum observed for the central emission line, i.e. such as $v_{em}=0$, are reported in Table 1 for the line profiles of C IV and Si IV. With the use of relation (1), the maximal expansion velocity v_0 can be deduced: it is remarkable to see that the two values v_0 and v_c measured for C IV are identical, within the error measurements, to the ones determined independently for Si IV. These results strongly support the model of the D.E envelope we adopted. Indeed, in such a case, the velocities v_0 and v_c must be independent of the maximal extension of the envelope and, consequently, of the considered line profile, whereas for an A.E envelope one would have expected an L_{max} dependence of the velocities v_0 and v_c. With the help of relation (7), the observed scale of velocities v_s can then be calibrated onto the frequency scale $X \in [-1-\Delta X_{23}, 1]$. The frequencies $X_c = v_c/v_0$ and $X_t = v_t/v_0$ associated, respectively, with the total occultation of the surface of equal frequency $X = X_c$ by the quasi-stellar disk and with the abrupt transition observed between the P Cygni absorption and emission components in the resonance doublet profiles of C IV and Si IV, are also reported in Table 1.

Table 1. Velocities v_i, v_c, and v_t measured from the profiles of C IV and Si IV in the spectrum of PHL 5200. The quantities v_0, X_c, and X_t are deduced from the first ones (see text)

C IV	
v_i =	$-10{,}500$ km s^{-1} ± 200 km s^{-1}
v_c =	6,250
v_t =	$-$ 500
v_0 =	10,000 km s^{-1} ± 200 km s^{-1}
X_c =	0.625 ± 0.020
X_t =	-0.050
Si IV	
v_i =	$-12{,}000$ km s^{-1} ± 200 km s^{-1}
v_c =	6,250
v_t =	$-$ 1,750
v_0 =	10,000 km s^{-1} ± 200 km s^{-1}
X_c =	0.625 ± 0.020
X_t =	-0.175

Since for the values of the decelerating parameter, $G \to \infty$ and $G \simeq 23$, one finds $X_c = 0.62$ and $X_c = 0.63$ [see relation (8)], and since relation (9) gives a positive value for L_{max} if, and only if, the condition $G \geqq (1/X_t^2) - 1$ is satisfied, it can be concluded from the results in Table 1 that an acceptable solution must be such that $G \gtrsim 399$, i.e. [see relation (3)] that the terminal velocity v_∞ must be smaller than 5% of the ejection velocity v_0. If we adopt the value $G = 399$, relation (9) implies that the extent L_{max} of the D.E envelope in which the observed resonance doublet profile for C IV is formed is of the order $L_{max}^{\rm C\,IV} \gtrsim 400$ for $X_t \in [-0.03, -0.07]$ and $L_{max}^{\rm Si\,IV} \in [28, 46]$, assuming that $X_t \in [-0.155, -0.195]$.

Due to the fact that the P Cygni absorption component observed for the resonance doublet profile of C IV is nearly saturated in the frequency interval $X \in [-X_c - \Delta X_{23}, X_t]$, this necessarily implies that the medium is optically thick to the spectral line radiation ($\tau_{12} > 1$, $\tau_{13} > 1$) in the spatial interval $L \in [1, L_{max}]$. Concerning the P Cygni absorption component observed in the resonance doublet profile of Si IV, one establishes in a similar manner that $\tau_{12} > 1$, $\tau_{13} > 1$ around $X = X_t$, i.e. for $L \simeq L_{max}$, but that near the quasar one must have $\tau_{12} < 1$ in order to account for the non-saturation of the P Cygni absorption component around $X = -(X_c + \Delta X_{23})$. It would then be easy to show that if there is conservation of the total number of Si^{3+} ions ejected at the quasi-stellar surface into the whole space occupied by the D.E envelope, the distributions of the fictive opacities τ_{12} and τ_{13} [see relation (12.2) in Paper I] would be nearly constant along the radial direction and, on this basis, one could not explain their behaviour mentioned here above.

To overcome this difficulty, we follow Castor and Lamers (1979) in assuming that the density $n^i(r)$ of an atom which is $i-1$ times ionized is fixed by an ionization equation. These authors showed that, if the ionization balance is primarily controlled by photoionization and recombination such that the ionizing continuum is not optically thick, the ratio of two successive ionization stages, for instance $i+1$ and i, is proportional to the velocity $v(r)$ [see their Eq. (6)]. Now, if k is the dominant stage of ionization such that $n^k/(n^1+n^2+\ldots)$ is about constant in the envelope, the density distribution n^i of an atom which is $i-1$ times ionized may be written in the form [cf. their Eq. (7)]

$$n^i = (n^1 + n^2 + \ldots)\frac{n^k}{(n^1+n^2+\ldots)}\frac{n^i}{n^k} \propto L^{-2} v(r)^{i-k-1}. \quad (11)$$

For the velocity field given in (2) and recalling the definition (12.2) in Paper I for the fictive opacity τ_{12}, the following expression is easily found:

$$\left.\begin{array}{l}\tau_{12}=\tau_{12}^{l}v(r)^{\alpha}F(L,\theta)\left(1-\frac{g_1n_2}{g_2n_1}\right)\Big/\left(1+\frac{n_2}{n_1}+\frac{n_3}{n_1}\right),\\ \text{with}\\ \alpha=i-k.\end{array}\right\}\quad(12)$$

In that expression, τ_{12}^{l} stands for a constant, n_1, n_2, n_3 denote the volume populations of levels 1, 2, 3, and g_1, g_2, g_3 their respective statistical weights. The function $F(L, \theta)$ expresses the angular dependence of the fictive optical depth τ_{12} as a function of L and θ:

$$F(L,\theta)=1/|2(L/G+1)-(2\,L/G+3)\cos^2(\theta)|, \quad (13)$$

θ being the angle between the direction along which is evaluated τ_{12} and the radial direction. Because for the considered resonance doublets $(^2S_{1/2}-{}^2P^0_{1/2,3/2})$ the oscillator strength f_{13} for the line transition $1\leftrightarrows 3$ is twice the value of the oscillator strength f_{12} for the line transition $1\leftrightarrows 2$, we get the obvious relation

$$\tau_{13}=2\tau_{12}. \quad (14)$$

If we represent by T_{12} the total fictive opacity for the resonance line $1\leftrightarrows 2$,

$$T_{12}=\int_{v(L_{\max})}^{v_0}\tau_{12}(\theta=0)\,dv, \quad (15)$$

it is easy to show, by means of relations (14), (15), and (41) of Paper II, that this last relation may be rewritten in the form

$$\left.\begin{array}{l}T_{12}=\frac{\pi e^2}{mc}f_{12}\lambda_{12}N,\\ \text{where}\\ N\;=\int_{R^*}^{r_{\max}}n_1(r)\,dr\end{array}\right\}\quad(16)$$

represents the column density of the absorbing ion in the envelope. Similarly, substituting in relation (15) the expression for the radial fictive opacity $\tau_{12}(\theta=0)$ by the one given in (12), and assuming that $n_1\gg n_2$, $n_1\gg n_3$, we find a new relation for T_{12} which, combined with (16), enables us to define the constant τ_{12}^{l} in terms of physical quantities. Indeed,

$$\left.\begin{array}{l}\tau_{12}^{l}=(\alpha+1)\frac{\pi e^2}{mc}f_{12}\lambda_{12}N\left[v_0^{\alpha+1}-v(L_{\max})^{\alpha+1}\right]^{-1},\quad \text{if}\quad \alpha\neq-1,\\ \text{and}\\ \tau_{12}^{l}=\frac{\pi e^2}{mc}f_{12}\lambda_{12}N\ln\,[v_0/v(L_{\max})]^{-1},\quad\text{if}\quad\alpha=-1.\end{array}\right.\quad(17)$$

Finally, we have determined via numerical applications the sets of values for the physical and geometrical parameters α, τ_{12}^{l}, G, and $L_{\max}$, which give the best agreement between the calculated and observed resonance doublet profiles of C IV ($\Delta X_{23}=0.05$) and Si IV ($\Delta X_{23}=0.20$). We find (see Fig. 2, full line) that the calculated profile for C IV is optimal for $\alpha=0$, $\tau_{12}^{l}>1$, $G=399$, and $L_{\max}\simeq 400$, and in the same way (see Fig. 3, full line) that $\alpha=-1.27$, $\tau_{12}^{l}=4.83\ 10^{10}$, $G=399$, and $L_{\max}\simeq 40$ give the best fit for the observed profile of Si IV.

F. Discussion of the Results

Within the observational error measurements ($\Delta X\simeq 0.05$), we can state that the agreement reached between the results of our numerical applications ($\Delta X\simeq 0.01$) and the resonance doublet profiles observed for C IV and Si IV is excellent (see Figs. 2 and 3).

We recall that for the profile of C IV, the D.E envelope is optically thick to the spectral radiation ($\tau_{12}>1$, $\tau_{13}>1$) and that, consequently, it is not possible to infer the distribution of the fictive opacity τ_{12}, nor a rate of mass-loss for PHL 5200 on the basis of these observations only. Because the condition (10) is not fulfilled ($\Delta X_{23}=0.05$, $X_c+X_t=0.575$, $X_0=0.06$), the calculated profile is characterized by the presence of a single emission line component (see Fig. 2).

Concerning the calculated profile for Si IV, the agreement with the observations is also good. As predicted [see condition (10), $\Delta X_{23}=0.20$, $X_0=0.14$] we do indeed observe, in the calculated profile, the presence of two distinct emission line components, the first and the most important one being centred around the frequency $X=0$, and the second one (weaker) around the frequency $X=-0.30$. While the profile observed for Si IV, illustrated by the dashed line in Fig. 3, has been filtered (see Scargle et al., 1972) and does not show that second component, the original profile illustrated by Fig. 1 in Scargle et al. (1970) reveals possible signs of that secondary emission at the expected frequency $X=-0.30$. Although the calculated and observed equivalent widths of that component differ somewhat between themselves, we nevertheless believe that the agreement is satisfactory, taking into account the possible errors due to spectral resolution and intensity calibration of the original plate.

For the values of the parameters $\alpha=-1.27$, $\tau_{12}^{l}=4.83\ 10^{10}$, $v_0=10^9$ cm/s, $G=399$, and $L_{\max}=40$, corresponding to the calculated profile of Si IV ($f_{12}=0.262$, $\lambda_{12}=1402.77\ 10^{-8}$ cm), it is possible to deduce from relation (17) the value for the column density of Si^{3+} ions: $N^{Si^{3+}}=4.076\ 10^{15}$ cm^{-2}.

With the help of relation (12), we find that the radial fictive opacity evaluated at the quasi-stellar surface is $\tau_{12}(\theta=0, L=1)\simeq 0.17$ and, recalling the definition for the mass-loss rate

$$-\frac{dM}{dt}=4\pi R^{*2}v_0 n_0^{Si^{3+}}m_{at}^{Si^{3+}}/\eta_0^{Si^{3+}}, \quad (18)$$

it is seen that the determination of that rate will be possible only if we can adopt plausible values for the quasi-stellar radius R^* and the mass abundance $\eta_0^{Si^{3+}}$ of the Si^{3+} ions. In relation (18), $n_0^{Si^{3+}}$ represents the density per volume unit of the Si^{3+} ions at the quasi-stellar surface, and $m_{at}^{Si^{3+}}$ is the mass of such an ion.

Before proceeding to such an evaluation, it is interesting to write the equation describing the motion of an atom initially ejected with a velocity v_0, further on decelerated in the gravitational field of the quasar, and such that $v(r)\rightarrow v_\infty$ when $L\rightarrow\infty$. This approach will allow us to establish the relation between the mass M of the quasar and its radius R^* as well as to estimate the time t required by such an atom to travel a given distance r. The equation of motion is of course expressed by

$$\frac{dv}{dt}=-\frac{MG_g}{r^2}, \quad (19)$$

where G_g represents the constant of gravitation. Since an atom moving with a velocity $v(r)$ travels a distance dr between the points r and $r+dr$ in a time

$$dt=\frac{dr}{v(r)}, \quad (20)$$

the integration of (19) between two points r_1 and r_2, where the velocities are respectively v_1 and v_2, leads to the result

$$v_1^2-v_2^2=2\,MG_g\left(\frac{1}{r_1}-\frac{1}{r_2}\right). \quad (21)$$

For the pairs of values ($r_1=R^*$, $r_2=\infty$) and ($v_1=v_0$, $v_2=v_\infty$), the relation between the mass M of the quasar and its radius R^*

is straightforward:

$$M=\frac{(v_0^2-v_\infty^2)R^*}{2\,G_g}. \quad (22)$$

Integrating Eq. (20) between $r_1=R^*$ and $r_2=r$, corresponding to $t_1=0$ and $t_2=t$, one easily finds that the time t required by an atom to travel a distance $L=r/R^*$ is

$$t=\frac{GR^*}{v_\infty}\left\{\frac{[1+(G/L)]^{1/2}}{G/L}-\frac{[1+G]^{1/2}}{G}+\frac{1}{2}\ln\left(\frac{[(1+(G/L))^{1/2}-1]\,[(1+G)^{1/2}+1]}{[(1+(G/L))^{1/2}+1]\,[(1+G)^{1/2}-1]}\right)\right\}. \quad (23)$$

If we suppose that the slight spectral variations detected by Burbidge (1968, 1969) in the P Cygni absorption component of Si IV around the frequency $X=-0.9$ (corresponding to $Z_a=1.891$) are due to variations of the physical conditions (S_{12}, τ_{12}) at a typical distance $L=L(X)$ where the surface of equal frequency $X=-0.9$ is located, we are able to deduce from relation (23) the value R^* for the quasi-stellar radius such that the time required by an ion to travel the distance $r=L(X)R^*$ is the time scale of the observed variations, i.e. about one year. For the velocity distribution given in relation (2), the radial distance $L(X)$ of the corresponding surface of equal frequency is given by

$$L(X)=\frac{G}{(Xv_0/v_\infty)^2-1}, \quad (24)$$

and for $X=-0.9$ we find that $L(X)\simeq 1.24$. Substituting this result and $t\simeq 1$ yr in relation (23), we obtain $R^*\simeq 0.05$ pc. The time required by an ion to travel a distance $L_{\max}=400$, equal to the size of the D.E envelope in which the profile of C IV is formed, is then about $t\simeq 2\,10^4$ yr, and by means of relation (22) we find for the mass of the quasar $M\simeq 5.8\,10^8 M_\odot$. It should be noted here that the slight spectral variations detected by Burbidge around the frequency $X=-0.30$ (i.e. $Z_a=1.950$), and which corresponds exactly to the location of the second emission line component in the profile calculated for Si IV (see Fig. 3), can also be interpreted in terms of slight variations of the physical conditions (S_{12}, τ_{12}, S_{13}, τ_{13}) at the basis of the surfaces of equal frequencies $X=-0.30$ and $Y=-0.10$ (cf. Fig. 5); consequently, the characteristic time of these variations is essentially of the same order as the one determined above. This picture also supports the fact that no similar spectral variations were detected by Burbidge (1968, 1969) in the profile of C IV. Indeed, the envelope of C^{3+} ions being optically thick ($\tau_{12}>1$, $\tau_{13}>1$) to the spectral line radiation, slight variations of the fictive opacities τ_{12}, τ_{13} are not likely to affect the shape of the profile. Let us finally remark that our determination of a mass $M\simeq 5.8\,10^8 M_\odot$ for PHL 5200 is within the range of critical masses $M_c\simeq 5\,10^7$–$2\,10^9 M_\odot$ reported by Burbidge and Perry (1976), for which the radiative forces capable of accelerating outwards the material initially expelled by the quasar are overwhelmed by the force of gravitation.

By means of relations (14), (15), and (41) of Paper II we can write the expression for the radial fictive opacity $\tau_{12}(\theta=0, L=1)$ evaluated at the quasi-stellar surface, in the form

$$\tau_{12}(\theta=0, L=1)=\frac{\pi e^2}{mc} f_{12}\lambda_{12}\,\frac{2\,n_0^{\mathrm{Si}^{3+}} v_0 R^*}{G v_\infty^2}. \quad (25)$$

Recalling definition (18) for the mass-loss rate and using relations (22) and (25), one finds that the relative rate of mass-loss for the quasar in a time interval dt is given by

$$-\frac{dM}{M}=\frac{4\pi G_g \tau_{12}(\theta=0, L=1)\, m_{at}^{\mathrm{Si}^{3+}}\, dt}{(\pi e^2/mc) f_{12}\lambda_{12}\eta_0\chi^{\mathrm{Si}^{3+}}}, \quad (26)$$

where η_0 represents the mass abundance of silicon and $\chi^{\mathrm{Si}^{3+}}$ the fraction of silicon ionized in the form of Si^{3+}. If we adopt the cosmic abundance value $\eta_0=6.85\,10^{-4}$ (Allen, 1973) and, because Si^{3+} is not the dominant stage of ionization ($\alpha\neq 0$), we find it reasonable to suppose that $\chi^{\mathrm{Si}^{3+}}<0.10$, then we obtain for the value $\tau_{12}(\theta=0, L=1)=0.17$:

$$-\frac{dM}{M}\gtrsim 3.2\,10^{-5} \quad (27)$$

in the time interval of 10^6 yr, assuming that the mass-loss of the quasar remained constant in time. In conclusion, we see that the fraction of mass lost by the quasar over one million years is important and that it could affect the evolution of the quasar itself over longer intervals. With this last result and for $M\simeq 5.8\,10^8 M_\odot$, we deduce a rate of mass-loss

$$-\frac{dM}{dt}\gtrsim 0.02 M_\odot/\mathrm{yr}. \quad (28)$$

From relation (25) it is possible to evaluate the density $n_0^{\mathrm{Si}^{3+}}$ of the Si^{3+} ions at the quasi-stellar surface. We obtain directly

$$n_0^{\mathrm{Si}^{3+}}\simeq 5.68\,10^{-3}\,\mathrm{cm}^{-3}, \quad (29)$$

from which we deduce that the electron density is of the order $n_e\lesssim 10^2$ cm^{-3}. This justifies a posteriori the fact that we neglected the role of thermal excitation by collisions when calculating the profiles of C IV and Si IV. Indeed, Scargle et al. (1970) have shown that for a fictive optical depth $\tau_{12}\simeq 1$, the role of collisions is negligible as long as $n_e<10^{16}$ cm^{-3}.

Let us now mention that for the values of the parameters $\alpha=-1$ and $\tau_{12}^l=2.42\,10^8$ the profile calculated for Si IV does not differ appreciably from the one illustrated in Fig. 3. Yet the agreement with the observations is not quite as good. If the continuum of the ionizing radiation is effectively responsible for the ionization of Si into Si^{3+}, the result $\alpha\simeq -1$ would imply that the Si^{2+} ion represents the dominant stage of ionization of silicon. Unfortunately, the resonance line of Si III λ 1206.51 Å falls exactly in the emission line component of Lyα λ 1215.67 Å (cf. Burbidge, 1969) and thus the spectroscopic observations of PHL 5200 are not sufficient to test this possibility. Furthermore, the fact that the C^{3+} ion represents the dominant stage of ionization of carbon ($\alpha=0$) and that this is not the case for the Si^{3+} ion ($\alpha\simeq -1$), would explain rather simply the result $r_{\max}^{\mathrm{C\,IV}}\simeq 10\, r_{\max}^{\mathrm{Si\,IV}}$.

Although the resonance doublet profile of N V ($\lambda\lambda$ 1238.808, 1242.796 Å) is present in the spectrum of PHL 5200, we do not attempt to interpret it because it is contaminated by the emission component of Lyα λ 1215.67 Å and very probably by Si III λ 1206.51 Å. Also, the recorded tracing in that region (see Fig. 1 in Scargle et al., 1970) is very poor because of the rapidly dropping ultraviolet transmission of the Earth's atmosphere.

Stockman and Angel (1978) have detected a linear polarization $P=(4.1\pm 0.8)\%$ for the radiation emitted by PHL 5200 in the spectral range $\lambda\lambda$ 3200–8600 Å. Following Scargle et al. (1970), they argue that these observations could be interpreted as being due to an intrinsic polarization of the P Cygni lines, assuming that the scattering of line photons takes place in an expanding asymmetric envelope. However, Stockman et al. (1978) have later obtained moderate resolution spectropolarimetry of PHL 5200, and found that only the continuum is strongly polarized with $P\simeq 5\%$ throughout the spectral range $\lambda\lambda$ 3900–7000 Å. In the vicinity of the strong emission lines Si IV and C IV the polarization is depressed, indicating that the emission lines are unpolarized. We can therefore conclude that the model of a spherically symmetric D.E envelope that we adopted here in order to simulate the

P Cygni profiles observed in the spectrum of PHL 5200 is consistent with the polarimetric measurements reported by Stockman et al. (1978).

Lynds (1967) has reported that the C III] λ 1909 Å intercombination line appears in the spectrum of PHL 5200 as a relatively strong diffuse emission. In order to account for such a profile, one must naturally supply the line photons in the envelope by collisional excitation ($\varepsilon \neq 0$). One possible way to render our previous model consistent with the formation of the C III] line profile by collisional excitation would be to suppose that at great distances from the quasar ($L \gg 100$), the C^{2+} ion represents the dominant stage of ionization of carbon ($\alpha = 0$). Indeed, at such distances, a sufficiently high density for the C^{2+} ions combined with small values for the dilution factor W and for the radial velocity gradient $dv(r)/dr$ (see Chapt. IIIa in Castor and Lamers, 1979) can make the role of collisions very efficient in the formation of the intercombination line profile. In order to prove this quantitatively, one should build up a rigorous ionization model throughout the expanding medium and calculate the resulting (C IV, Si IV, C III], etc.) line profiles. However, this is a difficult task to perform and (for lack of proof) we are aware that our model may fail to account for the diffuse character of the C III] emission line.

Finally, let us remark that in the context of cosmological distances there is no chance to resolve the envelope ($r_{max}^{C\,IV} \simeq 20$ pc) of PHL 5200, even with an angular resolution as good as 0.″01. Narrow-band direct plates of PHL 5200 have been obtained with the 120-inch and Crossley reflectors (Scargle et al., 1970). Plates taken in both the absorption or emission components of C IV have not shown signs of resolution.

3. RS 23

A. Observations

The spectrum of the quasi-stellar object RS 23 (Q 1334+285, BO 14, see Richter and Sahakjan, 1965; $m_b = 18^{m}8$) reveals profiles for the resonance doublets of C IV, N V, and the Ly α line very similar to those observed in the spectrum of PHL 5200. According to Burbidge (1970): "This radio-quiet QSO has rather broad, strong absorptions, adjacent to and on the short-wavelength side of the emissions, like those seen in PHL 5200 ≡ 4 C − 5.93, and like absorptions produced in an expanding nova or supernova shell."

The redshift of RS 23 measured from the positions of the emission lines is found to be $Z_e = 1.908$ (Burbidge, 1970). We have reproduced in Fig. 6 (see the dashed line) the profile observed by Burbidge (1970) for the resonance doublet of C IV. This profile has been calibrated in intensity and normalized to the quasi-stellar continuum (Scargle et al., 1970). The broad and intense emission line component lies approximately in the range $Z_e \in [1.88–1.95]$ with a peak at $Z_e = 1.908$, while the P Cygni absorption component extends over the range $Z_a \in [1.85–1.88]$. The profiles observed for N V and Ly α are similar to the one illustrated for C IV, but Si IV seems to be absent (Burbidge, 1970).

The continuity observed between the redshifts Z_a and Z_e strongly suggests that the profiles observed in the spectrum of RS 23 are formed in a rapidly expanding envelope around the quasar (cf. Burbidge and Burbidge, 1969; Burbidge, 1970; Scargle et al., 1970, 1972; Strittmatter and Williams, 1976; Boksenberg, 1977).

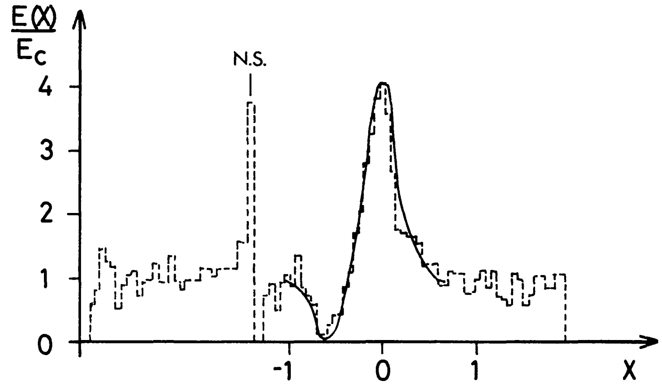

Fig. 6. Comparison between the profiles calculated (full line) and observed (dashed line) for the resonance doublet of C IV in the spectrum of RS 23 (see text)

B. Analysis and Calculation of the Resonance Doublet Profile for C IV

From the original tracing of the P Cygni profile observed for C IV and published by Scargle et al. (1970), we can determine the velocities (defined in the rest frame of the quasar!) corresponding to the location of the P Cygni absorption component that is the most displaced towards the short wavelengths $v_i = -7150 \pm 300$ km s^{-1} as well as the one characterizing the sharp cut-off of the red wing of the emission line $v_c = 4200 \pm 300$ km s^{-1}. We recall that these velocities are measured with respect to the velocity $v_e = 0$ observed for the maximum of the central emission component. The relative separation of the two upper atomic levels for the resonance doublet of C IV being $\Delta v_{23} = 498$ km s^{-1}, one deduces from relation (1) the maximum expansion velocity $v_0 = 6650 \pm 300$ km s^{-1}. It is then remarkable to see that the ratio v_c/v_0 which defines the value of the frequency $X_c = 0.63 \pm 0.05$ [see relation (8)] is in perfect agreement with the hypothesis that the profile observed for C IV is formed in a spherical envelope decelerated outwards in the gravitational field of the quasar.

The fact that the equivalent width EW_{em} of the emission component is about four times greater than the equivalent width EW_{ab} of the P Cygni absorption component necessarily implies the existence of an additional source of line photons created in the medium. Supposing that the probability ε of destruction of a line photon by collisional de-excitation is total ($\varepsilon = 1$) everywhere in the medium, we have calculated, via the model of radiative transfer presented in Sect. 2.D, a profile accounting for the observations. The theoretical profile is illustrated in Fig. 6 by the full line: the values of the physical and geometrical parameters we used for this fit are $\Delta X_{23} = 0.075$, $\varepsilon = 1$, $\tau_{12}^{l} = 3$, $\alpha = 0$, $G = 10^3$, and $L_{max} = 8$, assuming that the electron temperature distribution is such that the Planck function $B_{v_{12}}(T_e) \simeq 0.053\, I_c$.

C. Discussion of the Results

As reported in Paper IV, when collisions ($\varepsilon \neq 0$) are involved in a model of radiative transfer it is no longer possible, from the analysis of only one observed profile at least, to infer univocally the values of the physical and geometrical parameters ε, τ_{12}^{l}, α, L_{max}, and $T_e(r)$ prevailing in the medium. Therefore we do not

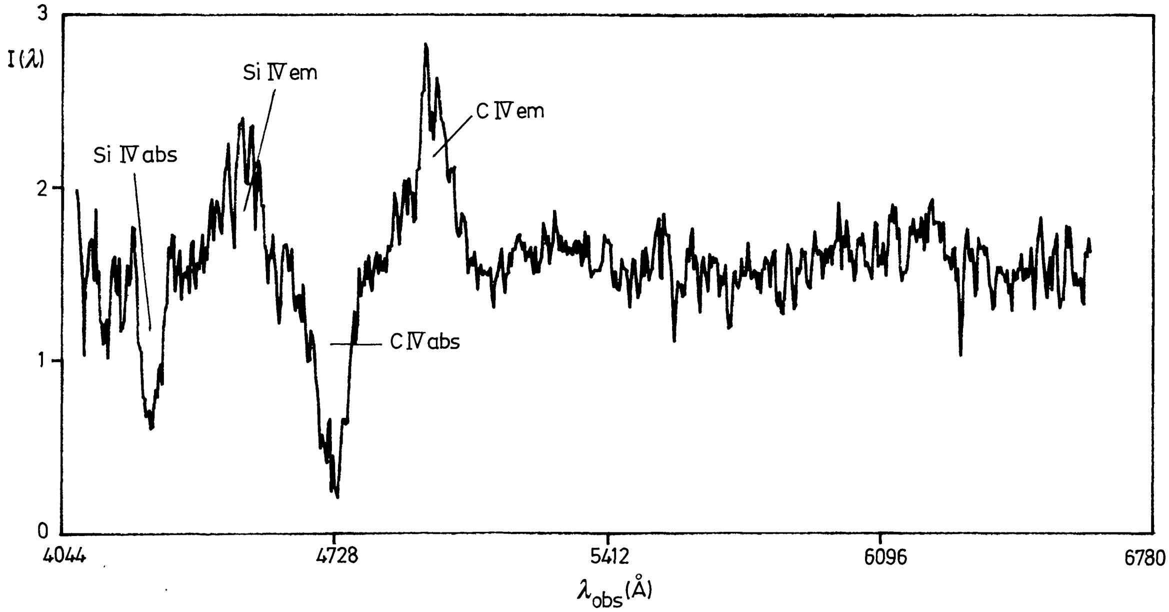

Fig. 7. Intensity tracing for the spectrum of Q 1246–057 recorded with the Boller and Chivens spectrograph (dispersion: 171 Å/mm, IDS system) attached to the Cassegrain focus of the 3.6 m ESO telescope (February, 1979)

pretend that the values given above for these parameters characterize the physical conditions of the medium surrounding RS 23, but simply state that it is possible to interpret the profile observed for C IV as being formed in an envelope decelerated outwards in the gravitational field of the quasar. Moreover, for other values of the physical and geometrical parameters, we reached a fair agreement with the observations; and we can only state that the value $G \simeq 10^3$ for the decelerating parameter is necessary in order to account for the observed profile of C IV, and that the deep absorption of the P Cygni component around the frequency $X = -X_c$ absolutely requires the medium to be optically thick ($\tau_{12} > 1$, $\tau_{13} > 1$) to the spectral line radiation in the neighbourhood of the surface of the quasar.

4. Two Additional Mass-losing Quasars: Q 1246 − 057 and Q 0932 + 501

A. Q 1246 − 057

The quasi-stellar object Q 1246 − 057 ($m_b = 16\overset{m}{.}8$, $Z_e = 2.212$) has recently been discovered by Osmer and Smith (1977) during an objective-prism survey of emission line objects with the Curtis Schmidt telescope at Cerro Tololo observatory.

Osmer and Smith report: "The broad absorption features, which appear at wavelengths 1471, 1327, 1176, and 1150 Å in the rest frame of the emission lines, are reminiscent of the ones in PHL 5200, although they are not as closely associated with the emission lines."

Boksenberg et al. (1978) have confirmed these results on the basis of higher resolution spectra (dispersion: 34 Å/mm) characterized by a very good signal-to-noise ratio. We illustrate in Fig. 7 the spectral region covering the resonance doublets of C IV and Si IV obtained with the Boller and Chivens spectrograph (IDS system) attached to the Cassegrain focus of the 3.6 m ESO telescope. The intensity tracing illustrated in that figure has been corrected for night-sky contribution and instrumental response. We confirm the redshift value $Z_e = 2.212$; and furthermore our measurements indicate that the redshift Z_a associated with the most displaced feature in the P Cygni absorption component has a value $Z_a \lesssim 2.0$, which in turn implies a maximal expansion velocity $v_{\max} \gtrsim 19{,}000$ km s^{-1} in the rest frame of the quasar.

In agreement with the data of Osmer and Smith (1977) and of Boksenberg et al. (1978) the P Cygni absorption components observed for the resonance doublets of C IV and Si IV appear to be totally separated from their associated emission line components. Furthermore, the frequency locating the sharp cut-off of the red wing of the emission line is about $X_c = 0.25$, and it is very difficult to reconcile this value with predictions from theoretical models (A.E or D.E envelopes).

We thus conclude that the profiles observed for the resonance doublets of C IV and Si IV in the spectrum of Q 1246 − 057 cannot be interpreted in terms of a spherically symmetric flow continuously ejected from the quasar. We suggest that Q 1246 − 057 may well represent an "intermediate" quasar between PHL 5200, RS 23, and those for which the absorption components ($Z_a \ll Z_e$) arise in circumquasi-stellar clouds that have been ejected by the quasar at much earlier epochs.

B. Q 0932 + 501

The quasi-stellar object Q 0932 + 501 has been detected by Notni et al. (1979) during a search for objects with ultraviolet excess included in the field of the radio survey 5 CI. This quasar ($m_b \simeq 17\overset{m}{.}4$) possesses a redshift $Z_e = 1.92$ and shows in its spectrum P Cygni-like profiles for the resonance doublets of C IV and Si IV. According to these authors: "The profile of the absorptions is qualitatively very similar to that of PHL 5200: the red edge is much sharper (it is, in fact, not resolved with our resolution) than the blue edge, and the C IV feature is more pronounced than the Si IV feature. As in PHL 5200, the central intensities in all three bands (C IV, Si IV, N V + Ly α) are near to zero. The similarity of the absorption profiles of PHL 5200 and Q 0932 + 501 implies that the structure of the absorbing cloud is similar to some extent."

These authors have determined the value of the redshift Z_a associated with the location of the P Cygni absorption component that is the most displaced towards the short wavelengths. They find $Z_a \lesssim 1.76$, which corresponds in the rest frame of the quasar to a maximum expansion velocity $v_{max} \gtrsim 16{,}000$ km s^{-1}.

Although the abrupt transition observed between the P Cygni absorption and emission components in the profile of C IV (cf. PHL 5200) constitutes a major feature of the profiles formed in D.E envelopes, it is not possible to test this possibility on the basis of only those observations carried out for Q 0932+501. Indeed, the profiles that Notni et al. published are not corrected for the instrumental response, and the red wing of the emission component of C IV has unfortunately been truncated.

5. Conclusions

In the framework of the Sobolev approximation, we performed line profile calculations in order to simulate the P Cygni-like profiles observed for the resonance doublets of C IV and Si IV in the spectrum of the quasar PHL 5200 and of C IV in that of RS 23. The confrontation between the results of our numerical applications and the observations is strongly in favour of the "intrinsic hypothesis" for the origin of the absorption components.

We have indeed shown for PHL 5200 that a flow of matter, initially ejected at the surface of the quasar with a velocity $v_0 = 10{,}000$ km s^{-1} and later decelerated in the gravitational field of the central core, could account for the observed profiles of C IV and Si IV. In order to explain the slight spectral variations detected by Burbidge (1968, 1969) in the P Cygni absorption component of the profile of Si IV within a time interval of about one year, we have adopted for the radius of the quasar $R^* = 0.05$ pc. From this result we have deduced for PHL 5200 a mass $M \simeq 5.8\ 10^8\ M_\odot$, comparable to the critical masses $M_c \simeq 5\ 10^7$–$2\ 10^9\ M_\odot$ (Burbidge and Perry, 1976) under which a decelerated flow cannot exist.

From other results of the numerical applications, we concluded that the profile observed for C IV is formed in a D.E envelope, optically thick to the spectral line radiation, and whose extent is $r_{max}^{C\,IV} \simeq 20$ pc. For the resonance doublet of Si IV we found $r_{max}^{Si\,IV} \simeq 2$ pc, but that the medium is not, strictly speaking, optically thick to the spectral line radiation. This fact enabled us to deduce that the fraction of the mass ejected by the quasar in a time interval of 10^6 yr is appreciable $[-(dM/M) \gtrsim 3.2\ 10^{-5}]$ and could possibly affect the evolution of the quasar itself over somewhat larger time intervals. The rate of mass-loss which results for PHL 5200 is then found to be $-(dM/dt) > 0.02\ M_\odot$/yr. Although the C^{3+} ion probably represents the dominant stage of ionization for carbon, we have seen that this was not the case for the Si^{3+} ion and that this result could explain the fact that $r_{max}^{C\,IV} \simeq 10\ r_{max}^{Si\,IV}$. We have also determined a column density $N^{Si^{3+}} \simeq 4\ 10^{15}$ cm^{-2} for the Si^{3+} ions, and the volume densities $n_0^{Si^{3+}} \simeq 5.7\ 10^{-3}$ cm^{-3}, $n_e \lesssim 10^2$ cm^{-3} at the surface of the quasar.

Concerning RS 23, we have similarly shown that a flow of matter decelerated outwards in the gravitational field of the quasar could satisfactorily account for the observed P Cygni profile of C IV. However, because the equivalent width EW_{em} of the emission component is much more important than the equivalent width EW_{ab} of the absorption component, it was not possible to infer univocally the values of the physical and geometrical parameters prevailing in the medium. We can only state that the flow is indeed decelerated outwards by gravitation, and that at the basis of the D.E envelope the medium is optically thick to the spectral line radiation.

For the quasar Q 1246−057, the near equality between the equivalent widths EW_{em} and EW_{ab} of the emission and absorption components observed for the resonance doublets of C IV, Si IV, N V, and the Lyα line, as well as the continuity between the redshifts Z_a and Z_e, strongly indicate that a flow of matter is associated with the quasar. However, we could not simulate these observations in terms of spherically symmetric flows (A.E or D.E envelopes).

Finally, while the abrupt transition observed between the P Cygni absorption and emission components in the profile of C IV for the quasar Q 0932+501 constitutes one of the major features of profiles formed in D.E envelopes, we could not test this possibility quantitatively because of the poor quality of the only available observations. Higher quality data are badly needed.

It is interesting to note that each of these peculiar quasars possesses a radio-quiet spectrum (cf. Kenderline et al., 1966; Ehmann et al., 1970; Mills and Little, 1970; Sramek and Weedman, 1978), and that their absolute magnitudes M_b(H=100 km s^{-1}/Mpc, see Notni et al., 1979) are $M_b = -27^m\!.0$ (Q 1246−057), $M_b = -26^m\!.0$ (Q 0932+501), $M_b = -25^m\!.3$ (PHL 5200), and $M_b = -24^m\!.7$ (RS 23). These quasars are thus among the most luminous ones. Furthermore, recalling that the maximal expansion velocities v_{max} observed in the spectrum of these quasars are $v_{max} \simeq 19{,}000$, 16,000, 10,000, and 6,650 km s^{-1}, respectively, the correlation which appears between the quantities M_b and v_{max} is striking.

Although the sample composed by these four quasars is not statistically significant, we are tempted to locate them in a possible evolutionary scheme: from analogy with stars (cf. Nugis et al., 1978), we suppose that vibrational instabilities of massive quasars (PHL 5200, RS 23, Q 0932+501?) could be responsible for the initial flow of matter at the quasi-stellar surface, further decelerated in the gravitational field of the central core. Because this mass-loss phenomenon can affect the evolution of the quasar itself on a time scale of some millions of years or more (cf. PHL 5200), it is likely that the intrinsic luminosity of the quasar must vary (increase?) as a function of time, just as its mass M will decrease. If, during such a process, the radiative forces overwhelm the gravity, one expects that the envelope may become disrupted and be driven at very high velocities and at great distances away from the quasar (Q 1246−057?). Let us also mention that the radiative forces acting on an element of gas in a D.E envelope are expected to increase as the size L_{max} of the medium becomes greater (see Surdej, 1978b). This effect could trigger instabilities and change an outward-decelerating flow into an outward-accelerating one. The selective effect of radiative forces acting via the resonance lines of the most abundant ions could then render the line-locking or edge-locking mechanisms very effective and explain the existence of observed absorption components totally detached from their corresponding emission components ($Z_a \ll Z_e$) in the spectrum of many quasars. According to such a scenario, the latter would indeed represent a late stage of evolution among quasars.

Acknowledgements. We thank L. Woltjer for discussion and criticisms about the subject.

Our thanks are also due to L. Lucy, as a referee, for his valuable comments on the required diagnostics of the proposed model.

We are grateful to the European Southern Observatory for having received computer and telescope time for this project, and we thank the staff of La Silla, in particular the night assistants A. Zuñiga, M. Pizarro, H. Herborn, and J. Yagnam, for their help in obtaining the data.

References

Allen, C.W.: 1973, Astrophysical Quantities, The Athlone Press, University of London

Bahcall, J.N., Greenstein, J.L., Sargent, W.L.W.: 1968, *Astrophys. J.* **153**, 689

Beals, C.S.: 1955, *Publ. Dominion Astron. Obs.* **9**, 1

Boksenberg, A.: 1977, in *Radio Astronomy and Cosmology*, I.A.U. *Symp.* No. **74**, 193

Boksenberg, A., Carswell, R.F., Smith, M.G., Whelan, J.A.J.: 1978, *Monthly Notices Roy. Astron. Soc.* **184**, 773

Burbidge, E.M.: 1968, *Astrophys. J. Letters* **152**, L111

Burbidge, E.M., Lynds, C.R., Stockton, A.N.: 1968, *Astrophys. J.* **152**, 1077

Burbidge, E.M.: 1969, *Astrophys. J. Letters* **155**, L43

Burbidge, G.R., Burbidge, E.M.: 1969, *Nature* **222**, 735

Burbidge, E.M.: 1970, *Astrophys. J. Letters* **160**, L33

Burbidge, E.M., Burbidge, G.R.: 1975, *Astrophys. J.* **202**, 287

Burbidge, G., Perry, J.: 1976, *Astrophys. J. Letters* **205**, L55

Caroff, L.J., Noerdlinger, P.D., Scargle, J.D.: 1972, *Astrophys. J.* **176**, 439

Castor, J.I., Lamers, H.J.G.L.M.: 1979, *Astrophys. J. Suppl.* **39**, 481

Ehmann, J.R., Dixon, R.S., Kraus, J.D.: 1970, *Astron. J.* **75**, 351

Grachev, S.I., Grinin, V.P.: 1975, *Astrophysics* **11**, 20

Kenderline, S., Ryle, Sir M., Pooley, G.G.: 1966, *Monthly Notices Roy. Astron. Soc.* **134**, 189

Lucy, L.B.: 1971, *Astrophys. J.* **163**, 95

Lynds, C.R.: 1967, *Astrophys. J.* **147**, 396

Lynds, C.R.: 1972, in *External Galaxies and Quasi-Stellar Objects*, I.A.U. *Symp.* No. **44**, 127

Magnan, C.: 1973, Ph. D. Dissertation

Mihalas, D.: 1970, Stellar Atmospheres, 356, ed. by Freeman W. H. and Company. San Francisco

Mills, B.Y., Little, A.G.: 1970, *Astrophys. Letters* **6**, 197

Milne, E.A.: 1926, *Monthly Notices Roy. Astron. Soc.* **86**, 459

Mushotzky, R.F., Solomon, P.M., Strittmatter, P.A.: 1972, *Astrophys. J.* **174**, 7

Notni, P., Karachentsev, I.D., Afanasjev, V.L.: 1979, *Astron. Nachr.* **300**, 121

Nugis, T., Kolka, I., Luud, L.: 1978, in *Mass Loss and Evolution of* O-*type Stars*, I.A.U. *Symp.* No. **83**, 39

Osmer, P.S., Smith, M.G.: 1977, *Astrophys. J.* **213**, 607

Richter, N., Sahakjan, K.: 1965, *Mitt. Tautenburg Obs.* (Berlin) **24**

Scargle, J.D., Caroff, L.J., Noerdlinger, P.D.: 1970, *Astrophys. J. Letters* **161**, L115

Scargle, J.D., Caroff, L.J., Noerdlinger, P.D.: 1972, in *External Galaxies and Quasi-Stellar Objects*, I.A.U. *Symp.* No. **44**, 151

Scargle, J.D.: 1973, *Astrophys. J.* **179**, 705

Scheuer, P.A.G., Wills, D.: 1966, *Astrophys. J.* **143**, 274

Sobolov, V.V.: 1947, Dnižuščiesja Oboločki Znezd, Leningrad; Transl.: Moving Envelopes of Stars, translated from the Russian by S. Gaposchkin, Harvard University Press, Cambridge, Mass., 1960

Sobolev, V.V.: 1958, Theoretical Astrophysics, Chapter 28, ed. by V. A. Ambartsumyan, Pergamon Press Ltd., London

Sramek, R.A., Weedman, D.W.: 1978, *Astrophys. J.* **221**. 468

Stockman, H.S., Angel, J.R.P.: 1978, *Astrophys. J. Letters* **220**, L67

Stockman, H.S., Angel, J.R.P., Hier, R.: 1978, *Bull. Amer. Astron. Soc.* **10**, 689

Strittmatter, P.A., Williams, R.E.: 1976, *Ann. Rev. Astron. Astrophys.* **14**, 307

Surdej, J.: 1977, *Astron. Astrophys.* **60**, 303 (Paper I)

Surdej, J.: 1978a, *Astron. Astrophys.* **66**, 45 (Paper II)

Surdej, J.: 1978b, *Astron. Astrophys.* **62**, 135

Surdej, J.: 1979a, *Astron. Astrophys.* **73**, 1 (Paper III)

Surdej, J.: 1979b, Ph.D. Dissertation

Surdej, J.: 1980, *Astrophys. Space Sci.* **73**, 101 (Paper IV)

Van Blerkom, D.: 1973, in *Wolf-Rayet and High-Temperature Stars,* I.A.U. *Symp.* No. **49**, 165