# THE PHYSICAL PROPERTIES OF THE ABSORPTION ENVELOPES OF TWO QSOs

JEFFERY D. SCARGLE

*Lick Observatory, Board of Studies in Astronomy and Astrophysics, University of California, Santa Cruz, and Ames Research Center, NASA, Moffett Field, Calif., U.S.A.*

LAWRENCE J. CAROFF

*Ames Research Center, NASA, Moffett Field, Calif., U.S.A.*

and

PETER D. NOERDLINGER

*New Mexico Institute of Mining and Technology, Socorro and Ames Research Center, NASA, Moffett Field, Calif., U.S.A.*

**Abstract.** The wide absorption troughs of certain resonance lines in the spectra of the QSOs PHL 5200 and RS 23 are produced by pure scattering and must therefore be compensated by an equal amount of emission. Analysis of the transfer of resonance-line radiation through a differentially expanding atmosphere shows that the absorption-emission profiles can be quantitatively understood on this basis.

We have been studying the transfer of radiation by resonant scattering in an expanding nebula with application to QSOs having absorption wings or troughs to the blue of emission. The study was prompted by the absorption troughs running from the resonance lines of C IV, Si IV, N V, and Ly-$\alpha$ to a velocity $c/30$ blueward in the object PHL 5200 (Lynds, 1967). (The necessary figures to accompany this talk appear in Lynds (1967), Burbidge (1968, 1969, 1970) and our own paper (1970).) In Burbidge (1968, 1969), tentative evidence is presented for changes in the Si IV trough in about 9 months. These changes must involve material comprising $>1\%$ of the envelope. If they are real, the envelope must contain such a component $<1$ pc in diameter.

By averaging tracings of three spectra kindly loaned by E. M. Burbidge, we can estimate that the optical depth in the Si IV and C IV troughs in PHL 5200 must be at least $\tau=3$, whatever happens to the light. If we use

$$\tau = N\sigma/\delta v,$$

where $N$=column density, $\sigma$=integrated scattering cross-section and $\delta v \approx v_0/30 = $ =width of trough, we may estimate the column densities and get minimum mass values, by using cosmic abundance ratios. The result is

$$M > 5\, M_{\odot}\, (R_{pc})^2\, (\Omega/4\pi),$$

where $\Omega$ is the solid angle subtended by the envelope at the central source.

Since the envelope is known to have existed for three years, this gives $M > 5 M_{\odot}$ unless $\Omega$ is small.

We can show collisional de-excitation is small, and photo-ionization out of the

*D. S. Evans (ed.), External Galaxies and Quasi Stellar Objects, 151–154.*

https://doi.org/10.1017/S0074180900009839 Published online by Cambridge University Press

upper state is negligible at distances greater than $3 \times 10^{14}$ cm from the center. Therefore, the light 'absorbed' in the troughs must all come out. If the envelope is a jet directed toward us, the light can go to the sides and not be seen. However, there is a symmetric C III] 1909 emission line, whose width is about that of the troughs, and so it seems reasonable that this line comes from the envelope. If so, a jet is excluded. In addition, our more spherical models produce good fits to the lines.

If the envelope is spherical but too diffuse to be seen against the sky, it must be $\geqslant 25$ arc sec in diameter. This implies $R \approx 100$ kpc and leads to very large masses.

Therefore, we believe the envelope is unresolved. Radiation from the central object that is scattered to us from the back side of the nebula is shifted from the blue of the line to the red side of the line (all frequencies here being defined in the QSO rest frame). Light scattered by material out towards the side is seen at the line center, and so on. Thus the 'missing' light has been redistributed in frequency.

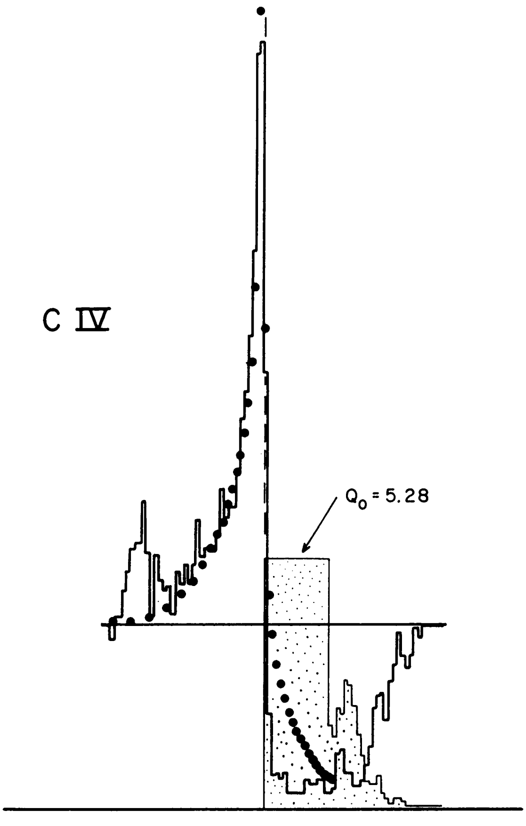


Fig. 1. Comparison of the theoretical (filled circles) and observed (heavy lines) profiles for the C IV line in PHL 5200. The observed curve has been referred to the estimated continuum level. The profile has been force-fit as well as possible to the blue of the zero-velocity point (vertical dashed line), and the theoretical curve is not plotted where the agreement is exact. The redward profile is determined completely independently of the data. Dotted histogram, run of $Q_0$ in the absorption trough; vertical scale is indicated by the maximum value (5.28 is an artificial cutoff and the true value is indeterminate).

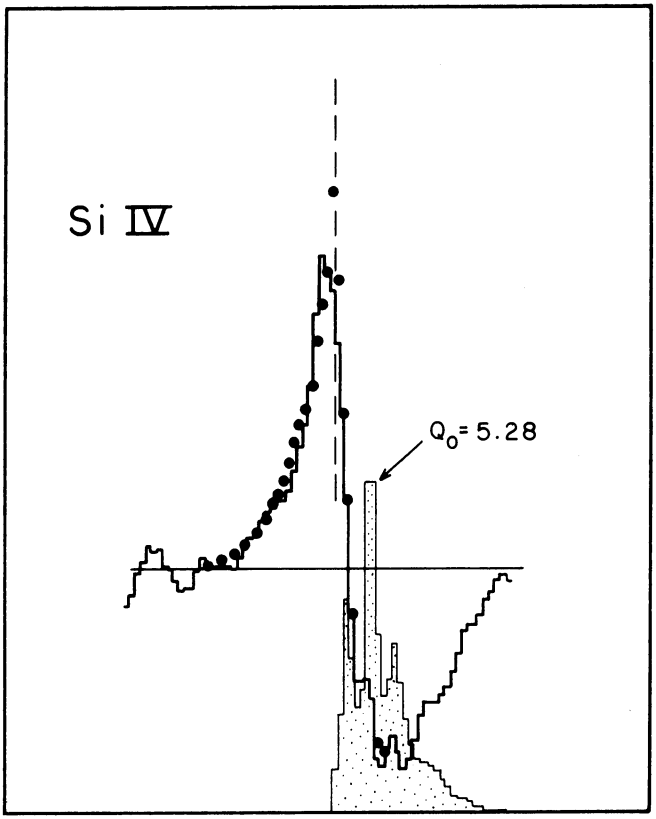


Fig. 2. Same as Figure 1 for the Si IV profile in PHL 5200, except that the observed curve has been slightly smoothed.

Our Monte Carlo program traces photons through an expanding nebula under these assumptions:

(a) uniform, isotropic expansion;

(b) thermal width small compared with width of trough;

(c) there is no physical boundary, although the density can be set equal to zero in velocity space. Thus, the photons see material always moving away from them, and they eventually escape in velocity space, being unable any longer to find material of the correct velocity to scatter them.

There is only one parameter left at any frequency, an effective optical depth

$$Q_0 = \frac{n\sigma}{K\nu_0}$$

$n$ = number density, $K = c^{-1}\, \mathrm{d}v/\mathrm{d}r$, where $v$ = radial velocity of expansion and $r$ is distance from the central source.

Here $n$ is a function of $v$, and $\nu = \nu_0\,(1 - v/c)$ so $Q_0$ is a function of $v$ or $\nu$. The

https://doi.org/10.1017/S007418090000543X Published online by Cambridge University Press

Monte Carlo program tells us how light from frequency $\nu$ in an absorption trough is redistributed over the range $(2\nu_0 - \nu, \nu)$ extending an equal distance on either side of rest frequency $\nu_0$.

When $Q_0$ is small (of the order 1–3) the redistribution is rather uniform, and at higher values, up to our largest value $Q_0 = 12$ it develops a moderate preference toward the red.

Using our redistribution profiles, we start at the blue end of an absorption trough, and trace redward. At each frequency, we allow residual (unscattered) light $I_0 \exp(-Q_0)$ and we add in all light scattered from larger frequency. The local $Q_0$ value must be adjusted to bring the total

$$I_{\text{scattered}} + I_0 \exp(-Q_0)$$

equal to the observed intensity. When too much light has been scattered from previously considered frequencies (further in the blue), no fit can be obtained.

Our published graphs (Scargle *et al.*, 1970) show good fits obtained by this method, except that we cannot get the C IV trough as deep as observed. Even in this case, the redward profile is good.

The trough can be made deeper by taking a non-uniform expansion, $v/r > \mathrm{d}v/\mathrm{d}r$. This throws more light into the line and the red. Exact equality is still preserved between integrated absorption and re-emission. A recent scan by Oke (1970) suggests that our continuum may have been taken too low in the red. If so, absorption exceeds emission and the envelope is probably asymmetric, although other possibilities exist.

The QSO known as RS 23 (Burbidge, 1970) shows similar troughs, but cannot be fitted by our present models, because emission exceeds absorption. It would appear interesting to consider models with some emission by collisional excitation in the envelope.

## References

Burbidge, E. M.: 1968, *Astrophys. J. Letters* **152**, L777.
Burbidge, E. M.: 1969, *Astrophys. J. Letters* **155**, L43.
Burbidge, E. M.: 1970, *Astrophys. J. Letters* **160**, L533.
Lynds, C. R.: 1967, *Astrophys. J.* **147**, 396.
Oke, J. B.: 1970, private communication.
Scargle, J., Caroff, L., and Noerdlinger, P.: 1970, *Astrophys. J. Letters* **161**, L115.

## Discussion

*Rees:* The light travel time across your assumed envelope may be thousand of years and your calculations also involve the further assumption that the continuum strength has remained constant over this period. Otherwise, you have another free parameter available.

*Noerdlinger:* We assumed a steady continuum. If it had increased during the light travel time across the nebula, this could explain the possible imbalance between emission and absorption, since the redward redistributed light comes from an earlier period in the life of the envelope. Incidentally, we had very few free parameters. The zero of velocity had to be picked just right, or the fits came out very badly. Also, $Q_0$ had to go zero at zero velocity to give good fits; there was no in-falling material.